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ENERGY MANAGEMENT GUIDELINES FOR RAIL TRANSIT SYSTEMS VOLUME II

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16. Abstract

The cost of electricity is a significant portion of the operating costs of rail transit systems. The impact of increasing energy costs is felt by those systems presently in operation and will be felt by those in the planning or construction phases. Because of the number of nuclear power plants coming on line in areas served by transit, the influence of electricity costs on operating and design policies of rail transit authorities is expected to grow in future years.

Concerned by rising energy costs, managers of several rail transit authorities have established energy management programs. The objectives of these programs are energy cost reduction and improved energy efficiency. Energy management is a process of understanding a system's energy requirements, with the goals of reduced energy cost and increased energy efficiency. Both goals enhance rail transit productivity. The bottom line is lower electric bills for the transit authority.

As a rule, energy management can foster its largest payoff when it is initiated during the design and construction phase of a rail transit system. The high dollar savings occur because low energy cost technology and operating practices can be engineered into the system at the outset. However, changes in technology and operations of present transit systems can also reduce the electric bill. Reduction of energy cost can be achieved through energy conservation, load management, and power rate intervention. These guidelines describe the tools and methodologies for assessing energy conservation strategies and power rate structure modifications.

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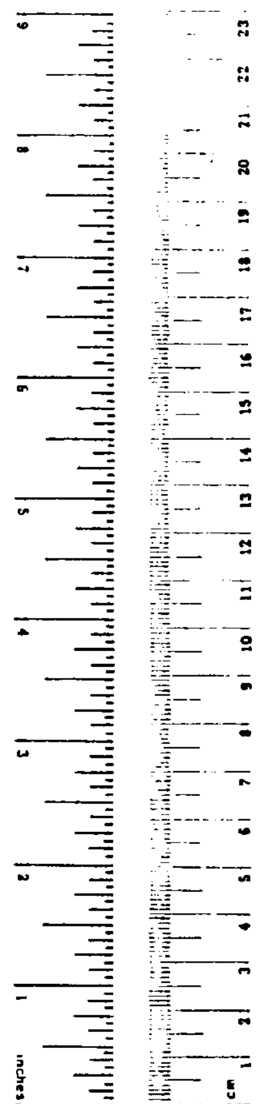
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

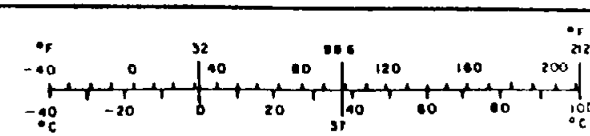
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. ENERGY CONSERVATION STRATEGIES

1.1. DESCRIPTIONS OF BASE AND CASE STUDY TRANSIT SYSTEMS

1.1.1. Description of Base Transit System

A base rail transit system was designed to illustrate the effects of energy conservation strategies on power demand and energy use. The baseline system has been made simple. The simplicity, however, does not mask reality. The effects observed in the application of traction energy cost reduction strategies are of the same nature as would be seen on real transit systems.

1.1.1.1. Right of Way

The physical layout of the base system is shown in Figure 1-1. There are no curves nor grades, and only one speed limit is designated, a speed of 40 MPH between mileposts 3.8 and 5.1. The maximum speed of 70 MPH is allowed everywhere else on the double track line.

The location of the passenger stations and substations are also shown in Figure 1-1. The passenger stations are either 0.5, 1.0 or 1.5 miles apart. All mileposts (MP) are measured from passenger station A, designated as the western terminal. The eastern terminal is located at MP 8.0.

1.1.1.2. Vehicles

The fleet of vehicles contain cars with identical characteristics. The fleet has 114 cars, 90% (or 102) of which are available and are used for peak transit service. The vehicle physical characteristics are listed in Table 1-1. The propulsion and braking characteristics are listed in Table 1-2.

The traction effort curves for power and electrical braking are shown in Figure 1-2. These curves represent the maximum capability of each car.

The propulsion system efficiencies in the power and braking modes are shown in Figures 1-3 and 1-4, respectively. Each of the curves in the figures represent the efficiencies at different percentages (20, 40, 60, 80 and 100%) of maximum tractive effort.

1.1.1.3. Operating Scenario

Table 1-3 provides a summary of the operating timetable. Passenger loading between all stations during the peak periods was assumed to be 50% of crush load. At all other time, passenger loading is assumed to be 25% of crush load. Dwell times at all passenger stations are 20 seconds.

1.1.1.4. Power Transmission and Distribution

The nodal diagram for the power transmission and distribution for traction power is shown in Figure 1-5. The unit power is taken as 5MW and the unit voltage is taken as 750V on the track side of the substation. This means that the unit resistance is [$(750V)^2/(5000000W)=$]0.11 ohms. If the third rail resistance in series with the resistance of four parallel running rails (two parallel tracks) is 0.00321 ohms per 1000 ft., then the per unit resistance is 0.154/mile [.00642 * 5.28/0.11].

The substations are all rated at 10000 MW with an impedance of 6%. Each substation feeds each third rail and four parallel rails of the ground return circuit.

1.1.1.5. Normal Traction Operation

1.1.1.5.1 Moving Trains

The speed profile superimposed on the speed restrictions for normal operation during the peak period for eastbound and westbound trains is shown in Figures 1-6 and 1-7, respectively. Figures 1-8 and 1-9 show the power profiles for the same operations (eastbound and westbound). The negative values of power in the last two figures represent the power available during regenerative braking.

Terminal to terminal summaries of run time and energy use (minimum with full receptivity and with natural receptivity) are listed in Table 1-4. The minimum energy consumption is measured at the third rail shoe or trolley. The energy use with natural receptivity is measured at the meters. Energy use during dwell times at stations is also included. Energy use during turnaround and layup (storage) was not included, and is estimated separately.

1.1.1.5.2 Estimate of Train Turnaround and Storage Energy Use

For a simple two track system with two terminals and a fixed headway, the power use during turnaround at the terminals due to on-board auxiliaries is

$$P = P_o \bullet TT / HW$$

where P_o is the power use of a single train, TT is the total turnaround time (min) and HW is the headway (min). For the base transit system, the minimum turnaround time is taken as 3 minutes per terminal or 6 minutes round trip.

Likewise, the minimum number of trains required to run the schedule specified in the operating timetable of Table 1-3 is given by the expression

$$N_o = RT + TT_{min} + \Delta T$$

where N_o is an integer, RT is the round trip running time (sum of eastbound and westbound run times) expressed in units of headway (HW) and TT_{min} is the minimum turnaround time expressed in units of headway. The quantity, ΔT

$$0 \leq \Delta T \leq 1$$

expressed in units of headway is called the slack time.

Table 1-5 shows the details of the turnaround and storage power estimates based on the formulae above and operating scenario of the base transit system.

It is well to note that the turnaround and storage power were estimated independent of train movement. Some of this power requirement can be met by regenerating trains. During the peak period, the power requirement is smallest.

1.1.1.5.3 Summary of Traction Power Requirements

Table 1-6 presents a summary of estimated power and energy use for traction operation for the normal conditions of the base rail transit system. It was assumed that none of the turnaround and storage power was supplied by regenerating trains. On the other hand, no network losses were included for the turnaround and storage power.

It was also assumed that on-board auxiliaries on the cars remained operating during storage periods. This assumption can cause the energy use per car-mile during off-peak operating periods to seem exaggerated.

The traction power requirement during the peak period is 16340 kW and the annual energy use 55.1 MkWh.

1.1.1.6. Normal Support Operation

A facility breakdown of support power by support function and season of the year is presented in Table 1-7 for the base rail transit system. These power requirements are for normal operation.

1.1.1.7. Summary of Power and Energy Use

Table 1-8 summarizes the energy use and power demand billing determinants of traction and support power for the base rail transit system. For the power demand component, the support power portion is 34% of the total demand, while for the energy use component, it is 57% of the total energy use.

1.1.1.8. Power Bill Analysis for Normal Operation

Table 1-9 contains the power bill analysis for normal operation. The rates are expressed in units of the annual power bill, which is assumed 1.00. The rate is also shown as a function of the portion of the power bill which is demand (which varies from 0 - 1 in steps of .25). It is also assumed that the facilities charge is negligible so that

Demand Portion + Energy Use Portion = Power Bill

As an example, if the power bill is 50% demand related (and thus 50% energy use related) the unit rates are 0.00154/MW for demand and 0.00376/MKWH for energy. So if the total power bill were $10M, the demand charge is $15.40/kW ($15400/MW) and 3.7 cents/KWH ($37,000/MkWH).

1.1.2. Description of WMATA and MARTA Systems

The operation studied at WMATA consisted of the RED, BLUE and ORANGE lines. At the time (1980-82), the RED line ran from Dupont Circle to Silver Spring, a distance of 9.9 miles. The BLUE line ran from National Airport to Addison Road, a distance of 15.9 miles. The ORANGE line ran from Ballston to New Carrollton, a distance of 16.6 miles. The ORANGE and BLUE lines shared common track from a point slightly west of Rosslyn Station to D/G Junction, a point east of Stadium Armory Station. Figure 1-10 shows a map of the WMATA rail system as it was in 1980-82, during the time of the study.

The operation studied at MARTA consisted of the North-South (NS) and East-West (EW) lines shown in Figure 1-11. During the early stages of the study, the service extended from West End to Arts Center on the NS line, but during 1985, the service was expanded so that it extended from Lakeview to Brookhaven. On the EW line, trains operated between Hightower and Avondale.

Table 1-10 shows the physical, propulsion and braking characteristics of the vehicle for both rail systems. During the time of the WMATA study, the cars were propelled using cam-controlled resistor switching (cam-control), which was not capable of regeneration. Cars which use chopper control were on order, and are now in service.

Table 1-11 lists the route and operating characteristics of the two rail systems. Although the maximum speed of the WMATA system (75 MPH) is higher than that of MARTA (70 MPH), the average speed of MARTA is higher than WMATA.

Table 1-12 lists the timetable data for both systems; namely, the headway and number of cars per train for both systems during various operating periods. These were the data used for the studies.

Table 1-13 shows the annual car-miles and the car-miles per hour normally scheduled for peak operation for both systems. These numbers when multiplied by the KWHPCM yield the traction component of energy consumption and demand.

Table 1-14 lists the principal structure of the electric bills. The electric power service to the WMATA rail system is provided by two utilities: the Potomac Electric Power Company (PEPCO), and the Virginia Electric Power Company (VEPCO). The PEPCO service to Metrorail is under three jurisdictions: District of Columbia (DC), Maryland (MD), and Virginia (VA). VEPCO provides power to WMATA under the VA jurisdiction.

WMATA is considered a separate customer class (RT rate) by PEPCO in all three jurisdictions. The service supplied by VEPCO is part of a government rate with just an energy charge.

Electric service to MARTA is provided by the Georgia Power Company (GPC) under a modified industrial rate (ET rate). Presently, MARTA is not classified separately. However, its unique load and customer characteristics are recognized by GPC.

Both MARTA and WMATA rail systems rely on automatic train control (ATC) to drive the trains.

Energy audits were conducted on both rail systems by examining and analyzing the metering records of the electric utilities serving the authorities. Regression analyses were conducted to determine the KWHPCM based on daily energy consumption and daily car-miles. The results are shown for both systems in Table

1-15. Also included in the table is a prediction using the Energy Management Model (EMM).

All of the subsequent estimates of traction energy consumption reduction were made using the EMM.

1.2. TECHNICAL STRATEGIES

1.2.1. Vehicle Weight Reduction

The base rail transit system is used to illustrate the example of vehicle weight reduction. The empty weight of the vehicle was reduced by 10%. All other system characteristics remained the same including the initial acceleration rate and the propulsion system.

Table 1-16 shows the energy analysis of the vehicle weight reduction strategy. Because of the decreased empty weight of the vehicle, the run time has decreased (peak period from 13.85 min to 13.79 min).

Table 1-17 shows the power bill analysis using the new fleet of reduced weight vehicles.

The net effect for vehicle weight reduction under the postulated circumstances is marginal (less than 1% change in the power bill).

There are three basic causes for this marginal behaviour:

1. Because of the lower weight vehicle and under the circumstances postulated (no change in the propulsion system), acceleration on the motor curve is higher causing more high speed running and higher performance. This counteracts the reduced energy effect of lower weight.

2. Vehicle weight affects the braking and train resistance energy end uses. The effect on train resistance is small since it does not influence the aerodynamic portion. Because of regeneration, the weight influence in the braking energy end use is also small. Weight has no affect on the auxiliary power and propulsion system losses. Thus, the weight influence on energy consumption is small, so that a change in weight produces a much smaller change in energy consumption.

3. Because of the change in train performance (run time) receptivity of braking energy is also changed. This effect could be either positive or negative.

1.2.2. Vehicle Streamlining

Vehicle streamlining was also tested on the base rail transit system using simulation. The aerodynamic factor of the front end of the train was reduced from the standard Davis equation value of (.0024) to .00226, a reduction of 6%.

Table 1-18 shows the energy analysis of the effects of improved vehicle streamlining. Table 1-19 shows the power bill analysis. In this case, there is little or no effect on train performance or run time, since the propulsion system or initial accelerating rate remains unchanged.

The overall effect of streamlining is small (<1%). The cause for this marginal effect is that the energy end use of the aerodynamic drag portion of train resistance is small. Thus small changes in this end use have a very small effect on system energy.

1.2.3. Propulsion System Efficiency

One energy end use of a moving train is the propulsion system losses caused in the conversion process of line electrical power to rail mechanical power and visa-versa during regeneration. Domestic rail transit service is in trains propelled by DC motors, either using cam-controlled resistor switching or chopper control of these motors. It is interesting to observe the effect of cam-control vs. chopper control on the same system without the effect of regeneration.

Two vehicle fleets were simulated. The base fleet was provided with cam-control. The propulsion system provided the same performance as the chopper. A traction energy summary of this base system is provided in Table 1-20. Table 1-21 presents a power bill analysis of the base system, similar to Table 1-9, where the power bill has been set to unit value. This cam-control base system is used for further analysis in applying the energy conservation strategies in the following sections of this chapter.

To make the comparison of cam-control vs. chopper propulsion without regeneration, the chopper propulsion system regeneration was turned off. The energy analysis is presented in Table 1-22. The power bill analysis, using the cam-control system as the base is presented in Table 1-23. Observation of these tables shows that the cam-control is slightly more energy cost-effective than the chopper without regeneration. The difference is approximately 1% in the power bill.

Cam-control losses occur during acceleration in the resistors. Chopper losses occur for both acceleration and constant speed running. Thus, chopper control tends to be more efficient for small interstation distances, while the cam-control tends to be more efficient for large interstation distances. In the case of the base transit system, the cam-control wins out, but only marginally.

1.2.4. Regeneration

Regeneration is the conversion of mechanical power during braking into electrical power, which may be used by other trains on the system, stored aboard the train (flywheel), stored in devices off-board the train or sold to the electric utility.

Regeneration with natural receptivity refers to the condition where only other trains on the system use the regenerated power. This case is the norm for all rail transit systems which use regeneration.

Regeneration with assured receptivity has not progressed beyond experiment, anywhere in the world. Assured receptivity means that some positive action is taken in the form of additional equipment to capture regenerated power, which would otherwise be lost under conditions of natural receptivity. This positive action can take the form of energy storage systems both on-board and off-board the trains, or regenerative substations, by which power can either be delivered back to the electric utility or used to power other portions of the transit system. The electric utility may give credit for the regenerated power, which it receives.

In the discussion of regeneration in the next few sections, the cam-control vehicle fleet is used as the base operation. It was described in the preceding section. Various comparisons are made using natural receptivity and the on-board storage and regenerative substation approach to assured receptivity. The results obtained in the WMATA study are also presented and discussed.

Regeneration does not change the schedule performance of trains, unless additional weight must be added such as is the case with on-board energy storage.

1.2.4.1. Regeneration with Natural Receptivity

Two cases are of interest. The first is a system where all cars can regenerate power. This condition applies at MARTA, MIAMI, BALTIMORE and BART, and most probably, in all new systems in the future. The second case relates to older systems and WMATA, which are in the process of adding regeneration to new cars, but the old ones remain as cam-control.

1.2.4.1.1 Case 1: All Cars Regenerate

The proper comparison is the all chopper car base fleet (with regeneration) to the cam-control base fleet.

Table 1-24 shows the energy analysis of the comparison. Table 1-25 provides the power bill analysis of the chopper (with regeneration) vs. the cam-control fleet.

Because of the better regeneration receptivity during peak operation, savings become larger as the demand portion of the bill increases. Substantial power cost savings are possible. The MARTA study concluded that 14% of a total power bill of $4.8M (1984) was saved because regeneration was selected.

1.2.4.1.2 Case 2: Some Cars Regenerate

The proper comparison is a fleet of some chopper cars mixed with cam-control cars against the cam-control base fleet. It is further assumed that the chopper cars with regeneration are used whenever possible, to save energy.

Out of the 102 cars required for peak service, it is assumed that 36 cars have chopper propulsion. These cars can be used as 6 six-car trains running together in the same consist, or as part of mixed consists. As mixed consist, there would be 2 trains with 3 chopper cars and 15 trains with 2 chopper cars, with an average of 2.12 chopper cars per train.

During off-peak periods, all chopper cars are used. Table 1-26 shows the energy analysis of the comparison of the scenario of running with the chopper cars in separate trains versus the base case of all cam-control trains. The power bill analysis for the same scenario is shown in Table 1-27.

Table 1-28 shows the energy analysis of the comparison of the scenario of running the chopper cars in mixed consists versus the base case of all cam-control trains. Table 1-29 presents the power bill analysis for this scenario.

The results show that running the chopper-cars in mixed consists is better from the point of view of energy cost savings than running them in separate consists. Since the on-board auxiliary loads are fed first during regenerative braking, with mixed consists, there is a larger fraction of regenerated power being accepted by the regenerating train. This condition increases the natural receptivity of the mixed consist over the separate consist scenario.

The rule can be generalized. When the fleet consists of mixed chopper and cam-control cars which can be trained, use the maximum number of chopper cars with the minimum number of cars per train in mixed consist. Under most circumstances this will provide the best energy savings.

A comparison of cost differences between cam-control and chopper cars was possible on the WMATA cars, because both types of cars were ordered simultaneously in 1982. This cost difference was $25,000/car (chopper > cam-control).

1.2.4.2. Regeneration with Assured Receptivity - On-Board Storage

The base fleet was modified so that all of the cars consisted of on-board storage devices. These devices increased the empty weight of the cars by 10%; however, because the propulsion system was not changed, the cars lost performance capability.

Table 1-30 shows the energy analysis comparison of the energy storage car fleet with the base cam-control fleet. Table 1-31 presents the power bill analysis for the same scenario.

The results again show substantial energy cost savings. There are two other effects which must be considered here. The increased weight of the cars reduced their performance causing both an increase of energy use (weight) and a decrease of energy use (performance reduction).

1.2.4.3. Regeneration with Assured Receptivity - Regenerative Substations

It was assumed for this case, that the base transit system had inverter substations, which could feed power back to the electric utility. It was further assumed that the utility gave full credit for this power (meters could rotate in both directions).

Table 1-32 provides the energy analysis of the comparison of the assured receptivity (regenerative substations) with the base cam-control operation. The power bill analysis is shown in Table 1-33.

This scenario has by far the largest energy cost savings. However, the assumption that the utility will give full credity or that the full regenerated energy could be used to power support functions may not be the best. Anything less than this assumption results in diminished savings.

1.2.4.4. Assured vs. Natural Receptivity

1.2.4.4.1 Base Transit System

A comparison of assured vs. natural receptivity is shown in Figure 1-12.

Regeneration with assured receptivity, using inverter substations, certainly leads in the energy savings category.

1.2.4.4.2 WMATA Case Study

During the WMATA study, assured receptivity was investigated using regenerative substations on on-board storage as alternative means for assuring that regenerated power would be used.

During the WMATA study, assured receptivity was investigated using regenerative substations and on-board energy storage as alternative means of assuring that regenerated power would be used. In the case of on-board storage, a flywheel was increased by 10%. A comparison of the 1981 $ savings among natural receptivity and the assured receptivity conditions of regenerative substations and on-board storage is shown in Figure 1-13. As compared to the natural receptivity case of 17% savings, the use of regenerative substations increases the savings to 20% and the use of on-board storage shows a 17% savings, the same as for natural receptivity. The reason for the small increase in savings for regenerative substations is that the WMATA rail system under natural conditions is already highly receptive, and that regenerative substations compete with natural receptivity.

1.3. OPERATIONAL STRATEGIES

1.3.1. Performance Modification

Performance modification strategies are those that reduce the normal train performance (run time increase) in order to reduce energy consumption. If performance is reduced too much, it will be necessary to add another train thus adding additional operating cost. The strategies to be considered are acceleration reduction, braking reduction, top speed reduction, coasting and optimum performance modification. The latter strategy represents the best energy trajectory per fixed schedule time increase. The effect of performance modification strategies depends upon whether a system is regenerative.

1.3.1.1. General

An illustration of the speed profiles and the power profile for both cam-control and chopper control (with regeneration) are shown for the base transit system in the several figures which follow:

Table 1-34

Length of Run (miles)		1.0			1.5	
Type Profile	Speed	Power	Power/Regen	Speed	Power	Power/Regen
Strategy			FIGURE #			
Minimum Time	1-14A	1-14B	1-14C	1-15A	1-15B	1-15C
Acceleration Reduction	1-16A	1-16B	1-16C	1-17A	1-17B	1-17C
Deceleration Reduction	1-18A	1-18B	1-18C	1-19A	1-19B	1-19C
Speed Reduction	1-20A	1-20B	1-20C	1-21A	1-21B	1-21C
Coasting	1-22A	1-22B	1-22C	1-23A	1-23B	1-23C

Table 1-35 summarizes the result of all of the runs depicted in Figures 1-14 (A, B, C) through Figures 1-23 (A, B, C).

The area under speed profiles must remain the same for a fixed run length, since the area is just the distance. The area under the power profile curves is just the energy.

1.3.1.2. Acceleration Reduction

The base transit system with chopper control was used to illustrate the effect of acceleration reduction on energy. The acceleration rate was reduced from 3.0 to 2.5 mphps.

The energy analysis of the acceleration reduction strategy is shown in Table 1-36A. The power bill analysis is presented in Table 1-36B.

The major energy effect of acceleration reduction occurs when the rate is reduced enough so that the train does not reach its former top speed within the interstation distance. This occurs for short station spacings.

1.3.1.3. Braking Reduction

For the purpose of illustrating the result of braking reduction on energy, the base transit system braking rate was reduced from 3.0 to 2.5 mphps. The result is shown in the energy analysis of Table 1-37A. The power bill analysis of this scenario is presented in Table 1-37B.

As in the case of acceleration reduction, a large effect on energy is realized when the braking rate is reduced enough so that the train is prevented from reaching its former top speed within the interstation distance. A second effect is the increased natural receptivity caused by the rate decrease. Less power is regenerated but over longer periods of time. Thus there is more of a chance that other trains on the system will use it.

1.3.1.4. Speed Reduction

The base transit system was used to illustrate the reduced energy and increased running time effect of the speed reduction strategy. This is one of the energy conservation strategies which is seriously considered by transit management, and, in fact is used on a regular basis. This strategy is discussed using the chopper control propulsion as the base system (regeneration) and the cam-control propulsion as the base system (no regeneration).

1.3.1.4.1 Speed Reduction with Regenerative Systems

The following tables show the energy and power bill analysis for the chopper control propulsion (with regeneration) on the base transit system for increasing values of run time (decreasing values of maximum speed)

Table 1-38

Increased Run Time* (minutes)	Maximum Speed* (mph)	Energy Analysis	Power Bill Analysis
+.25	62.4	1-39A	1-39B
+.50	58.0	1-40A	1-40B
+.75	54.8	1-41A	1-41B
+1.00	52.1	1-42A	1-42B
+1.25	49.9	1-43A	1-43B

* Normal run time is 13.85 min and normal maximum speed is 70 mph.

The results are summarized in Figure 1-24.

1.3.1.4.2 Speed Reduction with Non-Regenerative Systems

The following tables show the energy and power bill analysis for the cam-control propulsion with no regeneration on the base transit system for increasing values of run time (decreasing values of maximum speed)

Table 1-44

Increased Run Time* (minutes)	Maximum Speed (mph)	Energy Analysis	Power Bill Analysis
+.25	62.4	1-45A	1-45B
+.50	58.0	1-46A	1-46B
+.75	54.8	1-47A	1-47B
+1.00	52.1	1-48A	1-48B
+1.25	49.9	1-49A	1-49B

* Normal run time is 13.85 min and normal maximum speed is 70 mph.

The results are summarized in Figure 1-25.

1.3.1.5. Coasting

The base transit system was used to show the reduced energy and increased running time effect of the coasting strategy. This strategy is another that is seriously considered by transit management.

To effect coasting, acceleration occurs in the normal speed maintaining practice until a maximum (coast) speed is reached. Power is removed from the train and it is allowed to drift until the lower speed of a speed band error is reached. At this time, power is reapplied again and the cycle is repeated. For reasonable speed error bands (> 3 MPH), there is usually one cycle per interstation run. This strategy is discussed using two speed error bands (3 mph, 5 mph) and using the chopper control propulsion as the base system (regeneration) and the cam-control propulsion as the base system (no regeneration).

1.3.1.5.1 Coasting with Regenerative Systems

The following tables show the energy and power bill analysis for the chopper control propulsion (regeneration) on the base transit system for increasing values of run time (decreasing values of coast speed) at two speed error bands:

TABLE 1-50

Increased Run Time* (minutes)	Coast Speed (mph)	Energy Analysis	Power Bill Analysis
Case 1: Speed Error Band = 3 mph			
+.25	63.8	1-51A	1-51B
+.50	59.4	1-52A	1-52B
+.75	56.0	1-53A	1-53B
+1.00	53.4	1-54A	1-54B
+1.25	51.2	1-55A	1-55B
Case 2: Speed Error Band = 5 mph			
+.25	64.0	1-56A	1-56B
+.50	60.0	1-57A	1-57B
+.75	57.0	1-58A	1-58B
+1.00	54.5	1-59A	1-59B
+1.25	52.2	1-60A	1-60B

* Normal run time is 13.85 minutes

The results are summarized in Figures 1-26 (3 mph band) and 1-27 (mph band).

1.3.1.5.2 Coasting with Non-Regenerative Systems

The following tables show the energy and power bill analysis for the cam-control propulsion (no regeneration) on the base transit system for increasing values of run time (decreasing values of coast speed at two speed error bands):

TABLE 1-61

Increased Run Time* (minutes)	Coast Speed (mph)	Energy Analysis	Power Bill Analysis
Case 1: Speed Error Band = 3 mph			
+.25	63.8	1-62A	1-62B
+.50	59.4	1-63A	1-63B
+.75	56.0	1-64A	1-64B
+1.00	53.4	1-65A	1-65B
+1.25	51.2	1-66A	1-66B
Case 2: Speed Error Band = 5 mph			
+.25	64.0	1-67A	1-67B
+.50	60.0	1-68A	1-68B
+.75	57.0	1-69A	1-69B
+1.00	54.5	1-70A	1-70B
+1.25	52.2	1-71A	1-71B

* Normal run time is 13.85 minutes.

The results are summarized in Figures 1-28 (3 mph band) and 1-29 (5 mph band).

1.3.1.6. Optimum Performance Modification

Optimum performance modification is a future development for rail transit (just as assured receptivity is in regeneration).

1.3.1.6.1 General

Low energy consumption and minimum running time are conflicting objectives in a transit system. Transit cars are generally used to their maximum capability so that over given running profiles, the minimum running time is achieved. Usage of full capability does not result in minimum energy consumption.

Figure 1-30 shows a two dimensional objective space for the two conflicting objectives, running time and energy. The accessible region is the area in the running time vs. energy consumption plane which can be realized by a train with a fixed passenger load factor between two stations. Any point in this plane is accessible to the train as it moves between the stations.

The border of the accessible region is the non-inferior curve. It represents the extremum of energy consumption for a fixed running time which is greater than the minimum running time.

The problem of finding the optimum performance modification strategy is to find those strategies which lie near the lower portion of the non-inferior curve, so that for a given small increase in running time, a maximum energy saving is possible.

Here the optimization of the trajectory of an individual train is considered. The physical and performance characteristics of the train and its tracks are specified. The principle concern is that total energy E and total running time T be as small as possible.

1.3.1.6.2 Problem Description

The problem is to minimize:

$$J = E$$

where E is the total energy, subject to the constraints on the speed and propulsion system.

The train must meet the speed limits along the route,

$$o \leq v(x) \leq v_{max}(x)$$

where x is the position along the route.

$$x_o \leq x \leq x_f$$

and where x_o, x_f are the positions of the beginning and end of the route. The quantity $v_{max}(x)$ is the speed limit at position x.

Propulsion system models can relate the electric power, P_e, at the third rail shoe of the vehicle to the applied force, u, of the propulsion system at the wheels and the speed of the train, v. This relation has the form,

$$P_e = g(u,v) \ .$$

The applied force at the wheel, u, has a maximum and minimum value depending on the speed of the train, which is expressed in the form,

$$u_{min}(v) \leq u \leq u_{max}(v) \ .$$

Figure 1-31 shows the equation of motion and describes its components. The position of the train along the route is related to its speed by the equation:

$$v = dx/dt \ .$$

The curve resistance, C, and the grade resistance, G, are functions of the position of the train and the train resistance terms T_{RR} and T_{RA} are functions of the speed (v) of the train.

The total running time, T, can be expressed as the quantity

$$T = \int_{x_0}^{x_f} \frac{dx}{v(x)}$$

while the total energy consumed is

$$E = \int [P_a(t) + P_e(t)]dt ,$$

where, $P_a(t)$, is the power drawn by the auxiliaries (such as heating and air conditioning units) which is generally assumed to be constant in time.

It is desired to make T and E as small as possible. This problem was solved using two approaches. In the first approach, Monte Carlo techniques are used to generate all feasible trajectories in the E-T plane and only those are selected which have minimum E for fixed T. The second approach is a multiobjective optimization technique which minimizes the quantity,

$$J = E .$$

1.3.1.6.3 Monte Carlo Algorithm

A Monte Carlo Simulation was done for the problem of the form described in the previous section, namely,

$$\text{Min } E\ (\underline{v},\underline{t})$$

subject to:

$$T < T_a \text{ (prespecified)}$$
$$\alpha \leq v \leq \beta \text{ (prespecified)}$$
$$o \leq v \leq v_{max}(x) .$$

Here α and β are the minimum and maximum speeds generated by the propulsion system, i.e., speeds corresponding to minimum and maximum applied force that can be delivered through the propulsion system at the wheels.

The Monte Carlo procedure generates random vectors v distributed on two-way negative exponential distribution with mean $R_1\alpha + R_2\beta$ ($R_1 + R_2 = 1$) and variance R_3.

The quantities R_1, R_2 and R_3 are randomly generated using a Random Number Generator, and these are the same for a set of speeds.

Each v_i randomly generated was checked for the three constraints. v_i was set to the constraint each time it violated a constraint. Energy was calculated for the vector v and T. Energy was retained if it did not violate the time constraint, and energy was less than the previously stored values. In this way, the lower most bottom portion of the accessible region was traced.

Appropriate choice of R_1, R_2 and R_3 ranges have provided fairly efficient runs of Monte Carlo. Overall, as long as $R_1\alpha+R_2\beta$ is tilted towards β, and R_3 is around 20, it provides good results.

Description of Random Number Generator.

The Random Number Generator used for the purpose was system routine RAN(IDUM) which generates random number uniformly distributed between 0 and 1. Figure 1-32 provides the probability density function f(x) and probability distribution function F(x) for RAN(IDUM).

For the purpose of simulation, it was better to use negative exponential distribution as uniform random numbers provide large changes more often, and thus leading to a higher probability of sub-optimal results. Negative exponential distribution, on the other hand, provides a tapering in the density function. Figure 1-32 provides the probability density and probability distribution function for negative exponential distribution.

Now, in order to generate negative exponential distributed random numbers, it is necessary to use $F^{-1}(x)$ where x is uniformly distributed random number. For negative exponential distribution,

$$F(0) = 0$$

$$F(\infty) = 1$$

$$F(x) = -e^{\mu x}/\mu$$

Hence, if random number selected from a uniform distribution is y, then:

$$y = \log x/\mu \quad \text{or}$$

$$x = -\mu \log \mu y.$$

1.3.1.6.4 The Trajectory Optimization Algorithm

The purpose of this algorithm is to minimize J = E, subject to all the constraints of the system, and $T = T_1$ where T_1 is a specific travel time assigned to route.

The steepest descent method is used in the minimization procedure because of its simplicity in programming and because for this specific problem, it converges in a reasonable amount of time. The algorithm is summarized below.

1. Generate a feasible trajectory to serve as an initial guess.

2. Discretize with respect to distance (divide the distance to be covered into appropriate intervals).

3. Calculate δJ_i for i = 1, 2, . . ., n-1.

Here J = E

$$E = \frac{x_1 - x_0}{v_0} P(v_0, u_0) + \frac{1}{2}\sum_{i=1}^{n-1} \frac{x_{i+1} - x_{i-1}}{v_i} P(v_i, u_i) + \frac{x_n - x_{n-1}}{v_n} P(v_n, u_n)$$

$$T = \frac{x_1 - x_0}{v_0} + \tfrac{1}{2}\sum_{i=1}^{n-1} \frac{x_{i+1} - x_{i-1}}{v_i} + \frac{x_n - x_{n-1}}{v_n}$$

Subject to $T = T_1$ where T_1 is a specific travel time assigned so that the solution of the problem generates a point on the convex portion as shown in Figure 1-33. Thus,

$$\frac{\partial E}{\partial v_i} = \tfrac{1}{2}\left(\frac{x_{i+1} - x_{i-1}}{v_i} \frac{\partial P(v_i, u_i)}{\partial v_i} - \frac{x_{i+1} - x_{i-1}}{v_i^2} P(v_i, u_i) + \frac{x_i - x_{i-2}}{v_{i-1}} \frac{\partial P(v_{i-1}, u_{i-1})}{\partial v_i} + \frac{x_{i+2} - x_i}{v_{i+1}} \frac{\partial P(v_{i+1}, u_{i+1})}{\partial v_i} \right)$$

because u_{i-1}, u_i, u_{i+1} are functions of v_i,

$$u_i = M_E a_i + G + C + T_{RR} + T_{RA}$$

$i = 1, 2, \ldots, n-1$

and

$$a_i = v_i \frac{v_{i+1} - v_{i-1}}{x_{i+1} - x_{i-1}}$$

Again,

$$\frac{\partial P}{\partial v_i}(v_i, u_i) = \left.\frac{\partial P}{\partial v_i}\right|_{\substack{u_i \\ \text{const.}}} + \left.\frac{\partial P}{\partial u_i}\right|_{\substack{v_i \\ \text{const.}}} \frac{\partial u_i}{\partial v_i}$$

$$\frac{\partial P}{\partial v_i}(v_{i-1}, u_{i-1}) = \left.\frac{\partial P}{\partial v_i}\right|_{\substack{u_{i-1} \\ \text{const.}}} + \left.\frac{\partial P}{\partial u_{i-1}}\right|_{\substack{v_{i-1} \\ \text{const.}}} \frac{\partial u_{i-1}}{\partial v_i}$$

$$\frac{\partial P}{\partial v_i}(v_{i+1}, u_{i+1}) = \left.\frac{\partial P}{\partial v_i}\right|_{\substack{u_{i+1} \\ \text{const.}}} + \left.\frac{\partial P}{\partial u_{i+1}}\right|_{\substack{v_{i+1} \\ \text{const.}}} \frac{\partial u_{i+1}}{\partial v_i}$$

and

4. Determine C^j such that

$$C^j = T(v^j) \;/\; T_1$$

5. Calculate $v^{j-1/2}$ such that

$$v^{j-1/2} = C^j v^j$$

6. Calculate $\delta J_i = \partial E \;/\; \partial v_i^{j-1/2}$.

7. Calculate new v_i^j by taking a small step in the direction of the gradient, i.e., set

$$v_i^j = v_i^{j-1/2} - \alpha \delta J_i$$

where v_i^j is the velocity, i, in j^{th} iteration and α is a constant which gives suitable step which minimizes the objective function J.

The step size α has been calculated using the quadratic approximation for the objective function described in the next section.

8. The gradient projection method is used to test all the constraints, i.e.,

- Verify if v_i^j abides by the speed restriction. If not, set v_i^j equal to the speed restriction.
- Calculate αi and β_i velocities corresponding to the minimum and maximum tractive force.

$$\text{If } v_i^j < \alpha_i \text{ set } v_i^j = \alpha_i$$

$$\text{If } v_i^j > \beta_i \text{ set } v_i^j = \beta_i$$

9. Test for convergence using the following criterion:

$$\| \delta J \| = \Sigma (\delta J_i)^2 \leq \in$$

and

$$|C^j - 1| \leq \delta$$

where $\in$ and δ have a prefixed value. If process has converged, stop, otherwise return to 4.

The algorithm for discretization and minimization is summarized in a flow chart shown in Figure 1-34.

1.3.1.6.5 Algorithm for Selecting Optimal Step Size

Consider approximating the function $J(\alpha)$ by a function $\mu(\alpha)$ which has an easily determined minimum point. The simplest 1- variable function possessing a minimum is the quadratic:

$$\mu(\alpha) = a + b\alpha + c\alpha^2$$

the minimum of which occurs where

$$(d\mu) \,/\, d\alpha) = 0 \Rightarrow b + 2c\alpha = 0$$

$$\text{or} \qquad \alpha* = (-b \,/\, 2c)$$

The constants b and c for the approximating quadratic can be determined by sampling the function at three different α values, e.g., 0, t and 2t where t is the preselected trial step and evaluating the functions at these three α values at:

$\alpha = 0$ $\qquad f_1 = a$

$\alpha = t$ $\qquad f_2 = a + bt + ct^2$

$\alpha = 2t$ $\qquad f_3 = a + 2bt + 4ct^2$

The above equations give

$a = f_1$

$b = (4f_2 - 3f_1 - f_3) \,/\, 2t$

$c = (f_3 + f_1 - 2f_2) \,/\, 2t^2$

therefore,

$$\alpha* = (-b/2c) \simeq (4f_2 - 3f_1 - f_3) \,/\, (4f_2 - 2f_3 - 2f_1)$$

Also, for $\alpha*$ to correspond a minimum it must satisfy

$$(d^2\mu \,/\, d\alpha^2) \,|_{\alpha*} > 0 \quad \Rightarrow \quad C > 0$$

For $C > 0$ we should have

$$f_3 + f_1 > 2f_2$$

This means that the value of f_2 must be below the line connecting f_1 and f_3.

The logic for the quadratic interpolation described above is given in the flow diagram shown in Figure 1-35.

1.3.1.6.6 WMATA Case Study

The WMATA Red Line running from Dupont Circle to Silver Spring was selected for the optimization purpose.

Using the actual motor and brake curve, the total run of 9.81 miles has been optimized using Monte Carlo and Steepest Descent. The results are summarized in Tables 1-72 and 1-73, respectively.

1.3.1.7. Coasting vs. Speed Reduction

1.3.1.7.1 On Regenerative Systems

Figure 1-36 shows a comparison of coasting and speed reduction with a vehicle fleet using the chopper propulsion with regeneration. Speed reduction saves the least energy per unit run time increase. As the coasting speed error band increases, the energy savings increase until a point is reached where no more physical coasting can be done within the longest station spacing on the system.

1.3.1.7.2 On Non-Regenerative Systems

Figure 1-37 shows a comparison of coasting and speed reduction strategies with a vehicle fleet using cam-control propulsion without regeneration. Again speed reduction saves the least energy per unit increase in run time.

1.3.1.8. Performance Modification Predictions on WMATA and MARTA

Several performance modification strategies were simulated on the WMATA and MARTA rail systems.

The results of speed reduction and anticipatory coasting on the Red line and Blue/Orange lines of WMATA are plotted in Figure 1-38. The graphs show the decrease in energy consumption at the train and do not include the effects of power distribution system losses.

Figure 1-39 shows the results of speed reduction and anticipatory coasting on the NS and EW lines of MARTA. The plots reflect the conditions of 100% receptivity upon regeneration. Again, power distribution losses are not included.

Several performance modification strategies were evaluated on the Red line of WMATA. The results are presented in Figure 1-40. Power distribution losses are not included.

In all cases, coasting is a better strategy than speed reduction in terms of energy saved for fixed schedule time increase. However, for the speed reduction strategy, only the top speed of the train was reduced. At schedule time increases of 2-3%, which limit increases in one way trip time to less than one minute, traction energy savings on WMATA ranged from 12-16%. On the Red line of WMATA, application of optimum performance reduction can result in energy consumption decreases of 17-20% with a 1% increase in schedule time. These decreases are estimated at the train rather than the meters.

Using the anticipatory coasting results in Figures 1-38 to 1-40 as a guide, energy cost savings were determined using sawtooth coasting. Power distribution losses were considered in these estimates. In all cases, the schedule time increase was limited to less than one minute. The results are detailed in Table 1-74. Coasting is predicted to save 5% of the power bill on WMATA and 6% of the power bill on MARTA. The one minute schedule time increase could be made up at turnaround; thus, the capacity of the system would be unaffected.

At the time, the cost to modify the cars was estimated at $32K (1981 $) at WMATA and $200K (1985 $) at MARTA. These low initial costs mean immediate payback if the strategy is applied.

1.3.2. Train Operation Strategies

1.3.2.1. Scheduling for Improved Passenger Load Factor

1.3.2.1.1 Base Transit System

The base transit system was used to illustrate the effect of improving passenger load factor by running shorter trains at higher load factors during the peak operating periods and running shorter trains during selected off-peak periods.

During the peak periods, the number of cars per train was reduced from six to four. This effectively increased the passenger load factor from 50% to 75%. During the daily evening operation, the number of cars per train was reduced from four to two, which effectively increased the passenger load factor from 25% to 37.5%.

The operating timetable for the passenger load factor improvement is shown alongside the original timetable in Table 1-75.

The energy analysis of the passenger load factor effect on energy is shown in Table 1-76A. The power bill analysis is shown in Table 1-76B.

In practice, more careful attention would be payed to scheduling but this analysis conveys the intention.

1.3.2.1.2 WMATA and MARTA Results

The original timetables used in the WMATA and MARTA studies together with car-miles/hr during the peak period and annual car-miles are listed in Tables 1-12 and 1-13, respectively. During the course of the studies, only one new scheduling strategy was suggested for WMATA operations. This strategy was the reduction of train consist size during off-peak operation. During midday on weekdays, alternate 4 and 6 car trains, instead of all 5 car trains, would be run and on evenings, Saturday and Sunday, alternate 2 and 4 car trains would be run instead of 6 car trains. The annual savings were 1.178M, 1.069M and 1.570M car-miles on the Red, Blue and Orange lines respectively. As presented in Table 1-13 this amounted to 5% in energy cost savings.

On the MARTA rail system, several scheduling strategies were analyzed, each one successively increasing the passenger load factor by reducing car-miles. At the lowest level of passenger load factor improvement, the principal changes in the schedule were:

1. Alternate trains on the EW line would run from Hightower to Candler Park, where they would turn back during weekday peak and midday. This schedule would be used instead of all trains running from Hightower to Avondale.

2. Four car trains would be used instead of six car trains on the run from Lakewood to Brookhaven on the NS line during peak and midday, weekday operation. All other service remains the same.

These strategies will reduce the annual car-mi on the NS line by 344K and on the EW line by 489K. In addition, since the scheduling reduces the car-mi/hr during the peak periods from 940 to 790 on the EW line and from 1427 to 1162 on the NS line, there is a savings in power demand as well. The demand and energy savings are detailed in Table 1-77. Application of this strategy reduces the electric bill by 7%.

1.3.2.2. Scheduling to Improve Regeneration Receptivity on MARTA

Regeneration receptivity is a measure of the ability for the trains on the system to use the power being regenerated by trains on the system. Consider a two track rail line such as the MARTA EW or NS line. The positions of the trains along the lines at any instant of time are determined by the headway and offset. The headway is the time between trains moving in any given direction, while the offset is the difference in time to within one headway of a train leaving one terminal and a train departing from the opposite terminal. For example, if the trains leave a terminal at 7:00 a.m., 7:05 a.m., 7:10 a.m., etc., and the schedule for trains leaving the opposite terminal is 6:58 a.m., 7:03 a.m., 7:08 a.m., etc., then the headway is 5 minutes and the offset is 3 minutes. As defined here, the offset can vary from zero to one headway. Under ideal conditions, a two track system operating at constant headway, with identical trains and train movement, is cyclic. Thus, train positions, speeds and power are repeated every headway in time and no offset has the same effect on power flow as one headway of offset.

To study the effect of scheduling on regeneration receptivity, the energy use per car-mile was estimated as a function of offset over the period of one headway. The higher the energy consumption per car-mile the less the regeneration receptivity.

Regeneration receptivity is difficult to define quantitatively because the condition of a 100% receptive system does not exist. In this study, receptivity is defined as the ratio (%) of energy saved as a result of regeneration to the maximum energy capable of being delivered by the trains to the third rail. It can only be determined through simulation, because the 100% receptive condition cannot be realized in actual operation. Table 1-78 shows the estimate of system receptivity under conditions of normal operation during 1983-1984. One would generally expect the receptivity to be high during the peak periods and low during non-peak periods. However, because regeneration receptivity depends on both offset and headway, this is not always the case.

Using the EMM, the schedule offset was varied in one-minute steps for both operating periods selected (AM peak and evening). The results are summarized in graphical form in Figure 1-41. During the peak period, maximum variations [(max-min)/average] in energy consumption of 7.2% and 2.7% were observed to occur on the NS and EW lines, respectively. During the evening operating period, a maximum variation of 9.9% and 9.2% was observed to occur on the NS and EW lines, respectively.

The energy variation as a function of schedule offset can be translated into energy $. Table 1-79 provides the details of this translation. The difference between the maximum and minimum annual energy cost as a result of schedule offset is estimated at $106K, or 2.6% of the electric bill.

Since scheduling trains without taking the offset energy effects into account would be expected to lie somewhere between the maximum and minimum, most probably half-way, taking energy effects of offset scheduling into account might save $53K per year. There are other scheduling constraints which may either enhance or diminish this estimated cost savings.

1.3.3. Support Energy Reduction

1.3.3.1. WMATA Case Study

Opportunities for support energy cost reduction at WMATA were identified in the lighting and escalator loads.

1.3.3.1.1 Lighting Load Reduction

Several recommendations were made by the General Manager's Lighting Task Force on lighting energy conservation opportunities.

One recommendation was to replace the indirect fluorescent lighting with direct mercury vapor lighting in both side and center platform underground stations. The estimated reduction in power was 82KW/side platform station, and 39KW/center platform station.

The peak power demand reduction and annual energy savings on incorporating these lighting changes are shown in Table 1-80.

There are two aspects to the lighting improvement costs which were used as the basis for the lighting energy cost reduction estimates. The capital cost for the improvement was $33,000 per underground station, and $28,000 for surface station. In addition, because of less labor and materials required in bulb replacement, there is an annual cost savings of $2,064 for side platform stations, and $1,216 for center platform stations. Above ground stations savngs are estimated at $521.

Based on these cost figures with 11 above ground stations and 23 underground stations at the time, of which 14 of the underground stations were center platform and 9 stations were side platform, the capital cost was estimated at $1,076,000, and the cost savings in addition to energy is $41,331.

The General Manager's Committee on Lighting recommended that the indirect fluorescent lighting at the passenger stations be replaced with direct mercury vapor lighting. The energy cost savings is estimated at $675,000/year (4-5% of the overall power cost) with an additional savings in replacement lamps estimated at $41,000/year, or a total annual savings of $716,000. The estimated capital cost is $1,067,000 which would be payed back in 1 1/2 years.

1.3.3.1.2 Escalator Load Reduction

A strategy for reducing escalator energy consumption would be to turn off all escalators under 16 ft. height of rise and the third escalator in areas where three escalators service the station from one entrance during off-peak periods.

Table 1-81 presents the results of this strategy. Since escalators are turned off during the non-peak periods, there is no effect on peak power demand reduction. The effect on support energy is very small (1%).

The annual energy cost savings achieved by turning off all escalators with less than 16 ft. height of rise, and the third escalator in areas where three are serving the station from one entrance, in off-peak periods, was $32,000 (< 1% of total power costs).

Unless this strategy is used for egress control, turning off "down" escalators during peak periods, was not recommended because heavily loaded down escalators can regenerate power.

1.3.3.2. MARTA Case Study

Because of the nature of the ratchet on the billing demand at MARTA [i.e., the billing demand remains at 95% of the maximum monthly demand obtained during the summer months (June-September)], an opportunity for effective load management exists. A true load managing strategy would be used during the weekday AM and PM peak operating periods, in anticipation of reducing a high power demand. Although traction load reduction will reduce power demand on a continuous basis, it is support load reduction which can be used as part of true load management strategy. For every 1000 KW of support load which is shed during the periods of highest demand during the summer months, annual savings of $122K are possible. The chosen load reduction strategy need only be used during the summer months.

1.3.3.2.1 Installed Support Power Tabulation

The last survey of installed support load on the MARTA rail system was conducted several years ago. This survey forms the basis of the analysis.

The installed support loads identified in the survey were divided into the general categories of VENTILATION, HEATING, LIGHTING, AIR CONDITIONING, ESCALATORS & ELEVATORS, TRAIN CONTROL & COMMUNICATIONS, FARE COLLECTION, and MISCELLANEOUS. The survey covered all of the EW line and the downtown portion of the NS line. The installed support loads are summarized by category in Table 1-82.

Because of the nature of the billing demand ratchet, it is clear that to be most effective, the load must be shed during the summer months. Since even one operating period of high power demand in which the load were not shed, could negate the load managing strategy, load shedding must be effected with equipment which is easily turned off and on and is reliable. It is also important that safety, security, comfort and convenience of passengers not be compromised.

At the outset, only two categories of load might satisfy the above mentioned conditions: LIGHTING and AIR CONDITIONING. The remaining load categories do not meet the conditions mentioned. The LIGHTING and AIR CONDITIONING represent 2000 KW and 6000 KW of surveyed installed load, respectively.

Reduction of lighting had been considered by MARTA staff as a method of reducing energy cost. It cannot be considered a load management strategy in the sense discussed, since

1. Any lighting which can be turned off without affecting passenger safety and security in structures not exposed to daylight should be permanently off.

2. For outside facilities which receive adequate natural lighting during the day, the lights should be turned off during daylight hours if the cost to do so is less than the cost to keep them lit.

During the summertime, daylight hours span the peak operating periods, so that turning off lights will naturally reduce peak demand. Because of the nature of the installed lighting loads, it is not easy to turn them off and on, and negligence could jeopardize safety and security.

The only remaining load category which satisfies the load managing strategy conditions is AIR CONDITIONING. Not all air conditioning would qualify (e.g., air conditioning in the central control facility or other vital equipment enclosures).

Since the chillers would operate during the summer months, it is natural to think of chiller plant load shedding as a potential strategy. By using the chillers to cool to lower, but comfortable temperatures during the hours just before the AM and PM peak operating periods, the chiller plants could be unloaded during the peak periods to keep the temperature just below the maximum for passenger comfort. In utility terms, this form of load management is known as peak shaving and valley filling. Three criteria must be satisfied before the strategy can be used.

1. The chillers can easily be loaded and unloaded.

2. The cost for loading and unloading must not exceed the cost of the savings.

3. The chiller load must be part of the peak load.

Further study of these requirements was recommended.

TABLE 1-1 VEHICLE CHARACTERISTICS

Empty Weight (tons)	36.0
Crush Load Weight (tons)	52.5
Vehicle Length (ft)	75.0
Cross Sectional Area (sq. ft.)	80.0
Measured Flange Coefficient (lbs/ton/mph)	0.071
Number of Axles (All Powered)	4
Auxiliary Power (kW)	30
Wheel Diameter (inches)	28
Lead Vehicle Air Drag Coefficient (lbs/ton/mph^2)	.0024
Trail Vehicle Air Drag Coefficient (lbs/ton/mph^2)	.00034

TABLE 1-2 VEHICLE PROPULSION AND BRAKING SYSTEM CHARACTERISTICS

Motors per vehicle - 4
Motor characteristic - (W) Type 1462
Chopper Control
Initial accelerating rate 3 MPHPS
Wheel diameter 28 inch
Gear ratio 5.414 to 1
Maximum speed - 70 MPH
Line voltage (V) (nominal, maximum, minimum) - 750, 860, 600
Field strengths available in power 1.00, 0.7, 0.5, 0.4
Field strengths available in brake 1.00

Motor Control Philosophy

Load weighing device aboard vehicle automatically sets the propulsion control so that initial accelerating rate is 3 MPHPS in acceleration, and that dynamic plus friction braking provides a constant rate of 3 MPHPS throughout all speed ranges. Dynamic braking provides as much of the braking effort being supplemented by friction braking when:

- enough braking effort cannot be provided to maintain the 3 MPHPS braking rate.
- the line voltage is too high to accept regenerative braking.
- regenerative braking is turned off.

Propulsion

- Motors are connected in two series/two parallel.
- To increase speed, the control sets motor amps to maximum possible acceleration rate not to exceed 3 MPHPS.
- A 60% field shunt (field strength = 40%) is brought in in three steps when request for tractive effort exceeds availability at 100% field.

Braking Control Philosophy

- Motors are connected in two series/two parallel.
- Note that a resistor is needed to limit line voltage at high speed.
- Friction braking is used to supplement dynamic braking effort and keep the total braking effort at 3.0 MPHPS.

TABLE 1-3
OPERATING TIMETABLE SUMMARY

SERVICE	TIME PERIOD	CARS/TRAIN	HEADWAY(MIN)
Weekday			
Morning	12:00 am-6:00 am	NO SERVICE	
Peak	6:00 am-9:00 am	6	2
Midday	9:00 am-3:00 pm	4	4
Peak	3:00 pm-6:00 pm	6	2
Evening	6:00 pm-12:00 pm	4	8
Sat., Sun. & Hol.			
Morning	12:00 am-6:00 am	NO SERVICE	
Day	6:00 am-6:00 pm	4	8
Evening	6:00 pm-12:00 am	2	8

Trains leave on the hour from both terminals.

TABLE 1-4 TRAIN PERFORMANCE AND ENERGY SUMMARY FOR NORMAL OPERATION

		RUN TIME(MIN)		KWHPCM	
PERIOD	TIME	EASTBOUND	WESTBOUND	MINIMUM*	NORMAL**
WEEKDAY					
MORNING	12:00AM - 6:00AM	NS	NS		
AM PEAK	6:00AM - 9:00AM	13.85	13.83	4.82	6.31
MIDDAY	9:00AM - 3:00PM	13.77	13.76	4.60	5.96
PM PEAK	3:00PM - 6:00PM	13.85	13.83	4.82	6.31
EVENING	6:00PM - 12:00AM	13.77	13.76	4.60	6.28
SAT & SUN					
MORNING	12:00AM - 6:00AM	NS	NS		
DAY	6:00AM - 6:00PM	13.77	13.76	4.60	6.28
EVENING	6:00PM - 12:00AM	13.76	13.76	4.79	5.73

NS - NO SERVICE
* 100% REGENERATION RECEPTIVITY
** NATURAL RECEPTIVITY

TABLE 1-5 NORMAL OPERATION CHOPPER(BASE)
ESTIMATE OF TURNAROUND AND CAR STORAGE POWER FOR BASE TRANSIT SYSTEM

NAME OF PERIOD	HEADWAY MINUTES	CARS PER TRAIN	MIN TURNAROUND TIME WEST	MIN TURNAROUND TIME EAST	RUN TIME EASTBOUND	RUN TIME WESTBOUND	SCHEDULE SLACK(MIN)	MIN # OF TRAINS	TOTAL CARS	CARS REQUIRED	CARS STORED	TURNAROUND POWER(KW)	STORAGE POWER(KW)	TOTAL POWER(KW)
PEAK	2	6	3	3	13.85	13.83	0.32	17	102	102	0	569	0	569
MIDDAY	4	4	3	3	13.77	13.76	2.47	9	102	36	66	254	1980	2234
EVENING	8	4	3	3	13.77	13.76	6.47	5	102	20	82	187	2460	2647
SAT&SUN EVENING	8	2	3	3	13.76	13.76	6.48	5	102	10	92	94	2760	2854
NO SERVICE		0							102	0	102	0	3060	3060

NOTES: 30 KW/CAR AUXILIARY POWER

TABLE 1-6

NORMAL OPERATION CHOPPER(BASE)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	
WEEKDAY												
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		
AM PEAK	6:00AM - 9:00AM	3	2877.90	5.48	8633.70	47313	15771	569	1706	49019	16340	
MIDDAY	9:00AM - 3:00PM	6	959.25	5.49	5755.50	31598		2234	13405	45002		
PM PEAK	3:00PM - 6:00PM	3	2877.90	5.48	8633.70	47313		569	1706	49019		
EVENING	6:00PM - 12:00AM	6	479.63	5.84	2877.75	16806		2647	15882	32688		32688
	O											
TOTAL		24		5.52	25901	143029			32700	175729		
SAT & SUN												
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		
DAY	6:00AM - 6:00PM	12	479.63	5.84	5755.50	33612		2647	31765	65377		
EVENING	6:00PM - 12:00AM	6	239.63	5.57	1437.75	8008		2854	17122	25130		
TOTAL		24		5.79	7193.25	41620			48886	90507		
WEEKLY				5.55	143890	798386	15771		261271	1059657	16340	
ANNUAL				5.55	7482267	41516088	189251		13586087	55102175	196076	

TABLE 1-7 SUPPORT POWER REQUIREMENTS BY FUNCTION BY SEASON

SPRING AND AUTUMN

SUPPORT LOAD FUNCTION	STATION A	STATION B	STATION C	STATION D	STATION E	STATION F	STATION G	STATION H	STATION I	STATION J	Maintnce	Central	TOTAL
Ventilation				200	200	200	200				200	100	1100
Heating												100	100
Air Conditioning													0
Lighting	100	100	50	100	100	100	100	50	50	100	100	50	1000
Escalators & Elevators				300	300	300	300						1200
Train Control & Communications	100	100	100	100	100	100	100	100	100	100		500	1500
Fare Collection	50	50	50	100	100	100	100	50	50	50			700
Miscellaneous	50	50	50	150	150	150	150	50	50	50	400	100	1400
TOTAL	300	300	250	950	950	950	950	250	250	300	700	850	7000

WINTER

SUPPORT LOAD FUNCTION	STATION A	STATION B	STATION C	STATION D	STATION E	STATION F	STATION G	STATION H	STATION I	STATION J	Maintnce	Central	TOTAL
Ventilation				200	200	200	200				200	100	1100
Heating	200	200	200	300	300	300	300	200	200	200	300		2700
Air Conditioning												100	100
Lighting	100	100	50	100	100	100	100	50	50	100	100	50	1000
Escalators & Elevators				300	300	300	300						1200
Train Control & Communications	100	100	100	100	100	100	100	100	100	100		500	1500
Fare Collection	50	50	50	100	100	100	100	50	50	50			700
Miscellaneous	50	50	50	150	150	150	150	50	50	50	400	100	1400
TOTAL	500	500	450	1250	1250	1250	1250	450	450	500	1000	850	9700

SUMMER

SUPPORT LOAD FUNCTION	STATION A	STATION B	STATION C	STATION D	STATION E	STATION F	STATION G	STATION H	STATION I	STATION J	Maintnce	Central	TOTAL
Ventilation	50	50	50	200	200	200	200	50	50	50	200	100	1400
Heating												50	50
Air Conditioning				500	500	500	500				50	300	2350
Lighting	100	100	50	100	100	100	100	50	50	100	100	50	1000
Escalators & Elevators				300	300	300	300						1200
Train Control & Communications	100	100	100	100	100	100	100	100	100	100		500	1500
Fare Collection	50	50	50	100	100	100	100	50	50	50			700
Miscellaneous	50	50	50	150	150	150	150	50	50	50	400	100	1400
TOTAL	350	350	300	1450	1450	1450	1450	300	300	350	750	1100	9600

TABLE 1-8 SUMMARY NORMAL POWER AND ENERGY USE

		SUPPORT POWER		TRACTION POWER		TOTAL POWER	
PERIOD	MONTHS	POWER	ENERGY USE	POWER	ENERGY USE	POWER	ENERGY USE
SPRING	3	7000	15330000	16340	13775544	23340	29105544
SUMMER	3	9600	21024000	16340	13775544	25940	34799544
AUTUMN	3	7000	15330000	16340	13775544	23340	29105544
WINTER	3	9700	21243000	16340	13775544	26040	35018544
ANNUAL	12	99900	72927000	196080	55102175	295980	128029175
PERCENT		0.34	0.57	0.66	0.43	1.00	1.00

POWER - KW ENERGY - KWH

TABLE 1-9

NORMAL OPERATION CHOPPER(BASE)
POWER BILL ANALYSIS

PORTION OF	DEMAND NORMAL	0.00	0.25	0.50	0.75	1.00
		RATE(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338
TRACTION(MW)	196.08					
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000
TRACTION(MKWH)	55.10					
SUPPORT(MKWH)	72.93					
TOTAL(MKWH)	128.03					

TABLE 1-10 VEHICLE, PROPULSION AND BRAKING CHARACTERISTICS

	WMATA	MARTA
VEHICLE PHYSICAL CHARACTERISTICS		
Empty Weight(tons)	36.0	38.0
Crush Load Weight(tons)*	52.5	58.5
Length(ft)	75.0	75.0
Cross Sectional Area(sq ft)	85.0	116.0
Flange Coefficient(lbs/ton/mph)	0.071	0.045
Average Auxiliary Power(kw)	30.0	35.0
Lead Vehicle Air Drag(lbs/ton/mph/mph)	0.0024	0.0024
Trail Vehicle Air Drag(lbs/ton/mph/mph)	0.00034	0.00034
PROPULSION AND BRAKING CHARACTERISTICS		
Motors	DC Series/Field Shunt	DC Separately Excited
Control	Cam Resistor Switching Chopper(Regeneration)	Chopper(Regeneration)
Normal Accelerating Rate(mphps)	3.0	2.6
Maximum Speed(mph)	75.0	70.0
Normal Braking Rate(mphps)	3.0	Tapered**
Line Voltage(Nominal, Max, Min)	755, 900, 600	750, 860, 600

* WMATA based on 220 - 150 lb passengers/car
MARTA based on 273 - 150 lb passengers/car

** Brake taper:
2.0 mphps 50 mph < v < 70 mph
3.0 mphps 20 mph < v < 50 mph
2.0 mphps 0 mph < v < 20 mph

TABLE 1-11 ROUTE AND OPERATING CHARACTERISTICS OF STUDY

			DISTANCE(mi)	NUMBER OF STATIONS	AVERAGE INTERSTATION SPACING(mi)	AVERAGE SPEED(mph)
WMATA						
	RED LINE	Dupont Circle to Silver Spring	9.89	11	0.99	31.4
	BLUE LINE	National Airport to Addison Road	15.87	21	0.79	33.3
	ORANGE LINE	Ballston to New Carrollton	16.57	22	0.79	27.7
MARTA						
	NS LINE	Lakewood to Brookhaven	13.25	13	1.10	35.0
	EW LINE	Hightower to Avondale	11.75	13	0.98	34.0

TABLE 1-12 TIMETABLE DATA

	HEADWAY (MIN)	CARS/TRAIN
WMATA		
RED LINE		
WEEKDAY PEAK	5	6&8
WEEKDAY OFF-PEAK	10	6
SATURDAY	10	6
SUNDAY	10	6
BLUE & ORANGE LINES**		
WEEKDAY PEAK	6	6
WEEKDAY OFF-PEAK	12	6
SATURDAY	12	6
SUNDAY	12	6
MARTA		
NS LINE		
WEEKDAY PEAK***	6	6
WEEKDAY MIDDAY***	6	4
WEEKDAY EVENING	10	4
SATURDAY	10	2
SUNDAY	15	2
EW LINE		
WEEKDAY PEAK	6	4
WEEKDAY MIDDAY	6	4
WEEKDAY EVENING	10	4
SATURDAY	10	2
SUNDAY	15	2

* During peak periods, six 6-car trains and five 8-car trains operate.

** Headway refers to route between Rossyln and DG Junction.

*** On weekdays during peak and midday periods, half of the trains run from Lakewood to Lenox while the other half run from Lenox to Brookhaven. The headway refers to route from Lakewood to Lenox.

TABLE 1-13 ANNUAL AND HOURLY CAR-MILES

	ANNUAL CAR-MI MILLIONS			CAR-MI/HR
	PEAK	OFF-PEAK	TOTAL	PEAK
WMATA(1980)				
RED LINE	2.467	3.057	5.524	1644
BLUE LINE	2.477	3.083	5.560	1470
ORANGE LINE	3.309	4.111	7.420	1988
TOTAL	8.253	10.251	18.504	5102
MARTA(1985)				
N-S LINE	3.172	1.336	4.507	1057
E-W LINE	2.815	0.908	3.724	938
TOTAL	5.987	2.244	8.231	1995

TABLE 1-14 ELECTRIC BILL ANALYSIS

	WMATA (1981)*	MARTA (1984)*
Annual Energy Cost ($M)	15.7	4.1
Demand Related	46%	50%
Energy Related	54%	50%
Traction Related	70%	40%
Support Related	30%	60%
Cost/kWH	$0.0561	$0.0435
Estimated Annual Demand	734,100 kW	179,800kW
Estimated Annual Energy	271000 MWh	951000 MWh

BILLING FACTORS

	DEMAND	ENERGY	DEMAND INTERVAL
WMATA*			
PEPCO DC	$11.70/kW	$0.028/kWh	30 min.
PEPCO MD	9.85/kW	0.024/kWh	30 min.
PEPCO VA	7.85/kW	0.022/kWh	30 min.
VEPCO VA		0.061/kWh	
MARTA GPC*	11.62/kW	0.0227/kWH	60 min.

* WMATA costs and rates in 1981 dollars
MARTA costs and rates in 1984 dollars

TABLE 1-15 PREDICTED VS ACTUAL ENERGY CONSUMPTION (KWHPCM)

	ACTUAL	PREDICTED	DIFFERENCE
WMATA (1980)			
RED LINE	6.87	6.63	-4%
BLUE/ORANGE LINE	5.73	6.16	+7%
MARTA (1983&1984)			
1983 OPERATING PERIOD	5.01	4.54	-9%
1984 OPERATING PERIOD	4.17	4.33	+4%
ALL	4.69	4.46	-5%

TABLE 1-16
TEN PERCENT VEHICLE WEIGHT REDUCTION(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2879.40	5.65	8638.20	48806	16269	580	1739	50545	16848	49019	16340	-1526	-509
MIDDAY	9:00AM - 3:00PM	6	959.40	5.25	5756.40	30221		2237	13424	43646		45002		1357	
PM PEAK	3:00PM - 6:00PM	3	2879.40	5.65	8638.20	48806		580	1739	50545		49019		-1526	
EVENING	6:00PM - 12:00AM	6	479.70	5.48	2878.20	15773		2649	15892	31665		32688		1024	
TOTAL		24		5.54	25911	143605			32794	176399		175729		-671	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.70	5.48	5756.40	31545		2649	31784	63329		65377		2047	
EVENING	6:00PM - 12:00AM	6	239.93	5.24	1439.55	7543		2854	17126	24669		25130		461	
TOTAL		24		5.43	7195.95	39088			48911	87999		90507		2508	
WEEKLY				5.53	143947	796203	16269		261792	1057995	16848	1059657	16340	1662	-509
ANNUAL				5.53	7485239	41402562	195223		13613184	55015746	202179	55102175	196076	86429	-6102

TABLE 1-17
TEN PERCENT VEHICLE WEIGHT REDUCTION(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00	DEMAND ENERGY SAVINGS	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						-6.10					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						-6.10	0.000	-0.005	-0.010	-0.015	-0.021
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						0.09					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						0.09	0.001	0.001	.000	.000	0.000
							FRACTION	0.001	-0.005	-0.010	-0.015	-0.021
							PERCENT	0.1	-0.5	-1.0	-1.5	-2.1

TABLE 1-18
VEHICLE STREAMLINING(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2878.20	5.47	8634.60	47231	15744	569	1706	48938	16313	49019	16340	81	27
MIDDAY	9:00AM - 3:00PM	6	959.25	5.47	5755.50	31483		2234	13406	44889		45002		113	
PM PEAK	3:00PM - 6:00PM	3	2878.20	5.47	8634.60	47231		569	1706	48938		49019		81	
EVENING	6:00PM - 12:00AM	6	479.63	5.82	2877.75	16749		2647	15883	32632		32688		57	
TOTAL		24		5.51	25902	142694			32702	175396		175729		333	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.63	5.82	5755.50	33497		2647	31766	65263		65377		113	
EVENING	6:00PM - 12:00AM	6	239.63	5.52	1437.75	7936		2854	17122	25058		25130		72	
TOTAL		24		5.76	7193.25	41433			48888	90321		90507		185	
WEEKLY				5.53	143899	796335	15744		261288	1057623	16313	1059657	16340	2034	27
ANNUAL				5.53	7482735	41409412	188925		13586976	54996388	195751	55102175	196076	105787	326

TABLE 1-19
VEHICLE STREAMLINING(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND / ENERGY / NORMAL	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND / ENERGY / SAVINGS	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						0.33					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						0.33	0.000	.000	0.001	0.001	0.001
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						0.11					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						0.11	0.001	0.001	.000	.000	0.000
							FRACTION	0.001	0.001	0.001	0.001	0.001
							PERCENT	0.1	0.1	0.1	0.1	0.1

TABLE 1-20
NORMAL OPERATION CAM-CONTROL(BASE)
ENERGY ANALYSIS

						RUNNING TRAINS		TURNAROUND & STORAGE		TOTAL	
PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	KWH	KW PEAK	KW	KWH	KWH	KW PEAK
WEEKDAY											
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360	
AM PEAK	6:00AM - 9:00AM	3	2877.90	9.02	8633.70	77876	25959	569	1706	79582	26527
MIDDAY	9:00AM - 3:00PM	6	959.25	8.63	5755.50	49670		2234	13405	63075	
PM PEAK	3:00PM - 6:00PM	3	2877.90	9.02	8633.70	77876		569	1706	79582	
EVENING	6:00PM - 12:00AM	6	479.63	8.61	2877.75	24777		2647	15882	40660	
TOTAL		24		8.89	25901	230199			32700	262899	
SAT & SUN											
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360	
DAY	6:00AM - 6:00PM	12	479.63	8.61	5755.50	49555		2647	31765	81319	
EVENING	6:00PM - 12:00AM	6	239.63	8.54	1437.75	12278		2854	17122	29400	
TOTAL		24		8.60	7193.25	61833			48886	110719	
WEEKLY				8.86	143890	1274663	25959		261271	1535934	26527
ANNUAL				8.86	7482267	66282485	311504		13586087	79868572	318329

TABLE 1-21
NORMAL OPERATION CAM-CONTROL(BASE)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>						
	DEMAND	0.00	0.25	0.50	0.75	1.00
	ENERGY	1.00	0.75	0.50	0.25	0.00
	NORMAL	RATE(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239
TRACTION(MW)	318.33					
SUPPORT(MW)	99.90					
TOTAL(MW)	418.23					
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000
TRACTION(MKWH)	79.87					
SUPPORT(MKWH)	72.93					
TOTAL(MKWH)	152.80					

TABLE 1-22
CHOPPER VS CAM-CONTROL NO REGENERATION
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.90	9.17	8633.70	79171	26390	569	1706	80877	26959	79582	26527	-1295	-432
MIDDAY	9:00AM - 3:00PM	6	959.25	8.70	5755.50	50073		2234	13405	63477		63075		-403	
PM PEAK	3:00PM - 6:00PM	3	2877.90	9.17	8633.70	79171		569	1706	80877		79582		-1295	
EVENING	6:00PM - 12:00AM	6	479.63	8.67	2877.75	24950		2647	15882	40832		40660		-173	
TOTAL		24		9.01	25901	233365			32700	266065		262899		-3166	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.63	8.67	5755.50	49900		2647	31765	81665		81319		-345	
EVENING	6:00PM - 12:00AM	6	239.63	8.56	1437.75	12307		2854	17122	29429		29400		-29	
TOTAL		24		8.65	7193.25	62207			48886	111094		110719		-374	
WEEKLY				8.97	143890	1291240	26390		261271	1552511	26959	1535934	26527	-16576	-432
ANNUAL				8.97	7482267	67144462	316684		13586087	80730549	323510	79868572	318329	-861976	-5180

TABLE 1-23
CHOPPER VS CAM-CONTROL NO REGENERATION
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 1.00	0.25 0.75	0.50 0.50 RATE(POWER BILL UNITS)	0.75 0.25	1.00 0.00	DEMAND ENERGY SAVINGS	0.00 1.00	0.25 0.75	0.50 0.50 SAVINGS(POWER BILL UNITS)	0.75 0.25	1.00 0.00
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						-5.18					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						-5.18	0.000	-0.003	-0.006	-0.009	-0.012
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						0.86					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						0.86	0.006	-0.004	-0.003	-0.001	0.000
							FRACTION	-0.006	-0.007	-0.009	-0.011	-0.012
							PERCENT	-0.6	0.7	-0.9	-1.1	-1.2

TABLE 1-24
CHOPPER(REGENERATION) VS CAM-CONTROL
ENERGY ANALYSIS

						RUNNING TRAINS		TURNAROUND & STORAGE		TOTAL		NORMAL TOTAL		DIFFERENCE	
PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	KWH	KW PEAK	KW	KWH	KWH	KW PEAK	KWH	KW PEAK	KWH	KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.90	5.48	8633.70	47313	15771	569	1706	49019	16340	79582	26527	30563	10188
MIDDAY	9:00AM - 3:00PM	6	959.25	5.49	5755.50	31598		2234	13405	45002		63075		18072	
PM PEAK	3:00PM - 6:00PM	3	2877.90	5.48	8633.70	47313		569	1706	49019		79582		30563	
EVENING	6:00PM - 12:00AM	6	479.63	5.84	2877.75	16806		2647	15882	32688		40660		7971	
TOTAL		24		5.52	25901	143029			32700	175729		262899		87170	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.63	5.84	5755.50	33612		2647	31765	65377		81319		15943	
EVENING	6:00PM - 12:00AM	6	239.63	5.57	1437.75	8008		2854	17122	25130		29400		4270	
TOTAL		24		5.79	7193.25	41620			48886	90507		110719		20213	
WEEKLY				5.55	143890	798386	15771		261271	1059657	16340	1535934	26527	476277	10188
ANNUAL				5.55	7482267	41516088	189251		13586087	55102175	196076	79868572	318329	24766397	122253

TABLE 1-25
CHOPPER(REGENERATION) VS CAM-CONTROL
POWER BILL ANALYSIS

PORTION OF	DEMAND	0.00	0.25	0.50	0.75	1.00	DEMAND	0.00	0.25	0.50	0.75	1.00
POWER BILL ==>	ENERGY	1.00	0.75	0.50	0.25	0.00	ENERGY	1.00	0.75	0.50	0.25	0.00
	NORMAL	RATE(POWER BILL UNITS)					SAVINGS	SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						122.25					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						122.25	0.000	0.073	0.146	0.219	0.292
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						24.77					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						24.77	0.162	0.122	0.081	0.041	0.000
							FRACTION	0.162	0.195	0.227	0.260	0.292
							PERCENT	16.2	19.5	22.7	26.0	29.2

TABLE 1-26
CHOPPER(1/4 FLEET) VS CAM-CONTROL SEPARATE TRAINS
ENERGY ANALYSIS

						RUNNING TRAINS		TURNAROUND & STORAGE		TOTAL		NORMAL TOTAL		DIFFERENCE	
PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	KWH	KW PEAK	KW	KWH	KWH	KW PEAK	KWH	KW PEAK	KWH	KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	3013.55	7.87	9040.65	71150	23717	569	1706	72856	24285	79582	26527	6726	2242
MIDDAY	9:00AM - 3:00PM	6	959.25	5.49	5755.50	31598		2234	13405	45002		63075		18072	
PM PEAK	3:00PM - 6:00PM	3	3013.55	7.87	9040.65	71150		569	1706	72856		79582		6726	
EVENING	6:00PM - 12:00AM	6	479.63	5.84	2877.75	16806		2647	15882	32688		40660		7971	
TOTAL		24		7.14	26715	190704			32700	223403		262899		39496	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.63	5.84	5755.50	33612		2647	31765	65377		81319		15943	
EVENING	6:00PM - 12:00AM	6	239.63	5.57	1437.75	8008		2854	17122	25130		29400		4270	
TOTAL		24		5.79	7193.25	41620			48886	90507		110719		20213	
WEEKLY				7.01	147959	1036759	23717		261271	1298030	24285	1535934	26527	237904	2242
ANNUAL				7.01	7693881	53911453	284600		13586087	67497539	291425	79868572	318329	12371033	26904

TABLE 1-27
CHOPPER(1/4 FLEET) VS CAM-CONTROL SEPARATE TRAINS
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND / ENERGY / NORMAL			RATE(POWER BILL UNITS)			DEMAND / ENERGY / SAVINGS			SAVINGS(POWER BILL UNITS)		
DEMAND		0.00	0.25	0.50	0.75	1.00	DEMAND	0.00	0.25	0.50	0.75	1.00
ENERGY		1.00	0.75	0.50	0.25	0.00	ENERGY	1.00	0.75	0.50	0.25	0.00
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						26.90					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						26.90	0.000	0.016	0.032	0.048	0.064
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						12.37					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						12.37	0.081	0.061	0.040	0.020	0.000
							FRACTION	0.081	0.077	0.073	0.068	0.064
							PERCENT	8.1	7.7	7.3	6.8	6.4

TABLE 1-28
CHOPPER(1/4 FLEET) VS CAM-CONTROL MIXED CONSISTS
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	3013.55	7.75	9040.65	70065	23355	569	1706	71771	23924	79582	26527	7811	2604
MIDDAY	9:00AM - 3:00PM	6	959.25	5.49	5755.50	31598		2234	13405	45002		63075		18072	
PM PEAK	3:00PM - 6:00PM	3	3013.55	7.75	9040.65	70065		569	1706	71771		79582		7811	
EVENING	6:00PM - 12:00AM	6	479.63	5.84	2877.75	16806		2647	15882	32688		40660		7971	
TOTAL		24		7.06	26715	188534			32700	221234		262899		41666	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.63	5.84	5755.50	33612		2647	31765	65377		81319		15943	
EVENING	6:00PM - 12:00AM	6	239.63	5.57	1437.75	8008		2854	17122	25130		29400		4270	
TOTAL		24		5.79	7193.25	41620			48886	90507		110719		20213	
WEEKLY				6.93	147959	1025910	23355		261271	1287181	23924	1535934	26527	248753	2604
ANNUAL				6.93	7693881	53347316	280260		13586087	66933403	287086	79868572	318329	12935169	31244

TABLE 1-29
CHOPPER(1/4 FLEET) VS CAM-CONTROL MIXED CONSISTS
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND / ENERGY / NORMAL	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND / ENERGY / SAVINGS	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						31.24					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						31.24	0.000	0.019	0.037	0.056	0.075
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						12.94					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						12.94	0.085	0.063	0.042	0.021	0.000
							FRACTION	0.085	0.082	0.080	0.077	0.075
							PERCENT	8.5	8.2	8.0	7.7	7.5

TABLE 1-30
ASSURED RECEPTIVITY - ON BOARD STORAGE
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2876.10	6.31	8628.30	54445	18148	572	1717	56162	18721	79582	26527	23421	7807
MIDDAY	9:00AM - 3:00PM	6	958.95	6.10	5753.70	35098		2231	13383	48481		63075		14594	
PM PEAK	3:00PM - 6:00PM	3	2876.10	6.31	8628.30	54445		572	1717	56162		79582		23421	
EVENING	6:00PM - 12:00AM	6	479.48	6.08	2876.85	17491		2645	15872	33363		40660		7297	
TOTAL		24		6.24	25887	161478			32689	194167		262899		68732	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.48	6.08	5753.70	34982		2645	31743	66725		81319		14594	
EVENING	6:00PM - 12:00AM	6	239.70	6.14	1438.20	8831		2852	17109	25940		29400		3460	
TOTAL		24		6.09	7191.90	43813			48852	92665		110719		18054	
WEEKLY				6.22	143820	895016	18148		261149	1156164	18721	1535934	26527	379770	7807
ANNUAL				6.22	7478617	46540827	217778		13579722	60120549	224647	79868572	318329	19748023	93682

TABLE 1-31
ASSURED RECEPTIVITY - ON BOARD STORAGE
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND / ENERGY / NORMAL	DEMAND 0.00 / ENERGY 1.00	DEMAND 0.25 / ENERGY 0.75	DEMAND 0.50 / ENERGY 0.50	DEMAND 0.75 / ENERGY 0.25	DEMAND 1.00 / ENERGY 0.00	SAVINGS	DEMAND 0.00 / ENERGY 1.00	DEMAND 0.25 / ENERGY 0.75	DEMAND 0.50 / ENERGY 0.50	DEMAND 0.75 / ENERGY 0.25	DEMAND 1.00 / ENERGY 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						93.68					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						93.68	0.000	0.056	0.112	0.168	0.224
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						19.75					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						19.75	0.129	0.097	0.065	0.032	0.000
							FRACTION	0.129	0.153	0.177	0.200	0.224
							PERCENT	12.9	15.3	17.7	20.0	22.4

TABLE 1-32
ASSURED RECEPTIVITY - REGENERATIVE SUBSTATIONS
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.90	5.21	8633.70	44982	14994	569	1706	46688	15563	79582	26527	32894	10965
MIDDAY	9:00AM - 3:00PM	6	959.25	5.31	5755.50	30562		2234	13405	43966		63075		19108	
PM PEAK	3:00PM - 6:00PM	3	2877.90	5.21	8633.70	44982		569	1706	46688		79582		32894	
EVENING	6:00PM - 12:00AM	6	479.63	5.29	2877.75	15223		2647	15882	31106		40660		9554	
TOTAL		24		5.24	25901	135748			32700	168448		262899		94451	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.63	5.29	5755.50	30447		2647	31765	62211		81319		19108	
EVENING	6:00PM - 12:00AM	6	239.63	5.03	1437.75	7232		2854	17122	24353		29400		5047	
TOTAL		24		5.24	7193.25	37678			48886	86565		110719		24155	
WEEKLY				5.24	143890	754098	14994		261271	1015369	15563	1535934	26527	520565	10965
ANNUAL				5.24	7482267	39213082	179926		13586087	52799169	186752	79868572	318329	27069403	131578

TABLE 1-33
ASSURED RECEPTIVITY - REGENERATIVE SUBSTATIONS
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND	0.00	0.25	0.50	0.75	1.00	DEMAND	0.00	0.25	0.50	0.75	1.00
	ENERGY	1.00	0.75	0.50	0.25	0.00	ENERGY	1.00	0.75	0.50	0.25	0.00
	NORMAL	RATE(POWER BILL UNITS)					SAVINGS	SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						131.58					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						131.58	0.000	0.079	0.157	0.236	0.315
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						27.07					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						27.07	0.177	0.133	0.089	0.044	0.000
							FRACTION	0.177	0.212	0.246	0.280	0.315
							PERCENT	17.7	21.2	24.6	28.0	31.5

TABLE 1-35

DEFINITION OF LEVEL-TANGENT TRACK RUNS FOR PERFORMANCE MODIFICATION
2/17/86

TPS	CL	T	ST	P	REMARKS	TIME	KWHPCM
CAM-CONTROL STATION SPACING = 1.0 MILE							
001	F01	CAM	E01	R1E1	MIN TIME	1.28	7.71
002	F02	CAM	E01	R1E2	SPEED RED	1.32	7.01
003	F03	CAM	E01	R1E3	ACCEL RED	1.32	7.74
004	F04	CAM	E01	R1E4	DECEL RED	1.32	7.62
005	F05	CAM	E01	R1E5	COASTING	1.32	6.00
CHOPPER-CONTROL STATION SPACING = 1.0 MILE							
101	F01	CHO	E01	C1E1	MIN TIME	1.28	4.31
102	F02	CHO	E01	C1E2	SPEED RED	1.32	4.08
103	F03	CHO	E01	C1E3	ACCEL RED	1.32	4.27
104	F04	CHO	E01	C1E4	DECEL RED	1.32	4.19
105	F05	CHO	E01	C1E5	COASTING	1.32	3.16
CAM-CONTROL STATION SPACING = 1.5 MILE							
0F1	G01	CAM	F01	R1F1	MIN TIME	1.71	6.16
0F2	G02	CAM	F01	R1F2	SPEED RED	1.76	5.91
0F3	G03	CAM	F01	R1F3	ACCEL RED	1.76	6.21
0F4	G04	CAM	F01	R1F4	DECEL RED	1.76	6.08
0F5	G05	CAM	F01	R1F5	COASTING	1.76	4.66
CHOPPER-CONTROL STATION SPACING - 1.5 MILE							
1F1	G01	CHO	F01	C1F1	MIN TIME	1.71	3.89
1F2	G02	CHO	F02	C1F2	SPEED RED	1.76	3.83
1F3	G03	CHO	F03	C1F3	ACCEL RED	1.76	3.91
1F4	G04	CHO	F04	C1F4	DECEL RED	1.76	3.77
1F5	G05	CHO	F05	C1F5	COASTING	1.76	2.77

TABLE 1-36A
ACCELERATION REDUCTION(2.5 MPHPS)(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2874.90	5.04	8624.70	43468	14489	524	1571	45040	15013	49019	16340	3979	1326
MIDDAY	9:00AM - 3:00PM	6	957.75	4.60	5746.50	26434		2219	13311	39745		45002		5257	
PM PEAK	3:00PM - 6:00PM	3	2874.90	5.04	8624.70	43468		524	1571	45040		49019		3979	
EVENING	6:00PM - 12:00AM	6	478.88	5.29	2873.25	15199		2639	15836	31035		32688		1653	
TOTAL		24		4.97	25869	128570			32289	160860		175729		14869	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	478.88	5.29	5746.50	30399		2639	31671	62070		65377		3307	
EVENING	6:00PM - 12:00AM	6	239.40	5.47	1436.40	7857		2850	17097	24954		25130		175	
TOTAL		24		5.33	7182.90	38256			48768	87024		90507		3482	
WEEKLY				5.01	143712	719364	14489		258983	978347	15013	1059657	16340	81310	1326
ANNUAL				5.01	7473001	37406929	173874		13467121	50874051	180160	55102175	196076	4228124	15917

TABLE 1-36B

ACCELERATION REDUCTION(2.5 MPHPS)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	DEMAND 0.00 / ENERGY 1.00	DEMAND 0.25 / ENERGY 0.75	DEMAND 0.50 / ENERGY 0.50	DEMAND 0.75 / ENERGY 0.25	DEMAND 1.00 / ENERGY 0.00	DEMAND ENERGY SAVINGS	DEMAND 0.00 / ENERGY 1.00	DEMAND 0.25 / ENERGY 0.75	DEMAND 0.50 / ENERGY 0.50	DEMAND 0.75 / ENERGY 0.25	DEMAND 1.00 / ENERGY 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						15.92					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						15.92	0.000	0.013	0.027	0.040	0.054
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						4.23					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						4.23	0.033	0.025	0.017	0.008	0.000
							FRACTION	0.033	0.038	0.043	0.049	0.054
							PERCENT	3.3	3.8	4.3	4.9	5.4

TABLE 1-37A
BRAKING REDUCTION(2.5 MPHPS)(CHOPPER)
ENERGY ANALYSIS

						RUNNING TRAINS		TURNAROUND & STORAGE		TOTAL		NORMAL TOTAL		DIFFERENCE	
PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	KWH	KW PEAK	KW	KWH	KWH	KW PEAK	KWH	KW PEAK	KWH	KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2876.10	5.07	8628.30	43745	14582	518	1553	45298	15099	49019	16340	3721	1240
MIDDAY	9:00AM - 3:00PM	6	958.65	5.56	5751.90	31981		2217	13302	45283		45002		-280	
PM PEAK	3:00PM - 6:00PM	3	2876.10	5.07	8628.30	43745		518	1553	45298		49019		3721	
EVENING	6:00PM - 12:00AM	6	479.33	6.11	2875.95	17572		2639	15831	33403		32688		-715	
TOTAL		24		5.29	25884	137044			32238	169282		175729		6447	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.33	6.11	5751.90	35144		2639	31662	66806		65377		-1429	
EVENING	6:00PM - 12:00AM	6	239.40	5.97	1436.40	8575		2849	17096	25671		25130		-541	
TOTAL		24		6.08	7188.30	43719			48758	92477		90507		-1970	
WEEKLY				5.37	143799	772657	14582		258705	1031362	15099	1059657	16340	28295	1240
ANNUAL				5.37	7477540	40178150	174982		13452660	53630810	181192	55102175	196076	1471365	14884

TABLE 1-37B
BRAKING REDUCTION(2.5 MPHPS)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND ENERGY SAVINGS	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						14.88					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						14.88	0.000	0.013	0.025	0.038	0.050
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						1.47					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						1.47	0.011	0.009	0.006	0.003	0.000
							FRACTION	0.011	0.021	0.031	0.041	0.050
							PERCENT	1.1	2.1	3.1	4.1	5.0

TABLE 1-39A
SPEED REDUCTION(MIN RUN TIME + .25 MIN)(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2874.90	5.29	8624.70	45625	15208	524	1571	47196	15732	49019	16340	1823	608
MIDDAY	9:00AM - 3:00PM	6	958.50	4.81	5751.00	27662		2218	13307	40970		45002		4033	
PM PEAK	3:00PM - 6:00PM	3	2874.90	5.29	8624.70	45625		524	1571	47196		49019		1823	
EVENING	6:00PM - 12:00AM	6	479.25	5.32	2875.50	15298		2639	15834	31131		32688		1557	
TOTAL		24		5.19	25876	134209			32284	166493		175729		9236	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.25	5.32	5751.00	30595		2639	31667	62263		65377		3114	
EVENING	6:00PM - 12:00AM	6	239.40	5.18	1436.40	7441		2850	17097	24538		25130		592	
TOTAL		24		5.29	7187.40	38036			48765	86801		90507		3706	
WEEKLY				5.20	143754	747118	15208		258949	1006067	15732	1059657	16340	53590	608
ANNUAL				5.20	7475224	38850148	182499		13465343	52315490	188784	55102175	196076	2786684	7292

TABLE 1-39B
SPEED REDUCTION(MIN RUN TIME + .25 MIN)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00	DEMAND ENERGY SAVINGS	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00
				RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)		
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						7.29					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						7.29	0.000	0.006	0.012	0.018	0.025
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						2.79					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						2.79	0.022	0.016	0.011	0.005	0.000
							FRACTION	0.022	0.022	0.023	0.024	0.025
							PERCENT	2.2	2.2	2.3	2.4	2.5

TABLE 1-40A
SPEED REDUCTION(MIN RUN TIME + .5 MIN)(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.30	5.11	8631.90	44109	14703	478	1434	45543	15181	49019	16340	3476	1159
MIDDAY	9:00AM - 3:00PM	6	959.25	5.19	5755.50	29871		2201	13208	43079		45002		1923	
PM PEAK	3:00PM - 6:00PM	3	2877.30	5.11	8631.90	44109		478	1434	45543		49019		3476	
EVENING	6:00PM - 12:00AM	6	479.63	5.60	2877.75	16115		2631	15784	31900		32688		789	
TOTAL		24		5.18	25897	134204			31860	166064		175729		9664	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.63	5.6	5755.50	32231		2631	31568	63799		65377		1578	
EVENING	6:00PM - 12:00AM	6	239.85	5.43	1439.10	7814		2846	17073	24887		25130		243	
TOTAL		24		5.57	7194.60	40045			48641	88687		90507		1820	
WEEKLY				5.22	143874	751113	14703		256583	1007695	15181	1059657	16340	51962	1159
ANNUAL				5.22	7481471	39057852	176436		13342306	52400158	182171	55102175	196076	2702017	13905

TABLE 1-40B
SPEED REDUCTION(MIN RUN TIME + .5 MIN)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	DEMAND 0.00 / ENERGY 1.00	DEMAND 0.25 / ENERGY 0.75	DEMAND 0.50 / ENERGY 0.50	DEMAND 0.75 / ENERGY 0.25	DEMAND 1.00 / ENERGY 0.00	DEMAND ENERGY SAVINGS	DEMAND 0.00 / ENERGY 1.00	DEMAND 0.25 / ENERGY 0.75	DEMAND 0.50 / ENERGY 0.50	DEMAND 0.75 / ENERGY 0.25	DEMAND 1.00 / ENERGY 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						13.91					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						13.91	0.000	0.012	0.023	0.035	0.047
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						2.70					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						2.70	0.021	0.016	0.011	0.005	0.000
							FRACTION	0.021	0.028	0.034	0.041	0.047
							PERCENT	2.1	2.8	3.4	4.1	4.7

TABLE 1-41A
SPEED REDUCTION(MIN RUN TIME + .75 MIN)(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.00	4.67	8631.00	40307	13436	433	1299	41605	13868	49019	16340	7414	2471
MIDDAY	9:00AM - 3:00PM	6	959.25	5.36	5755.50	30849		2186	13118	43968		45002		1034	
PM PEAK	3:00PM - 6:00PM	3	2877.00	4.67	8631.00	40307		433	1299	41605		49019		7414	
EVENING	6:00PM - 12:00AM	6	479.63	5.73	2877.75	16490		2623	15739	32229		32688		460	
TOTAL		24		4.94	25895	127953			31455	159408		175729		16321	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.63	5.73	5755.50	32979		2623	31478	64457		65377		919	
EVENING	6:00PM - 12:00AM	6	239.85	5.63	1439.10	8102		2842	17051	25153		25130		-23	
TOTAL		24		5.71	7194.60	41081			48529	89610		90507		897	
WEEKLY				5.02	143865	721925	13436		254333	976258	13868	1059657	16340	83399	2471
ANNUAL				5.02	7481003	37540097	161227		13225306	50765402	166422	55102175	196076	4336773	29654

TABLE 1-41B
SPEED REDUCTION(MIN RUN TIME + .75 MIN)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND ENERGY SAVINGS	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						29.65					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						29.65	0.000	0.025	0.050	0.075	0.100
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						4.34					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						4.34	0.034	0.025	0.017	0.008	0.000
							FRACTION	0.034	0.050	0.067	0.084	0.100
							PERCENT	3.4	5.0	6.7	8.4	10.0

TABLE 1-42A
SPEED REDUCTION(MINIMUM RUN TIME + 1.MIN)(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2879.70	4.53	8639.10	39135	13045	387	1161	40296	13432	49019	16340	8723	2908
MIDDAY	9:00AM - 3:00PM	6	958.95	4.99	5753.70	28711		2171	13025	41736		45002		3267	
PM PEAK	3:00PM - 6:00PM	3	2879.70	4.53	8639.10	39135		387	1161	40296		49019		8723	
EVENING	6:00PM - 12:00AM	6	479.48	5.37	2876.85	15449		2615	15692	31141		32688		1547	
TOTAL		24		4.73	25909	122430			31039	153469		175729		22260	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.48	5.37	5753.70	30897		2615	31385	62282		65377		3095	
EVENING	6:00PM - 12:00AM	6	239.78	5.19	1438.65	7467		2838	17027	24494		25130		636	
TOTAL		24		5.33	7192.35	38364			48412	86776		90507		3731	
WEEKLY				4.79	143928	688877	13045		252020	940897	13432	1059657	16340	118760	2908
ANNUAL				4.79	7484279	35821624	156540		13105030	48926654	161184	55102175	196076	6175521	34892

TABLE 1-42B
SPEED REDUCTION(MINIMUM RUN TIME + 1.MIN)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND / ENERGY / NORMAL	DEMAND 0.00 / ENERGY 1.00	DEMAND 0.25 / ENERGY 0.75	DEMAND 0.50 / ENERGY 0.50	DEMAND 0.75 / ENERGY 0.25	DEMAND 1.00 / ENERGY 0.00	SAVINGS	DEMAND 0.00 / ENERGY 1.00	DEMAND 0.25 / ENERGY 0.75	DEMAND 0.50 / ENERGY 0.50	DEMAND 0.75 / ENERGY 0.25	DEMAND 1.00 / ENERGY 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						34.89					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						34.89	0.000	0.029	0.059	0.088	0.118
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						6.18					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						6.18	0.048	0.036	0.024	0.012	0.000
							FRACTION	0.048	0.066	0.083	0.100	0.118
							PERCENT	4.8	6.6	8.3	10.0	11.8

TABLE 1-43A
SPEED REDUCTION(MIN RUN TIME + 1.25MIN)(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2874.30	5.04	8622.90	43459	14486	342	1026	44485	14828	49019	16340	4534	1511
MIDDAY	9:00AM - 3:00PM	6	958.80	4.65	5752.80	26751		2136	12935	39685		45002		5317	
PM PEAK	3:00PM - 6:00PM	3	2874.30	5.04	8622.90	43459		342	1026	44485		49019		4534	
EVENING	6:00PM - 12:00AM	6	479.40	5.01	2876.40	14411		2608	15647	30058		32688		2630	
TOTAL		24		4.95	25875	128080			30634	158714		175729		17014	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NG					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.40	5.01	5752.80	28822		2608	31295	60116		65377		5260	
EVENING	6:00PM - 12:00AM	6	239.70	4.96	1438.65	7136		2834	17004	24139		25130		990	
TOTAL		24		5.00	7191.45	35957			48299	84256		90507		6251	
WEEKLY				4.95	143758	712315	14486		249768	962083	14828	1059657	16340	97574	1511
ANNUAL				4.95	7475411	37040382	173838		12987936	50028318	177942	55102175	196076	5073857	18135

TABLE 1-43B
SPEED REDUCTION(MIN RUN TIME + 1.25MIN)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND / ENERGY / NORMAL	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND / ENERGY / SAVINGS	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						18.13					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						18.13	0.000	0.015	0.031	0.046	0.061
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						5.07					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						5.07	0.040	0.030	0.020	0.010	0.000
							FRACTION	0.040	0.045	0.050	0.056	0.061
							PERCENT	4.0	4.5	5.0	5.6	6.1

TABLE 1-45A
SPEED REDUCTION(MIN TIME + .25 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2874.90	8.58	8624.70	74000	24667	524	1571	75571	25190	80100	26700	4529	1510
MIDDAY	9:00AM - 3:00PM	6	958.50	7.80	5751.00	44858		2218	13307	58165		63075		4909	
PM PEAK	3:00PM - 6:00PM	3	2874.90	8.58	8624.70	74000		524	1571	75571		80100		4529	
EVENING	6:00PM - 12:00AM	6	479.25	7.77	2875.50	22343		2639	15834	38176		40660		2483	
TOTAL		24		8.32	25876	215200			32284	247484		263935		16451	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.25	7.77	5751.00	44685		2639	31667	76353		81319		4967	
EVENING	6:00PM - 12:00AM	6	239.40	7.67	1436.40	11017		2850	17097	28114		29400		1285	
TOTAL		24		7.75	7187.40	55702			48765	104467		110719		6252	
WEEKLY				8.26	143754	1187406	24667		258949	1446355	25190	1541114	26700	94759	1510
ANNUAL				8.26	7475224	61745130	296000		13465343	75210473	302285	80137944	320402	4927471	18116

TABLE 1-45B
SPEED REDUCTION(MIN TIME + .25 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	DEMAND 0.00 ENERGY 1.00	DEMAND 0.25 ENERGY 0.75	DEMAND 0.50 ENERGY 0.50	DEMAND 0.75 ENERGY 0.25	DEMAND 1.00 ENERGY 0.00	SAVINGS	DEMAND 0.00 ENERGY 1.00	DEMAND 0.25 ENERGY 0.75	DEMAND 0.50 ENERGY 0.50	DEMAND 0.75 ENERGY 0.25	DEMAND 1.00 ENERGY 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00059	0.00119	0.00178	0.00238						
TRACTION(MW)	320.40						18.12					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	420.30						18.12	0.000	0.011	0.022	0.032	0.043
ENERGY COMPONENT		0.00653	0.00490	0.00327	0.00163	0.00000						
TRACTION(MKWH)	80.14						4.93					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	153.07						4.93	0.032	0.024	0.016	0.008	0.000
							FRACTION	0.032	0.035	0.038	0.040	0.043
							PERCENT	3.2	3.5	3.8	4.0	4.3

TABLE 1-46A
SPEED REDUCTION(MIN RUN TIME + .5 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.30	8.06	8631.90	69573	23191	478	1434	71007	23669	80100	26700	9094	3031
MIDDAY	9:00AM - 3:00PM	6	959.25	7.45	5755.50	42878		2201	13208	56087		63075		6988	
PM PEAK	3:00PM - 6:00PM	3	2877.30	8.06	8631.90	69573		478	1434	71007		80100		9094	
EVENING	6:00PM - 12:00AM	6	479.63	7.43	2877.75	21382		2631	15784	37166		40660		3494	
TOTAL		24		7.85	25897	203406			31860	235266		263935		28669	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.63	7.43	5755.50	42763		2631	31568	74332		81319		6988	
EVENING	6:00PM - 12:00AM	6	239.85	7.33	1439.10	10549		2846	17073	27622		29400		1778	
TOTAL		24		7.41	7194.60	53312			48641	101953		110719		8766	
WEEKLY				7.81	143874	1123656	23191		256583	1380239	23669	1541114	26700	160876	3031
ANNUAL				7.81	7481471	58430105	278292		13342306	71772411	284027	80137944	320402	8365533	36374

TABLE 1-46B
SPEED REDUCTION(MIN RUN TIME + .5 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00	DEMAND ENERGY SAVINGS	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00059	0.00119	0.00178	0.00238	36.37					
TRACTION(MW)	320.40						0.00					
SUPPORT(MW)	99.90						36.37	0.000	0.022	0.043	0.065	0.087
TOTAL(MW)	420.30											
ENERGY COMPONENT		0.00653	0.00490	0.00327	0.00163	0.00000	8.37					
TRACTION(MKWH)	80.14						0.00					
SUPPORT(MKWH)	72.93						8.37	0.055	0.041	0.027	0.014	0.000
TOTAL(MKWH)	153.07						FRACTION	0.055	0.063	0.071	0.079	0.087
							PERCENT	5.5	6.3	7.1	7.9	8.7

TABLE 1-47A
SPEED REDUCTION(MIN RUN TIME +.75 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	MS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.00	7.72	8631.00	66631	22210	433	1299	67930	22643	80100	26700	12170	4057
MIDDAY	9:00AM - 3:00PM	6	959.25	7.45	5755.50	42878		2186	13118	55997		63075		7078	
PM PEAK	3:00PM - 6:00PM	3	2877.00	7.72	8631.00	66631		433	1299	67930		80100		12170	
EVENING	6:00PM - 12:00AM	6	479.63	7.43	2877.75	21382		2623	15739	37121		40660		3539	
TOTAL		24		7.63	25895	197523			31455	228978		263935		34957	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	MS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.63	7.43	5755.50	42763		2623	31478	74242		81319		7078	
EVENING	6:00PM - 12:00AM	6	239.85	7.33	1439.10	10549		2842	17051	27599		29400		1801	
TOTAL		24		7.41	7194.60	53312			48529	101841		110719		8879	
WEEKLY				7.61	143865	1094238	22210		254333	1348571	22643	1541114	26700	192544	4057
ANNUAL				7.61	7481003	56900372	266525		13225306	70125678	271720	80137944	320402	10012266	48682

TABLE 1-47B
SPEED REDUCTION(MIN RUN TIME +.75 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND / ENERGY	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND / ENERGY	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
	NORMAL	RATE(POWER BILL UNITS)					SAVINGS	SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00059	0.00119	0.00178	0.00238						
TRACTION(MW)	320.40						48.68					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	420.30						48.68	0.000	0.029	0.058	0.087	0.116
ENERGY COMPONENT		0.00653	0.00490	0.00327	0.00163	0.00000						
TRACTION(MKWH)	80.14						10.01					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	153.07						10.01	0.065	0.049	0.033	0.016	0.000
							FRACTION	0.065	0.078	0.091	0.103	0.116
							PERCENT	6.5	7.8	9.1	10.3	11.6

TABLE 1-48A
SPEED REDUCTION(MIN RUN TIME + 1 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2879.70	7.16	8639.10	61856	20619	387	1161	63017	21006	80100	26700	17083	5694
MIDDAY	9:00AM - 3:00PM	6	958.95	6.94	5753.70	39931		2171	13025	52955		63075		10119	
PM PEAK	3:00PM - 6:00PM	3	2879.70	7.16	8639.10	61856		387	1161	63017		80100		17083	
EVENING	6:00PM - 12:00AM	6	479.48	6.92	2876.85	19908		2615	15692	35600		40660		5060	
TOTAL		24		7.08	25909	183550			31039	214590		263935		49345	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.48	6.92	5753.70	39816		2615	31385	71200		81319		10119	
EVENING	6:00PM - 12:00AM	6	239.78	6.78	1438.65	9754		2838	17027	26781		29400		2619	
TOTAL		24		6.89	7192.35	49570			48412	97982		110719		12738	
WEEKLY				7.07	143928	1016891	20619		252020	1268911	21006	1541114	26700	272203	5694
ANNUAL				7.07	7484279	52878346	247424		13105030	65983375	252068	80137944	320402	14154569	68334

TABLE 1-48B
SPEED REDUCTION(MIN RUN TIME + 1 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND ENERGY SAVINGS	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00059	0.00119	0.00178	0.00238						
TRACTION(MW)	320.40						68.33					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	420.30						68.33	0.000	0.041	0.081	0.122	0.163
ENERGY COMPONENT		0.00653	0.00490	0.00327	0.00163	0.00000						
TRACTION(MKWH)	80.14						14.15					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	153.07						14.15	0.092	0.069	0.046	0.023	0.000
							FRACTION	0.092	0.110	0.128	0.145	0.163
							PERCENT	9.2	11.0	12.8	14.5	16.3

TABLE 1-49A
SPEED REDUCTION(MIN RUN TIME + 1.25 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

						RUNNING TRAINS		TURNAROUND & STORAGE		TOTAL		NORMAL TOTAL		DIFFERENCE	
PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	KWH	KW PEAK	KW	KWH	KWH	KW PEAK	KWH	KW PEAK	KWH	KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2874.30	7.30	8622.90	62947	20982	342	1026	63973	21324	80100	26700	16127	5376
MIDDAY	9:00AM - 3:00PM	6	958.80	6.95	5752.80	39982		2156	12935	52917		63075		10158	
PM PEAK	3:00PM - 6:00PM	3	2874.30	7.30	8622.90	62947		342	1026	63973		80100		16127	
EVENING	6:00PM - 12:00AM	6	479.40	6.93	2876.40	19933		2608	15647	35581		40660		5079	
TOTAL		24		7.18	25875	185810			30634	216444		263935		47491	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.40	6.93	5752.80	39867		2608	31295	71162		81319		10158	
EVENING	6:00PM - 12:00AM	6	239.78	6.87	1438.65	9884		2834	17004	26887		29400		2513	
TOTAL		24		6.92	7191.45	49750			48299	98049		110719		12671	
WEEKLY				7.15	143758	1028550	20982		249768	1278318	21324	1541114	26700	262797	5376
ANNUAL				7.15	7475411	53484580	251789		12987936	66472516	255893	80137944	320402	13665428	64509

TABLE 1-49B
SPEED REDUCTION(MIN RUN TIME + 1.25 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF	DEMAND	0.00	0.25	0.50	0.75	1.00	DEMAND	0.00	0.25	0.50	0.75	1.00
POWER BILL ==>	ENERGY	1.00	0.75	0.50	0.25	0.00	ENERGY	1.00	0.75	0.50	0.25	0.00
	NORMAL	RATE(POWER BILL UNITS)					SAVINGS	SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00059	0.00119	0.00178	0.00238						
TRACTION(MW)	320.40						64.51					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	420.30						64.51	0.000	0.038	0.077	0.115	0.153
ENERGY COMPONENT		0.00653	0.00490	0.00327	0.00163	0.00000						
TRACTION(MKWH)	80.14						13.67					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	153.07						13.67	0.089	0.067	0.045	0.022	0.000
							FRACTION	0.089	0.105	0.121	0.137	0.153
							PERCENT	8.9	10.5	12.1	13.7	15.3

TABLE 1-51A
COASTING(3 MPH BAND)(MIN RUN TIME + .25 MIN)(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.30	4.27	8631.90	36858	12286	523	1569	38427	12809	49019	16340	10592	3531
MIDDAY	9:00AM - 3:00PM	6	958.65	4.57	5751.90	26286		2218	13307	39594		45002		5409	
PM PEAK	3:00PM - 6:00PM	3	2877.30	4.27	8631.90	36858		523	1569	38427		49019		10592	
EVENING	6:00PM - 12:00AM	6	479.33	5.08	2875.95	14610		2639	15834	30444		32688		2245	
TOTAL		24		4.43	25892	114612			32279	146891		175729		28838	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.33	5.08	5751.90	29220		2639	31667	60887		65377		4490	
EVENING	6:00PM - 12:00AM	6	239.70	5.18	1438.20	7450		2850	17097	24547		25130		583	
TOTAL		24		5.10	7190.10	36670			48765	85434		90507		5072	
WEEKLY				4.49	143838	646401	12286		258922	905323	12809	1059657	16340	154334	3531
ANNUAL				4.49	7479599	33612864	147433		13463939	47076803	153708	55102175	196076	8025372	42369

TABLE 1-51B
COASTING(3 MPH BAND)(MIN RUN TIME + .25 MIN)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF	DEMAND	0.00	0.25	0.50	0.75	1.00	DEMAND	0.00	0.25	0.50	0.75	1.00
POWER BILL ==>	ENERGY	1.00	0.75	0.50	0.25	0.00	ENERGY	1.00	0.75	0.50	0.25	0.00
	NORMAL		RATE(POWER BILL UNITS)				SAVINGS		SAVINGS(POWER BILL UNITS)			
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						42.37					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						42.37	0.000	0.036	0.072	0.107	0.143
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						8.03					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						8.03	0.063	0.047	0.031	0.016	0.000
							FRACTION	0.063	0.083	0.103	0.123	0.143
							PERCENT	6.3	8.3	10.3	12.3	14.3

TABLE 1-52A
COASTING(3 MPH BAND)(MIN RUN TIME + .5 MIN)(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2874.60	4.14	8623.80	35703	11901	478	1434	37136	12379	49019	16340	11883	3961
MIDDAY	9:00AM - 3:00PM	6	956.70	4.63	5740.20	26577		2202	13212	39789		45002		5213	
PM PEAK	3:00PM - 6:00PM	3	2874.60	4.14	8623.80	35703		478	1434	37136		49019		11883	
EVENING	6:00PM - 12:00AM	6	478.35	5.01	2870.10	14379		2631	15786	30165		32688		2523	
TOTAL		24		4.35	25858	112361			31865	144227		175729		31502	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	478.35	5.01	5740.20	28758		2631	31572	60330		65377		5046	
EVENING	6:00PM - 12:00AM	6	239.55	4.95	1437.30	7115		2846	17073	24188		25130		942	
TOTAL		24		5.00	7177.50	35873			48645	84518		90507		5989	
WEEKLY				4.41	143645	633553	11901		256617	890170	12379	1059657	16340	169487	3961
ANNUAL				4.41	7469514	32944758	142810		13344084	46288842	148545	55102175	196076	8813333	47531

TABLE 1-52B
COASTING(3 MPH BAND)(MIN RUN TIME + .5 MIN)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00	DEMAND ENERGY SAVINGS	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						47.53					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						47.53	0.000	0.040	0.080	0.120	0.161
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						8.81					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						8.81	0.069	0.052	0.034	0.017	0.000
							FRACTION	0.069	0.092	0.115	0.138	0.161
							PERCENT	6.9	9.2	11.5	13.8	16.1

TABLE 1-53A
COASTING(3 MPH BAND)(MIN RUN TIME + .75 MIN)(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2879.40	4.08	8638.20	35244	11748	432	1296	36540	12180	49019	16340	12479	4160
MIDDAY	9:00AM - 3:00PM	6	958.80	4.43	5752.80	25485		2185	13111	38596		45002		6406	
PM PEAK	3:00PM - 6:00PM	3	2879.40	4.08	8638.20	35244		432	1296	36540		49019		12479	
EVENING	6:00PM - 12:00AM	6	479.40	4.77	2876.40	13720		2623	15736	29456		32688		3232	
TOTAL		24		4.23	25906	109693			31439	141132		175729		34597	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.40	4.77	5752.80	27441		2623	31471	58912		65377		6465	
EVENING	6:00PM - 12:00AM	6	239.70	4.84	1438.20	6961		2841	17049	24010		25130		1120	
TOTAL		24		4.78	7191.00	34402			48520	82922		90507		7585	
WEEKLY				4.29	143910	617269	11748		254234	871503	12180	1059657	16340	188155	4160
ANNUAL				4.29	7483320	32097973	140975		13220158	45318130	146159	55102175	196076	9784045	49917

TABLE 1-53B
COASTING(3 MPH BAND)(MIN RUN TIME + .75 MIN)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND / ENERGY / NORMAL	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND / ENERGY / SAVINGS	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						49.92					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						49.92	0.000	0.042	0.084	0.126	0.169
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						9.78					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						9.78	0.076	0.057	0.038	0.019	0.000
							FRACTION	0.076	0.099	0.123	0.146	0.169
							PERCENT	7.6	9.9	12.3	14.6	16.9

TABLE 1-54A
COASTING(3 MPH BAND)(MIN RUN TIME + 1 MIN)(CHOPPER)
ENERGY ANALYSIS

						RUNNING TRAINS		TURNAROUND & STORAGE		TOTAL		NORMAL TOTAL		DIFFERENCE	
PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	KWH	KW PEAK	KW	KWH	KWH	KW PEAK	KWH	KW PEAK	KWH	KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2876.70	4.42	8630.10	38145	12715	387	1161	39306	13102	49019	16340	9713	3238
MIDDAY	9:00AM - 3:00PM	6	958.50	4.21	5751.00	24212		2170	13019	37231		45002		7771	
PM PEAK	3:00PM - 6:00PM	3	2876.70	4.42	8630.10	38145		387	1161	39306		49019		9713	
EVENING	6:00PM - 12:00AM	6	479.25	4.59	2875.50	13199		2615	15690	28888		32688		3800	
TOTAL		24		4.39	25887	113700			31031	144731		175729		30997	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.25	4.59	5751.00	26397		2615	31379	57776		65377		7600	
EVENING	6:00PM - 12:00AM	6	239.70	3.83	1438.20	5508		2838	17026	22535		25130		2595	
TOTAL		24		4.44	7189.20	31905			48406	80311		90507		10196	
WEEKLY				4.40	143812	632312	12715		251967	884279	13102	1059657	16340	175378	3238
ANNUAL				4.40	7478219	32880249	152580		13102268	45982518	157224	55102175	196076	9119657	38852

TABLE 1-54B
COASTING(3 MPH BAND)(MIN RUN TIME + 1 MIN)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	DEMAND 0.00 ENERGY 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00	DEMAND ENERGY SAVINGS	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						38.85					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						38.85	0.000	0.033	0.066	0.098	0.131
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						9.12					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						9.12	0.071	0.053	0.036	0.018	0.000
							FRACTION	0.071	0.086	0.101	0.116	0.131
							PERCENT	7.1	8.6	10.1	11.6	13.1

TABLE 1-55A
COASTING(3 MPH BAND)(MIN RUN TIME + 1.25 MIN)(CHOPPER)
ENERGY ANALYSIS

						RUNNING TRAINS		TURNAROUND & STORAGE		TOTAL		NORMAL TOTAL		DIFFERENCE	
PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	KWH	KW PEAK	KW	KWH	KWH	KW PEAK	KWH	KW PEAK	KWH	KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2880.00	3.63	8640.00	31363	10454	341	1023	32387	10796	49019	16340	16633	5544
MIDDAY	9:00AM - 3:00PM	6	958.20	3.97	5749.20	22824		2154	12926	35750		45002		9252	
PM PEAK	3:00PM - 6:00PM	3	2880.00	3.63	8640.00	31363		341	1023	32387		49019		16633	
EVENING	6:00PM - 12:00AM	6	479.10	4.32	2874.60	12418		2607	15643	28061		32688		4627	
TOTAL		24		3.78	25904	97969			30615	128584		175729		47145	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.10	4.32	5749.20	24837		2607	31286	56122		65377		9254	
EVENING	6:00PM - 12:00AM	6	239.70	4.17	1438.20	5997		2834	17003	23000		25130		2130	
TOTAL		24		4.29	7187.40	30834			48289	79122		90507		11384	
WEEKLY				3.83	143894	551513	10454		249654	801166	10796	1059657	16340	258491	5544
ANNUAL				3.83	7482478	28678658	125453		12981992	41660651	129546	55102175	196076	13441524	66530

TABLE 1-55B
COASTING(3 MPH BAND)(MIN RUN TIME + 1.25 MIN)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 1.00	0.25 0.75	0.50 0.50 RATE(POWER BILL UNITS)	0.75 0.25	1.00 0.00	DEMAND ENERGY SAVINGS	0.00 1.00	0.25 0.75	0.50 0.50 SAVINGS(POWER BILL UNITS)	0.75 0.25	1.00 0.00
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						66.53					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						66.53	0.000	0.056	0.112	0.169	0.225
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						13.44					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						13.44	0.105	0.079	0.052	0.026	0.000
							FRACTION	0.105	0.135	0.165	0.195	0.225
							PERCENT	10.5	13.5	16.5	19.5	22.5

TABLE 1-56A
COASTING(5 MPH BAND)(MIN RUN TIME + .25 MIN)(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.00	4.37	8631.00	37717	12572	523	1569	39286	13095	49019	16340	9733	3244
MIDDAY	9:00AM - 3:00PM	6	959.25	4.50	5755.50	25900		2217	13300	39200		45002		5802	
PM PEAK	3:00PM - 6:00PM	3	2877.00	4.37	8631.00	37717		523	1569	39286		49019		9733	
EVENING	6:00PM - 12:00AM	6	479.63	5.06	2877.75	14561		2638	15830	30392		32688		2297	
TOTAL		24		4.48	25895	115896			32268	148164		175729		27565	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.63	5.06	5755.50	29123		2638	31660	60783		65377		4594	
EVENING	6:00PM - 12:00AM	6	239.78	4.61	1438.65	6632		2849	17094	23726		25130		1404	
TOTAL		24		4.97	7194.15	35755			48754	84509		90507		5998	
WEEKLY				4.53	143865	650991	12572		258846	909837	13095	1059657	16340	149820	3244
ANNUAL				4.53	7480957	33851508	150870		13460008	47311516	157145	55102175	196076	7790659	38932

TABLE 1-56B
COASTING(5 MPH BAND)(MIN RUN TIME + .25 MIN)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00	DEMAND ENERGY SAVINGS	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						38.93					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						38.93	0.000	0.033	0.066	0.099	0.132
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						7.79					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						7.79	0.061	0.046	0.030	0.015	0.000
							FRACTION	0.061	0.079	0.096	0.114	0.132
							PERCENT	6.1	7.9	9.6	11.4	13.2

TABLE 1-57A
COASTING(5 MPH BAND)(MIN RUN TIME + .5 MIN)(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.00	4.05	8631.00	34956	11652	477	1431	36387	12129	49019	16340	12633	4211
MIDDAY	9:00AM - 3:00PM	6	960.15	4.46	5760.90	25694		2200	13201	38895		45002		6107	
PM PEAK	3:00PM - 6:00PM	3	2877.00	4.05	8631.00	34956		477	1431	36387		49019		12633	
EVENING	6:00PM - 12:00AM	6	480.08	4.87	2880.45	14028		2630	15781	29808		32688		2880	
TOTAL		24		4.23	25903	109633			31844	141476		175729		34253	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	480.08	4.87	5760.90	28056		2630	31561	59617		65377		5760	
EVENING	6:00PM - 12:00AM	6	239.70	4.84	1438.20	6961		2845	17070	24031		25130		1099	
TOTAL		24		4.86	7199.10	35016			48632	83648		90507		6859	
WEEKLY				4.30	143915	618195	11652		256482	874677	12129	1059657	16340	184980	4211
ANNUAL				4.30	7483577	32146164	139822		13337064	45483228	145546	55102175	196076	9618947	50530

TABLE 1-57B
COASTING(5 MPH BAND)(MIN RUN TIME + .5 MIN)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND / ENERGY	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND / ENERGY	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
	NORMAL	RATE(POWER BILL UNITS)					SAVINGS	SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						50.53					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						50.53	0.000	0.043	0.085	0.128	0.171
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						9.62					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						9.62	0.075	0.056	0.038	0.019	0.000
							FRACTION	0.075	0.099	0.123	0.147	0.171
							PERCENT	7.5	9.9	12.3	14.7	17.1

TABLE 1-58A
COASTING(5 MPH BAND)(MIN RUN TIME + .75 MPH)(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2874.30	3.52	8622.90	30353	10118	432	1296	31649	10550	49019	16340	17370	5790
MIDDAY	9:00AM - 3:00PM	6	958.65	4.55	5751.90	26171		2185	13111	39282		45002		5720	
PM PEAK	3:00PM - 6:00PM	3	2874.30	3.52	8622.90	30353		432	1296	31649		49019		17370	
EVENING	6:00PM - 12:00AM	6	479.33	4.84	2875.95	13920		2623	15736	29655		32688		3033	
TOTAL		24		3.90	25874	100796			31439	132235		175729		43494	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.33	4.84	5751.90	27839		2623	31471	59310		65377		6066	
EVENING	6:00PM - 12:00AM	6	239.85	5.06	1439.10	7282		2842	17051	24332		25130		798	
TOTAL		24		4.88	7191.00	35121			48522	83643		90507		6864	
WEEKLY				3.99	143750	574222	10118		254237	828459	10550	1059657	16340	231198	5790
ANNUAL				3.99	7475013	29859538	121410		13220345	43079883	126594	55102175	196076	12022292	69482

TABLE 1-58B
COASTING(5 MPH BAND)(MIN RUN TIME + .75 MPH)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND ENERGY SAVINGS	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						69.48					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						69.48	0.000	0.059	0.117	0.176	0.235
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						12.02					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						12.02	0.094	0.070	0.047	0.023	0.000
							FRACTION	0.094	0.129	0.164	0.200	0.235
							PERCENT	9.4	12.9	16.4	20.0	23.5

TABLE 1-59A
COASTING(5 MPH BAND)(MIN RUN TIME + 1 MIN)(CHOPPER)
ENERGY ANALYSIS

						RUNNING TRAINS		TURNAROUND & STORAGE		TOTAL		NORMAL TOTAL		DIFFERENCE	
PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	KWH	KW PEAK	KW	KWH	KWH	KW PEAK	KWH	KW PEAK	KWH	KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2874.30	3.85	8622.90	33198	11066	387	1161	34359	11453	49019	16340	14660	4887
MIDDAY	9:00AM - 3:00PM	6	959.25	4.58	5755.50	26360		2171	13025	39385		45002		5617	
PM PEAK	3:00PM - 6:00PM	3	2874.30	3.85	8622.90	33198		387	1161	34359		49019		14660	
EVENING	6:00PM - 12:00AM	6	479.63	4.87	2877.75	14015		2615	15692	29707		32688		2981	
TOTAL		24		4.13	25879	106771			31039	137810		175729		37918	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.63	4.87	5755.50	28029		2615	31385	59414		65377		5963	
EVENING	6:00PM - 12:00AM	6	239.63	5.03	1437.75	7232		2838	17030	24262		25130		868	
TOTAL		24		4.90	7193.25	35261			48415	83676		90507		6831	
WEEKLY				4.20	143782	604378	11066		252025	856403	11453	1059657	16340	203254	4887
ANNUAL				4.20	7476651	31427664	132793		13105310	44532974	137437	55102175	196076	10569201	58640

TABLE 1-59B
COASTING(5 MPH BAND)(MIN RUN TIME + 1 MIN)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00	DEMAND ENERGY SAVINGS	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						58.64					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						58.64	0.000	0.050	0.099	0.149	0.198
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						10.57					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						10.57	0.083	0.062	0.041	0.021	0.000
							FRACTION	0.083	0.111	0.140	0.169	0.198
							PERCENT	8.3	11.1	14.0	16.9	19.8

TABLE 1-60A
COASTING(5 MPH BAND)(MIN RUN TIME + 1.25 MIN)(CHOPPER)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.00	3.90	8631.00	33661	11220	341	1023	34684	11561	49019	16340	14335	4778
MIDDAY	9:00AM - 3:00PM	6	958.95	3.89	5753.70	22382		2156	12935	35317		45002		9686	
PM PEAK	3:00PM - 6:00PM	3	2877.00	3.90	8631.00	33661		341	1023	34684		49019		14335	
EVENING	6:00PM - 12:00AM	6	479.48	4.24	2876.85	12198		2608	15647	27845		32688		4843	
TOTAL		24		3.94	25893	101902			30629	132530		175729		43198	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.48	4.24	5753.70	24396		2608	31295	55690		65377		9686	
EVENING	6:00PM - 12:00AM	6	239.55	4.22	1437.30	6065		2834	17006	23072		25130		2058	
TOTAL		24		4.24	7191.00	30461			48301	78762		90507		11744	
WEEKLY				3.97	143845	570430	11220		249746	820176	11561	1059657	16340	239481	4778
ANNUAL				3.97	7479927	29662353	134644		12986813	42649166	138737	55102175	196076	12453009	57340

TABLE 1-60B
COASTING(5 MPH BAND)(MIN RUN TIME + 1.25 MIN)(CHOPPER)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00	DEMAND ENERGY SAVINGS	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						57.34					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						57.34	0.000	0.048	0.097	0.145	0.194
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						12.45					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						12.45	0.097	0.073	0.049	0.024	0.000
							FRACTION	0.097	0.121	0.145	0.170	0.194
							PERCENT	9.7	12.1	14.5	17.0	19.4

TABLE 1-62A
COASTING(3 MPH BAND)(MIN RUN TIME + .25 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.30	7.52	8631.90	64912	21637	523	1569	66481	22160	79582	26527	13102	4367
MIDDAY	9:00AM - 3:00PM	6	958.65	7.51	5751.90	43197		2218	13307	56504		63075		6570	
PM PEAK	3:00PM - 6:00PM	3	2877.30	7.52	8631.90	64912		523	1569	66481		79582		13102	
EVENING	6:00PM - 12:00AM	6	479.33	7.49	2875.95	21541		2639	15834	37375		40660		3285	
TOTAL		24		7.51	25892	194561			32279	226840		262899		36059	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.33	7.49	5751.90	43082		2639	31667	74749		81319		6570	
EVENING	6:00PM - 12:00AM	6	239.70	7.49	1438.20	10772		2850	17097	27869		29400		1531	
TOTAL		24		7.49	7190.10	53854			48765	102619		110719		8101	
WEEKLY				7.51	143838	1080515	21637		258922	1339437	22160	1535934	26527	196497	4367
ANNUAL				7.51	7479599	56186767	259648		13463939	69650706	265922	79868572	318329	10217866	52407

TABLE 1-62B
COASTING(3 MPH BAND)(MIN RUN TIME + .25 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND ENERGY SAVINGS	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						52.41					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						52.41	0.000	0.031	0.063	0.094	0.125
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						10.22					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						10.22	0.067	0.050	0.033	0.017	0.000
							FRACTION	0.067	0.081	0.096	0.111	0.125
							PERCENT	6.7	8.1	9.6	11.1	12.5

TABLE 1-63A
COASTING(3 MPH BAND)(MIN RUN TIME + .5 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

						RUNNING TRAINS		TURNAROUND & STORAGE		TOTAL		NORMAL TOTAL		DIFFERENCE	
PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	KWH	KW PEAK	KW	KWH	KWH	KW PEAK	KWH	KW PEAK	KWH	KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2874.60	7.40	8623.80	63816	21272	478	1434	65250	21750	79582	26527	14333	4778
MIDDAY	9:00AM - 3:00PM	6	956.70	7.06	5740.20	40526		2202	13212	53738		63075		9337	
PM PEAK	3:00PM - 6:00PM	3	2874.60	7.40	8623.80	63816		478	1434	65250		79582		14333	
EVENING	6:00PM - 12:00AM	6	478.35	7.04	2870.10	20206		2631	15786	35992		40660		4668	
TOTAL		24		7.28	25858	188364			31865	220229		262899		42670	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	478.35	7.04	5740.20	40411		2631	31572	71983		81319		9336	
EVENING	6:00PM - 12:00AM	6	239.55	7.03	1437.30	10104		2846	17073	27177		29400		2223	
TOTAL		24		7.04	7177.50	50515			48645	99160		110719		11559	
WEEKLY				7.26	143645	1042848	21272		256617	1299465	21750	1535934	26527	236469	4778
ANNUAL				7.26	7469514	54228108	255264		13344084	67572192	260999	79868572	318329	12296380	57330

TABLE 1-63B
COASTING(3 MPH BAND)(MIN RUN TIME + .5 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF	DEMAND	0.00	0.25	0.50	0.75	1.00	DEMAND	0.00	0.25	0.50	0.75	1.00
POWER BILL ==>	ENERGY	1.00	0.75	0.50	0.25	0.00	ENERGY	1.00	0.75	0.50	0.25	0.00
	NORMAL	RATE(POWER BILL UNITS)					SAVINGS	SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						57.33					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						57.33	0.000	0.034	0.069	0.103	0.137
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						12.30					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						12.30	0.080	0.060	0.040	0.020	0.000
							FRACTION	0.080	0.095	0.109	0.123	0.137
							PERCENT	8.0	9.5	10.9	12.3	13.7

TABLE 1-64A
COASTING(3 MPH BAND)(MIN RUN TIME + .75 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2879.40	6.66	8638.20	57530	19177	432	1296	58826	19609	79582	26527	20756	6919
MIDDAY	9:00AM - 3:00PM	6	958.80	6.13	5752.80	35265		2185	13111	48376		63075		14699	
PM PEAK	3:00PM - 6:00PM	3	2879.40	6.66	8638.20	57530		432	1296	58826		79582		20756	
EVENING	6:00PM - 12:00AM	6	479.40	6.12	2876.40	17604		2623	15736	33339		40660		7321	
TOTAL		24		6.48	25906	167929			31439	199368		262899		63531	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.40	6.12	5752.80	35207		2623	31471	66678		81319		14641	
EVENING	6:00PM - 12:00AM	6	239.70	6.45	1438.20	9276		2841	17049	26325		29400		3075	
TOTAL		24		6.19	7191.00	44484			48520	93003		110719		17716	
WEEKLY				6.45	143910	928612	19177		254234	1182846	19609	1535934	26527	353088	6919
ANNUAL				6.45	7483320	48287841	230122		13220158	61507999	235306	79868572	318329	18360573	83024

TABLE 1-64B
COASTING(3 MPH BAND)(MIN RUN TIME + .75 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00	DEMAND ENERGY SAVINGS	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						83.02					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						83.02	0.000	0.050	0.099	0.149	0.199
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						18.36					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						18.36	0.120	0.090	0.060	0.030	0.000
							FRACTION	0.120	0.140	0.159	0.179	0.199
							PERCENT	12.0	14.0	15.9	17.9	19.9

TABLE 1-65A
COASTING(3 MPH BAND)(MIN RUN TIME + 1.0 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2876.70	6.71	8630.10	57908	19303	387	1161	59069	19690	79582	26527	20513	6838
MIDDAY	9:00AM - 3:00PM	6	958.50	6.06	5751.00	34851		2170	13019	47870		63075		15204	
PM PEAK	3:00PM - 6:00PM	3	2876.70	6.71	8630.10	57908		387	1161	59069		79582		20513	
EVENING	6:00PM - 12:00AM	6	479.25	6.04	2875.50	17368		2615	15690	33058		40660		7602	
TOTAL		24		6.49	25887	168035			31031	199066		262899		63833	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.25	6.04	5751.00	34736		2615	31379	66115		81319		15204	
EVENING	6:00PM - 12:00AM	6	239.70	5.28	1438.20	7594		2838	17026	24620		29400		4780	
TOTAL		24		5.89	7189.20	42330			48406	90735		110719		19984	
WEEKLY				6.43	143812	924835	19303		251967	1176801	19690	1535934	26527	359133	6838
ANNUAL				6.43	7478219	48091398	231632		13102268	61193667	236276	79868572	318329	18674906	82054

TABLE 1-65B
COASTING(3 MPH BAND)(MIN RUN TIME + 1.0 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	DEMAND 0.00 ENERGY 1.00	DEMAND 0.25 ENERGY 0.75	DEMAND 0.50 ENERGY 0.50 RATE(POWER BILL UNITS)	DEMAND 0.75 ENERGY 0.25	DEMAND 1.00 ENERGY 0.00	DEMAND ENERGY SAVINGS	DEMAND 0.00 ENERGY 1.00	DEMAND 0.25 ENERGY 0.75	DEMAND 0.50 ENERGY 0.50 SAVINGS(POWER BILL UNITS)	DEMAND 0.75 ENERGY 0.25	DEMAND 1.00 ENERGY 0.00
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						82.05					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						82.05	0.000	0.049	0.098	0.147	0.196
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						18.67					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						18.67	0.122	0.092	0.061	0.031	0.000
							FRACTION	0.122	0.141	0.159	0.178	0.196
							PERCENT	12.2	14.1	15.9	17.8	19.6

TABLE 1-66A
COASTING(3 MPH BAND)(MIN RUN TIME + 1.25 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

						RUNNING TRAINS		TURNAROUND & STORAGE		TOTAL		NORMAL TOTAL		DIFFERENCE	
PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	KWH	KW PEAK	KW	KWH	KWH	KW PEAK	KWH	KW PEAK	KWH	KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2880.00	6.00	8640.00	51840	17280	341	1023	52863	17621	79582	26527	26719	8906
MIDDAY	9:00AM - 3:00PM	6	958.20	6.04	5749.20	34725		2154	12926	47651		63075		15424	
PM PEAK	3:00PM - 6:00PM	3	2880.00	6.00	8640.00	51840		341	1023	52863		79582		26719	
EVENING	6:00PM - 12:00AM	6	479.10	6.03	2874.60	17334		2607	15643	32977		40660		7683	
TOTAL		24		6.01	25904	155739			30615	186354		262899		76545	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.10	6.03	5749.20	34668		2607	31286	65953		81319		15366	
EVENING	6:00PM - 12:00AM	6	239.70	5.76	1438.20	8284		2834	17003	25287		29400		4113	
TOTAL		24		5.98	7187.40	42952			48289	91240		110719		19479	
WEEKLY				6.01	143894	864598	17280		249654	1114252	17621	1535934	26527	421682	8906
ANNUAL				6.01	7482478	44959119	207360		12981992	57941112	211453	79868572	318329	21927461	106876

TABLE 1-66B
COASTING(3 MPH BAND)(MIN RUN TIME + 1.25 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	DEMAND 0.00 ENERGY 1.00	DEMAND 0.25 ENERGY 0.75	DEMAND 0.50 ENERGY 0.50 RATE(POWER BILL UNITS)	DEMAND 0.75 ENERGY 0.25	DEMAND 1.00 ENERGY 0.00	DEMAND ENERGY SAVINGS	DEMAND 0.00 ENERGY 1.00	DEMAND 0.25 ENERGY 0.75	DEMAND 0.50 ENERGY 0.50 SAVINGS(POWER BILL UNITS)	DEMAND 0.75 ENERGY 0.25	DEMAND 1.00 ENERGY 0.00
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						106.88					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						106.88	0.000	0.064	0.128	0.192	0.256
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						21.93					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						21.93	0.144	0.108	0.072	0.036	0.000
							FRACTION	0.144	0.172	0.200	0.228	0.256
							PERCENT	14.4	17.2	20.0	22.8	25.6

TABLE 1-67A
COASTING(5 MPH BAND)(MIN RUN TIME + .25 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.00	7.70	8631.00	66459	22153	523	1569	68027	22676	79582	26527	11555	3852
MIDDAY	9:00AM - 3:00PM	6	959.25	7.38	5755.50	42476		2217	13300	55776		63075		7299	
PM PEAK	3:00PM - 6:00PM	3	2877.00	7.70	8631.00	66459		523	1569	68027		79582		11555	
EVENING	6:00PM - 12:00AM	6	479.63	7.36	2877.75	21180		2638	15830	37010		40660		3649	
TOTAL		24		7.59	25895	196573		.	32268	228841		262899		34058	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.63	7.36	5755.50	42360		2638	31660	74021		81319		7299	
EVENING	6:00PM - 12:00AM	6	239.78	7.11	1438.65	10229		2849	17094	27323		29400		2077	
TOTAL		24		7.31	7194.15	52589			48754	101343		110719		9376	
WEEKLY				7.56	143865	1088045	22153		258846	1346891	22676	1535934	26527	189043	3852
ANNUAL				7.56	7480957	56578325	265835		13460008	70038333	272110	79868572	318329	9830240	46220

TABLE 1-67B
COASTING(5 MPH BAND)(MIN RUN TIME + .25 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND / ENERGY / NORMAL	DEMAND 0.00 / ENERGY 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND / ENERGY / SAVINGS	DEMAND 0.00 / ENERGY 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						46.22					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						46.22	0.000	0.028	0.055	0.083	0.111
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						9.83					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						9.83	0.064	0.048	0.032	0.016	0.000
							FRACTION	0.064	0.076	0.087	0.099	0.111
							PERCENT	6.4	7.6	8.7	9.9	11.1

TABLE 1-68A
COASTING(5 MPH BAND)(MIN RUN TIME + .5 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

						RUNNING TRAINS		TURNAROUND & STORAGE		TOTAL		NORMAL TOTAL		DIFFERENCE	
PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	KWH	KW PEAK	KW	KWH	KWH	KW PEAK	KWH	KW PEAK	KWH	KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.00	6.92	8631.00	59727	19909	477	1431	61158	20386	79582	26527	18425	6142
MIDDAY	9:00AM - 3:00PM	6	960.15	6.60	5760.90	38022		2200	13201	51223		63075		11851	
PM PEAK	3:00PM - 6:00PM	3	2877.00	6.92	8631.00	59727		477	1431	61158		79582		18425	
EVENING	6:00PM - 12:00AM	6	480.08	6.59	2880.45	18982		2630	15781	34763		40660		5897	
TOTAL		24		6.81	25903	176457			31844	208301		262899		54598	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	480.08	6.59	5760.90	37964		2630	31561	69526		81319		11794	
EVENING	6:00PM - 12:00AM	6	239.70	6.92	1438.20	9952		2845	17070	27023		29400		2377	
TOTAL		24		6.66	7199.10	47917			48632	96548		110719		14171	
WEEKLY				6.80	143915	978119	19909		256482	1234601	20386	1535934	26527	301333	6142
ANNUAL				6.80	7483577	50862192	238906		13337064	64199256	244630	79868572	318329	15669316	73699

TABLE 1-68B
COASTING(5 MPH BAND)(MIN RUN TIME + .5 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND / ENERGY	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND / ENERGY	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
	NORMAL	RATE(POWER BILL UNITS)					SAVINGS	SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						73.70					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						73.70	0.000	0.044	0.088	0.132	0.176
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						15.67					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						15.67	0.103	0.077	0.051	0.026	0.000
							FRACTION	0.103	0.121	0.139	0.158	0.176
							PERCENT	10.3	12.1	13.9	15.8	17.6

TABLE 1-69A
COASTING(5 MPH BAND)(MIN RUN TIME + .75 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2874.30	6.37	8622.90	54928	18309	432	1296	56224	18741	79582	26527	23359	7786
MIDDAY	9:00AM - 3:00PM	6	958.65	6.34	5751.90	36467		2185	13111	49578		63075		13496	
PM PEAK	3:00PM - 6:00PM	3	2874.30	6.37	8622.90	54928		432	1296	56224		79582		23359	
EVENING	6:00PM - 12:00AM	6	479.33	6.32	2875.95	18176		2623	15736	33912		40660		6748	
TOTAL		24		6.36	25874	164499			31439	195938		262899		66961	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.33	6.32	5751.90	36352		2623	31471	67823		81319		13496	
EVENING	6:00PM - 12:00AM	6	239.85	6.48	1439.10	9325		2842	17051	26376		29400		3024	
TOTAL		24		6.35	7191.00	45677			48522	94199		110719		16520	
WEEKLY				6.36	143750	913849	18309		254237	1168086	18741	1535934	26527	367848	7786
ANNUAL				6.36	7475013	47520134	219711		13220345	60740479	224895	79868572	318329	19128093	93434

TABLE 1-69B
COASTING(5 MPH BAND)(MIN RUN TIME + .75 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND / ENERGY / NORMAL	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND / ENERGY / SAVINGS	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						93.43					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						93.43	0.000	0.056	0.112	0.168	0.223
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						19.13					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						19.13	0.125	0.094	0.063	0.031	0.000
							FRACTION	0.125	0.150	0.174	0.199	0.223
							PERCENT	12.5	15.0	17.4	19.9	22.3

TABLE 1-70A
COASTING(5 MPH BAND)(MIN RUN TIME + 1 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2874.30	6.33	8622.90	54583	18194	387	1161	55744	18581	79582	26527	23838	7946
MIDDAY	9:00AM - 3:00PM	6	959.25	6.36	5755.50	36605		2171	13025	49630		63075		13445	
PM PEAK	3:00PM - 6:00PM	3	2874.30	6.33	8622.90	54583		387	1161	55744		79582		23838	
EVENING	6:00PM - 12:00AM	6	479.63	6.34	2877.75	18245		2615	15692	33937		40660		6722	
TOTAL		24		6.34	25879	164016			31039	195055		262899		67844	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.63	6.34	5755.50	36490		2615	31385	67875		81319		13445	
EVENING	6:00PM - 12:00AM	6	239.63	6.48	1437.75	9317		2838	17030	26346		29400		3054	
TOTAL		24		6.37	7193.25	45806			48415	94221		110719		16498	
WEEKLY				6.34	143782	911692	18194		252025	1163717	18581	1535934	26527	372217	7946
ANNUAL				6.34	7476651	47407991	218332		13105310	60513301	222976	79868572	318329	19355271	95354

TABLE 1-70B
COASTING(5 MPH BAND)(MIN RUN TIME + 1 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND ENERGY NORMAL	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00	DEMAND ENERGY SAVINGS	0.00 1.00	0.25 0.75	0.50 0.50	0.75 0.25	1.00 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						95.35					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						95.35	0.000	0.057	0.114	0.171	0.228
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						19.36					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						19.36	0.127	0.095	0.063	0.032	0.000
							FRACTION	0.127	0.152	0.177	0.203	0.228
							PERCENT	12.7	15.2	17.7	20.3	22.8

TABLE 1-71A
COASTING(5 MPH BAND)(MIN RUN TIME + 1.25 MIN)(CAM-CONTROL)
ENERGY ANALYSIS

PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	RUNNING TRAINS KWH	RUNNING TRAINS KW PEAK	TURNAROUND & STORAGE KW	TURNAROUND & STORAGE KWH	TOTAL KWH	TOTAL KW PEAK	NORMAL TOTAL KWH	NORMAL TOTAL KW PEAK	DIFFERENCE KWH	DIFFERENCE KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	2877.00	6.07	8631.00	52390	17463	341	1023	53413	17804	79582	26527	26169	8723
MIDDAY	9:00AM - 3:00PM	6	958.95	5.85	5753.70	33659		2156	12935	46594		63075		16481	
PM PEAK	3:00PM - 6:00PM	3	2877.00	6.07	8631.00	52390		341	1023	53413		79582		26169	
EVENING	6:00PM - 12:00AM	6	479.48	5.83	2876.85	16772		2608	15647	32419		40660		8240	
TOTAL		24		5.99	25893	155212			30629	185840		262899		77059	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	479.48	5.83	5753.70	33544		2608	31295	64839		81319		16481	
EVENING	6:00PM - 12:00AM	6	239.55	5.78	1437.30	8308		2834	17006	25314		29400		4086	
TOTAL		24		5.82	7191.00	41852			48301	90153		110719		20567	
WEEKLY				5.98	143845	859761	17463		249746	1109507	17804	1535934	26527	426427	8723
ANNUAL				5.98	7479927	44707568	209561		12986813	57694381	213654	79868572	318329	22174191	104676

TABLE 1-71B
COASTING(5 MPH BAND)(MIN RUN TIME + 1.25 MIN)(CAM-CONTROL)
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND / ENERGY / NORMAL	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND / ENERGY / SAVINGS	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
		RATE(POWER BILL UNITS)						SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00060	0.00120	0.00179	0.00239						
TRACTION(MW)	318.33						104.68					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	418.23						104.68	0.000	0.063	0.125	0.188	0.250
ENERGY COMPONENT		0.00654	0.00491	0.00327	0.00164	0.00000						
TRACTION(MKWH)	79.87						22.17					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	152.80						22.17	0.145	0.109	0.073	0.036	0.000
							FRACTION	0.145	0.171	0.198	0.224	0.250
							PERCENT	14.5	17.1	19.8	22.4	25.0

TABLE 1-72

Monte Carlo Results for WMATA Red Line

Energy Consumption KWH/Car Mile	Time (min)	% Reduction In Energy	% Increase In Schedule Time
6.60	19.1	--	--
5.50	19.3	16.7	1.1
5.35	20.0	19.0	4.6
5.31	19.5	19.6	2.1

TABLE 1-73

Steepest Descent Results for WMATA Red Line

Energy Consumption (KWH/Car Mile)	Time (min)	%Reduction in Energy	% Increase in Schedule Time
6.60	19.1	--	---
5.47	19.3	17.1	0.84
5.16	19.7	21.8	2.72
4.88	20.1	26.1	4.81

TABLE 1-74
Summary of Coasting Predictions on WMATA and MARTA

	DEMAND RATE	ENERGY RATE	MONTHLY DEMAND SAVINGS (KW)	ANNUAL ENERGY SAVINGS (MWH)	ANNUAL DEMAND SAVINGS ($)	ANNUAL ENERGY SAVINGS ($)	ANNUAL TOTAL SAVINGS ($)	ANNUAL TOTAL SAVINGS (%)	
WMATA									
PEPCO DC	11.70	0.028	2300	8000	322920	224000	546920		
PEPCO MD	9.85	0.024	670	2400	79194	57600	136794		
PEPCO VA	7.85	0.022	150	600	14130	13200	27330		
VEPCO VA	0.00	0.061	0	100	0	6100	6100		
TOTAL			3120	11100	416244	300900	717144	4.6	(1981 $)
MARTA									
GPC	11.62	0.0227	1113	4068	155138	92350	247488	6.0	(1985 $)

TABLE 1-75

Passenger Load Factor Improvement
Operating Timetable Summary

SERVICE	TIME PERIOD	ORIGINAL CARS/TRAIN	ORIGINAL HEADWAY (MIN)	ORIGINAL PASS. LOAD FACTOR (%)	STRATEGIC CARS/TRAIN	STRATEGIC HEADWAY	STRATEGIC PASS. LOAD FACTOR (%)
Weekday							
Morning	12:00 am-6:00 am	NO SERVICE			NO SERVICE		
Peak	6:00 am-9:00 am	6	2	50	4	2	75
Midday	9:00 am-3:00 pm	4	4	25	4	4	25
Peak	3:00 pm-6:00 pm	6	2	50	4	2	75
Evening	6:00 pm-12:00 pm	4	8	25	2	8	37.5
Sat., Sun. & Hol.							
Morning	12:00 am-6:00 am	NO SERVICE					
Day	6:00 am-6:00 pm	4	8	25	4	8	25
Evening	6:00 pm-12:00 am	2	8	25	2	8	25

Trains leave on the hour from both terminals.

TABLE 1-76A
PASSENGER LOAD FACTOR IMPROVEMENT
ENERGY ANALYSIS

						RUNNING TRAINS		TURNAROUND & STORAGE		TOTAL		NORMAL TOTAL		DIFFERENCE	
PERIOD	TIME	HOURS	CM/HR	KWHPCM	CM	KWH	KW PEAK	KW	KWH	KWH	KW PEAK	KWH	KW PEAK	KWH	KW PEAK
WEEKDAY															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
AM PEAK	6:00AM - 9:00AM	3	1917.30	5.48	5751.90	31520	10507	555	1666	33186	11062	49019	16340	15833	5278
MIDDAY	9:00AM - 3:00PM	6	959.25	5.49	5755.50	31598		2234	13405	45002		45002		0	
PM PEAK	3:00PM - 6:00PM	3	1917.30	5.48	5751.90	31520		555	1666	33186		49019		15833	
EVENING	6:00PM - 12:00AM	6	239.85	5.58	1439.10	8030		2647	15882	23912		32688		8776	
TOTAL		24		5.49	18698	102669			32619	135287		175729		40441	
SAT & SUN															
MORNING	12:00AM - 6:00AM	6	NS					3060	18360	18360		18360		0	
DAY	6:00AM - 6:00PM	12	239.85	5.58	2878.20	16060		2647	31765	47825		65377		17552	
EVENING	6:00PM - 12:00AM	6	239.63	5.57	1437.75	8008		2853	17118	25126		25130		4	
TOTAL		24		5.58	4315.95	24069			48883	72951		90507		17555	
WEEKLY				5.50	102124	561481	10507		260859	822339	11062	1059657	16340	237318	5278
ANNUAL				5.50	5310443	29196998	126082		13564652	42761650	132745	55102175	196076	12340524	63331

TABLE 1-76B
PASSENGER LOAD FACTOR IMPROVEMENT
POWER BILL ANALYSIS

PORTION OF POWER BILL ==>	DEMAND / ENERGY	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00	DEMAND / ENERGY	0.00 / 1.00	0.25 / 0.75	0.50 / 0.50	0.75 / 0.25	1.00 / 0.00
	NORMAL	RATE(POWER BILL UNITS)					SAVINGS	SAVINGS(POWER BILL UNITS)				
DEMAND COMPONENT		0.00000	0.00084	0.00169	0.00253	0.00338						
TRACTION(MW)	196.08						63.33					
SUPPORT(MW)	99.90						0.00					
TOTAL(MW)	295.98						63.33	0.000	0.053	0.107	0.160	0.214
ENERGY COMPONENT		0.00781	0.00586	0.00391	0.00195	0.00000						
TRACTION(MKWH)	55.10						12.34					
SUPPORT(MKWH)	72.93						0.00					
TOTAL(MKWH)	128.03						12.34	0.096	0.072	0.048	0.024	0.000
							FRACTION	0.096	0.126	0.155	0.185	0.214
							PERCENT	9.6	12.6	15.5	18.5	21.4

TABLE 1-77
Energy Cost Effect of Passenger Load Factor Improvement
on WMATA and MARTA

	DEMAND RATE	ENERGY RATE	MONTHLY DEMAND SAVINGS (KW)	ANNUAL ENERGY SAVINGS (MWH)	ANNUAL DEMAND SAVINGS ($)	ANNUAL ENERGY SAVINGS ($)	ANNUAL TOTAL SAVINGS ($)	ANNUAL TOTAL SAVINGS (%)
WMATA								
PEPCO DC	11.70	0.028	0	18500	0	518000	518000	
PEPCO MD	9.85	0.024	0	2800	0	67200	67200	
PEPCO VA	7.85	0.022	0	2500	0	55000	55000	
VEPCO VA	0.00	0.061	0	2100	0	128100	128100	
TOTAL			0	25900	0	768300	768300	4.9
MARTA								
GPC	11.62	0.0227	1608	3071	224220	69715	293934	7.1

TABLE 1-78
ESTIMATES OF RECEPTIVITY FOR NORMAL OPERATION AT MARTA

PERIOD	DURATION	NAT RECEP	FULL RECEP	NO REGEN	% RECEP
	NORTH - SOUTH LINE ALL OPERATION (1983 & 1984)				
AM PEAK	6:45AM-9:15AM	4.81	3.40	7.06	61
MIDDAY	9:15AM-3:45PM 5:45AM-6:45AM	4.62	3.31	6.87	63
PM PEAK	3:45PM-6:15PM	4.84	3.27	7.15	60
EVENING	6:15PM-1:15AM	4.04	3.41	5.36	68
SATURDAY	5:45AM-1:15AM	3.89	3.28	5.35	71
SUNDAY	6:15AM-1:15AM	4.60	3.19	5.34	34
	EAST - WEST LINE 1984 OPERATION				
AM PEAK	6:45AM-9:15AM	4.22	3.22	6.51	70
MIDDAY	9:15AM-3:45PM 5:45AM-6:45AM	4.12	3.18	6.42	71
PM PEAK	3:45PM-6:15PM	4.22	3.21	6.54	70
EVENING	6:15PM-1:15AM	4.55	3.45	6.46	63
SATURDAY	5:45AM-1:15AM	4.31	3.11	6.45	64
SUNDAY	6:15AM-1:15AM	4.90	3.13	6.45	47
	EAST - WEST LINE 1983 OPERATION				
AM PEAK	6:45AM-9:15AM	4.66	3.11	6.48	54
MIDDAY	9:15AM-3:45PM 5:45AM-6:45AM	4.44	3.18	6.40	61
PM PEAK	3:45PM-6:15PM	4.70	3.13	6.51	54
EVENING	6:15PM-1:15AM	4.55	3.45	6.45	63
SATURDAY	5:45AM-1:15AM	4.31	3.11	6.45	64
SUNDAY	6:15AM-1:15AM	4.90	3.13	6.45	47

TABLE 1-79
ENERGY COST VARIATION RESULTING FROM OFFSET VARIATION AT MARTA

LINE AND OPERATING PERIOD	KWHPCM* VARIATION	CAR-MILES PER MONTH	COST+ PER MONTH
ENERGY USE COST RANGE			
NORTH-SOUTH AM PEAK	0.27	264326 **	1620
NORTH-SOUTH EVENING	0.42	111273 ***	1061
EAST-WEST AM PEAK	0.13	234580 **	692
EAST-WEST EVENING	0.40	75652 ***	687
TOTAL SAVINGS/MONTH ENERGY USE			4060
POWER DEMAND COST RANGE		CAR-MI/HR	
NORTH-SOUTH AM PEAK	0.27	1057	3331
EAST-WEST AM PEAK	0.13	938	1423
TOTAL VARIATION/MONTH DEMAND			4754
TOTAL MONTHLY VARIATION			8814
TOTAL ANNUAL VARIATION			105768
ANNUAL POWER BILL			4140000
VARIATION AS PERCENT OF POWER BILL			2.6

** INCLUDES AM PEAK, PM PEAK AND MIDDAY PERIODS
*** INCLUDES EVENING, SATURDAY AND SUNDAY PERIODS
+ COST PER MONTH
ENERGY USE SAVINGS = KWHPCM * CAR-MILES/MONTH * .0227
POWER DEMAND SAVINGS = KWHPCM * CAR-MILES/HOUR * 11.62

TABLE 1-80
REDUCTION OF POWER DEMAND AND ENERGY USE BY EMPLOYING DIRECT MERCURY VAPOR LIGHTING IN UNDERGROUND STATIONS

	PEPCO JURISDICTIONS			VEPCO
	DC	MD	VA	
NUMBER OF UNDERGROUND STATIONS				
Side Platform	6	0	2	5
Center Platform	14	0	0	1
PEAK POWER DEMAND SAVINGS				
KW	1040	0	165	450
Percent of Support Power	12	0	18	24
ANNUAL ENERGY SAVINGS				
MWH	9100	0	1400	3900
Percent of Support Energy	13	0	18	24

TABLE 1-81
ENERGY SAVINGS BY REDUCING ESCALATOR OPERATION DURING NON-PEAK HOURS OF OPERATION

	PEPCO JURISDICTIONS			VEPCO
	DC	MD	VA	
Normal Escalator Power (Peak Operation) (KW)	540	40	130	120
Escalator Power Reduction (Non-Peak Operation) (KW)	185	0	28	54
Annual Energy Savings				
MWH	750	0	100	200
Percent of Support Energy	1		1	1

*Escalators with heights of rise below 16 ft.and the third escalator of a three escalator grouping are turned off during non-peak.

TABLE 1-82
SURVEYED INSTALLED SUPPORT LOAD

SUPPORT POWER ITEM	INSTALLED KW
VENTILATION	3160
Ventilation	1037
Exhaust Fans	507
Air Handler	416
Mid Tunnel Exhaust	1200
HEATING	128
Hot Water Heaters	128
Space Heating	0
LIGHTING	2538
Interior Lighting	1753
Emergency Lighting	332
Parking Lot Lighting	453
ESCALATORS AND ELEVATORS	3400
Escalators	2128
Elevators	1272
AIR CONDITIONING	6146
Air Conditioning	275
Chillers	5871
TRAIN CONTROL & COMMUNICATIONS	1641
Train Control	1635
Communications	6
FARE COLLECTION	337
MISCELLANEOUS	2077
Miscellaneous Mechanical	742
Miscellaneous Electrical	28
Air Compressor	80
HVAC	101
Station Power	1077
Isolated T/C Room	49
TOTAL SUPPORT POWER	19427

SYSTEM LAYOUT

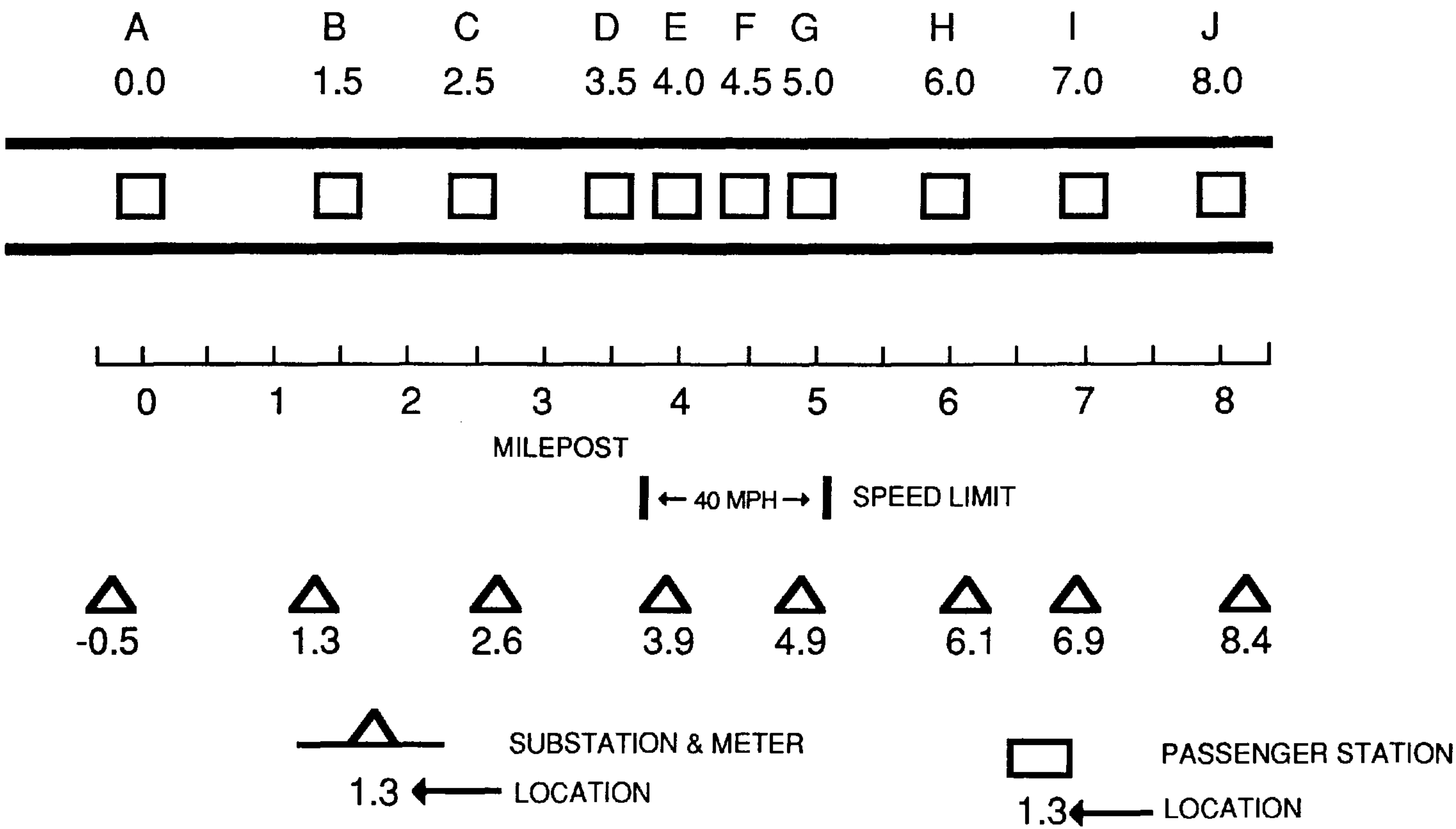


FIGURE 1-1

TRACTION CURVES
CHOPPER CONTROL

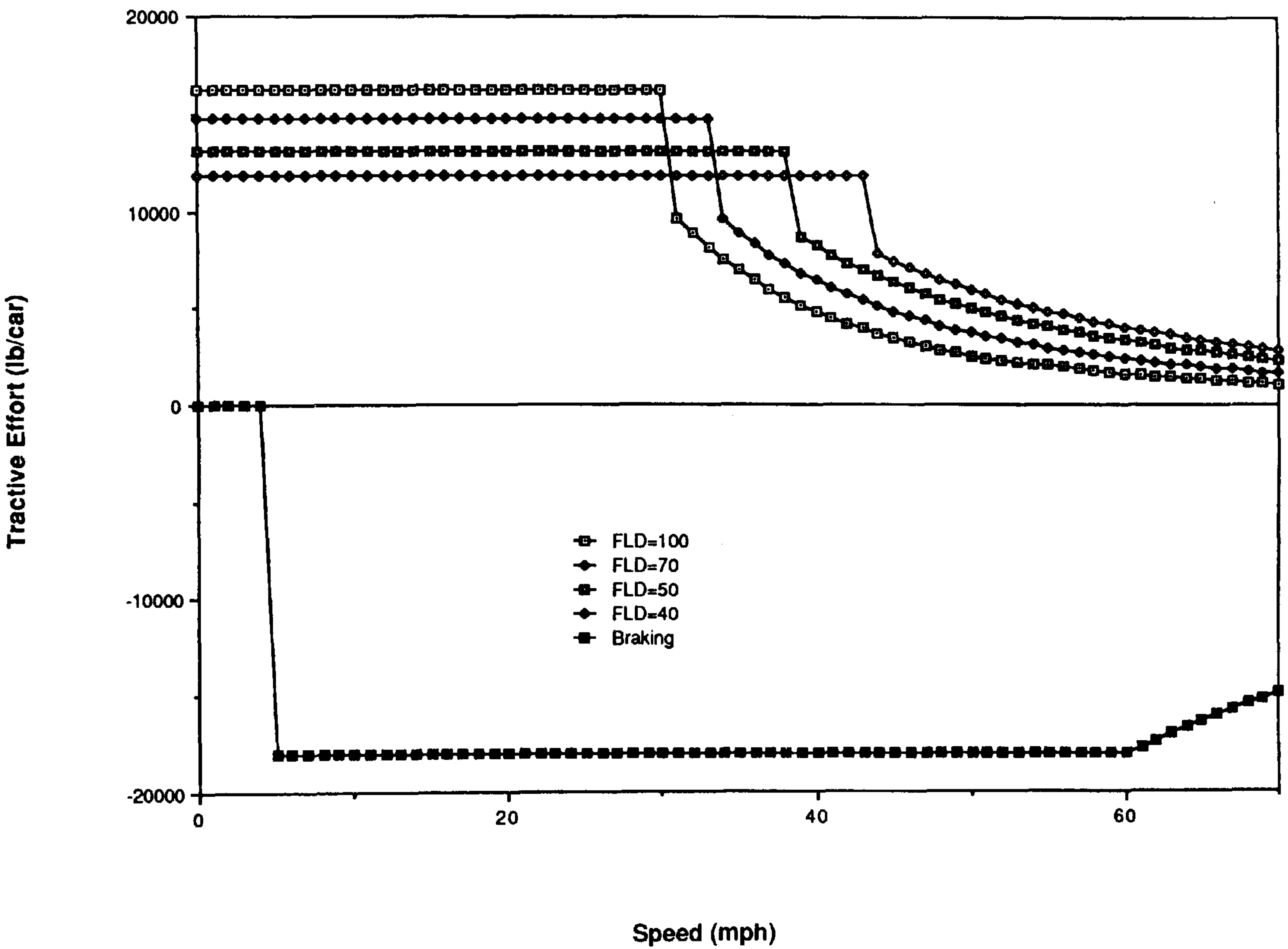


FIGURE 1-2

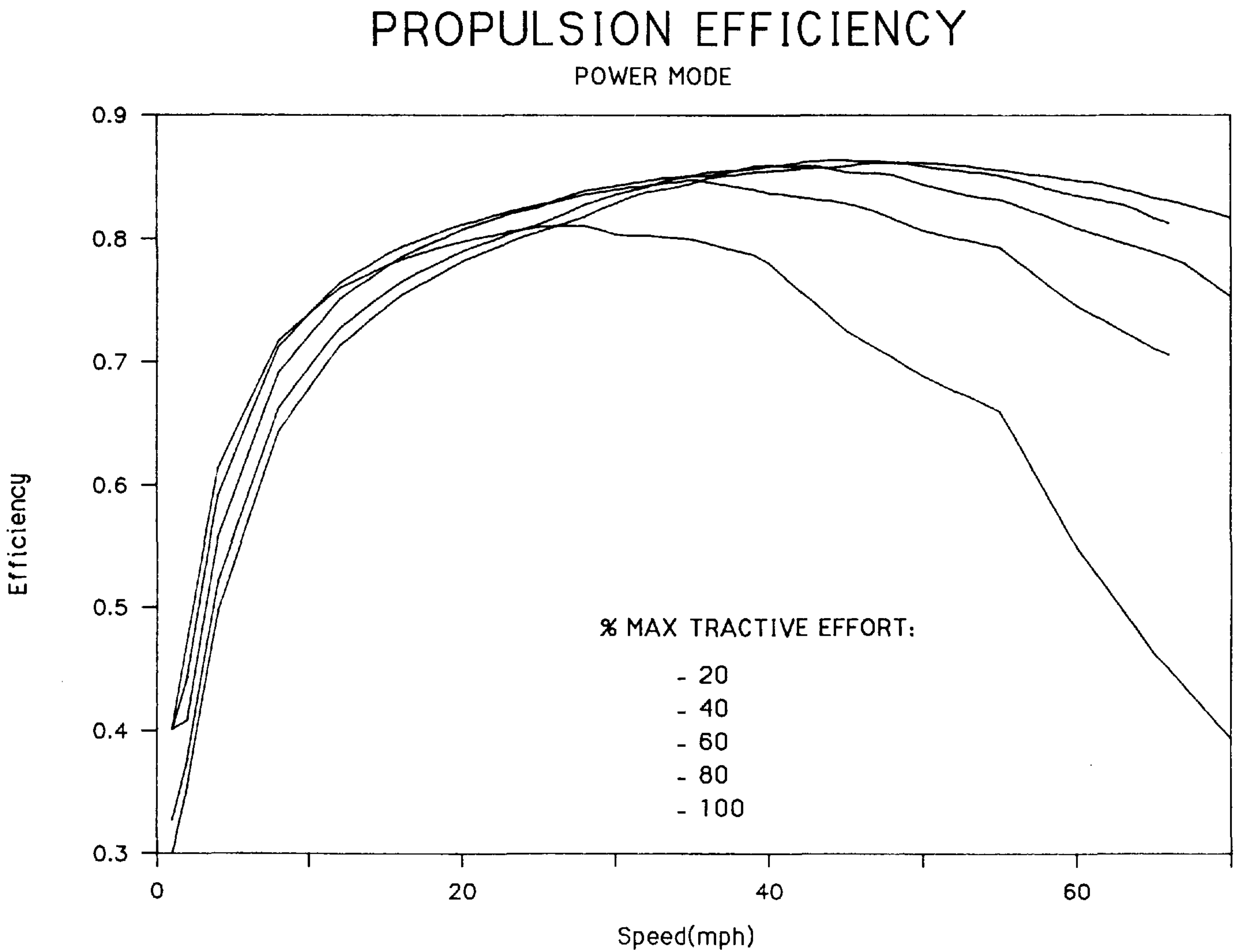

PROPULSION EFFICIENCY
POWER MODE
Efficiency
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
20
40
60
Speed(mph)
% MAX TRACTIVE EFFORT:
- 20
- 40
- 60
- 80
- 100

FIGURE 1-3

PROPULSION EFFICIENCY

BRAKING MODE

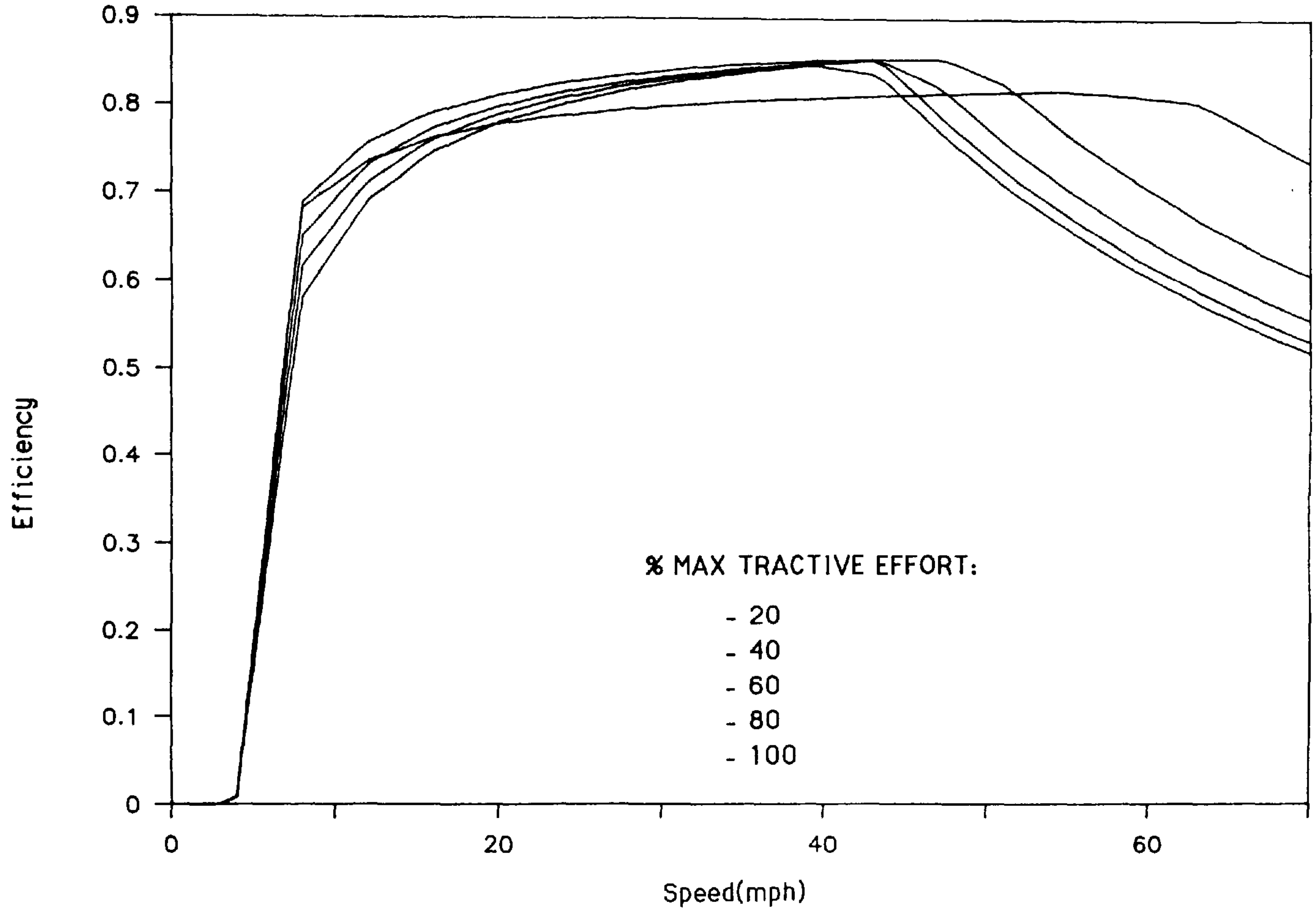


FIGURE 1-4

POWER DISTRIBUTION NODAL DIAGRAM

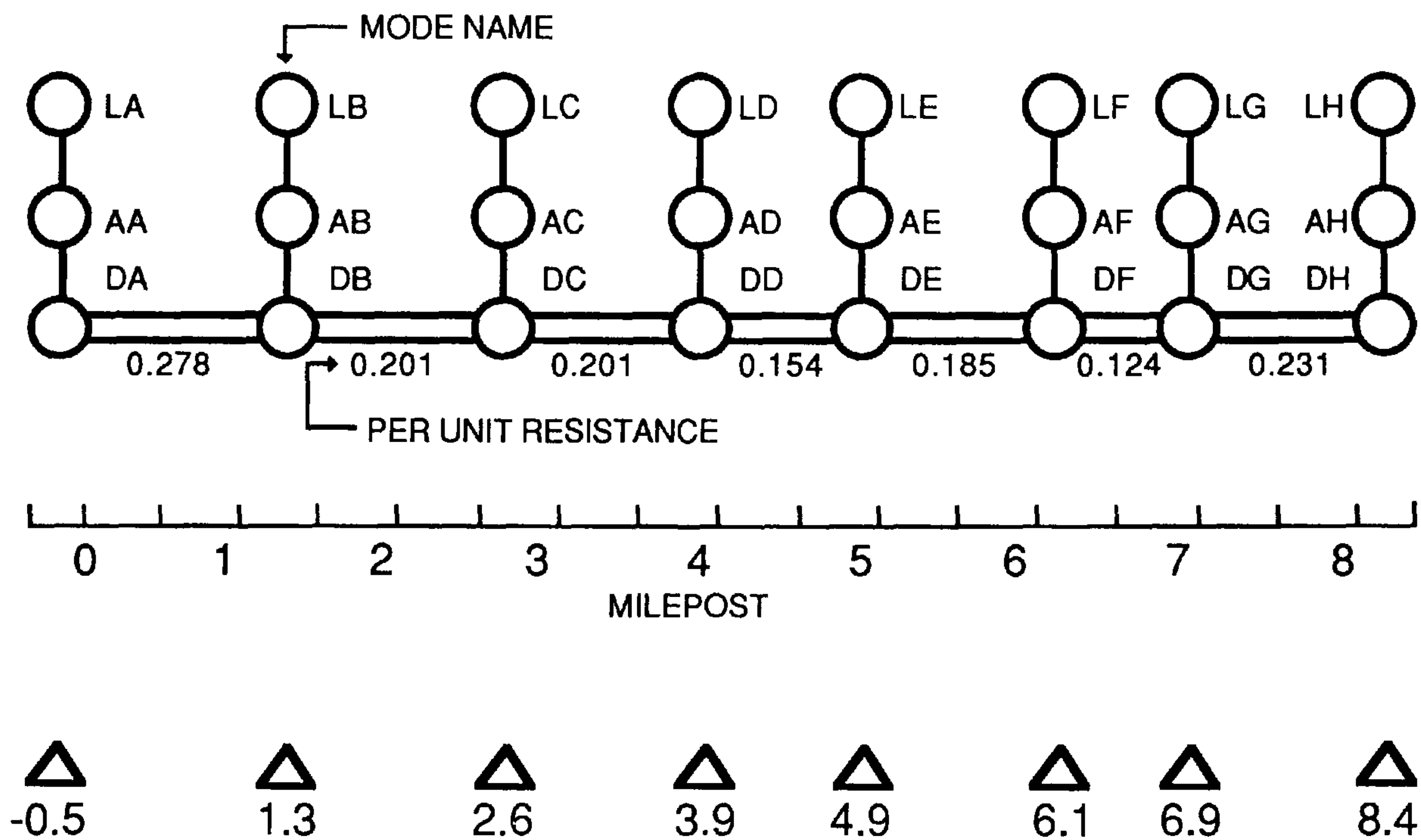


FIGURE 1-5

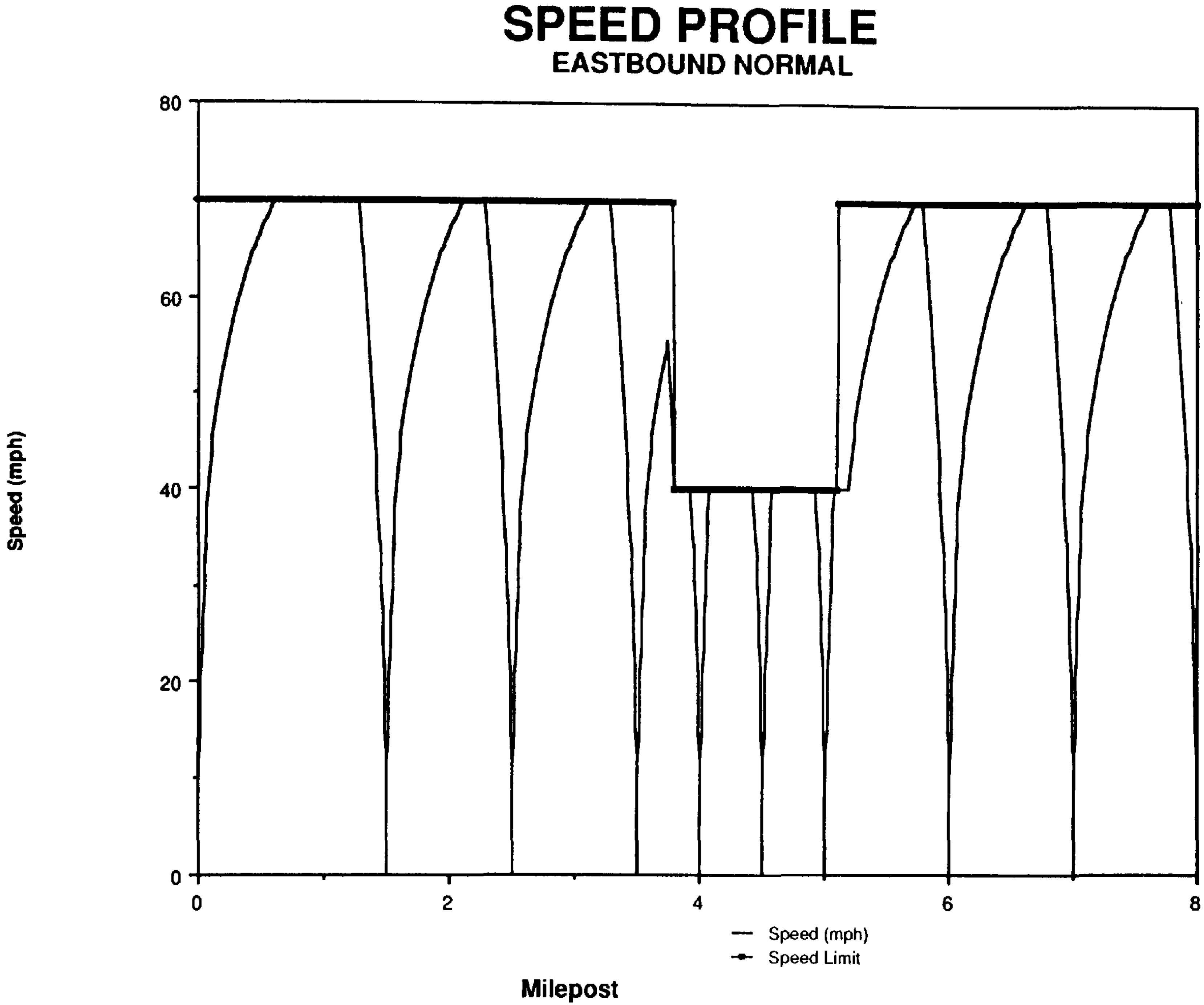

SPEED PROFILE
EASTBOUND NORMAL
Speed (mph)
80
60
40
20
0
0
2
4
6
8
Speed (mph)
Speed Limit
Milepost

FIGURE 1-6

SPEED PROFILE
WESTBOUND NORMAL

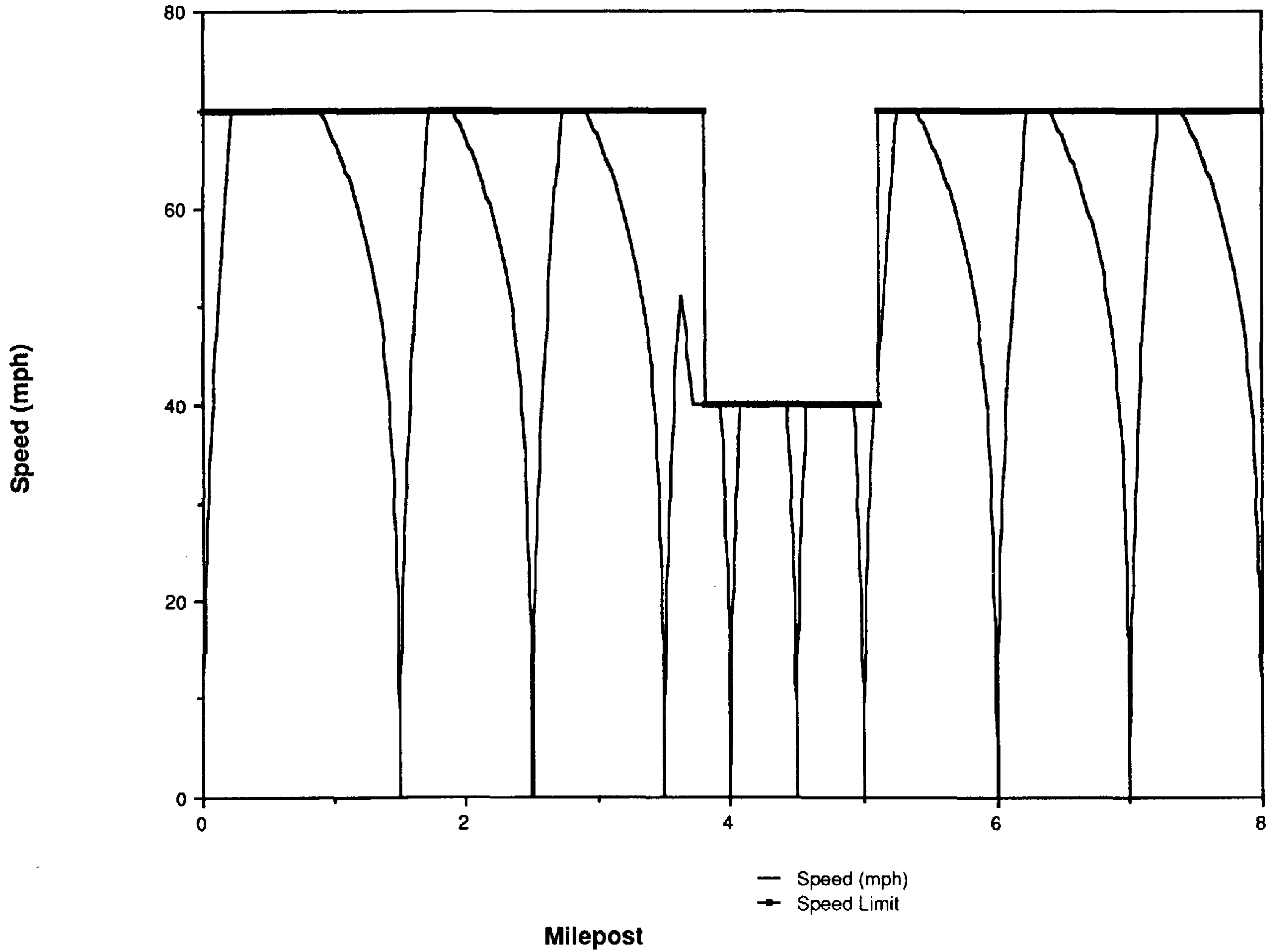


FIGURE 1-7

POWER PROFILE
EASTBOUND NORMAL

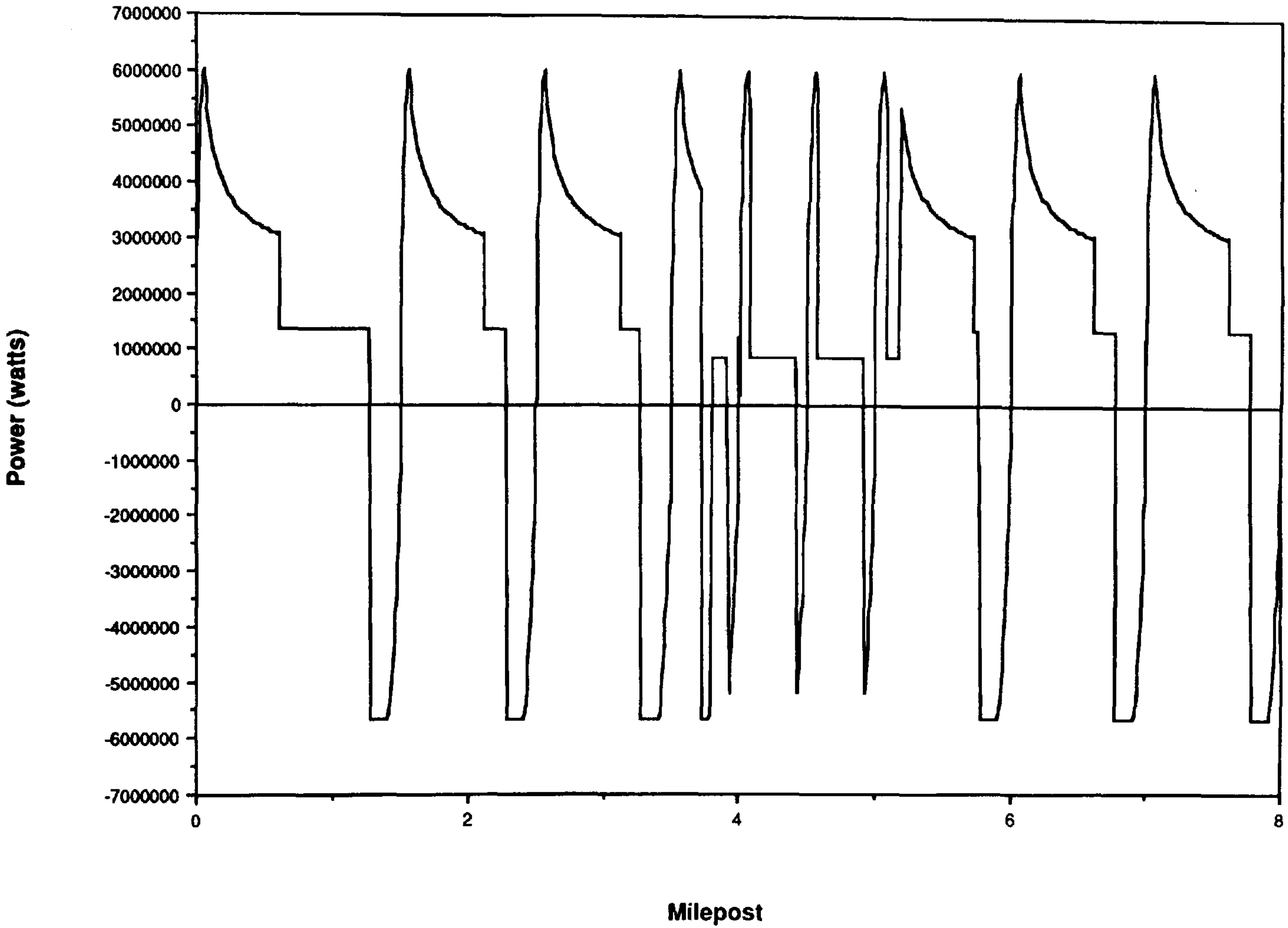


FIGURE 1-8

POWER PROFILE
WESTBOUND NORMAL

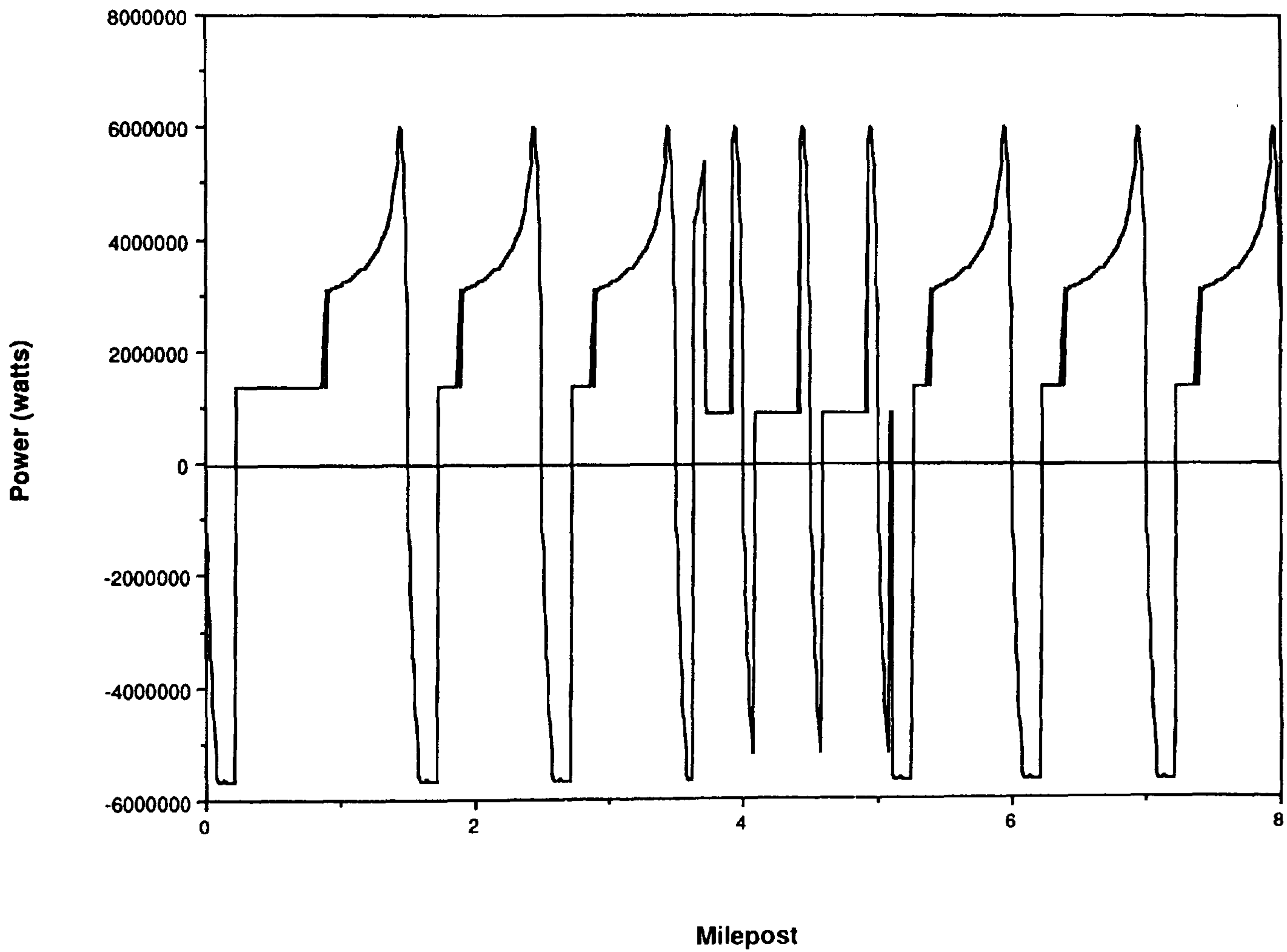


FIGURE 1-9

Regional Rapid Rail Transit System

Planned 101-Mile System

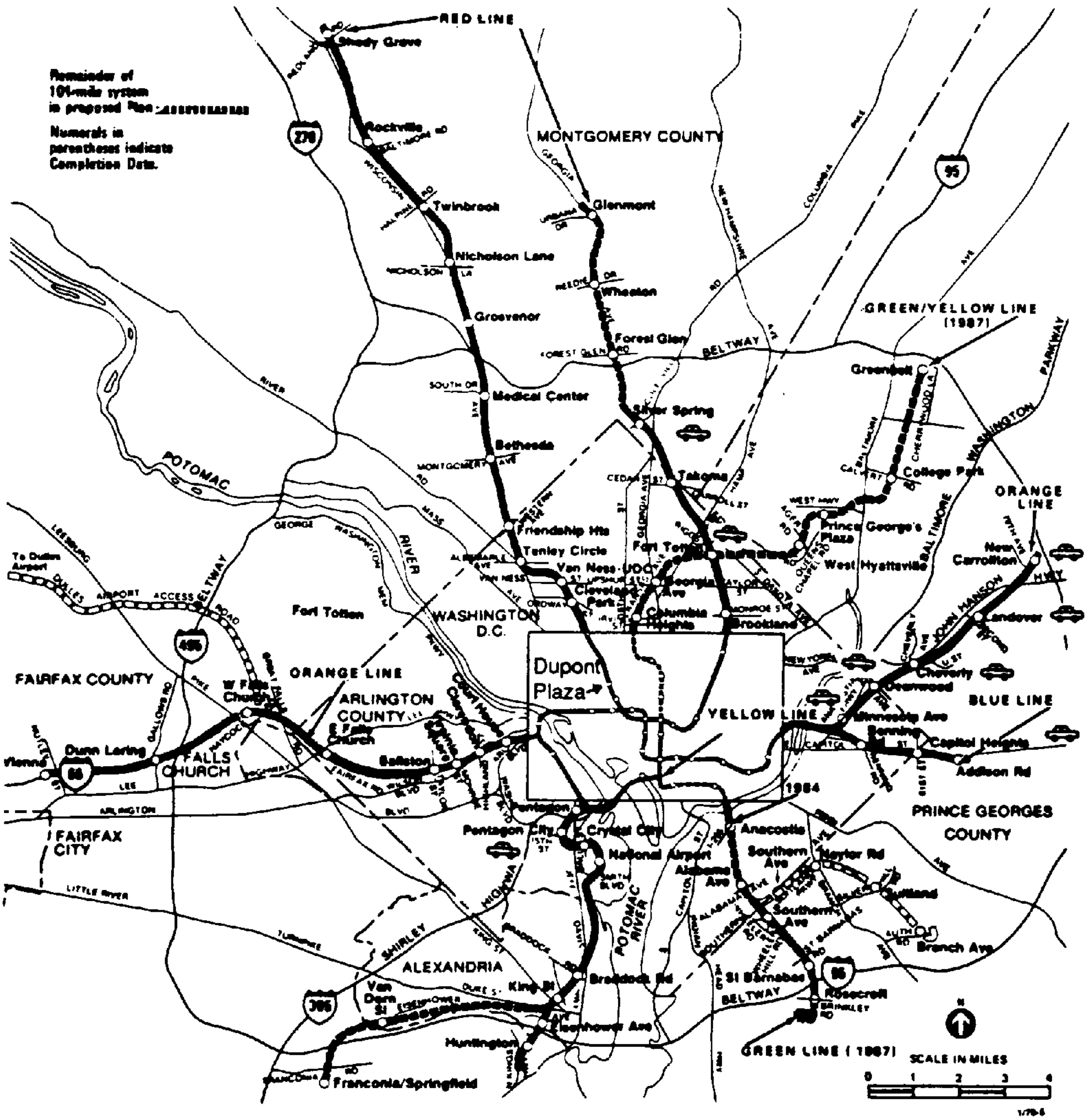


FIGURE 1-10

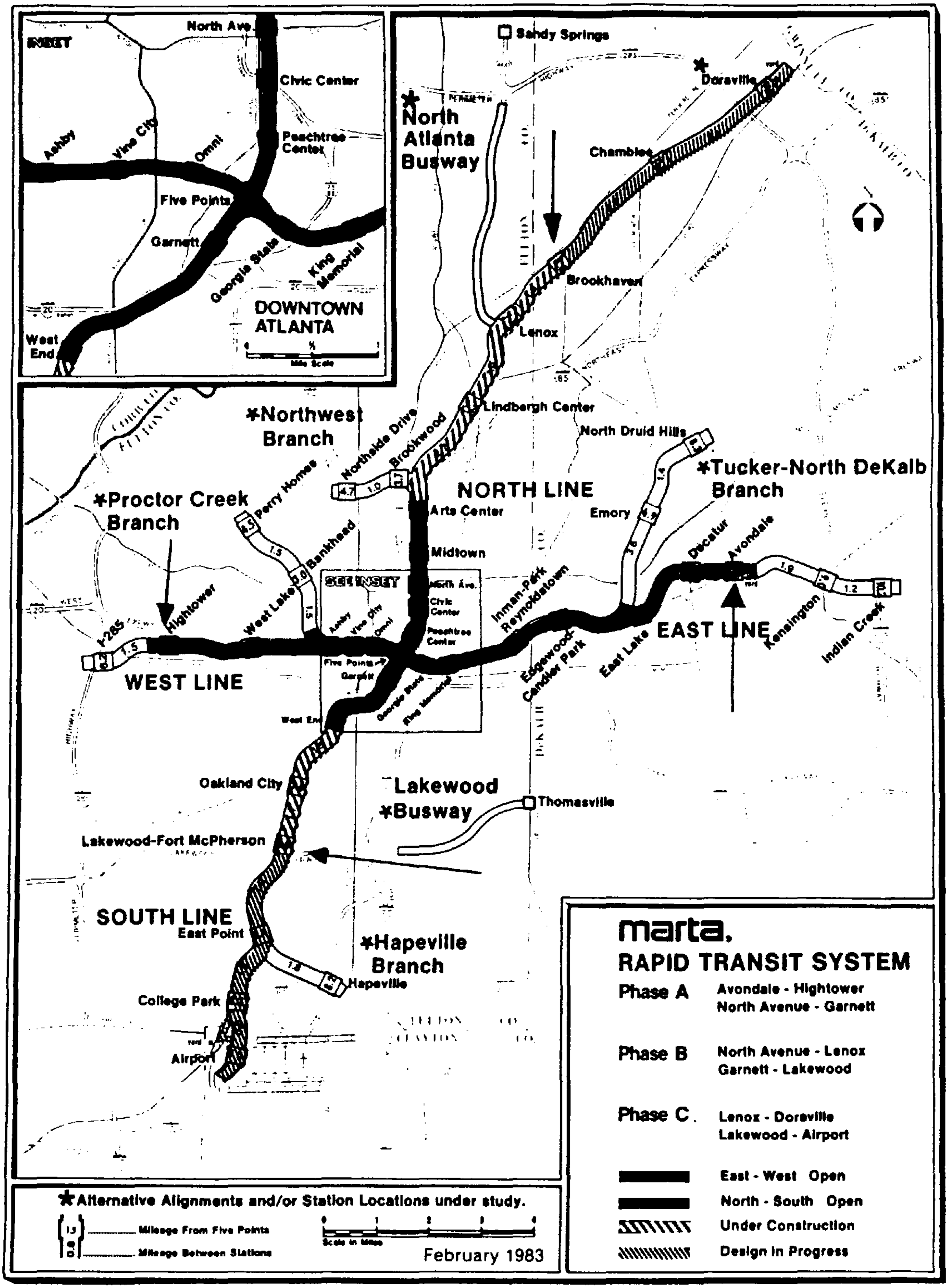

INSET
North Ave.
Civic Center
Peachtree Center
Ashby
Vine City
Omni
Five Points
Garnett
Georgia State
King Memorial
West End
DOWNTOWN ATLANTA
Mile Scale
Sandy Springs
Doraville
North Atlanta Busway
Chamblee
Brookhaven
Lenox
Lindbergh Center
North Druid Hills
*Northwest Branch
Northside Drive
Brookwood
Perry Homes
*Proctor Creek Branch
NORTH LINE
Arts Center
Midtown
Emory
*Tucker-North DeKalb Branch
Decatur
Avondale
Bankhead
West Lake
Hightower
SEE INSET
Inman Park Reynoldstown
Edgewood-Candler Park
East Lake
EAST LINE
Kensington
Indian Creek
WEST LINE
Oakland City
Lakewood *Busway
Thomasville
Lakewood-Fort McPherson
SOUTH LINE
East Point
*Hapeville Branch
Hapeville
College Park
Airport
marta.
RAPID TRANSIT SYSTEM
Phase A Avondale - Hightower
North Avenue - Garnett
Phase B North Avenue - Lenox
Garnett - Lakewood
Phase C Lenox - Doraville
Lakewood - Airport
East - West Open
North - South Open
Under Construction
Design In Progress
*Alternative Alignments and/or Station Locations under study.
Mileage From Five Points
Mileage Between Stations
Scale in Miles
February 1983

FIGURE 1-11

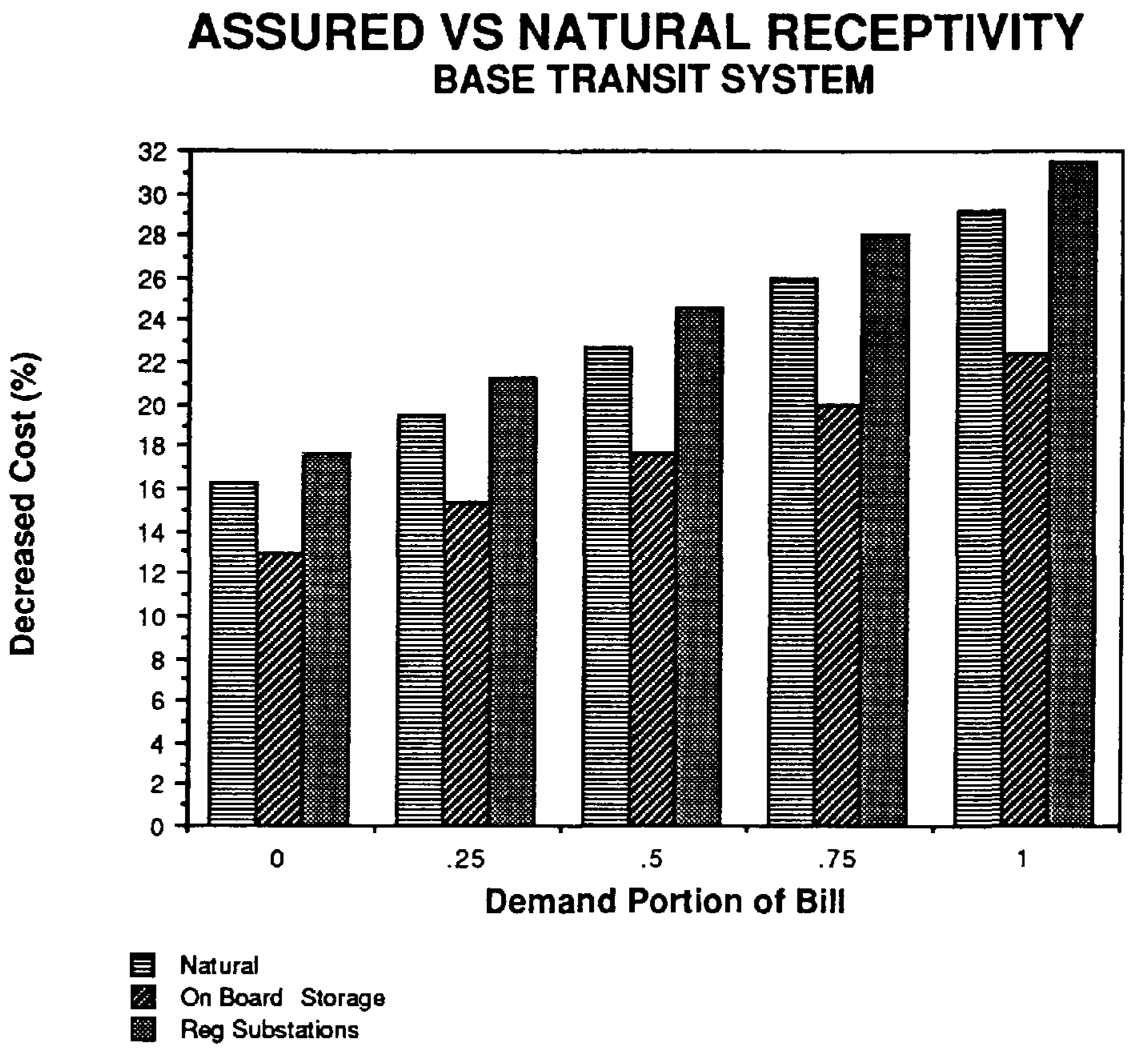

ASSURED VS NATURAL RECEPTIVITY
BASE TRANSIT SYSTEM
Decreased Cost (%)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
0
.25
.5
.75
1
Demand Portion of Bill
Natural
On Board Storage
Reg Substations

FIGURE 1-12

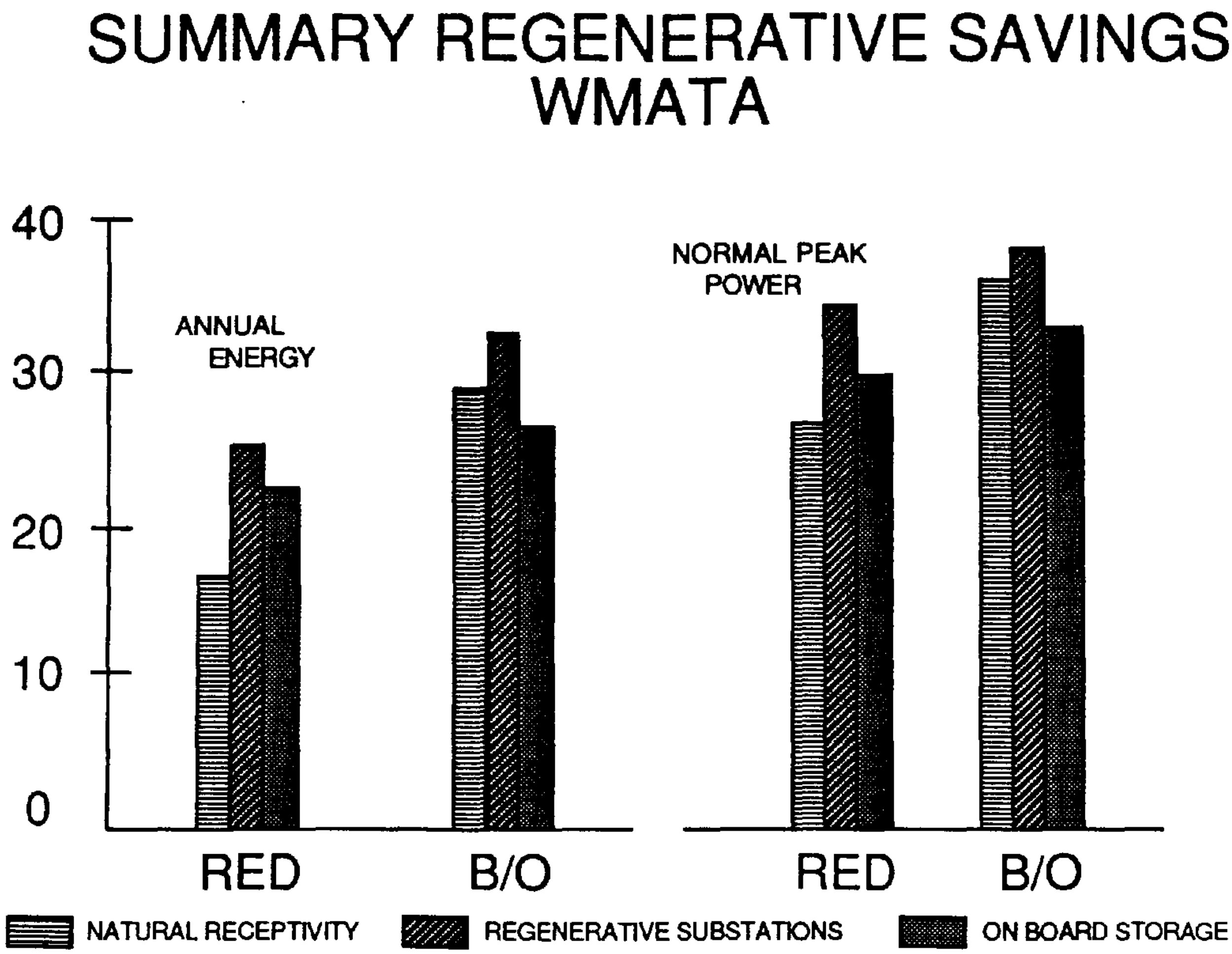

SUMMARY REGENERATIVE SAVINGS
WMATA
40
30
20
10
0
ANNUAL
ENERGY
NORMAL PEAK
POWER
RED
B/O
RED
B/O
NATURAL RECEPTIVITY
REGENERATIVE SUBSTATIONS
ON BOARD STORAGE

FIGURE 1-13

SPEED PROFILE
MINIMUM TIME

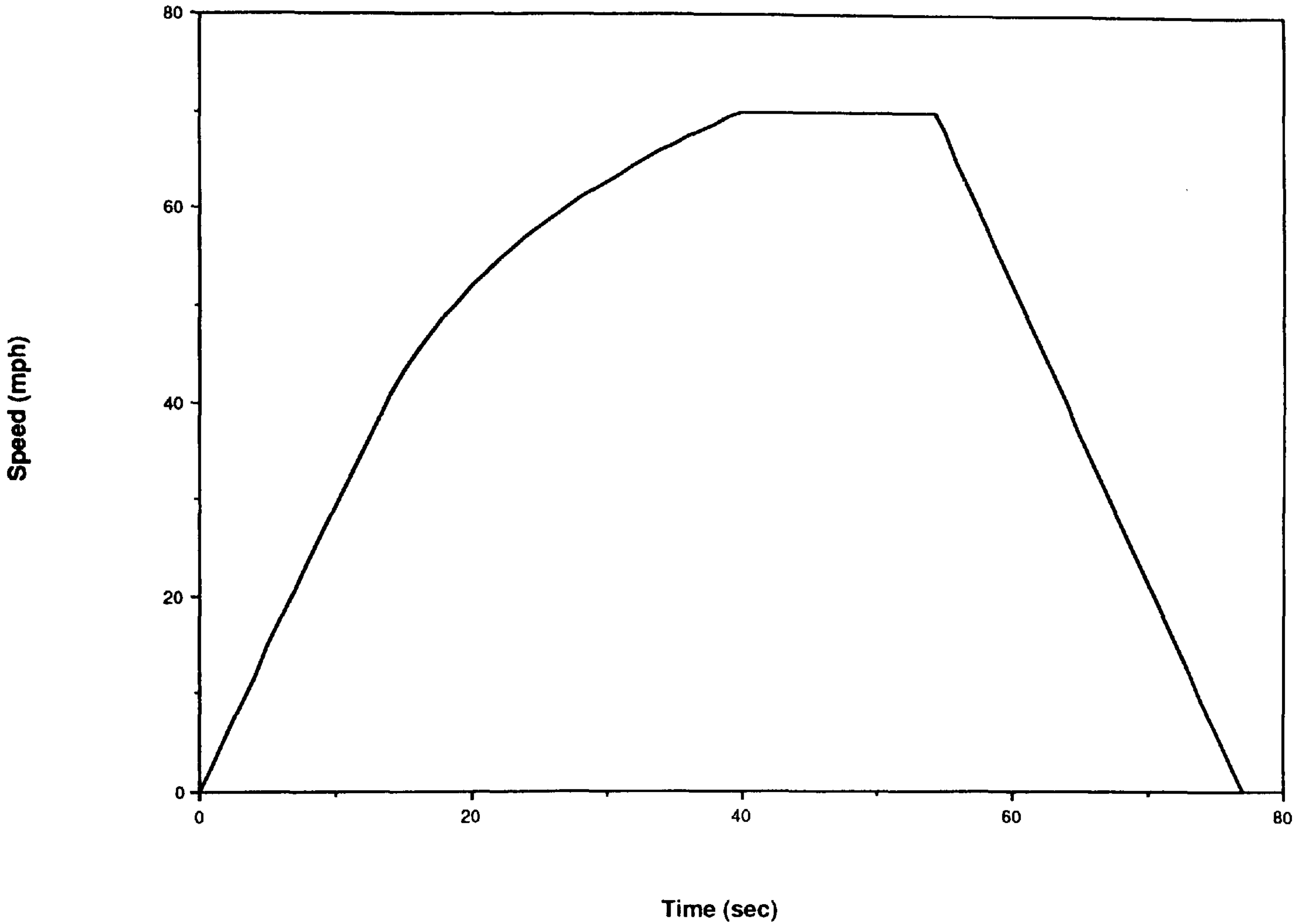


FIGURE 1-14A

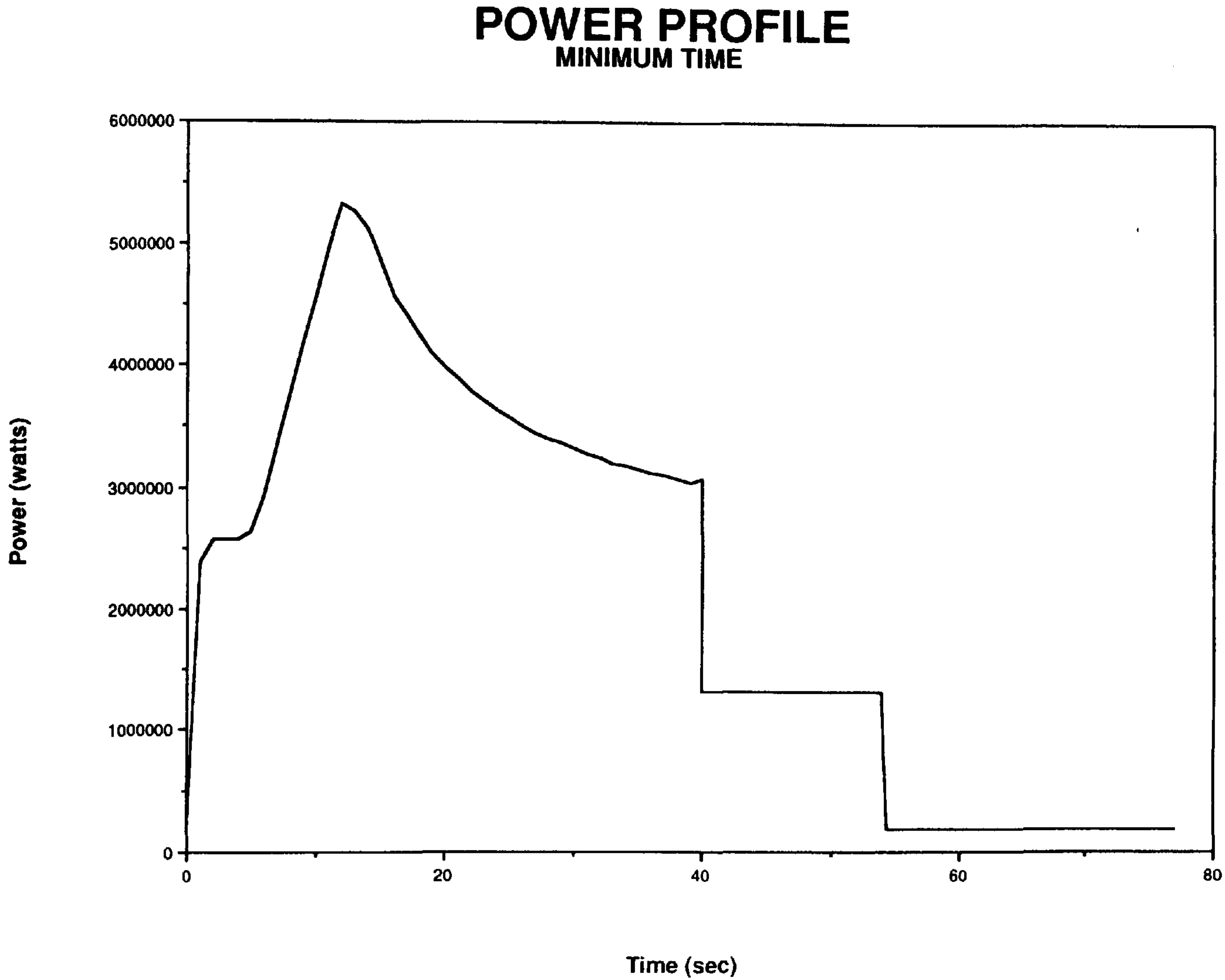

POWER PROFILE
MINIMUM TIME
6000000
5000000
4000000
3000000
2000000
1000000
0
Power (watts)
0
20
40
60
80
Time (sec)

FIGURE 1-14B

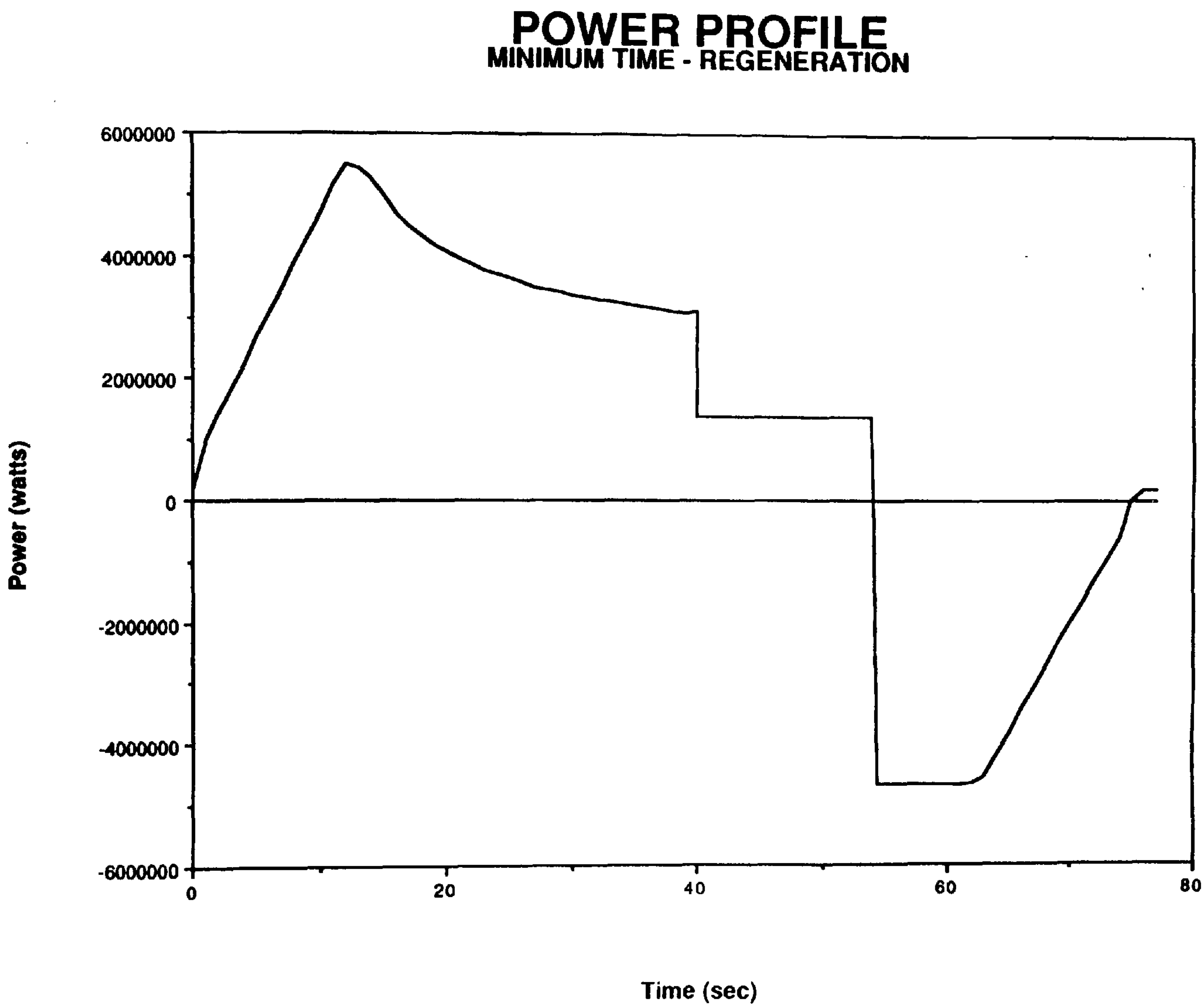

POWER PROFILE
MINIMUM TIME - REGENERATION
6000000
4000000
2000000
0
-2000000
-4000000
-6000000
Power (watts)
0
20
40
60
80
Time (sec)

FIGURE 1-14C

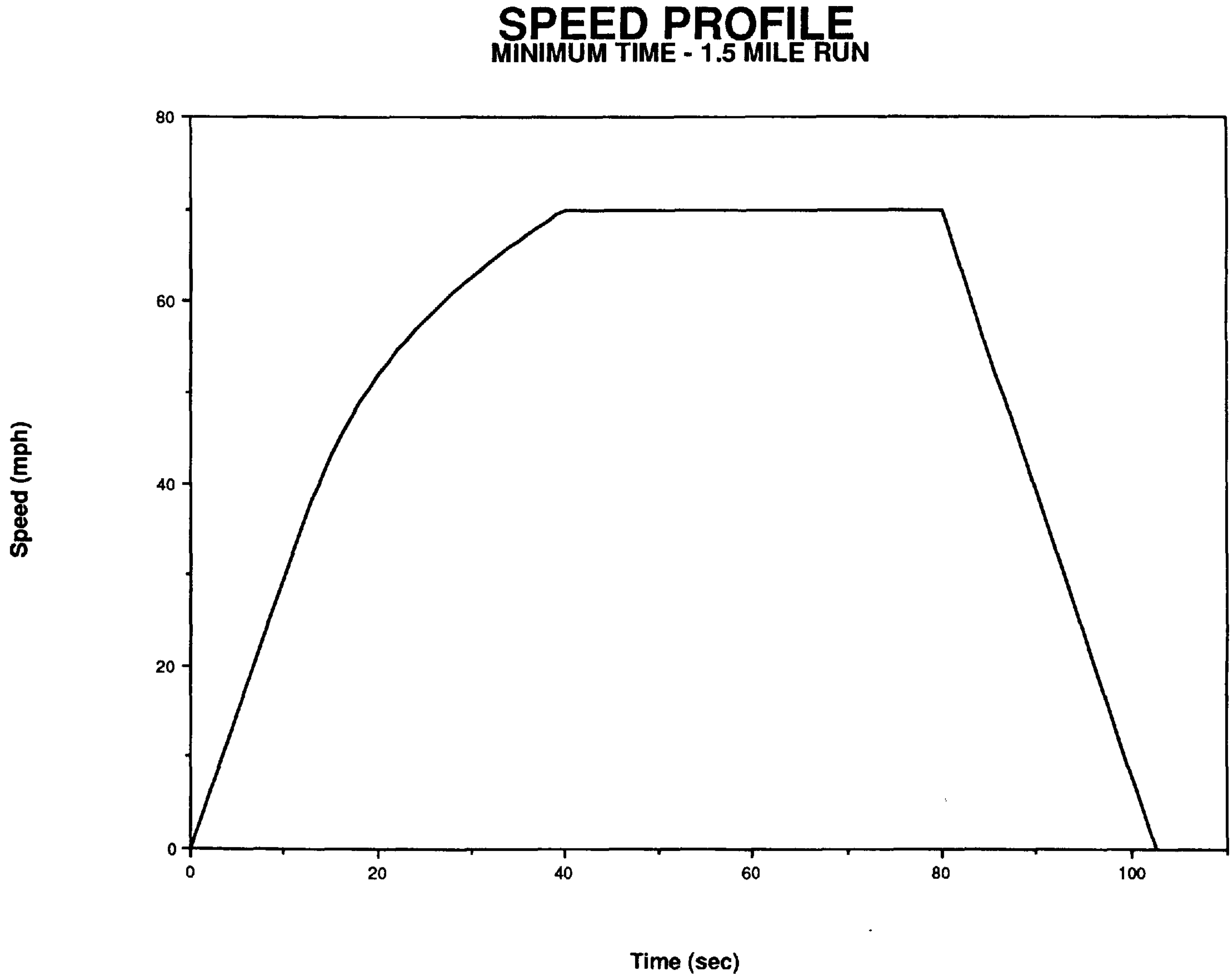

SPEED PROFILE
MINIMUM TIME - 1.5 MILE RUN
Speed (mph)
0
20
40
60
80
0
20
40
60
80
100
Time (sec)

FIGURE 1-15A

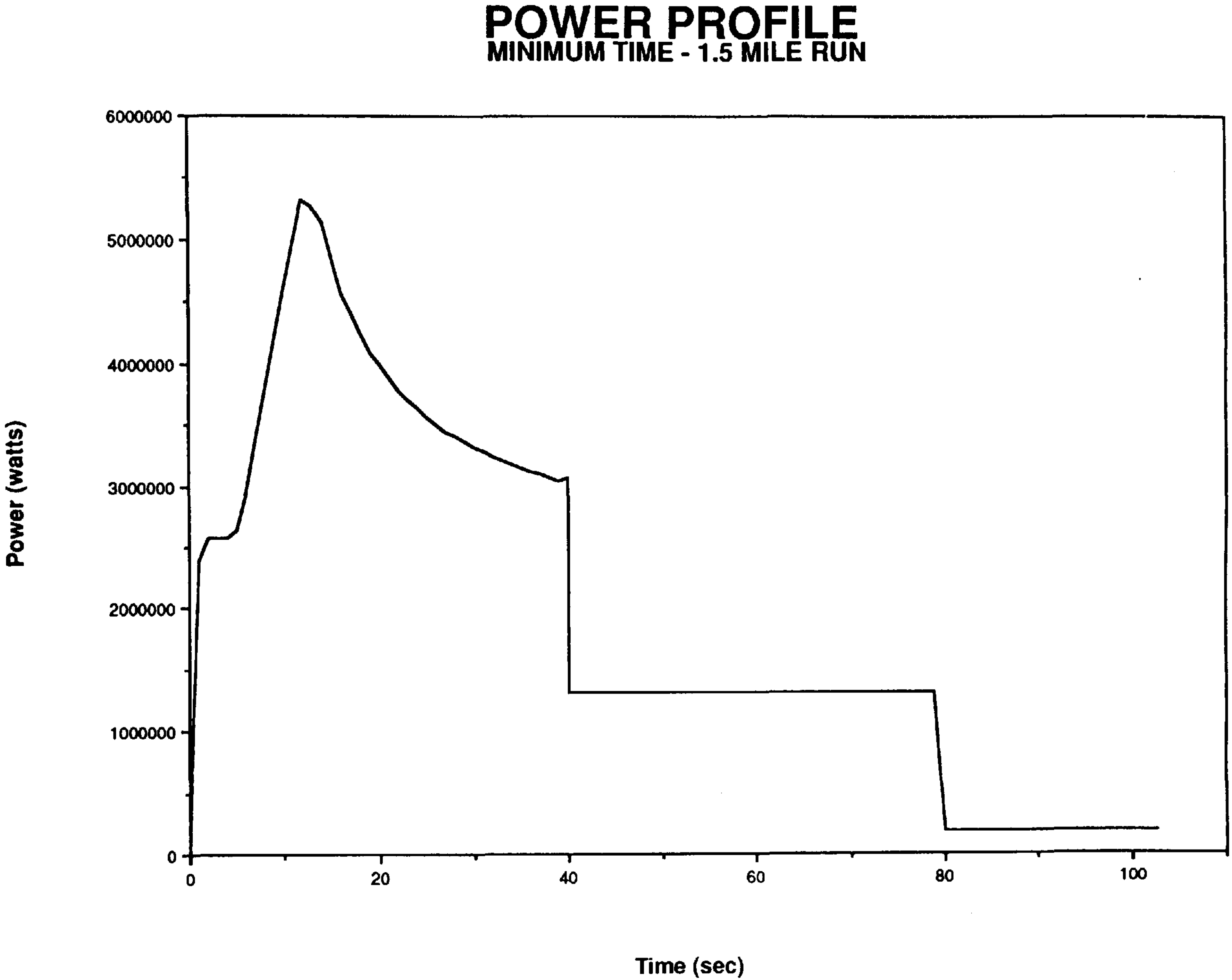
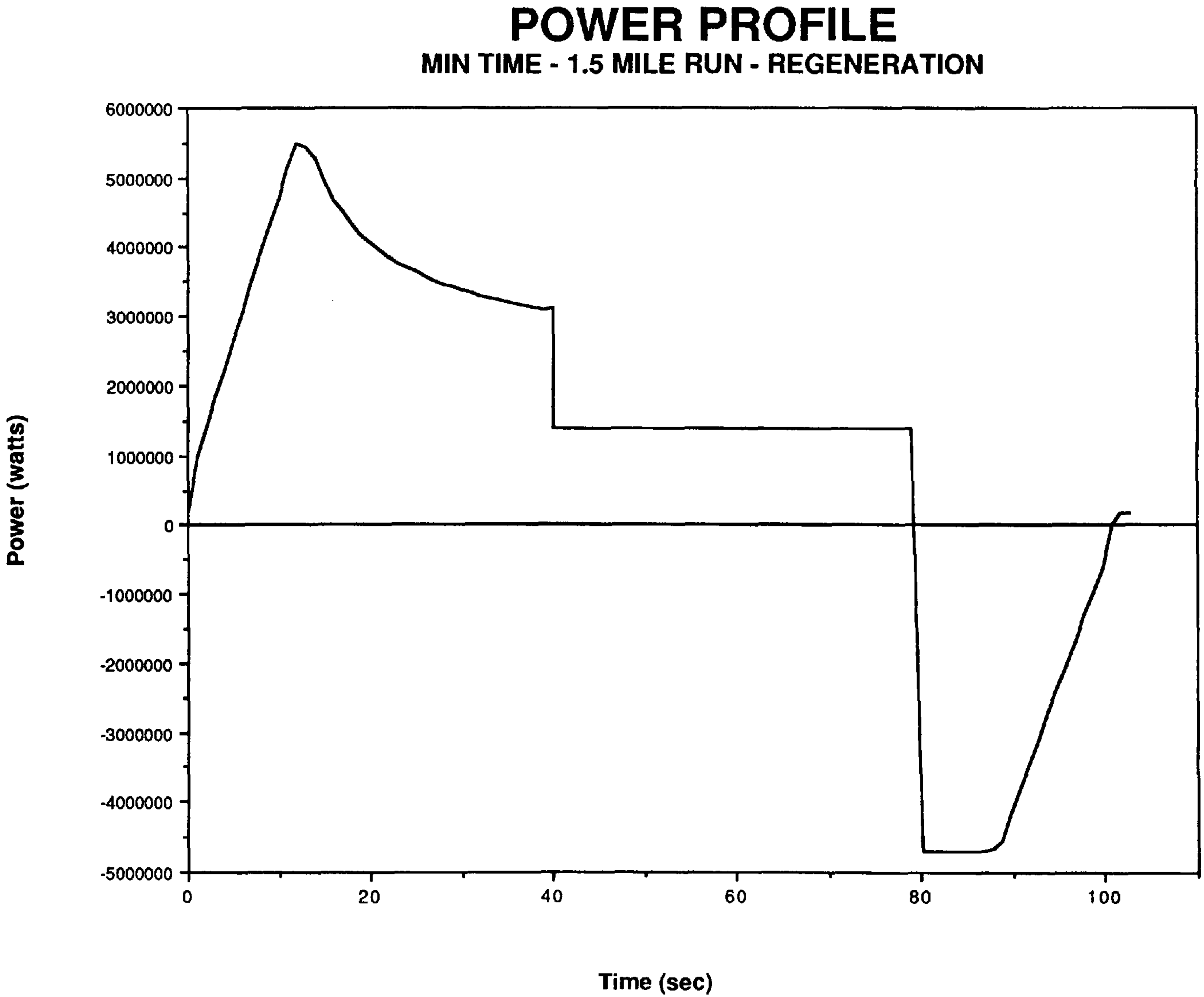

POWER PROFILE
MINIMUM TIME - 1.5 MILE RUN
Power (watts)
6000000
5000000
4000000
3000000
2000000
1000000
0
0
20
40
60
80
100
Time (sec)

FIGURE 1-15B



POWER PROFILE
MIN TIME - 1.5 MILE RUN - REGENERATION
Power (watts)
6000000
5000000
4000000
3000000
2000000
1000000
0
-1000000
-2000000
-3000000
-4000000
-5000000
0
20
40
60
80
100
Time (sec)

FIGURE 1-15C

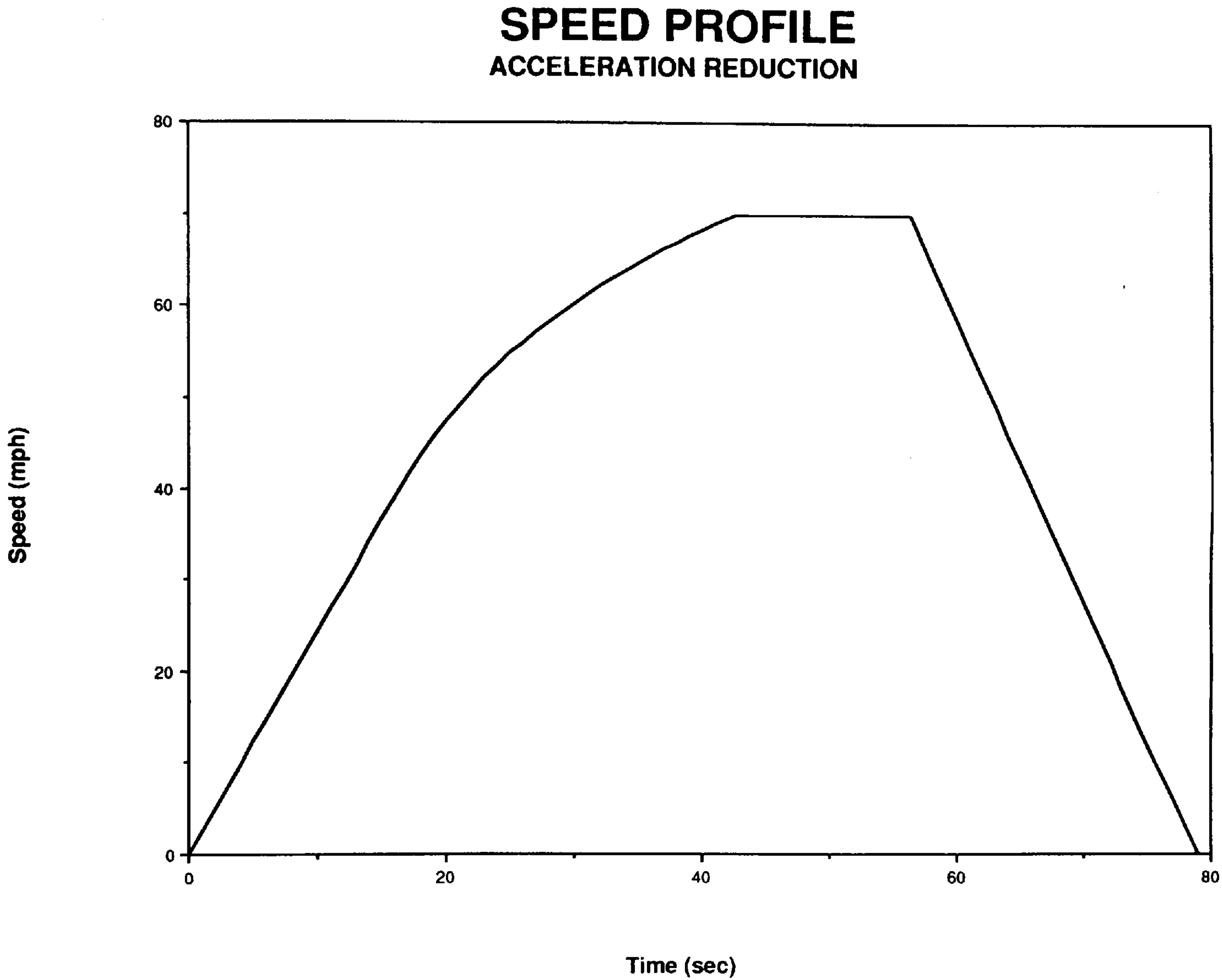

SPEED PROFILE
ACCELERATION REDUCTION
Speed (mph)
80
60
40
20
0
0
20
40
60
80
Time (sec)

FIGURE 1-16A

POWER PROFILE
ACCELERATION REDUCTION

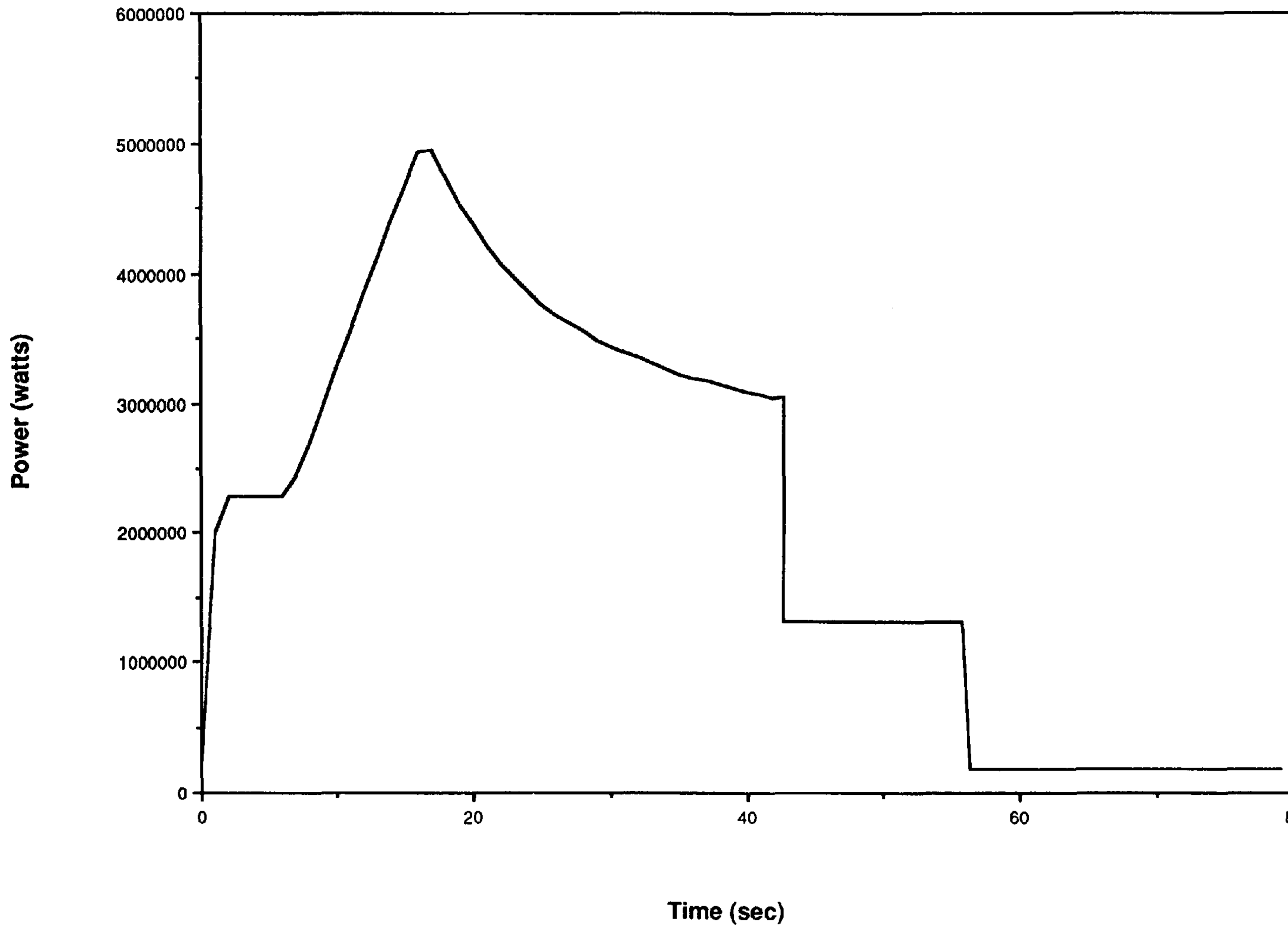


FIGURE 1-16B

POWER PROFILE
ACCELERATION REDUCTION - REGENERATION

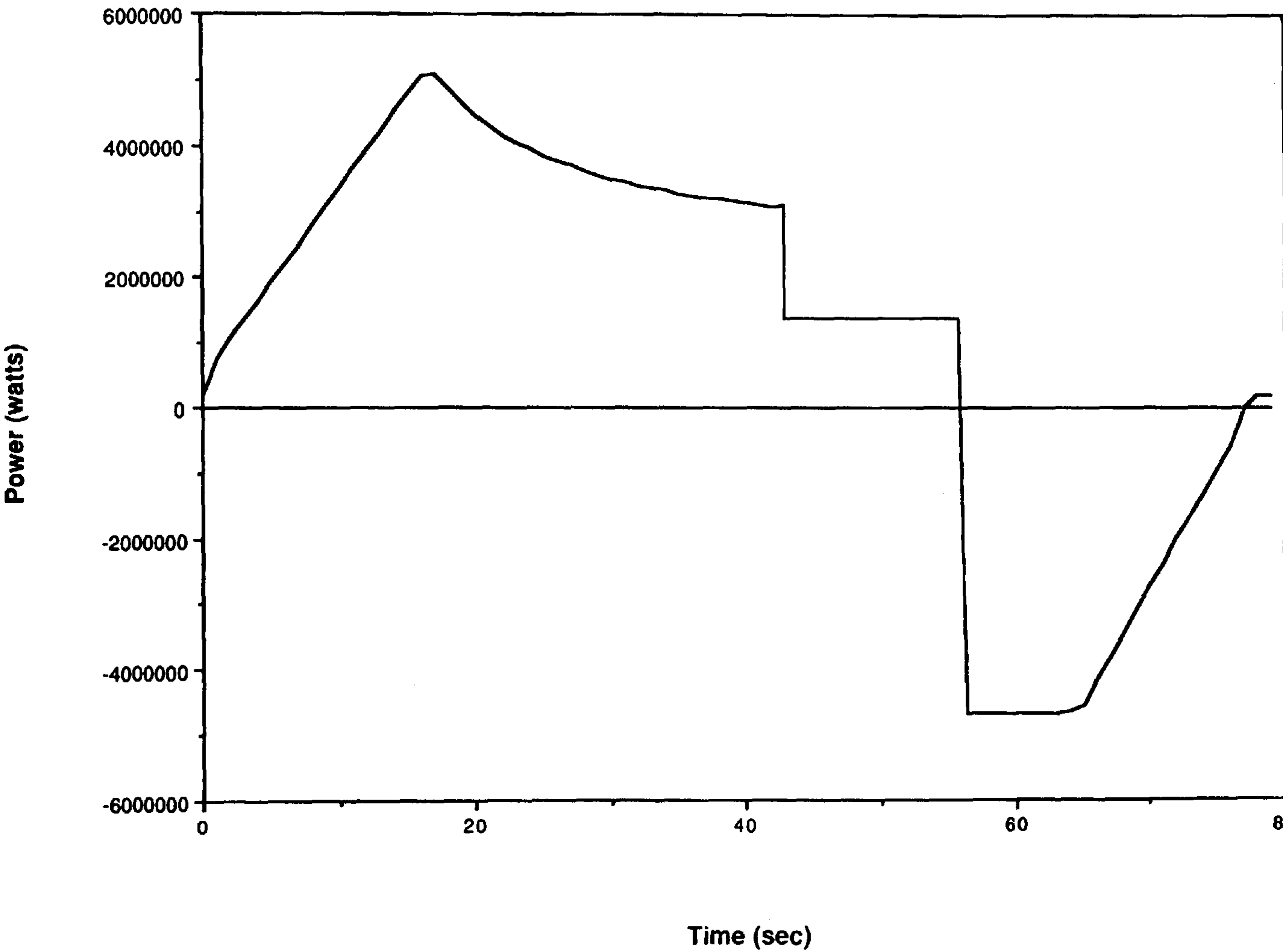


FIGURE 1-16C

SPEED PROFILE
ACCELERATION REDUCTION - 1.5 MILE RUN

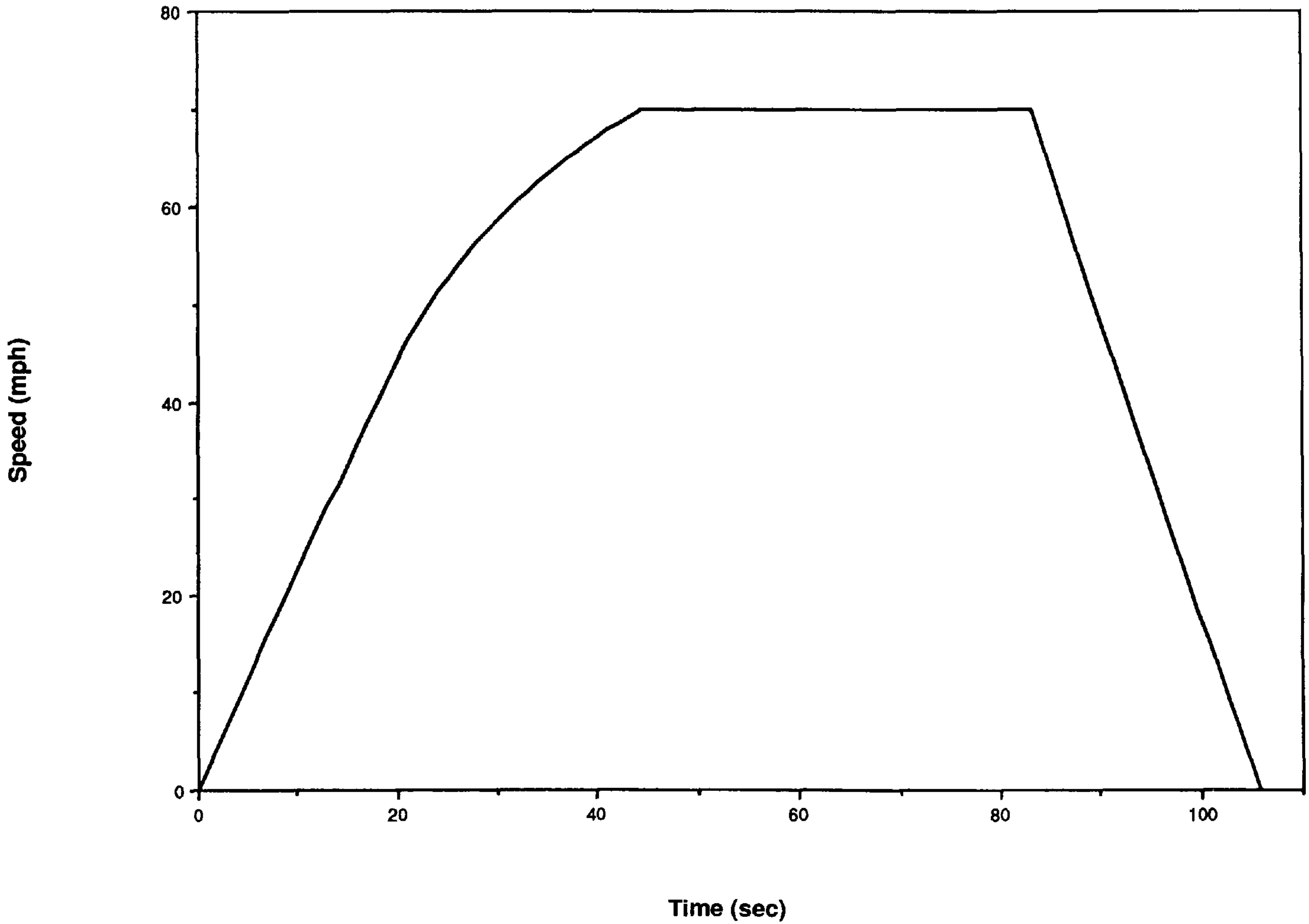


FIGURE 1-17A

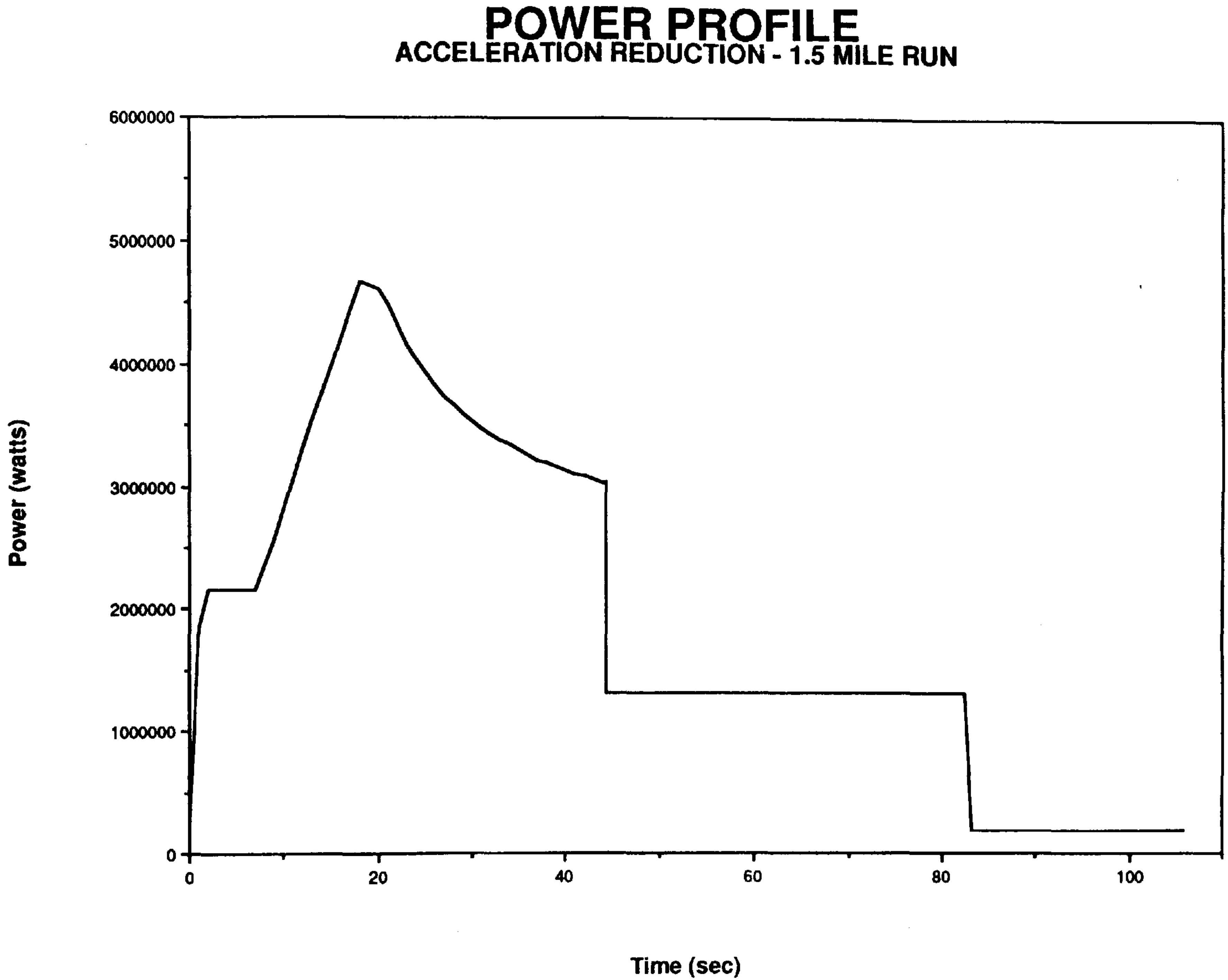

POWER PROFILE
ACCELERATION REDUCTION - 1.5 MILE RUN
Power (watts)
6000000
5000000
4000000
3000000
2000000
1000000
0
0
20
40
60
80
100
Time (sec)

FIGURE 1-17B

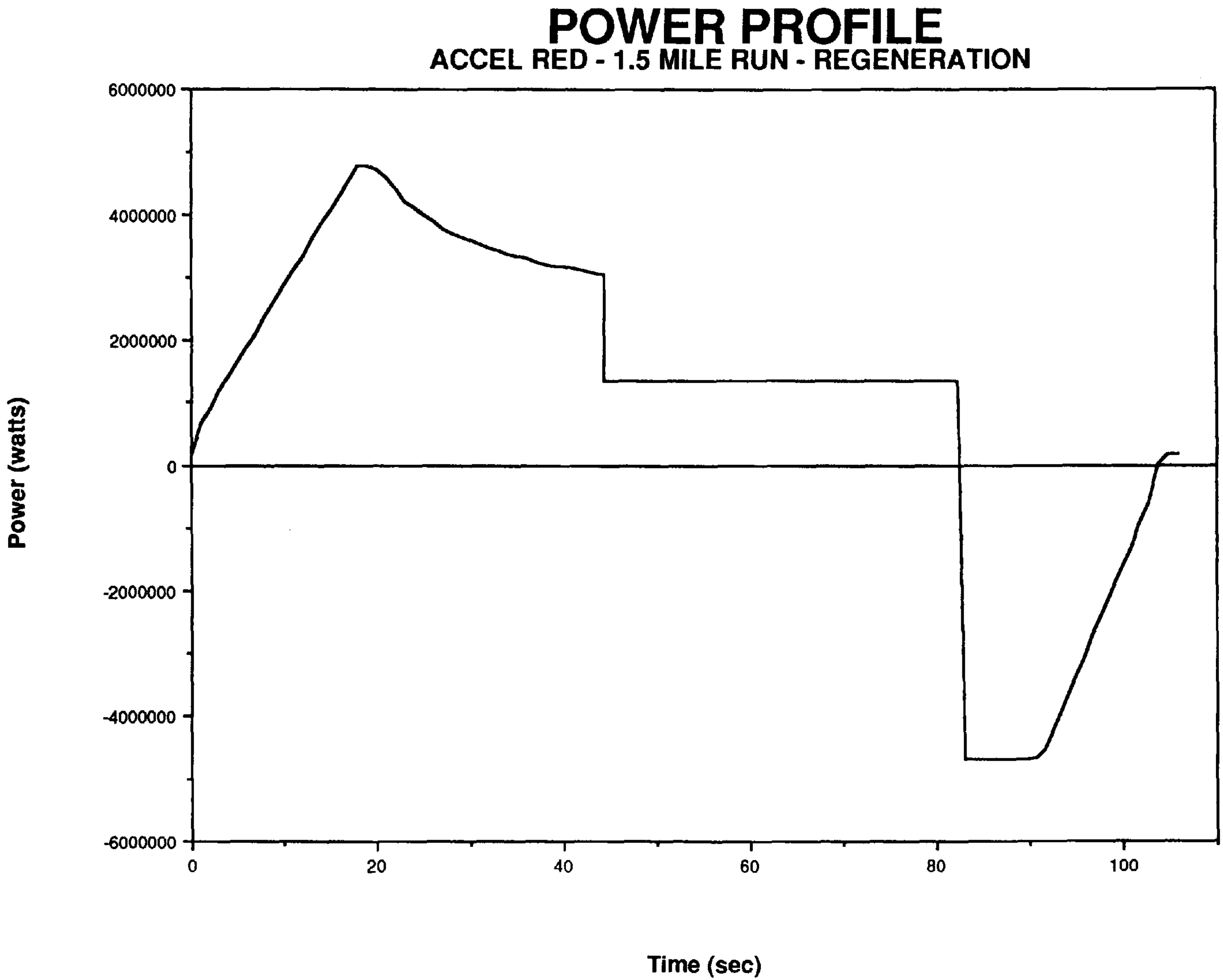

POWER PROFILE
ACCEL RED - 1.5 MILE RUN - REGENERATION
6000000
4000000
2000000
0
-2000000
-4000000
-6000000
Power (watts)
0
20
40
60
80
100
Time (sec)

FIGURE 1-17C

SPEED PROFILE
DECELERATION REDUCTION

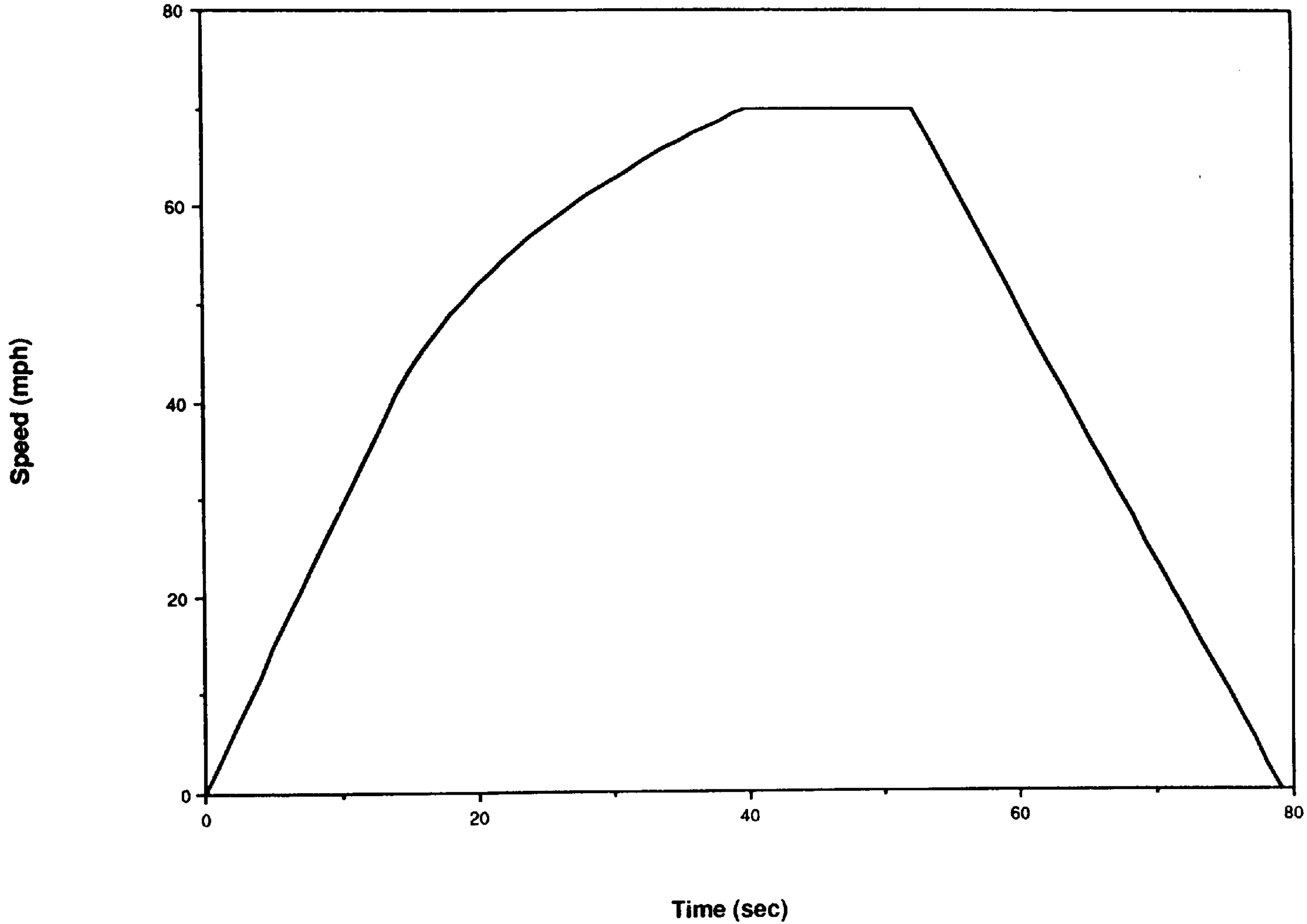


FIGURE 1-18A

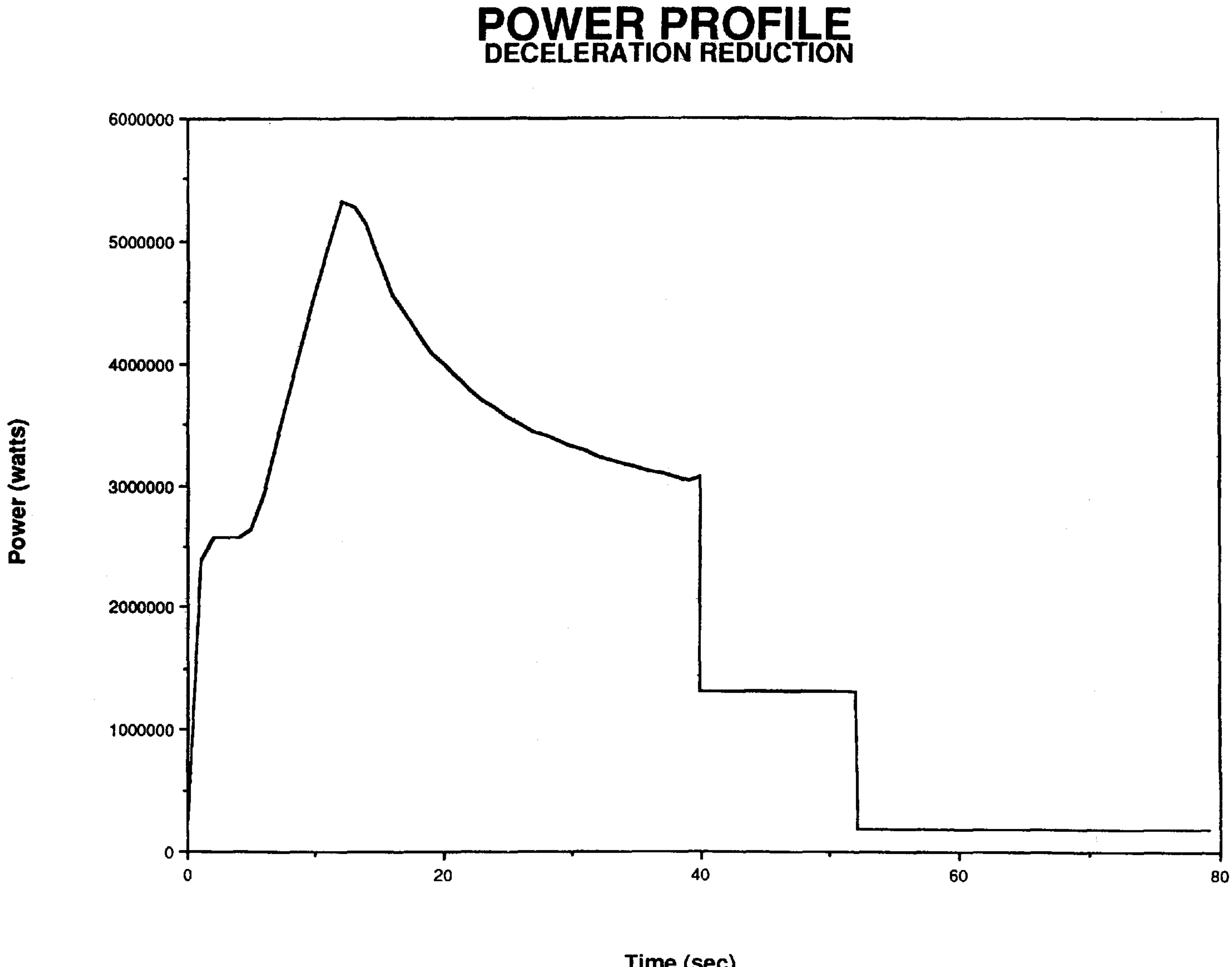

POWER PROFILE
DECELERATION REDUCTION
6000000
5000000
4000000
3000000
2000000
1000000
0
Power (watts)
0
20
40
60
80
Time (sec)

FIGURE 1-18B

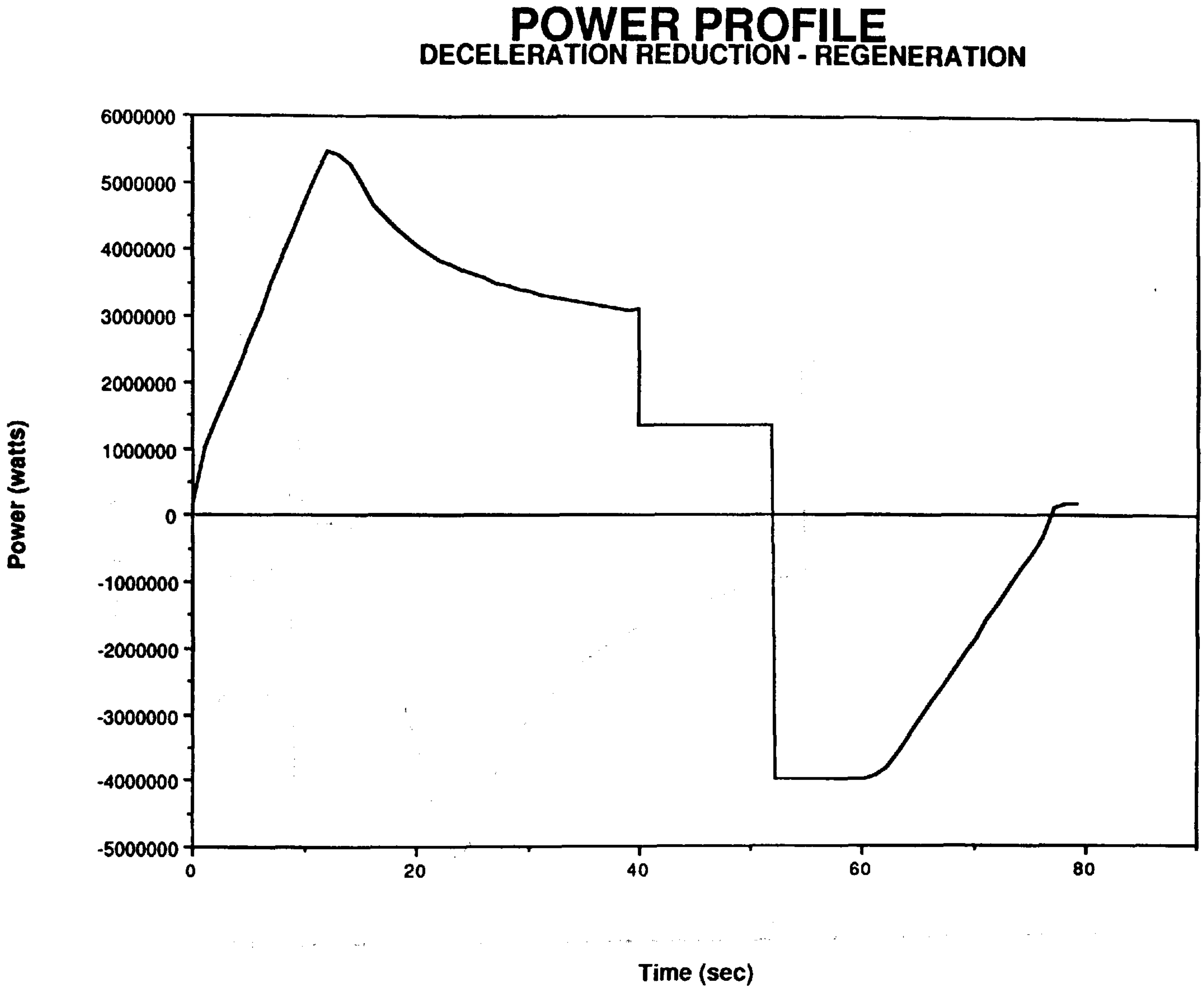

POWER PROFILE
DECELERATION REDUCTION - REGENERATION
6000000
5000000
4000000
3000000
2000000
1000000
0
-1000000
-2000000
-3000000
-4000000
-5000000
Power (watts)
0
20
40
60
80
Time (sec)

FIGURE 1-18C


SPEED PROFILE
DECELERATION REDUCTION - 1.5 MILE RUN
Speed (mph)
0
20
40
60
80
0
20
40
60
80
100
Time (sec)
FIGURE 1-19A

POWER PROFILE
DECELERATION REDUCTION - 1.5 MILE RUN

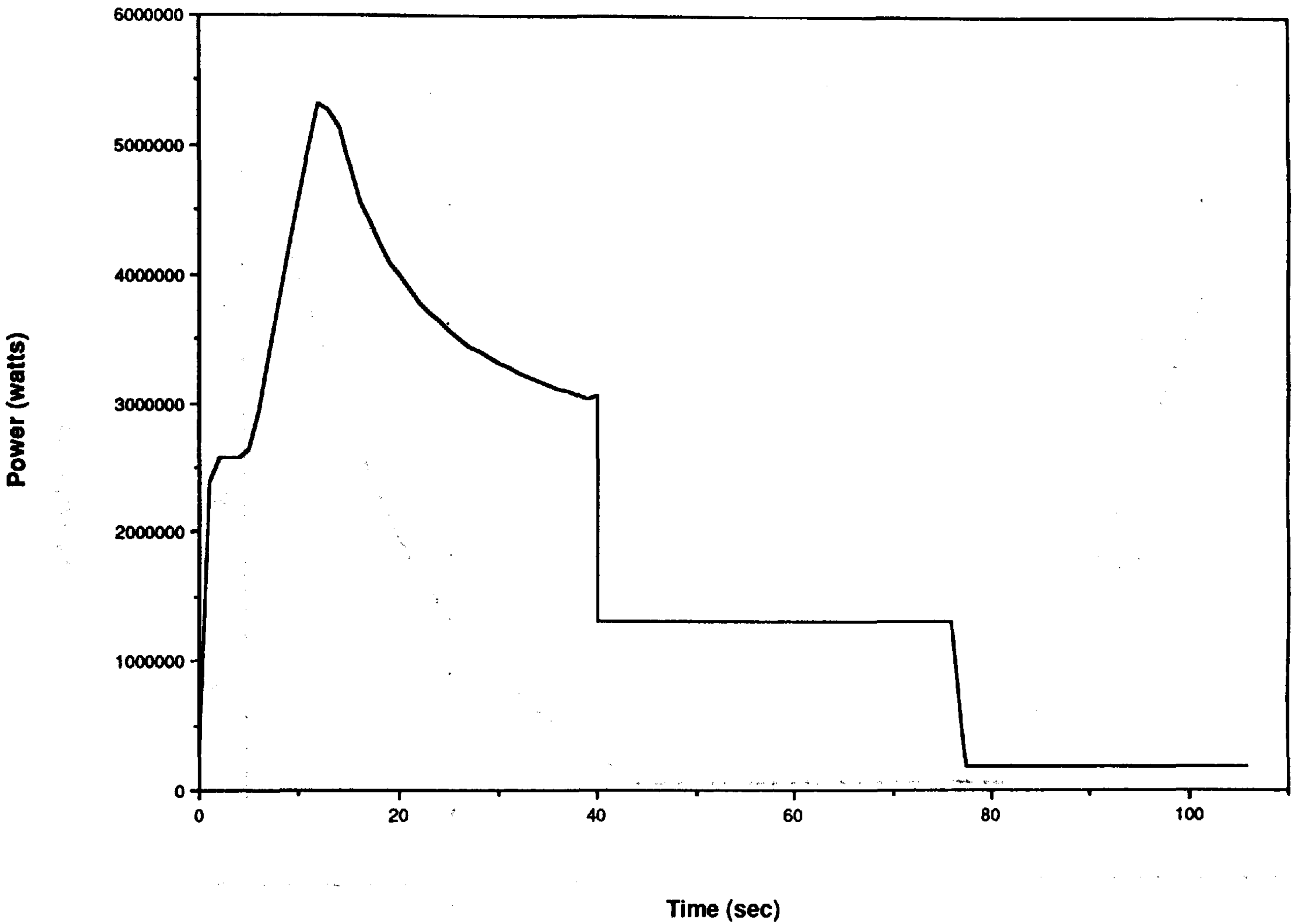


FIGURE 1-19B

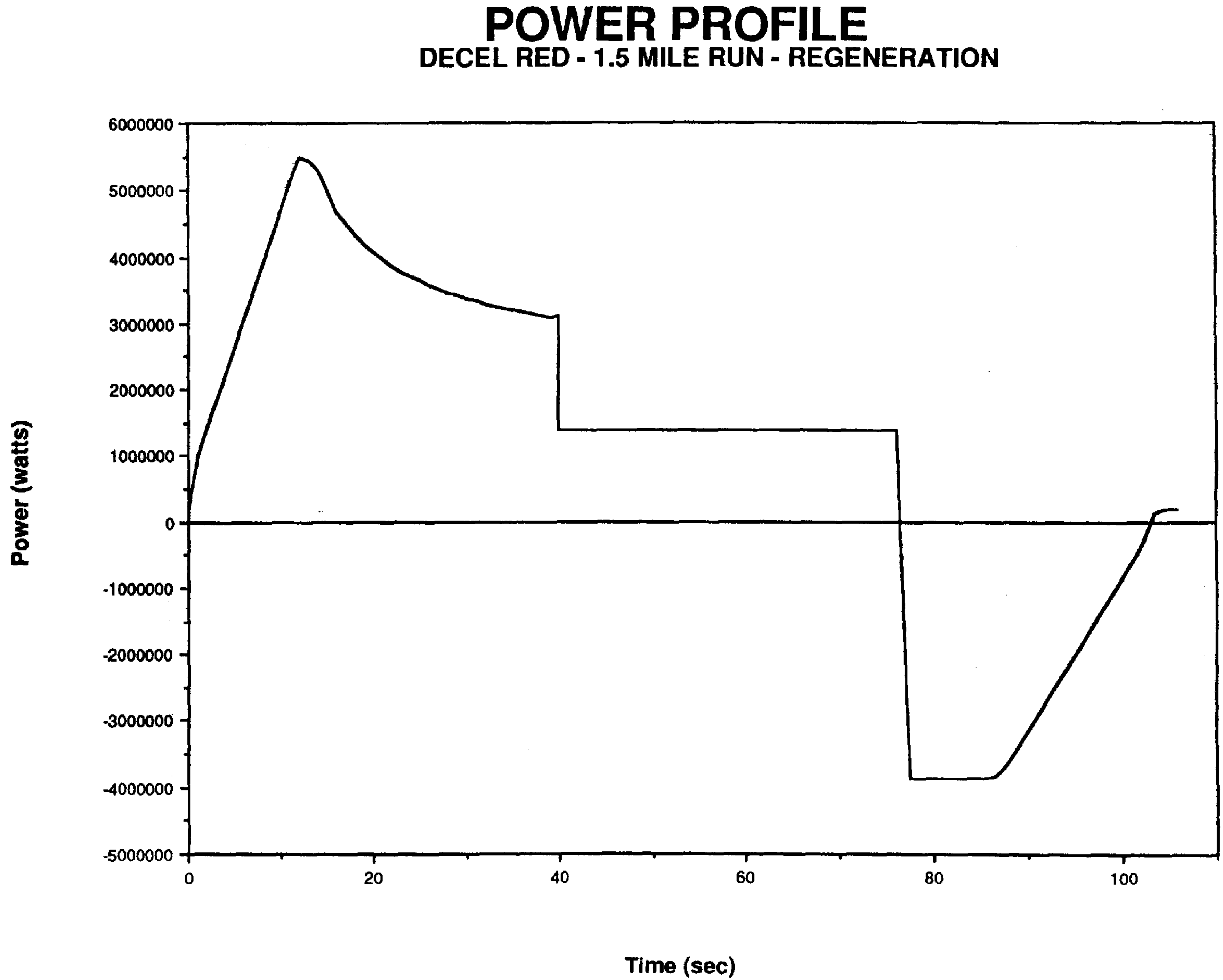

POWER PROFILE
DECEL RED - 1.5 MILE RUN - REGENERATION
6000000
5000000
4000000
3000000
2000000
1000000
0
-1000000
-2000000
-3000000
-4000000
-5000000
Power (watts)
0
20
40
60
80
100
Time (sec)

FIGURE 1-19C

SPEED PROFILE
SPEED REDUCTION

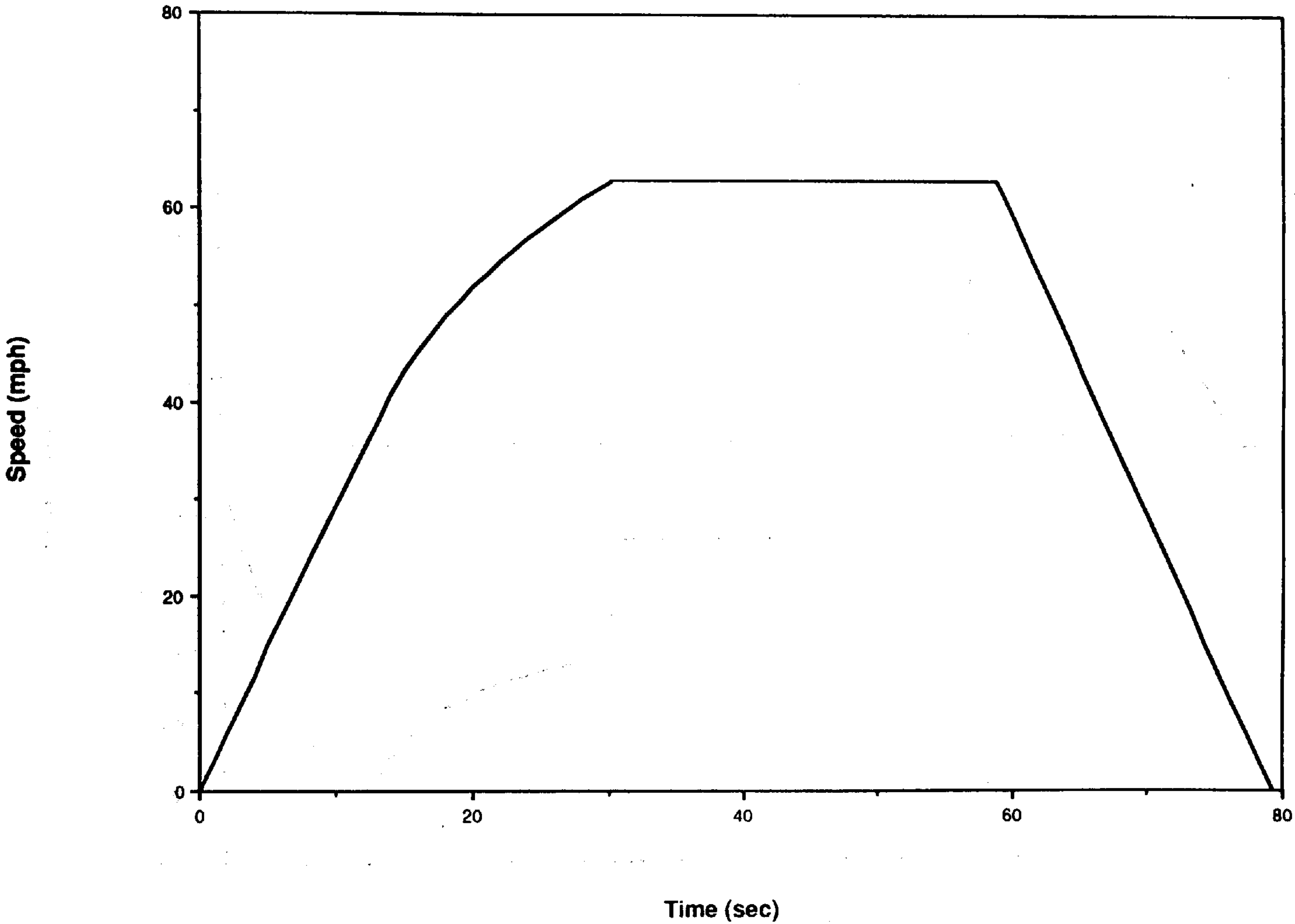


FIGURE 1-20A

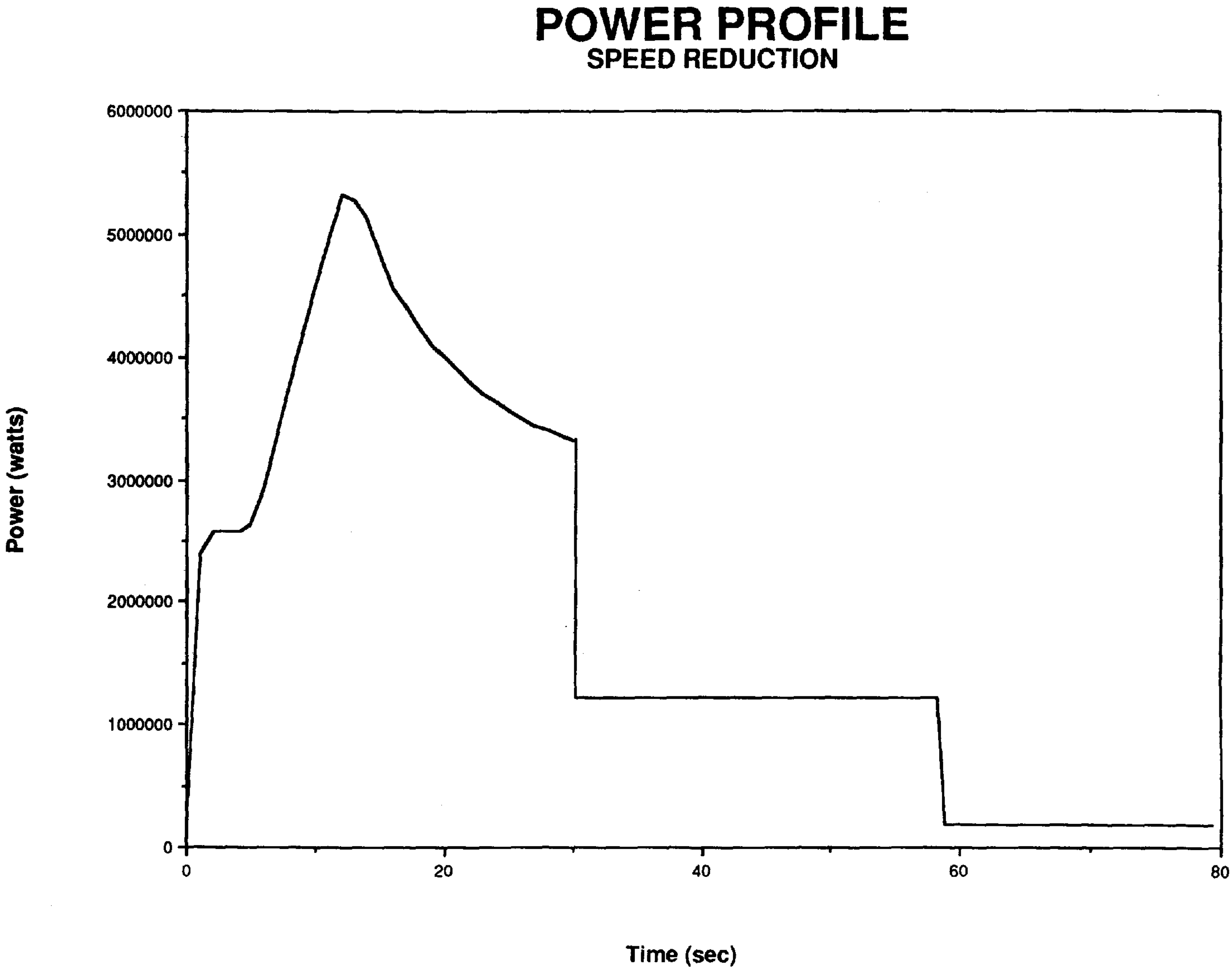

POWER PROFILE
SPEED REDUCTION
Power (watts)
6000000
5000000
4000000
3000000
2000000
1000000
0
0
20
40
60
80
Time (sec)

FIGURE 1-20B

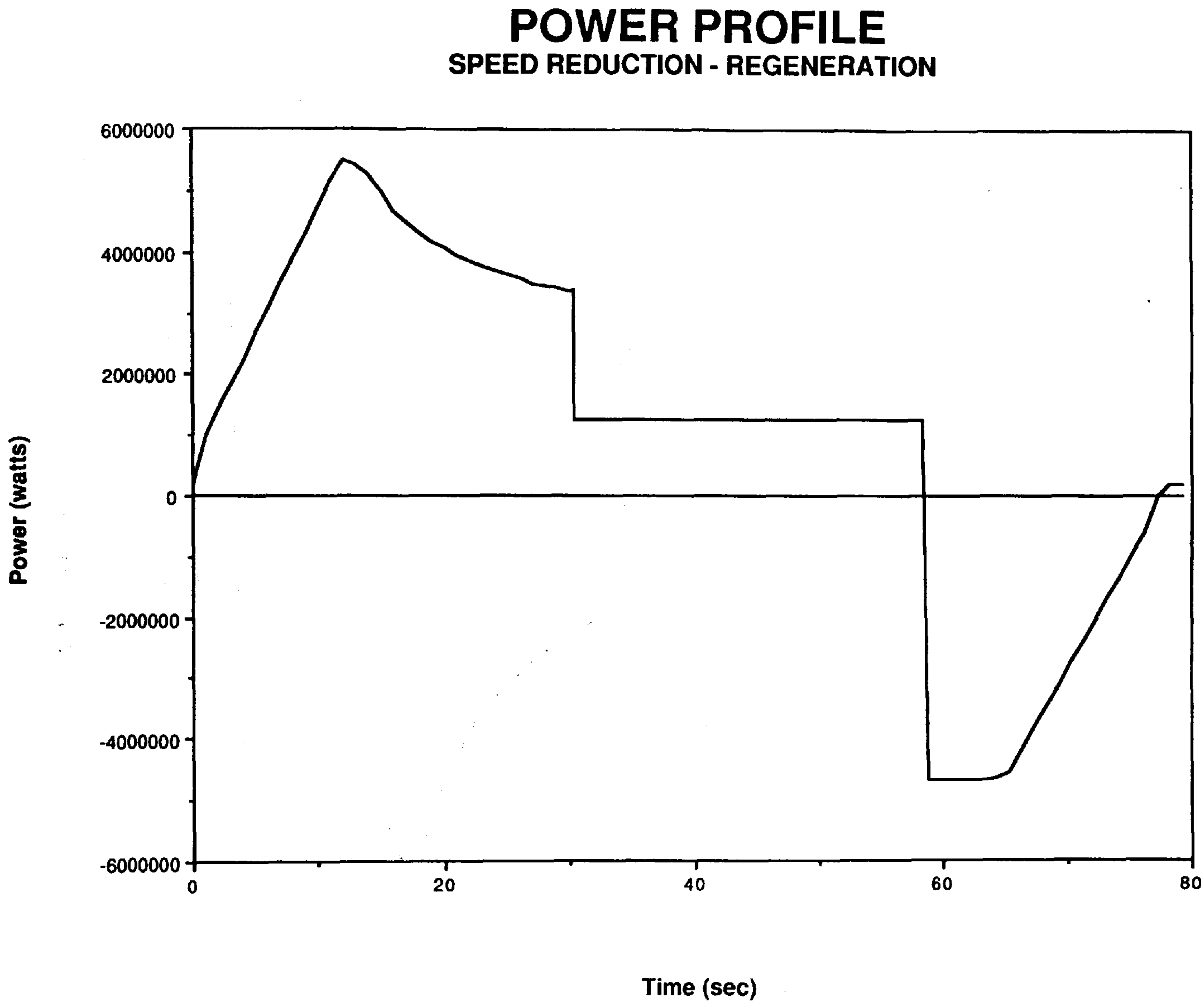

POWER PROFILE
SPEED REDUCTION - REGENERATION
6000000
4000000
2000000
0
-2000000
-4000000
-6000000
Power (watts)
0
20
40
60
80
Time (sec)

FIGURE 1-20C

SPEED PROFILE
SPEED REDUCTION - 1.5 MILE RUN

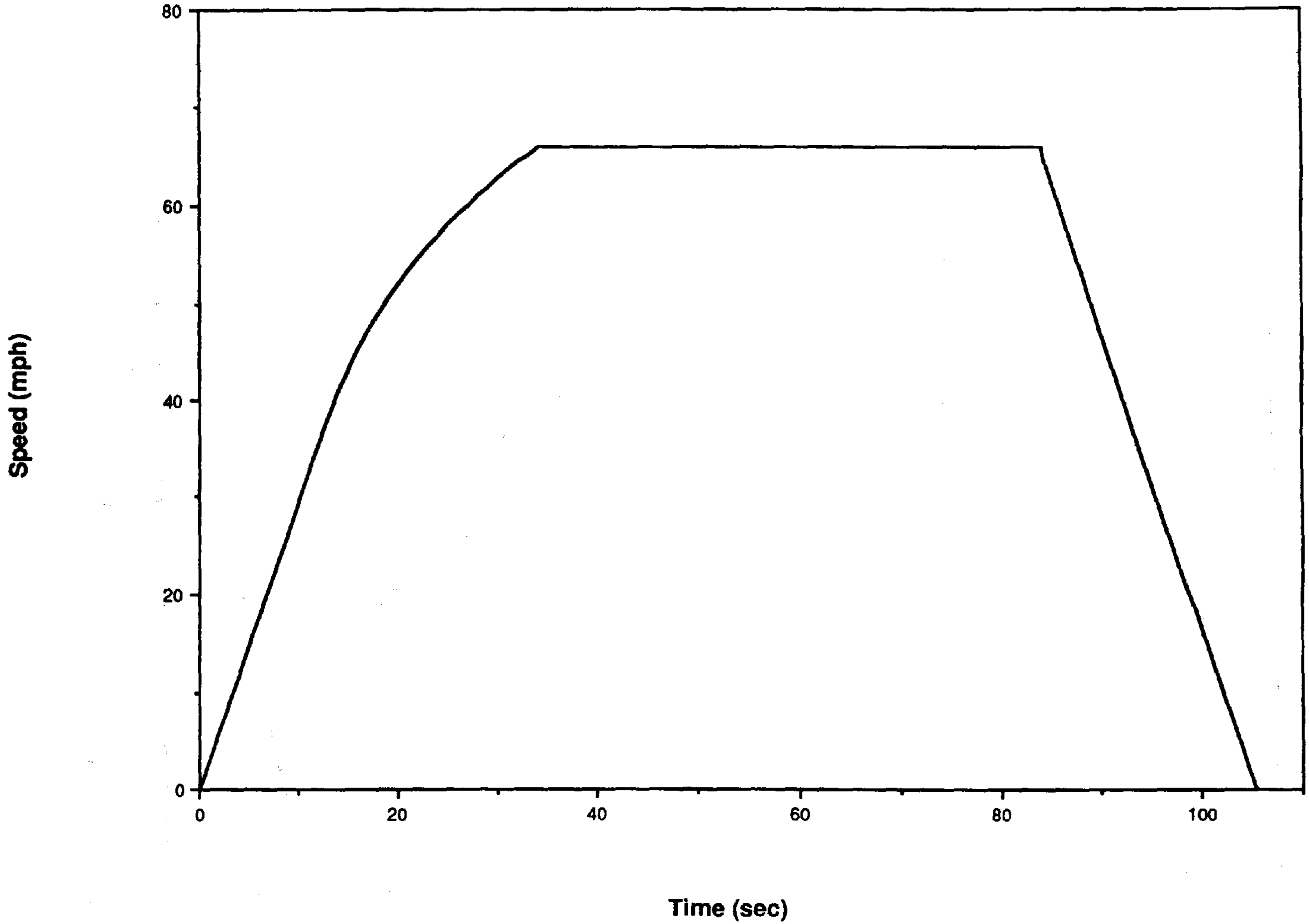


FIGURE 1-21A

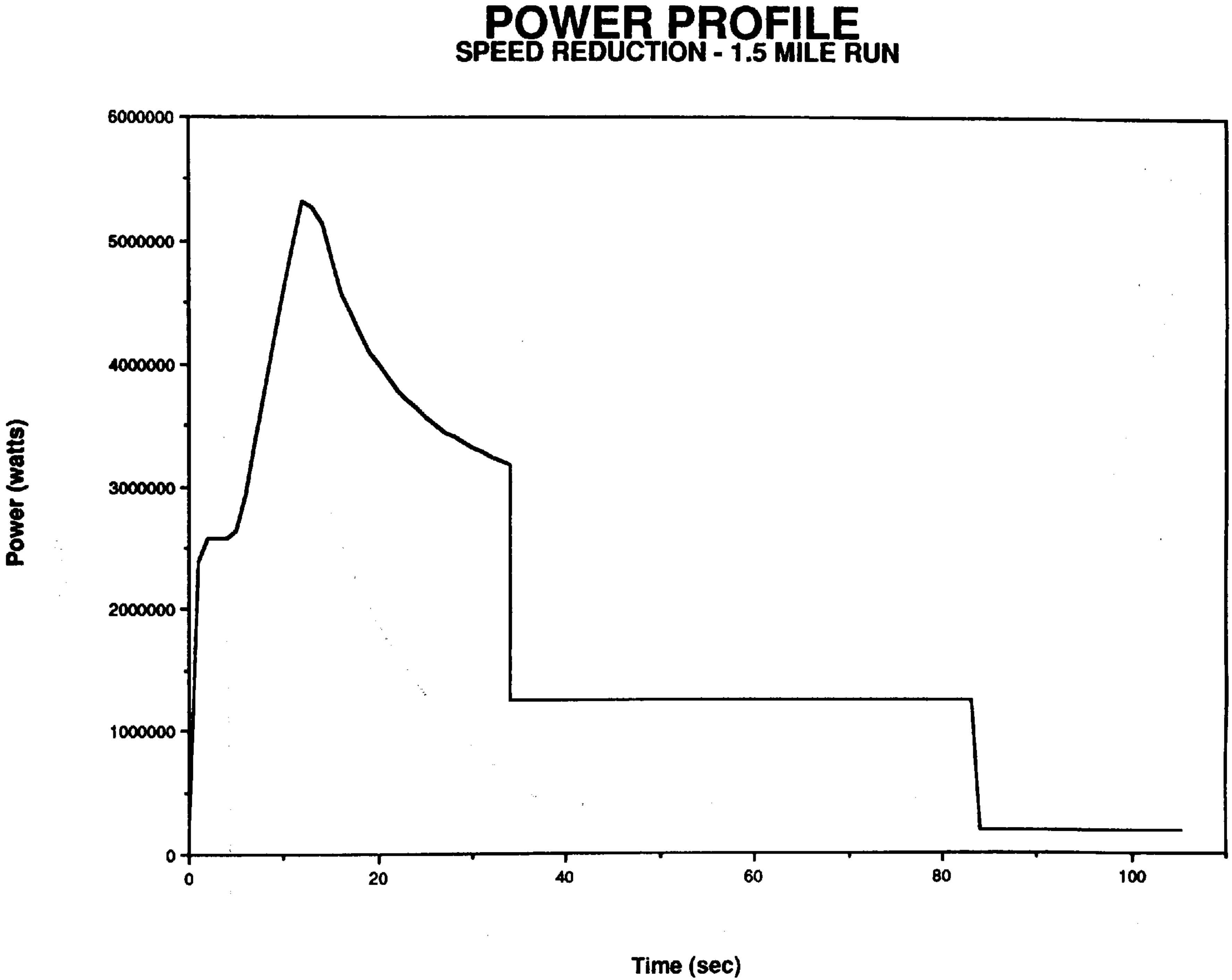

POWER PROFILE
SPEED REDUCTION - 1.5 MILE RUN
6000000
5000000
4000000
3000000
2000000
1000000
0
Power (watts)
0
20
40
60
80
100
Time (sec)

FIGURE I-21B

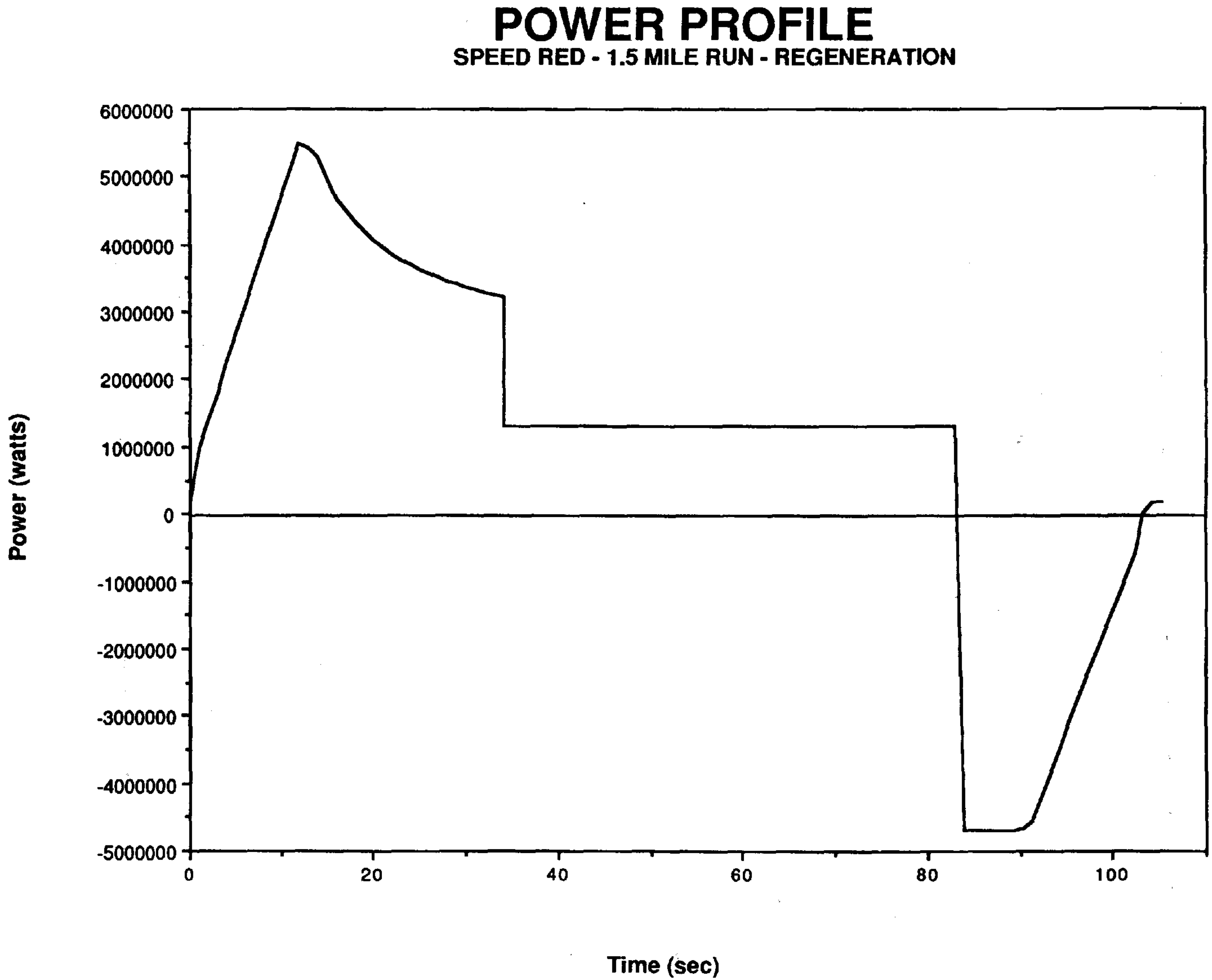

POWER PROFILE
SPEED RED - 1.5 MILE RUN - REGENERATION
6000000
5000000
4000000
3000000
2000000
1000000
0
-1000000
-2000000
-3000000
-4000000
-5000000
Power (watts)
0
20
40
60
80
100
Time (sec)

FIGURE 1-21C

SPEED PROFILE
COASTING

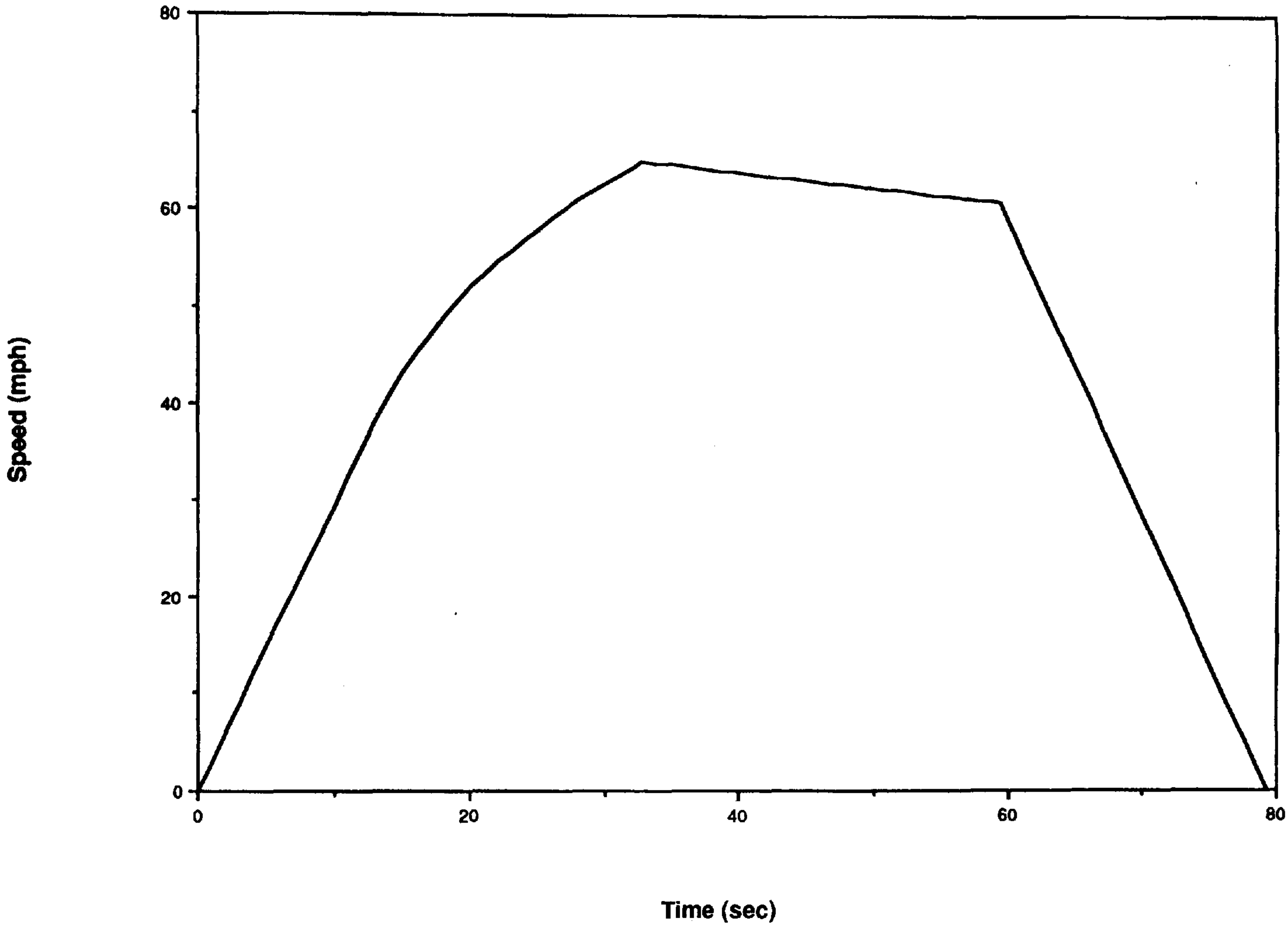


FIGURE 1-22A

POWER PROFILE
COASTING

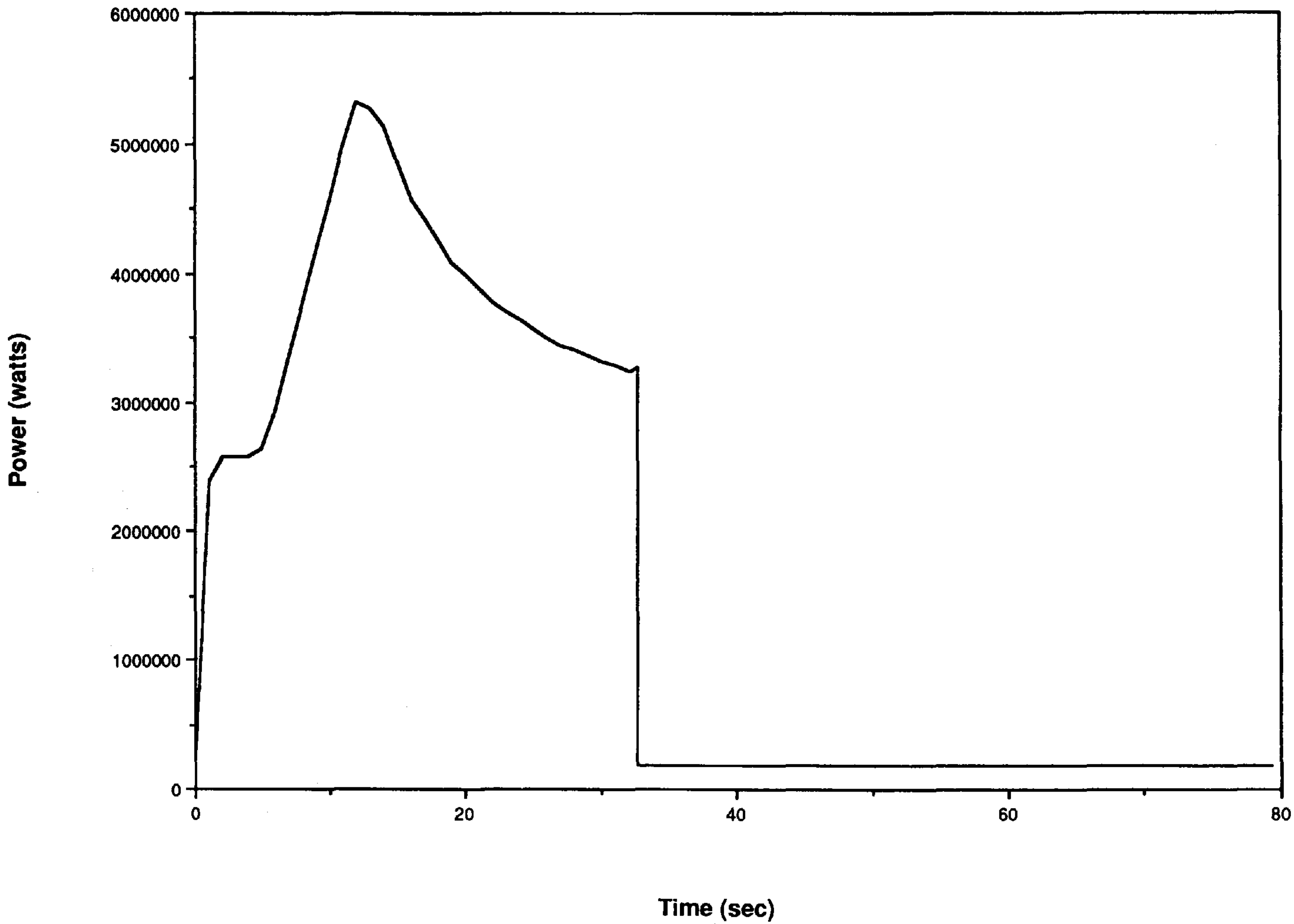


FIGURE 1-22B

POWER PROFILE
COASTING - REGENERATION

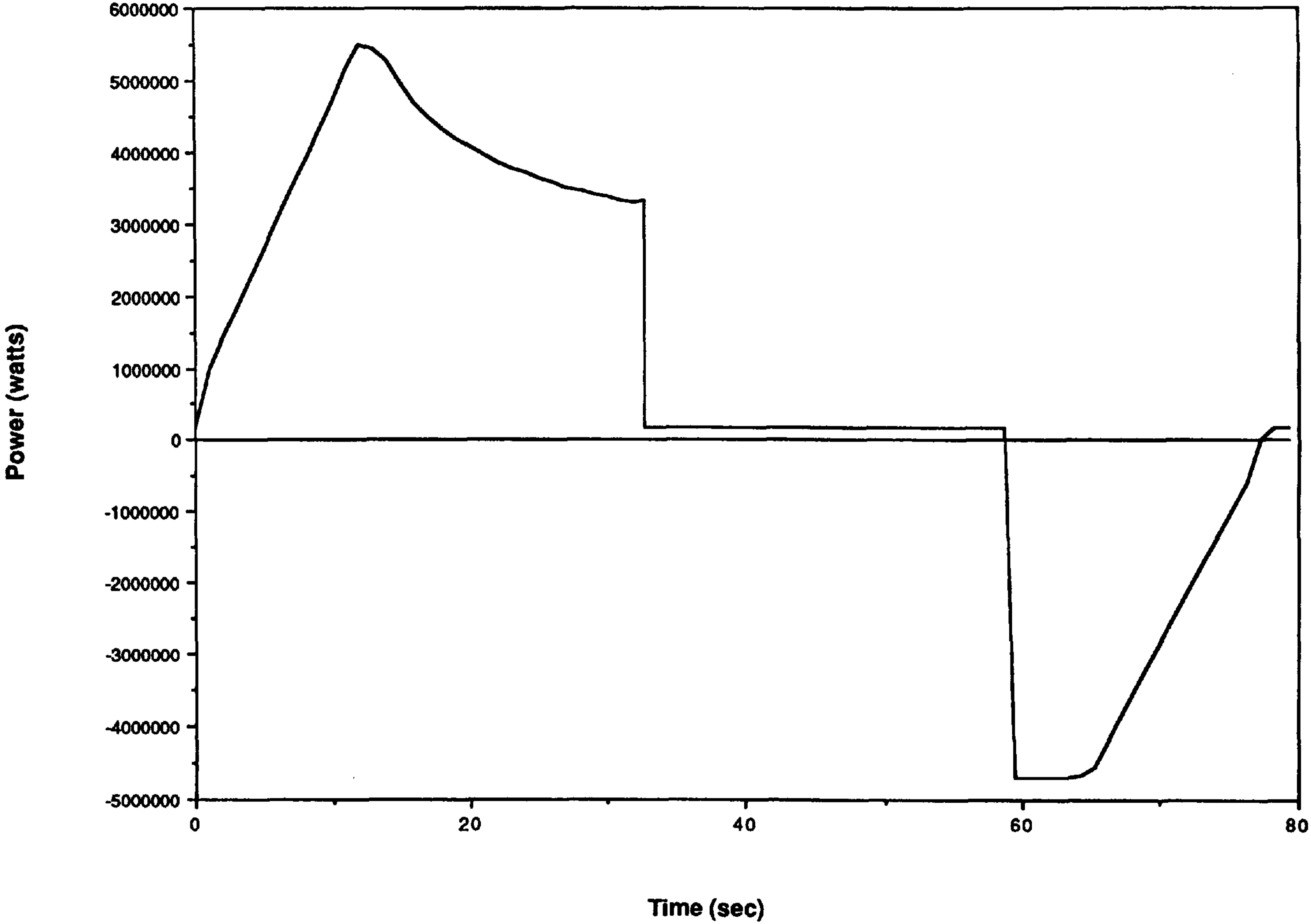


FIGURE 1-22C

SPEED PROFILE
COASTING - 1.5 MILE RUN

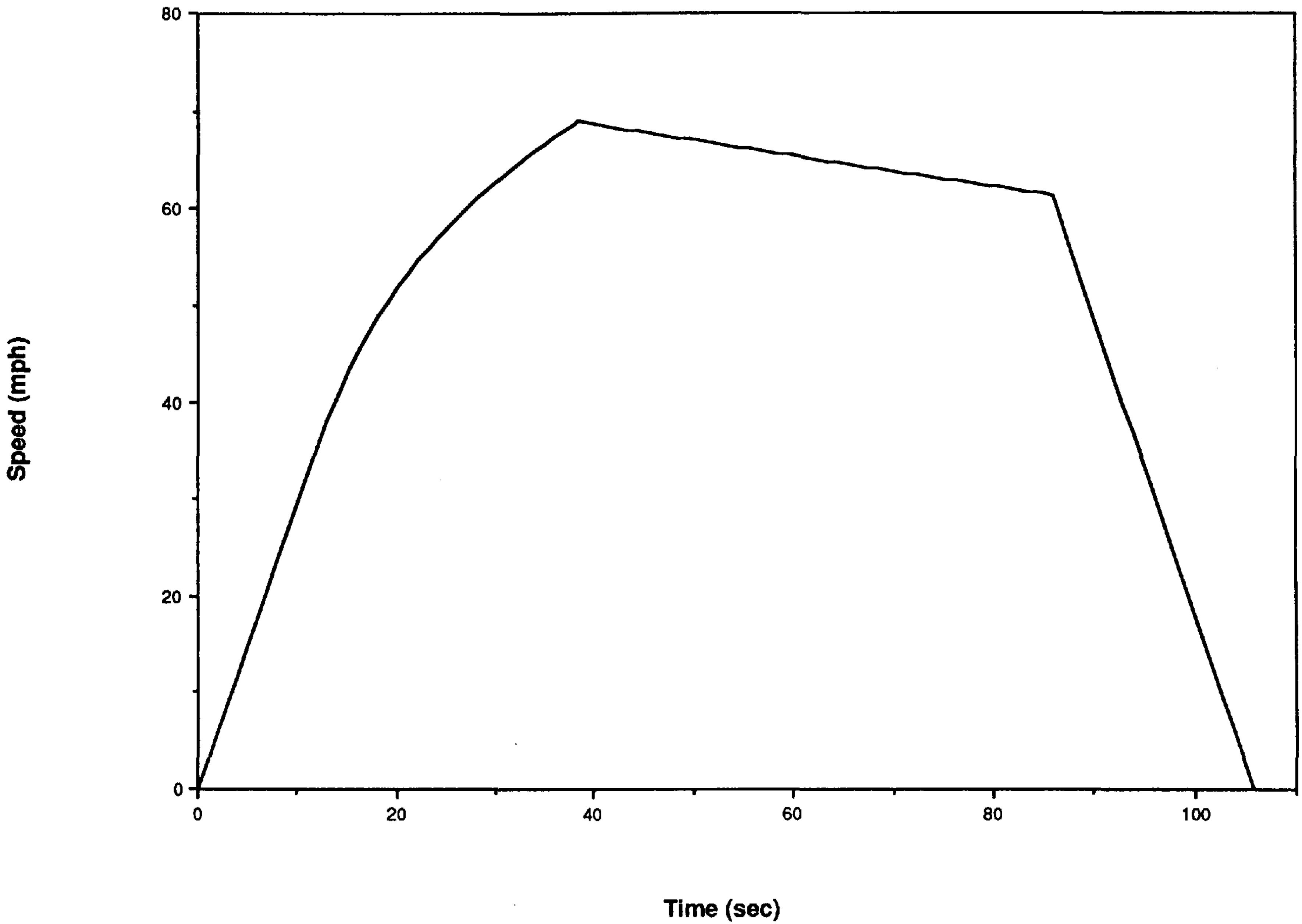


FIGURE 1-23A

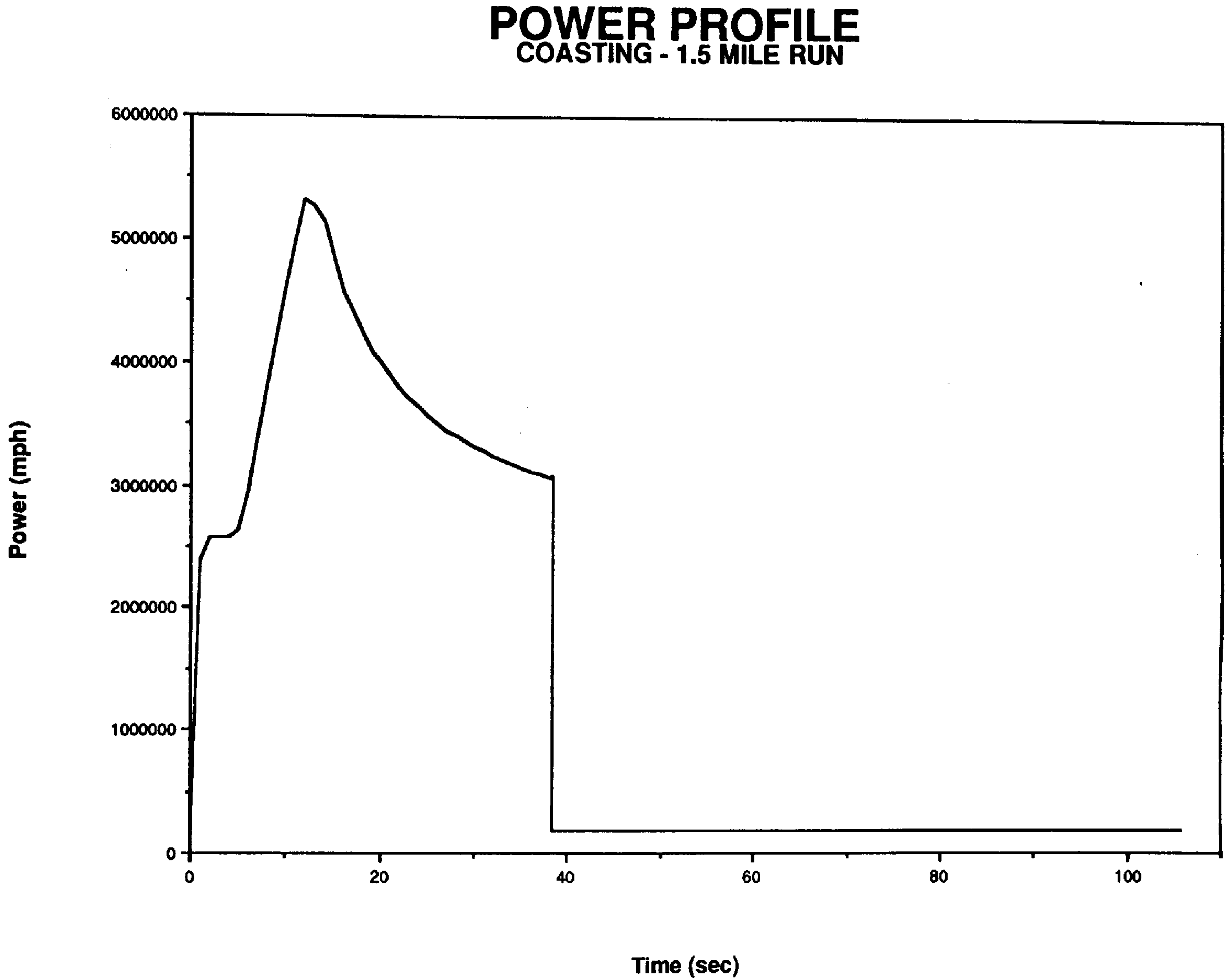

POWER PROFILE
COASTING - 1.5 MILE RUN
6000000
5000000
4000000
3000000
2000000
1000000
0
Power (mph)
0
20
40
60
80
100
Time (sec)

FIGURE 1-23B

POWER PROFILE
COASTING - 1.5 MILE RUN - REGENERATION

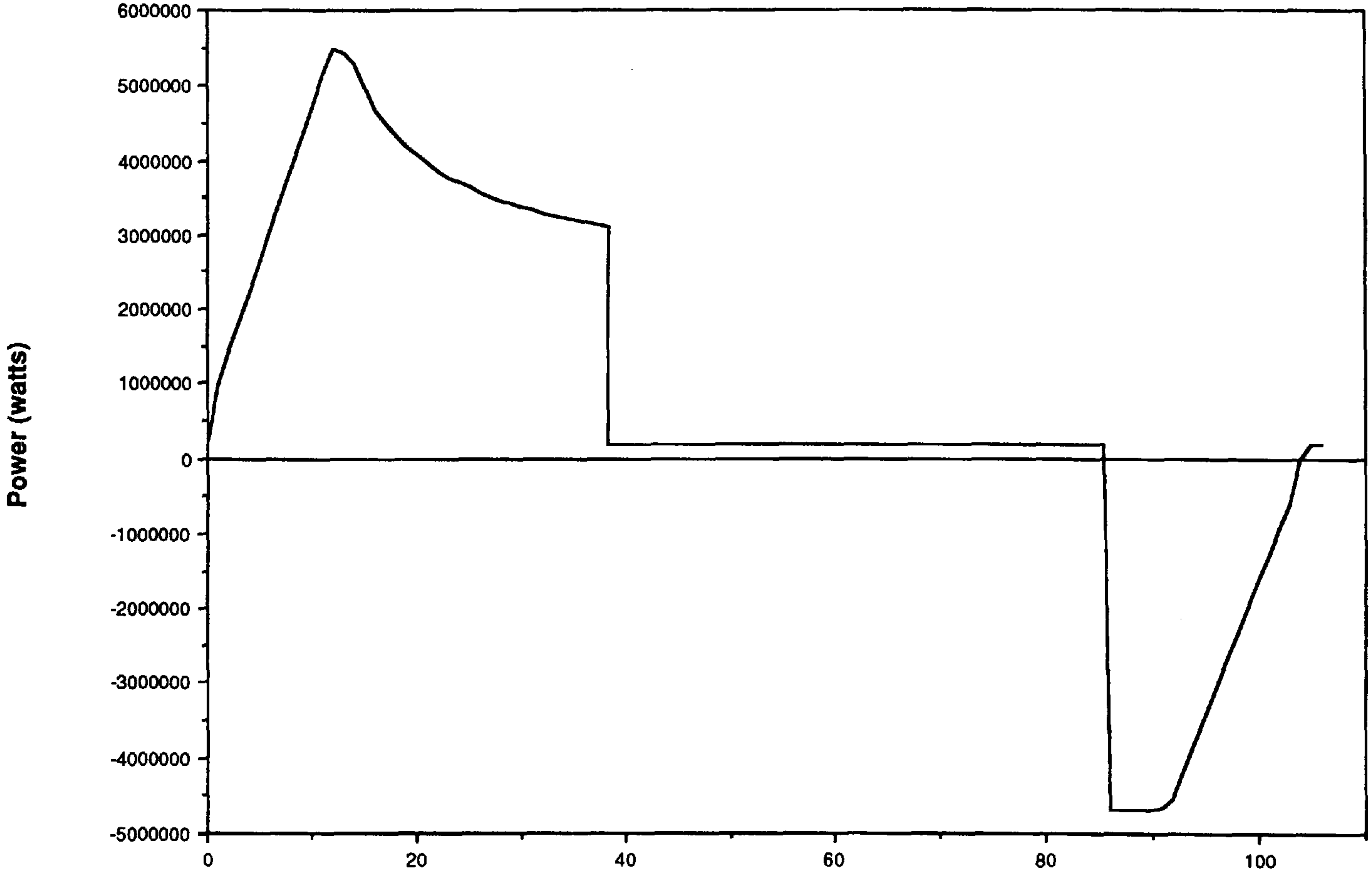


FIGURE 1-23C

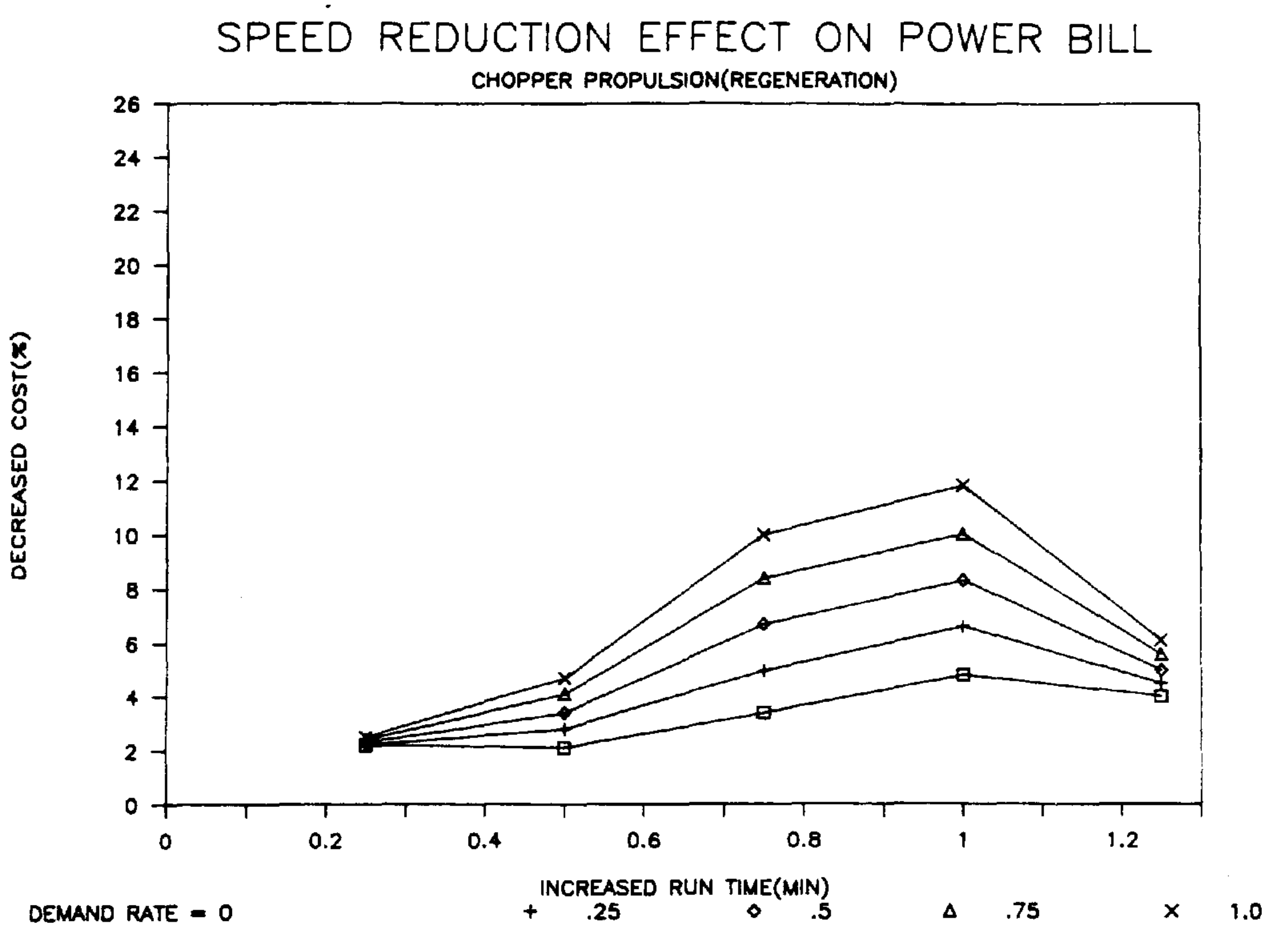

SPEED REDUCTION EFFECT ON POWER BILL
CHOPPER PROPULSION(REGENERATION)
DECREASED COST(%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
1.2
INCREASED RUN TIME(MIN)
DEMAND RATE = 0
+ .25
◇ .5
Δ .75
× 1.0

FIGURE 1-24

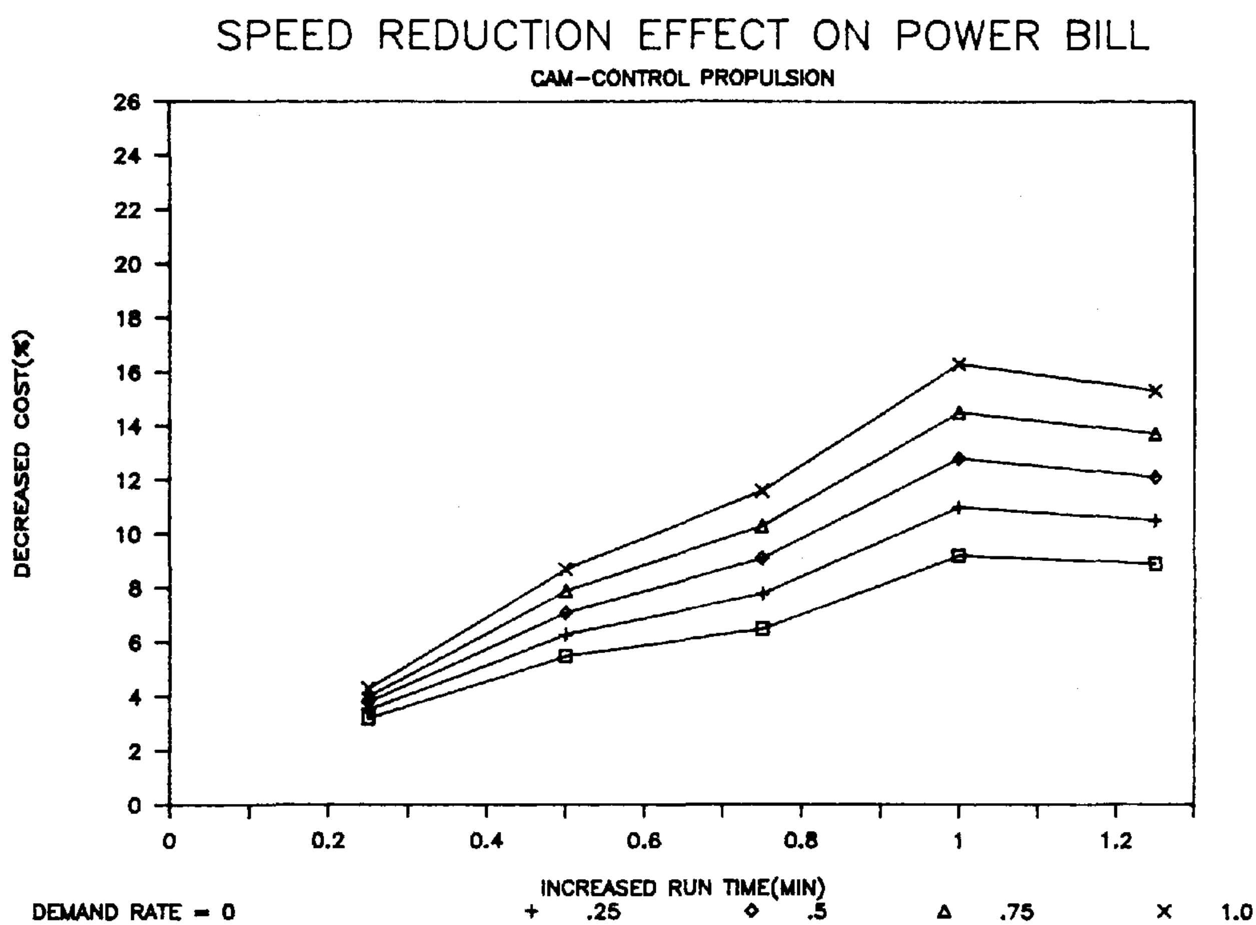

SPEED REDUCTION EFFECT ON POWER BILL
CAM-CONTROL PROPULSION
DECREASED COST(%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
1.2
INCREASED RUN TIME(MIN)
DEMAND RATE = 0
+ .25
◇ .5
Δ .75
× 1.0

FIGURE 1-25

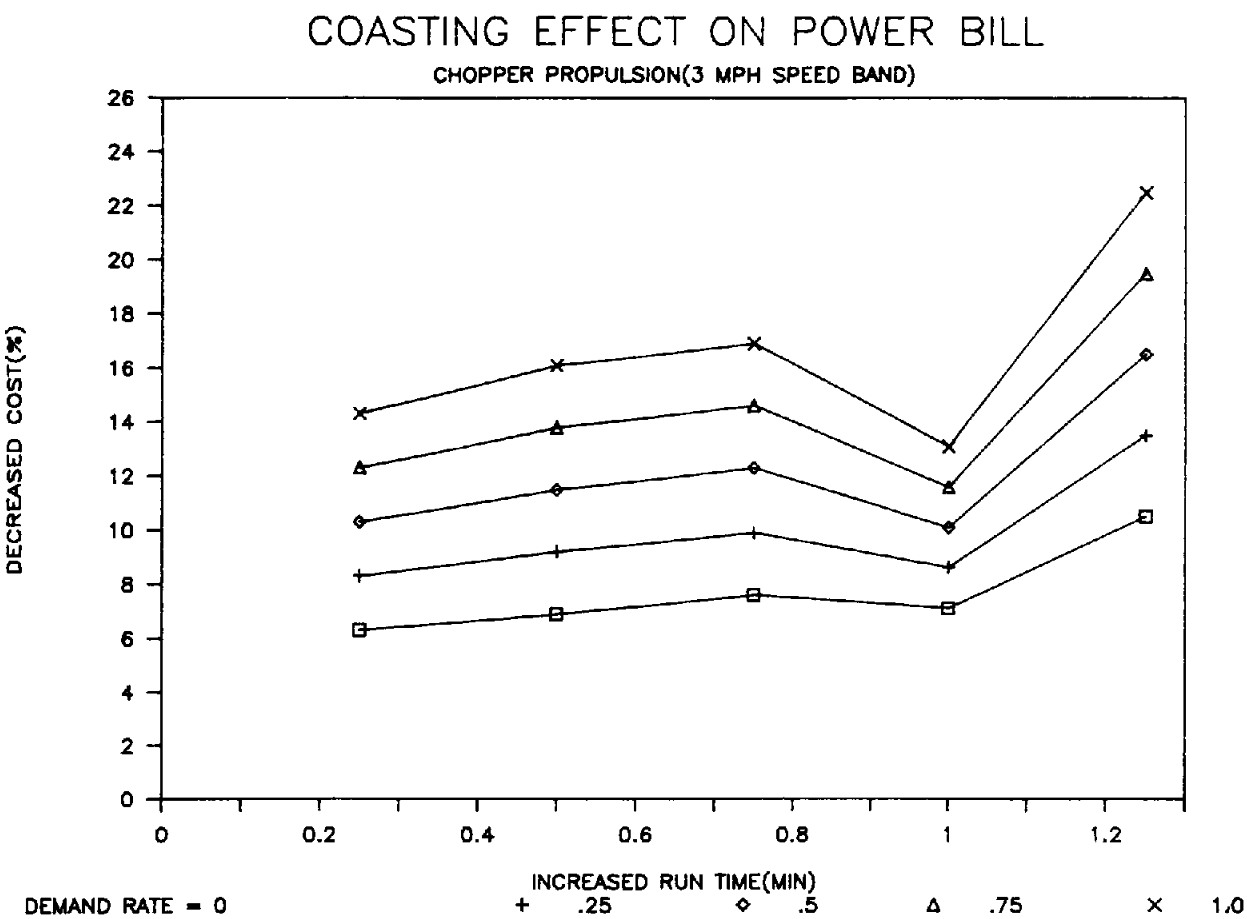

COASTING EFFECT ON POWER BILL
CHOPPER PROPULSION(3 MPH SPEED BAND)
DECREASED COST(%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
1.2
INCREASED RUN TIME(MIN)
DEMAND RATE = 0
+ .25
◇ .5
Δ .75
× 1.0

FIGURE 1-26

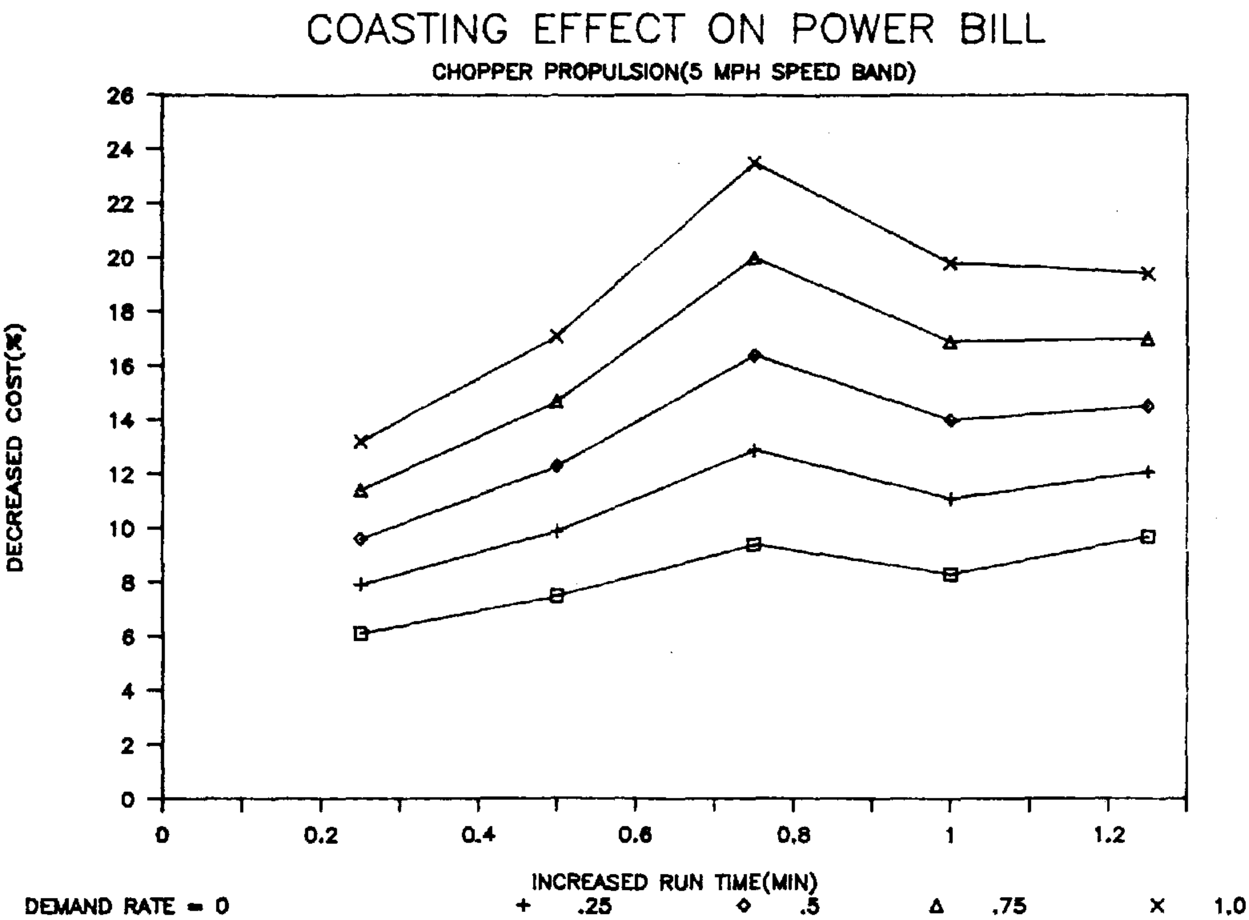

COASTING EFFECT ON POWER BILL
CHOPPER PROPULSION(5 MPH SPEED BAND)
DECREASED COST(%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
1.2
INCREASED RUN TIME(MIN)
DEMAND RATE = 0
+ .25
◇ .5
Δ .75
× 1.0

FIGURE 1-27

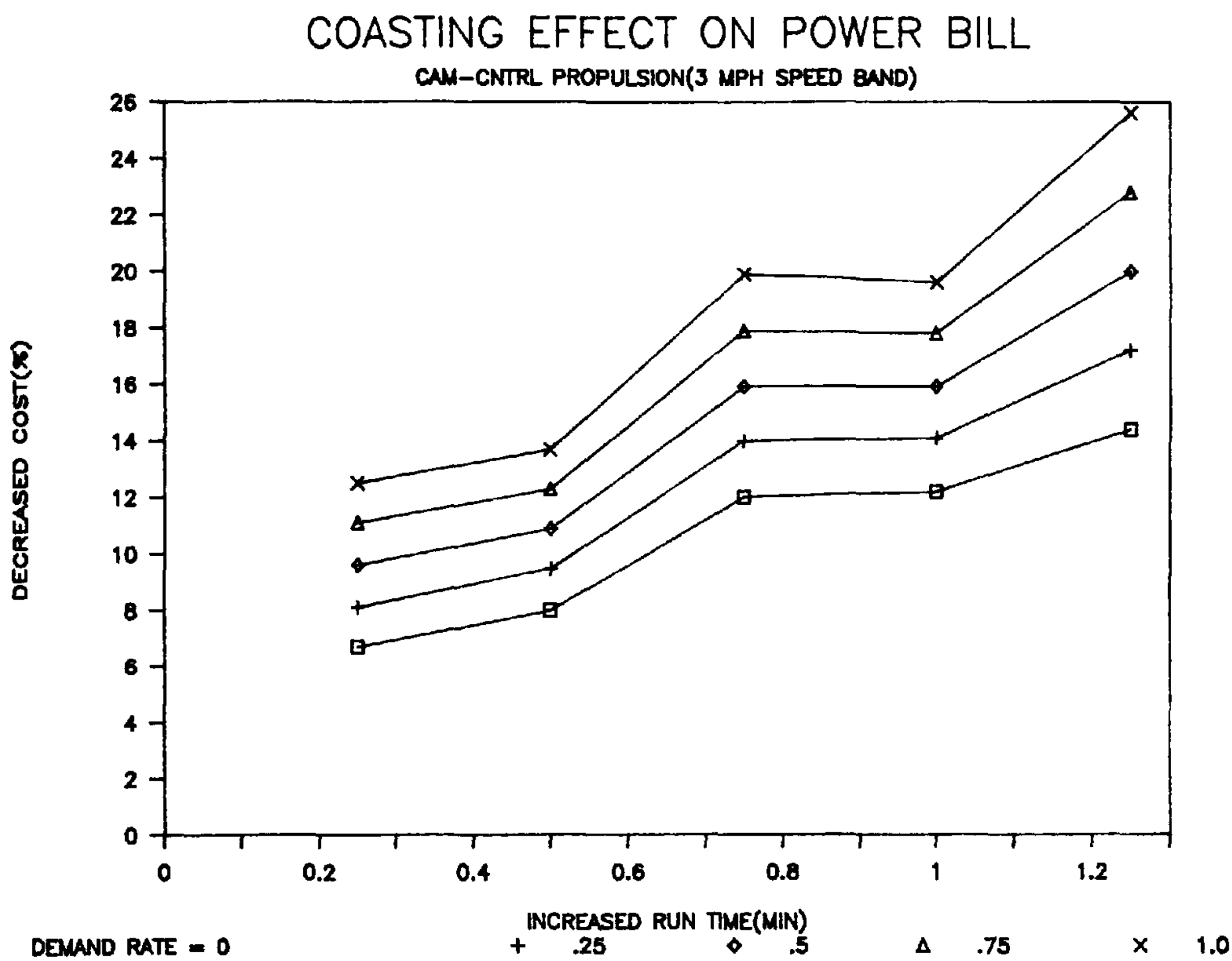

COASTING EFFECT ON POWER BILL
CAM-CNTRL PROPULSION(3 MPH SPEED BAND)
DECREASED COST(%)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
0
0.2
0.4
0.6
0.8
1
1.2
INCREASED RUN TIME(MIN)
DEMAND RATE = 0
+ .25
◇ .5
Δ .75
× 1.0

FIGURE 1-28

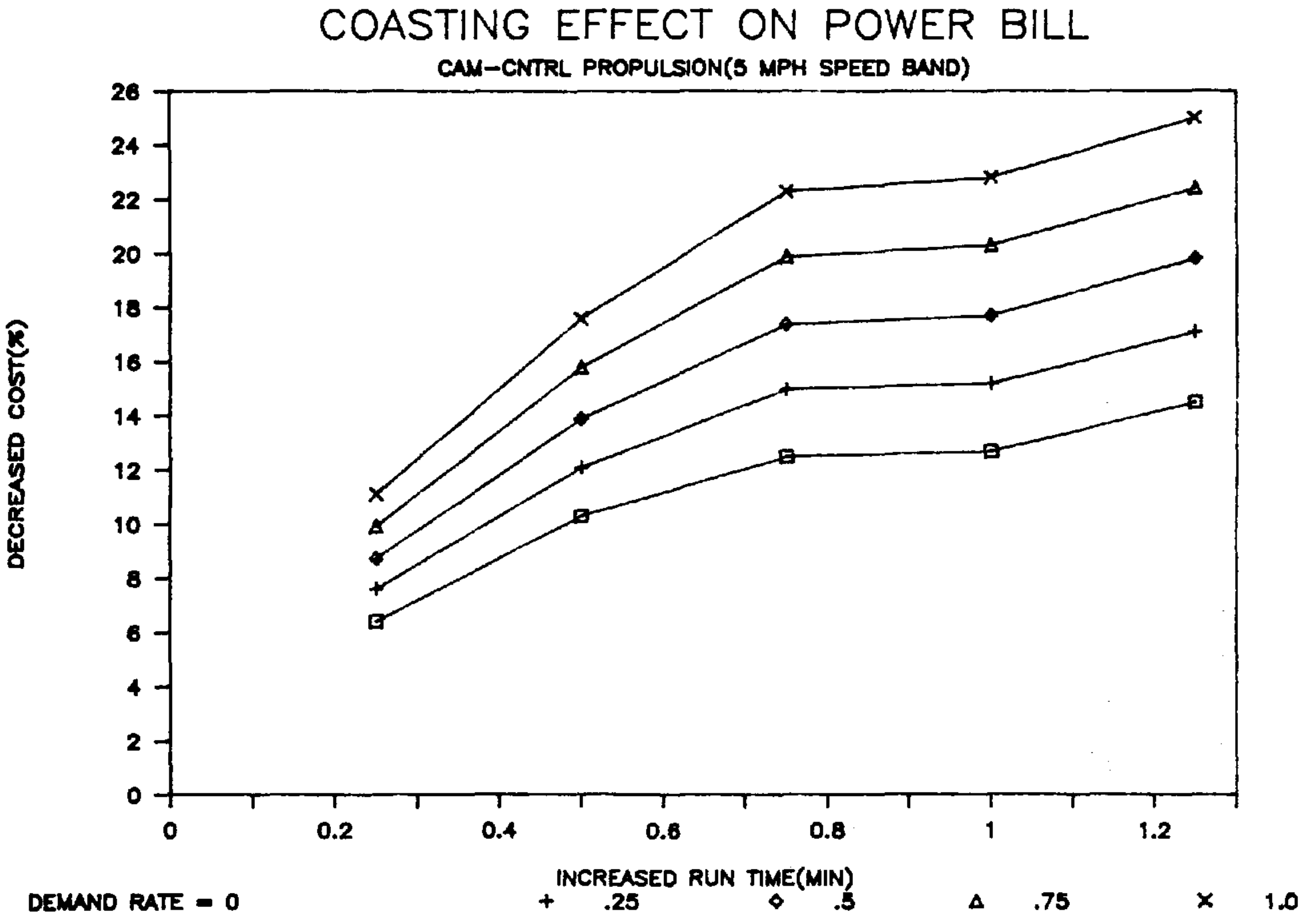

COASTING EFFECT ON POWER BILL
CAM-CNTRL PROPULSION(5 MPH SPEED BAND)
DECREASED COST(%)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
0
0.2
0.4
0.6
0.8
1
1.2
INCREASED RUN TIME(MIN)
DEMAND RATE = 0
+ .25
◇ .5
△ .75
× 1.0

FIGURE 1-29

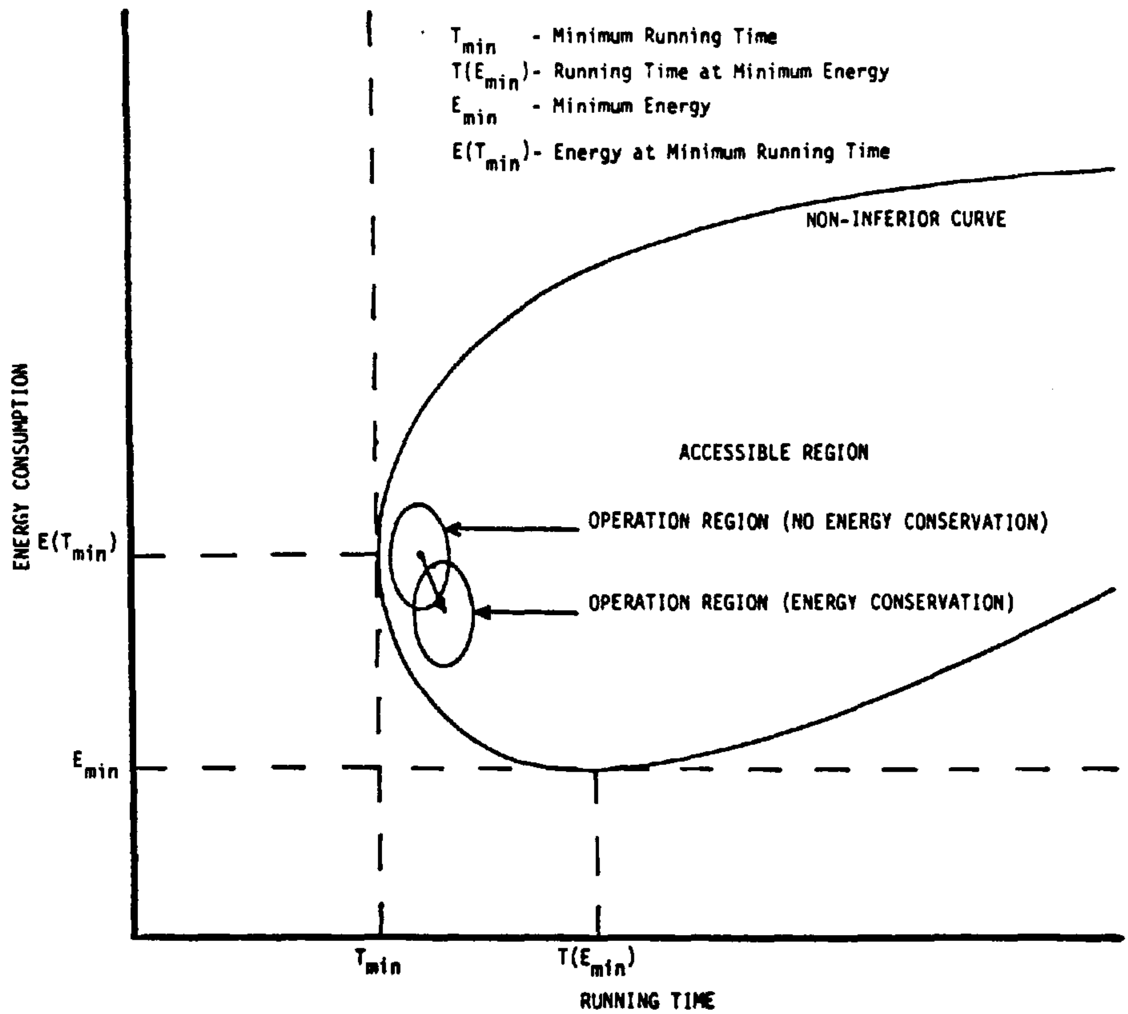
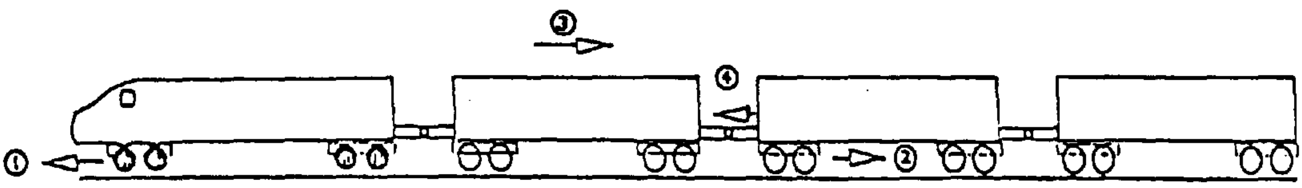


FIGURE 1-30

THE ENERGY-RUNNING TIME PLANE



EQUATION OF MOTION: $U - T_{RR} - T_{RA} - G - C = M_E \frac{dv}{dt}$

FORCES (INDICATED BY NUMERALS AND ARROWS)

1 APPLIED FORCE AT WHEELS BY PROPULSION SYSTEM

2 ROLLING PORTION OF TRAIN RESISTANCE, CURVE RESISTANCE, GRADE RESISTANCE AND BRAKING EFFORT (FRICTION BRAKES)

3 AERODYNAMIC PORTION OF TRAIN RESISTANCE

4 COUPLER FORCE

$U = T_E$ (TRACTIVE EFFORT)

$= -B_E$ (ELECTRICAL BRAKING EFFORT)

T_{RR} = ROLLING PORTION OF TRAIN RESISTANCE

T_{RA} = AERODYNAMIC PORTION OF TRAIN RESISTANCE

C = CURVE RESISTANCE

G = GRADE RESISTANCE

M_E = EQUIVALENT MASS

$\frac{dv}{dt}$ = ACCELERATION OR DECELERATION

● DRIVER WHEEL

○ NON-DRIVER WHEEL

FIGURE 1-31

DIAGRAM OF FORCES ACTING ON A TRAIN

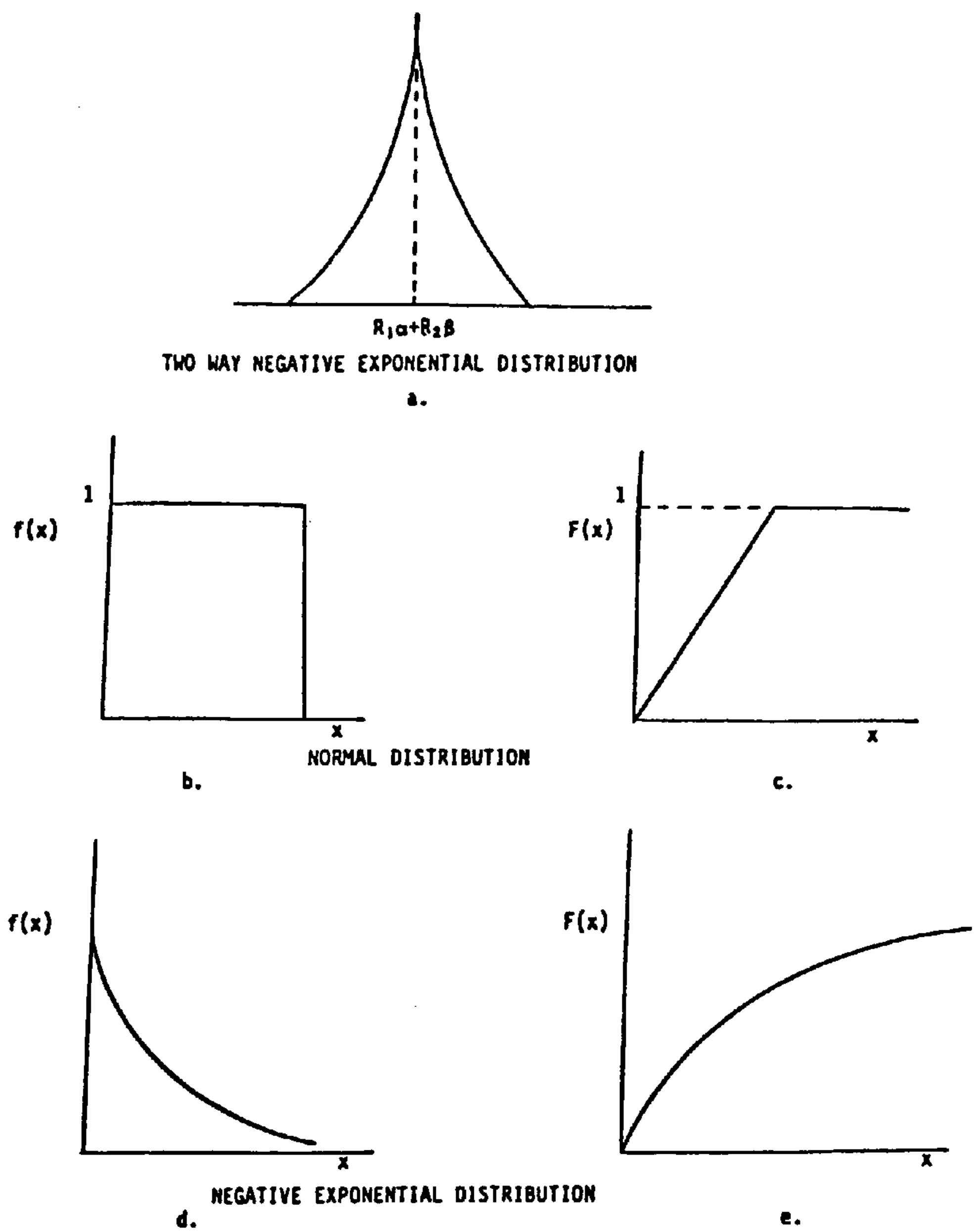


FIGURE 1-32

DISTRIBUTIONS USED IN MONTE CARLO SIMULATION

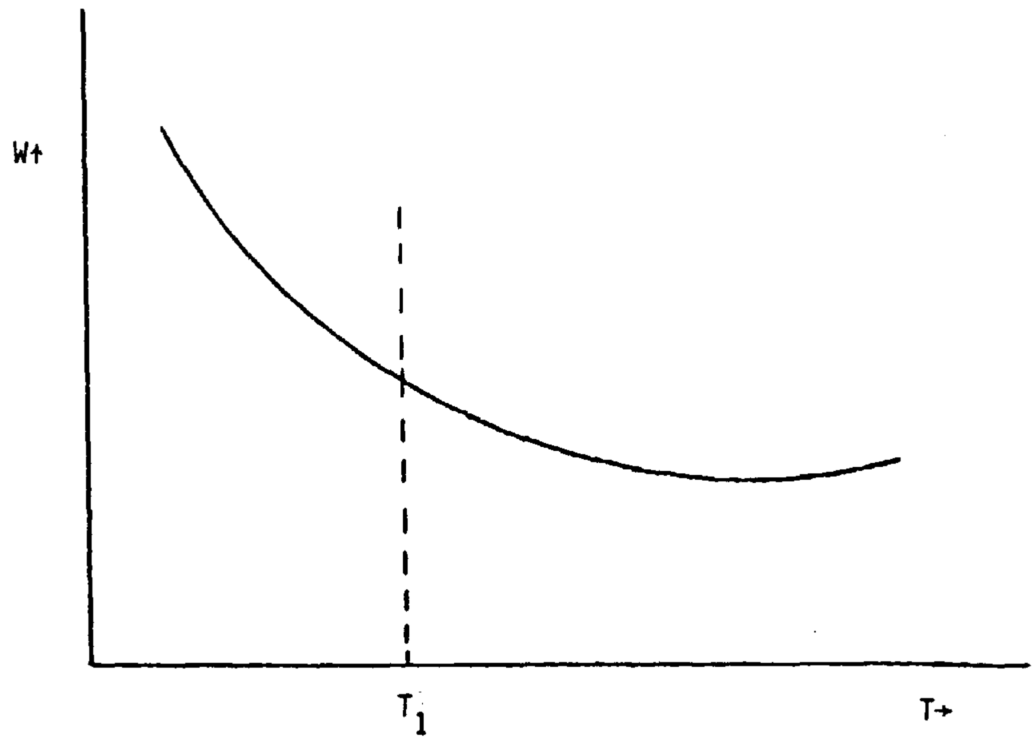


FIGURE 1-33

A POINT ON THE NON-INFERIOR PORTION OF THE CURVE WITH TRAVEL TIME $T=T_1$

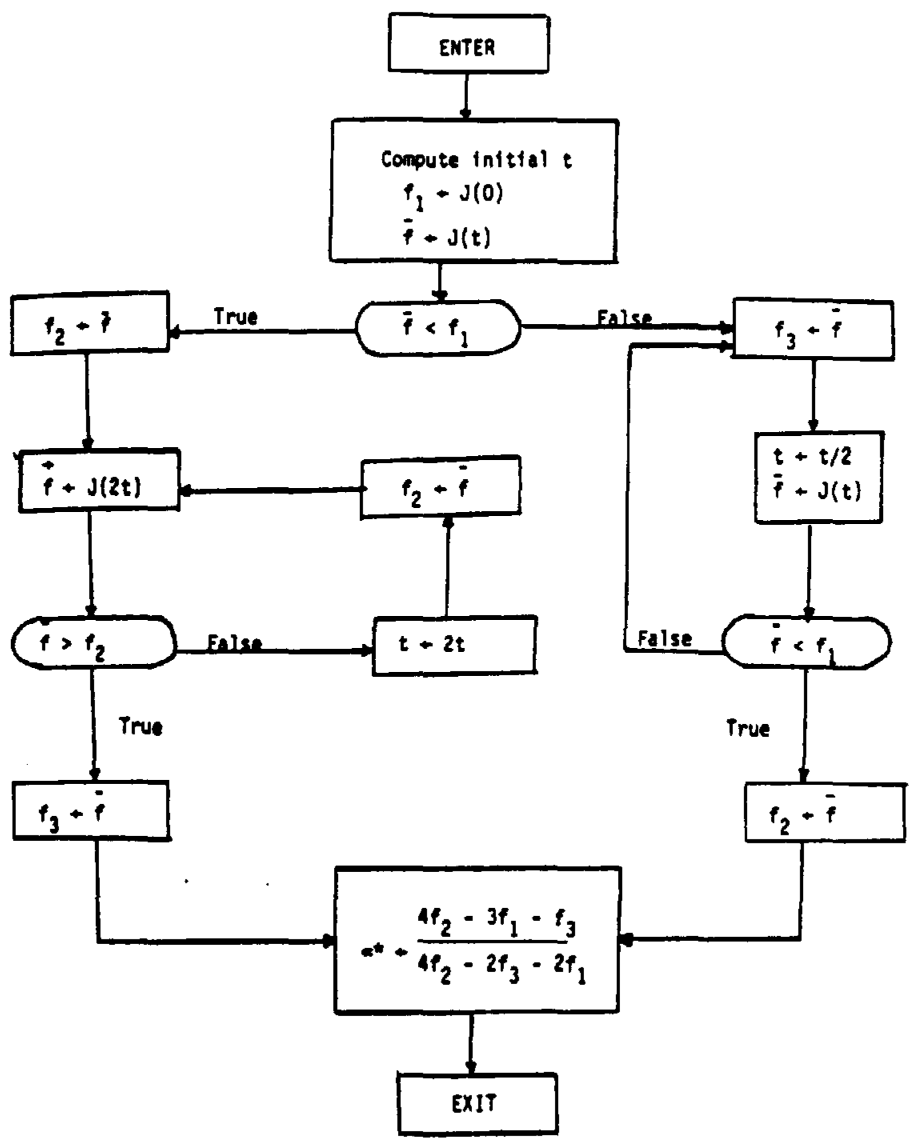


FIGURE 1-34

ALGORITHM FOR SELECTING OPTIMAL STEP SIZE

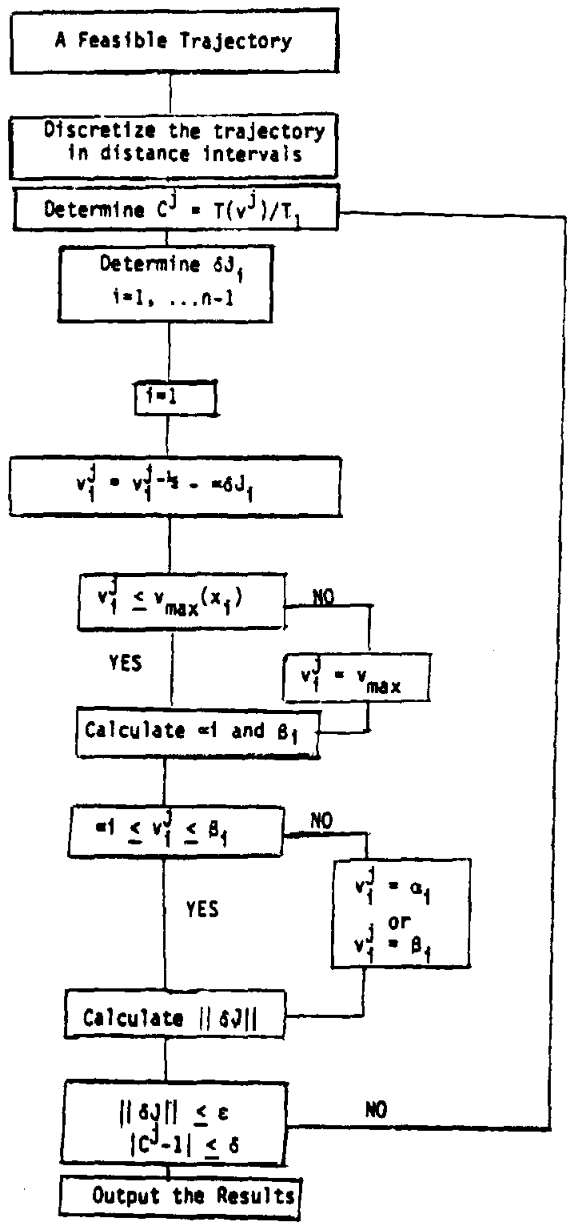


FIGURE 1-35

DISCRETIZATION AND MINIMIZATION FLOW CHART

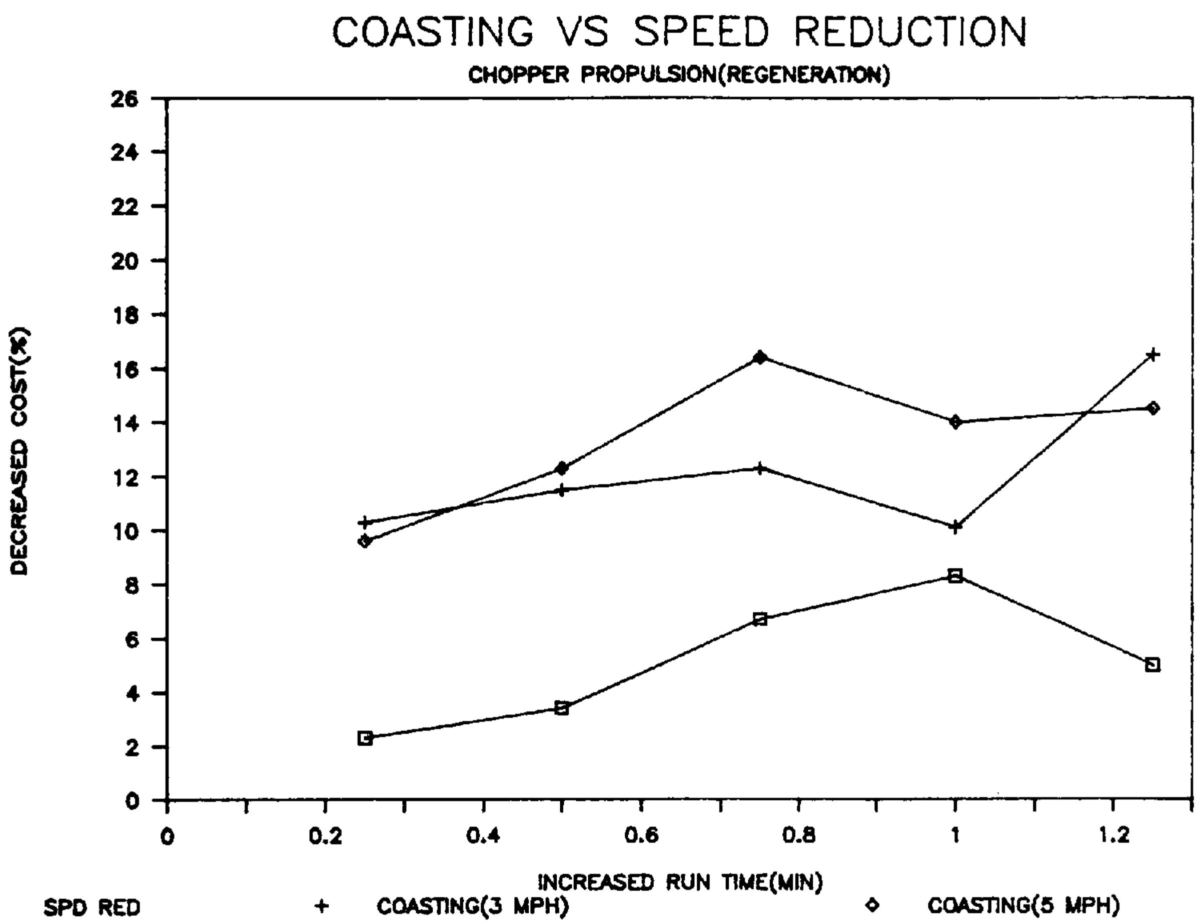

COASTING VS SPEED REDUCTION
CHOPPER PROPULSION(REGENERATION)
DECREASED COST(%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
1.2
INCREASED RUN TIME(MIN)
SPD RED
COASTING(3 MPH)
COASTING(5 MPH)

FIGURE 1-36

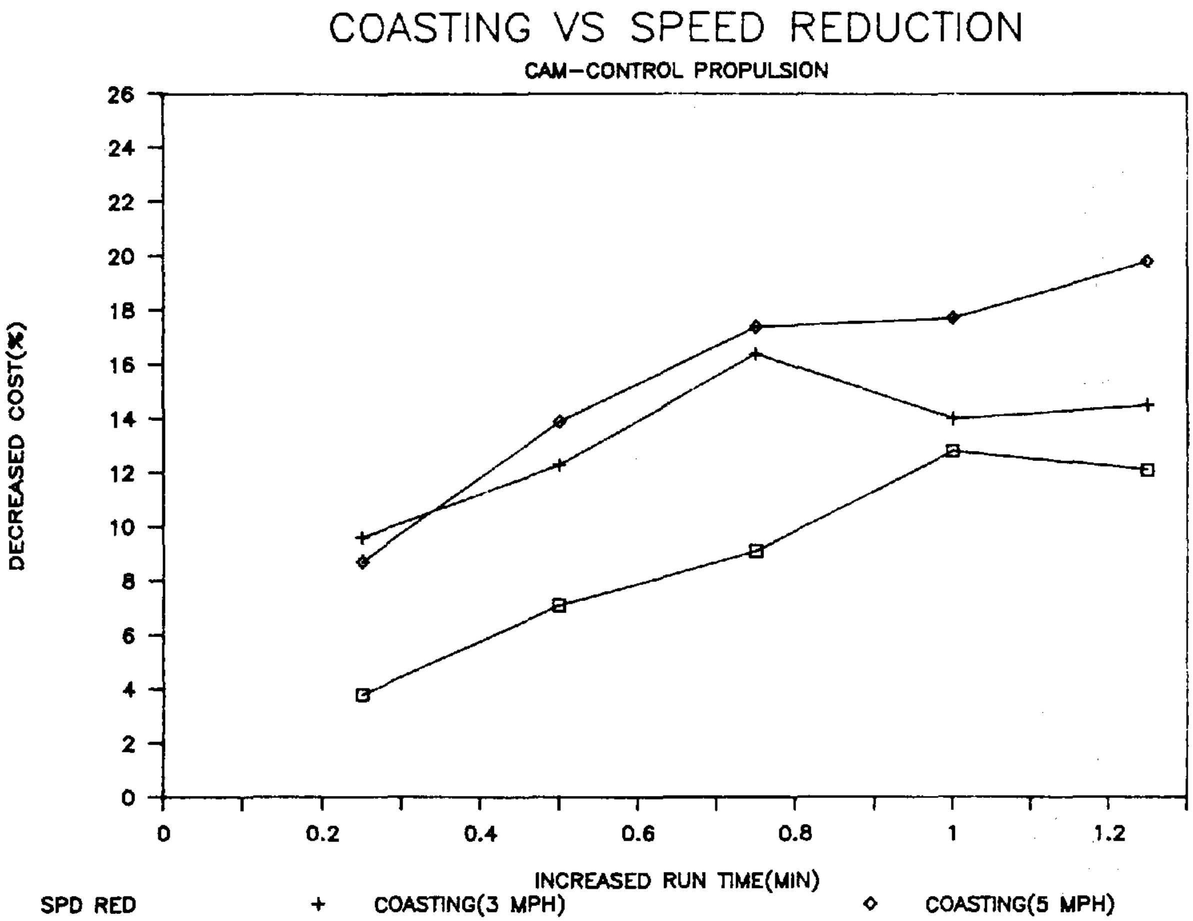

COASTING VS SPEED REDUCTION
CAM-CONTROL PROPULSION
DECREASED COST(%)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
0
0.2
0.4
0.6
0.8
1
1.2
INCREASED RUN TIME(MIN)
SPD RED
COASTING(3 MPH)
COASTING(5 MPH)

FIGURE 1-37

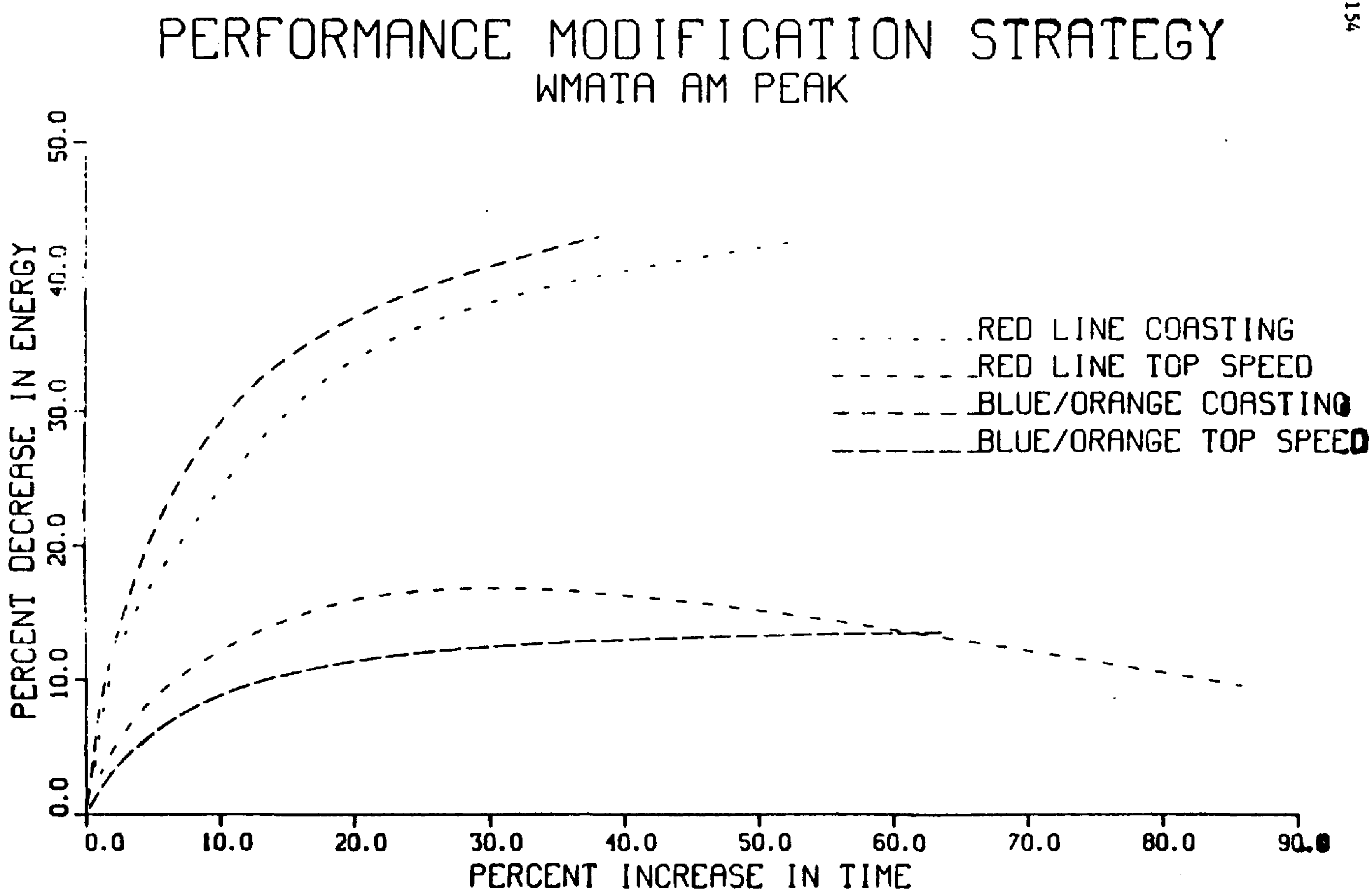

PERFORMANCE MODIFICATION STRATEGY
WMATA AM PEAK
PERCENT DECREASE IN ENERGY
0.0
10.0
20.0
30.0
40.0
50.0
PERCENT INCREASE IN TIME
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
RED LINE COASTING
RED LINE TOP SPEED
BLUE/ORANGE COASTING
BLUE/ORANGE TOP SPEED

FIGURE 1-38

MARTA PERFORMANCE MODIFICATION RESULTS
AM PEAK OPERATION 100% RECEPTIVITY

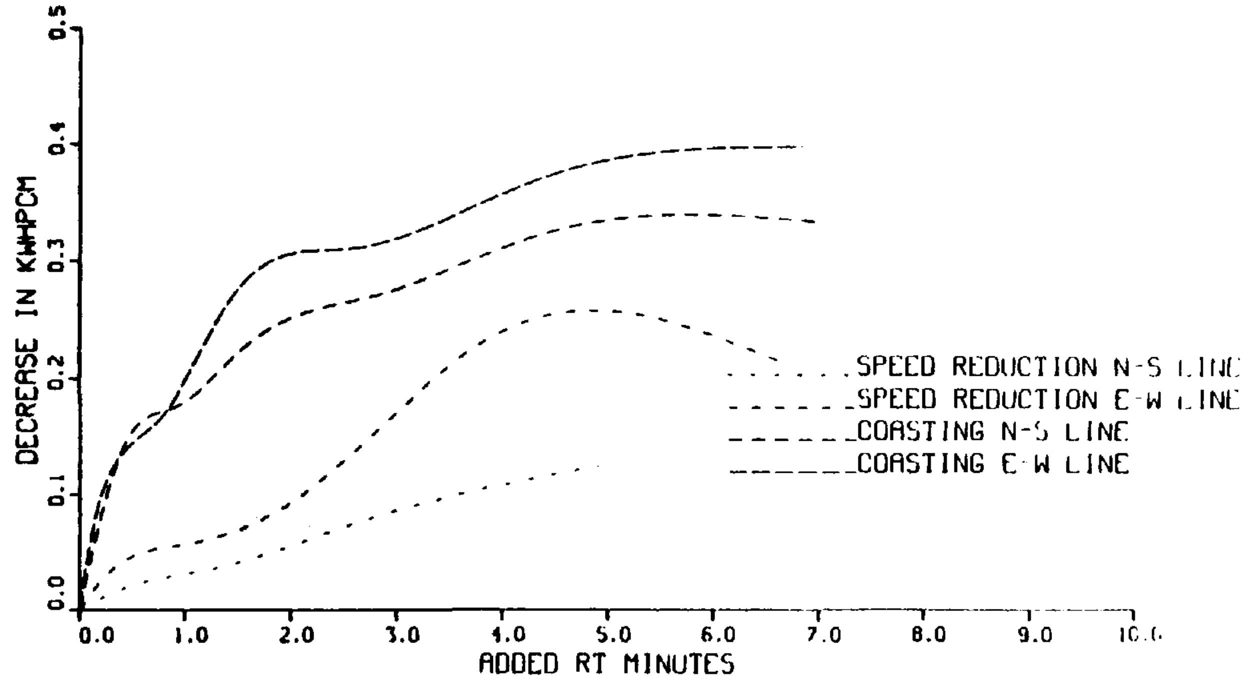


FIGURE 1-39

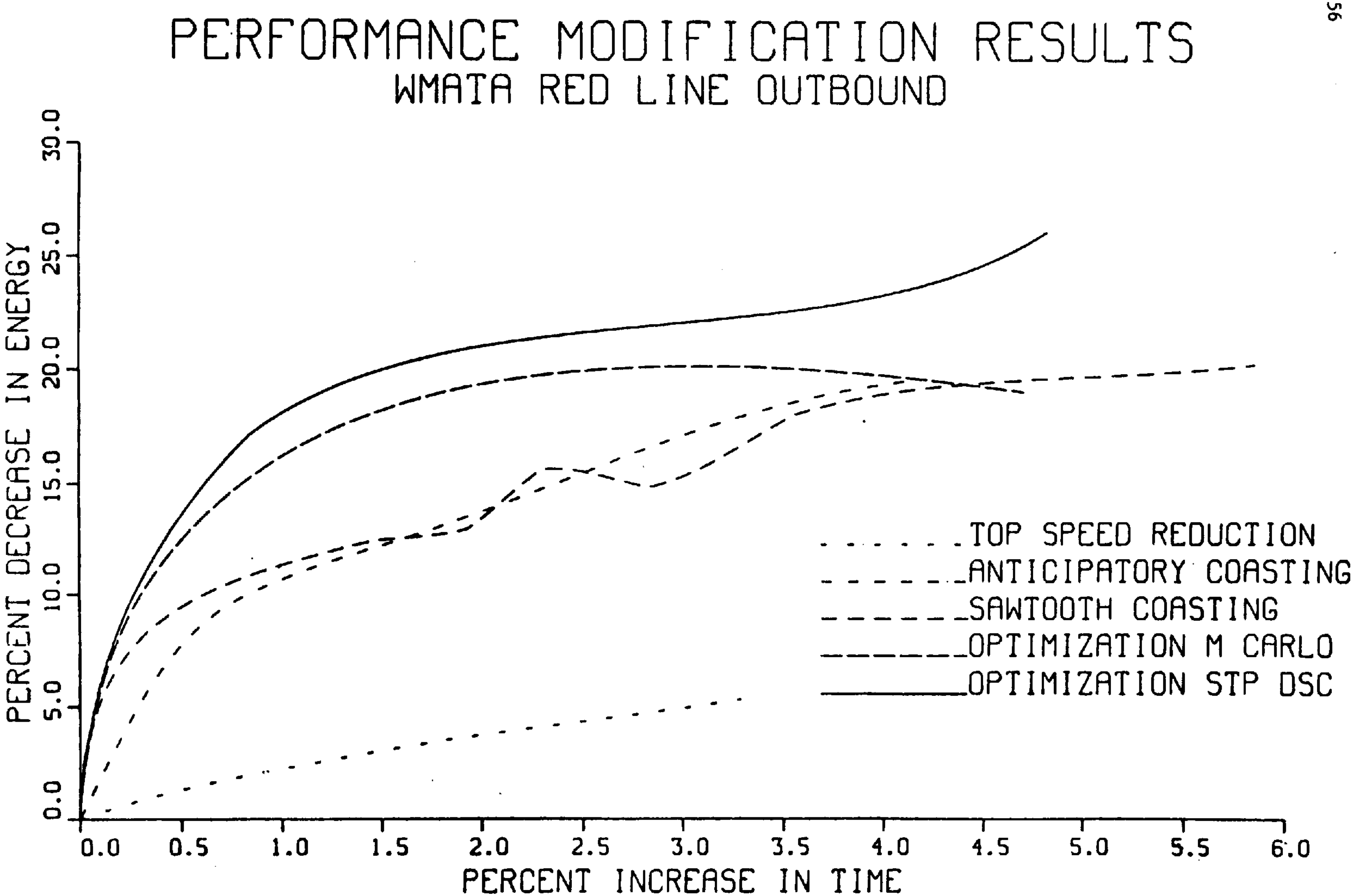

PERFORMANCE MODIFICATION RESULTS
WMATA RED LINE OUTBOUND
PERCENT DECREASE IN ENERGY
0.0
5.0
10.0
15.0
20.0
25.0
30.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
PERCENT INCREASE IN TIME
TOP SPEED REDUCTION
ANTICIPATORY COASTING
SAWTOOTH COASTING
OPTIMIZATION M CARLO
OPTIMIZATION STP DSC

FIGURE 1-40

ENERGY VARIATION WITH SCHEDULE OFFSET

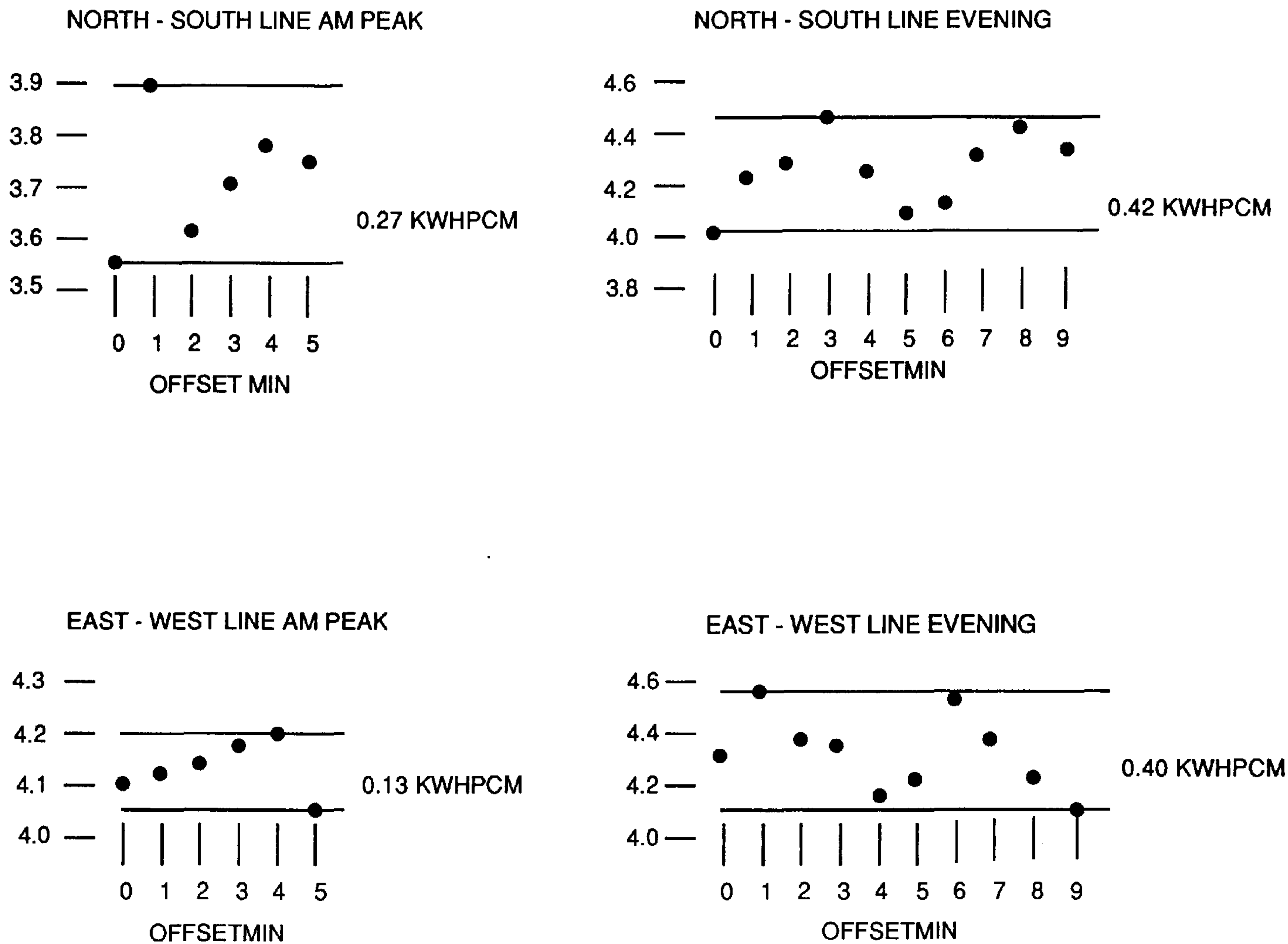


FIGURE 1-41

2. POWER RATE STRUCTURE EVALUATION

2.1. INTRODUCTION

The first major task in evaluating the rate structure involves the procurement of necessary data from the utility, the regulatory public service commission and various departments of the transit system itself. The include:

- Applicable utility tariff.
- Annual report of the utility.
- Utility tariffs applicable to governmental or other large customers.
- Utility's franchised service territory and its characteristics.
- Various customer classes, their revenue and load contributions to the system.
- Utility's generation mix and fuel cost characteristics.
- Peaking characteristics of the utility.
- Public Service Commission's (PSC) composition.
- Status of any pending rate proceedings of the utility.
- PSC's decisions in most recent rate proceedings of the utility.
- Transit system's power bills for two years covering the latest 12 months.
- Transit system's operating characteristics and its power requirements.
- Role of mass transit in utility's service territory.
- The transit system's organizational structure regarding utility bill approvals, audit, energy conservation and load management, and the department responsible for negotiations with utility or participation in utility rate proceedings before the Public Service Commission.

The general considerations in evaluating power rate structure for transit systems are substantially the same that arise in setting rates, whether through a regulatory proceeding or by negotiation. These include the necessity to establish a rate structure that assigns class revenue responsibility in accordance with the cost causation associated with each of the identifiable classes of customers. Rates based on cost of providing service are both equitable and economically efficient. Rates charged to a transit system should reflect the unique nature of mass transit, its loads, and the cost of service required to serve such loads. The economic and financial manifestation of the utility's risk associated with these rates for mass transit is comprehensively embodied in the statistical measure of the variance or variability of earnings or the rate of return. To attain this type of rate structure and end result, the following general issues must be carefully evaluated and assessed:

1. Determination of a utility's total cost of service and overall revenue requirement.
2. Determination of a cost of service allocation method among customer classes.
3. Determination of the revenue requirement including fair rate of return.
4. Determination of a suitable rate design, or rate structure, that would apply to all customer classes.

As a general proposition, cost of service analysis is a complex process because it involves assignment to customer classes all of the power company's embedded or booked accounting costs, as modified, adjusted, or normalized for rate-making purposes.

2.2. COST OF SERVICE - BASIC PRINCIPLES

Most of the costs incurred by an electric utility are incurred to provide electric service to all its customers. Total jurisdictional revenue requirements for a utility is the sum of jurisdictional operating expenses and the opportunity to earn the authorized rate of return on the jurisdictional rate base.

Electric utilities provide several different types of services to their customers, and they incur many different types of costs to provide these services. The cost of power production which includes the investment in various generating plants (coal, hydro, nuclear, gas and oil) as well as the cost of fuel and associated operating expenses, which generally constitutes more than half of the utility's total cost, are the costs incurred to serve all jurisdictional customers.

Some other costs are incurred to provide service to provide one or more different types of service, but they are not necessary for all types of service which a utility offers. A good example of this cost is the utility's secondary distribution lines at voltage level(s) below the voltage at which generally traction power is provided to a transit system.

For costs incurred to provide a service used by two or more different classes of customers, it is necessary, in accordance with the basic principle of cost allocation, to determine an appropriate distribution of these costs among the classes of customers which utilize the type of service for which costs are incurred. The distribution of these costs should be in proportion to the causes of the cost incurrence.

The development of a class cost-of-service is generally considered to have three stages: functionalization, classification and allocation. Functionalization is simply the identification of the different types of costs which a utility incurs. Classification is the determination of the types of service for which each kind of cost is incurred.

Classification relates each type of functionalized accounting cost to the different types of service which the utility provides. The primary types of service are:

1. DEMAND. Supply of the service (KW) whenever it is demanded by the customers. The utility must have a sufficient amount of generating and bulk power transmission capacity to meet the system coincident peak load. In addition, transmission and distribution facilities must be adequate to serve the maximum load of each customer in his local area.

2. ENERGY. The utility must generate and deliver electrical energy (kwh) required by the customers. Actual amounts of energy differ with hour of the day, day of the week and time of the year.

3. CUSTOMER or BASE. The utility must bring the electric service of DEMAND and ENERGY to the customer's premises, connect each customer to the system and provide metering of usage.

One major problem in classification arises when a single functionalized cost relates both to DEMAND and ENERGY services. Costs for generating capacity, bulk power investments and related operating expenses are incurred both to serve the coincident peak load and to provide energy throughout the year.

Costs which are incurred to meet the coincident peak demand of the system or the localized or class maximum demands (non-coincident peaks) should be related to the DEMAND service. Costs which depend on the number of customers should be classified as CUSTOMER service. Costs which depend on the amount of energy which the utility must apply should be classified as related to ENERGY service.

In the allocation phase, the functionalized and classified costs are distributed to the customer classes based costs caused to serve the consumption and load at production, transmission and distribution levels. There is a great amount of subjective judgement involved in determining the relationship between cost causation and customer service requirements because there is no universally accepted cost allocation methodology. It is not uncommon for a utility to undertake class cost-of-service analysis using more than one cost allocation methodology to evaluate relative customer class contribution to revenues and costs. (For further discussion on cost allocation methodologies see Sec. 2.5.3.)

2.3. RATE STRUCTURE

The components of the energy use pattern; namely, power facilities, energy consumption and power demand, are influenced by equipment and system design and operating practices which are controllable within limits by transit management. The power rate structure may be a matter of negotiation between the transit authority and the electric utilities. The ability to set a rate structure favorable to the transit system is dependent on both internal and external factors. It is by careful management of the internal ones (i.e., a vigorous energy conservation or load management program) and wise negotiations with knowledge of the external ones that optimum rate structures are secured.

The purpose of this section is to explore the power rate structures of typical U.S. rail transit systems and outline an approach to rate negotiations which can be used by rail transit authorities. Particular case studies which were conducted by the authors and which follow the outlined approach are also summarized.

2.4. SURVEY OF POWER RATE STRUCTURES OF U.S. TRANSIT AUTHORITIES

The power rate structures of the following rail transit systems were surveyed during the past few years:

- BART - San Fransisco Bay Area Rapid Transit District
- CTA - Chicago Transit Authority
- GCRTA - Greater Cleveland Regional Transit Authority
- MARTA - Metropolitan Atlanta Rapid Transit Authority
- MBTA - Massachusetts Bay Transportation Authority (BOSTON)
- MDCTA - Miami Dade County Rapid Transit Authority
- NYCTA - New York City Transit Authority
- PATCO - Port Authority Transit Corporation (Philadelphia-Lindenwold NJ)
- PATH - Port Authority Trans Hudson (New York City - NJ)
- SEPTA - Southeastern Pennsylvania Transportation Authority(Philadelphia)
- WMATA - Washington Metropolitan Area Transit Authority

These represent the major rail transit systems in the U.S. who take electric power. A summary of this survey is now presented.

2.4.1. Serving Electric Utilities and Jurisdictions

Table 2-1 lists the electric utilities serving the rail transit systems surveyed and the jurisdiction of regulatory control. Of the systems covered in the survey, four are served by more than one electric utility and rates of two are regulated under more than one jurisdiction.

WMATA is particularly complicated since it is served by two utilities, one of which; namely, the Potomac Electric Power Company (PEPCO) is regulated under three jurisdictions for WMATA service[1] This means that WMATA has four separate rate structures, depending on which utility is providing power and in what state the transit authority receives the power.

SEPTA also deserves special mention. Its principal power source is the Philadelphia Electric Company (PECO). However, it also runs some of its commuter service on an electrified railroad which is owned by the National Railroad Passenger Corporation (AMTRAK). Power to operate these trains is purchased from AMTRAK who in turn buys the power from PECO. In addition, SEPTA sells power purchased from PECO to PATCO for operation of its train within the city of Philadelphia. AMTRAK is also actively evaluating co-generation and alternative power supply sources.

All of the transit authorities surveyed have some form of contract with the electric utility supplying power. Most of these contracts provide for the firm supply of power requirements of the transit system for a fixed period of time (the term varies from month to month to thirty years), thereby assuring an adequate and reliable source of power. In addition, these contracts provide for the basis of a special facilities charge and/or reimbursement provision for construction costs of special facilities in the form of contributions in aid of construction required to meet the design and reliability criteria of rail transit systems.

Nineteen utility rate structures for rail transit were represented in the survey of the rail systems. Eight (including one pending) of the rate structures recognized rail transit operation as a separate customer class and ten considered rail transit electric service as part of the high voltage industrial class with some modifications. The details are presented in Table 2-2. Most utilities and regulatory agencies which

---

[1] Virginia Power Company is negotiating to acquire PEPCO's Northern Virginia service territory. At the consumation of the forthcoming sale, PEPCO's retail rate regulation will be limited to D.C. and Maryland.

regulate and approve rates for rail transit, recognize that these systems have unique load and customer characteristics which distinguish them from industrial class customers in their cost causation on the utility system.

2.4.2. Structure of Billing Demand

Determination of billing demand from actual power use varies widely among the utilities which serve rail transit systems. The principal demand time interval aspects of rail transit rate structures are listed by utility/rail transit system in Table 2-3.

The demand interval varies from 15-60 minutes. In general, maximum demand from day to day is more predictable with larger demand intervals.

If the electric utility feeds to the transit system are electrically connected to each other, usually on the DC side of the traction substations, the utility is parallel feeding power to the rail system. Under such circumstances, it is appropriate for the utility to meter demand coincidentally. The voltage fluctuations among these parallel feeds, some of which may be caused by loads from other utility customers, can cause power flows which do not reflect the true demand caused by the rail system. An example of this is demonstrated using the WMATA Red Line:

Noncoincident peak demands together with their times of occurrence are given in Table 2-4 for the meters through which power is supplied to the Red Line. The coincident peak demand is also shown in the table. The noncoincident peak demand is 30% higher than the coincident value.

The noncoincident peak demand is always larger than the coincident peak. The magnitude of the difference between the two is attributed to four major influences:

1. The variation in the number of passengers with time (thus influencing train weight) is likely to be more important on a local level, rather than over the whole system.

2. Abnormal operation (train delay and subsequent make up operation) is more likely to occur locally rather than globally at any time.

3. Several meters, especially those associated with yards, shops and storage tracks, can record peak power at off-peak transit operating times.

4. The voltage at which the utility supplies power can vary because of customer loads independent of the transit load.

The effect of voltage variation at the feed points on the altering of noncoincident demand is illustrated in Table 2-5 for the WMATA Red Line operation. The numbers in the table are the results of simulation of actual WMATA operation. In the first case, a normal off-peak operation of the transit system was simulated, with all feed points at nominal voltage. In the second case, the voltage at the New York Avenue feed was increased by one percent relative to the other feed points. (This could happen when another customer's load on the same utility circuit serving the New York Avenue feed is diminished.) The resulting power draw through the New York Avenue feed has increased by 40% while power draws from the adjacent feeds have decreased.

Since it is typical for utilities to guarantee voltage to within ± 5%, voltage variations, not caused by the transit system itself, can create situations where noncoincident peak demand can bear no relation to coincident demand. Note that practically no change occurred in the coincident demand in this example (Table 2-5).

Since it is the monthly demand combined with the ratchet which determines the demand portion of the electric bill, it is appropriate to discuss typical monthly demands and ratchets which are common to transit. Of the authorities surveyed, two utilities computed a monthly demand which was different from the maximum demand achieved in the month. The Public Service Electric and Gas Company in its service to PATCO and PATH, averages more than one daily maximum demand to obtain the monthly demand. Commonwealth Edison Company, in its service to CTA, averages several of the highest demands to obtain monthly demand.

Billing demand, in most cases is ratcheted. The ratchets are summarized in

Table 2-6 . It is difficult to see how any of the demand ratchets are based on cost of service. Demand ratchets tend to be anticonservation. In most cases, load management systems, which are designed to reduce peak demand, will look less effective in the presence of a ratcheted demand. In particular, MARTA has a ratchet in which one should be careful on load control during the summer months (June-September) and careless about load control during the winter months (October-May).

2.4.3. Structure of Energy Use Cost

The energy use pattern is measured in terms of kilowatt hour (kwh) consumption. It recognizes the utilization of power production facilities in terms of load factor and cost causation. It primarily consists of the fuel adjustment charge or the charges in cost of fuel burned to produce the kwh. The high volume discount or block energy charges are being replaced by flat, seasonal or time of use energy charges. The power rate structures for transit systems which are based on industrial or modified industrial customer class rates generally cause recovery of a portion of the demand cost through the energy charge. A pure energy charge based on energy cost recovery may vary from less than one third of a cent ($0.033) to more than $.6 cents ($.0600)per kwh for the transit systems surveyed.

2.4.4. Seasonal and Time of Use Rates

The Public Utilities Regulatory Policies Act of 1978 (PURPA) mandated that state utility regulatory commissions evaluate and consider implementation of seasonal and time of use rates for electric customers to promote conservation, equity and efficiency. The cost of producing electricity varies by season and time of day based on the load peaking characteristics of the utility which in turn depends on the peaking characteristics of the customer it serves. Principles that rates reflect the cost of providing service by season and time of use are likely to provide the customer with the correct price signal and the result is the most efficient use of the limited energy resources available to the society. Most of the rate structures applicable to rail transit systems reflect seasonal differential in energy charges.

Most transit systems who have dirannual load do not have peak loads that coincide with the seasonal load pattern of the utility. The implementation of seasonal rate differentials has generally been a benefit to the transit system. However, because of daily morning and evening peaking characteristics of rail transit systems coupled with the obligation to provide transit service and subsequent lack of opportunity to shift load, application of time of day rates to transit systems is likely to result in higher power cost than under a non-time differentiated power rate structure.

2.4.5. Electric Traction Annual Power Cost

Table 2-7 contains a summary of the annual traction power cost of several major rail transit systems. AMTRAK costs have also been included in the table.

2.5. REGULATORY CONSIDERATIONS AND RATE MAKING STANDARDS

A modern electric utility must provide the functions of production, transportation and delivery of electricity to a large number of customers. In pricing electric service, the utility is guided by regulatory principles of reasonable, just and non-discriminatory rates.

The first step toward reasonable, just and non-discriminatory pricing of electricity is proper customer classification. The second step is the proper rate structure for the customer classes.

The cost of service study methodology is used to assign proper cost responsibility to customer classes.

2.5.1. Customer Classification

Customer classes of an electric utility should be defined in such a way that only customers of similar customer and load characteristics are grouped together.

Customer characteristics relate primarily to the nature of the customer and have been traditionally recognized by most utilities, as residential, commercial, industrial, railways and street lighting.

The important load characteristics which form the basis for customer classification are:

1. Size of the load.

2. Coincidence factor, which is the ratio of the maximum demand of the class or system as a whole to the sum of the maximum demands of the components of the class or system as a whole.

3. Load factor, which is the ratio of the average demand over a designated period of time to the maximum demand occurring in that period. This can refer to customer, class or system.

4. Seasonal Time of Use of Power, (Summer/Winter).

5. On/Off System Peak Time of Use of Power.

6. Voltage level at delivery point.

7. Reliability of the Service Required (Firm or Interruptable).

8. Full or partial requirements for power.

By reason of the rising cost of producing electricity in recent years, it is common for utilities to place more emphasis on load rather than customer characteristics.

A utility generally provides service to a wide range of customers having different characteristics. These characteristics impose significantly different costs on the utility's system for production, transmission (transportation) and distribution (delivery). The basic regulatory principle states that rates developed for a customer should be such as to recover the costs incurred by the utility for serving that customer, plus a reasonable rate of return. Since the ideal approach of developing rates for each customer is impractical, it is a general practice to group customers with similar characteristics into classes and then determine the cost of service for the properly grouped classes.

2.5.2. Rate Design

The second and final step in the rate-making process is the pricing of electric service for each of the customer classes. Under conventional rate regulatory framework, responsibility for pricing the electric service is shared by the utility and a Public Utilities Commission, which has been delegated authority to legislate in the public interest (agency having jurisdiction over rates and conditions of providing electric service).

In addition to setting rates for the customer classes in such a way as to reflect cost of service to the classes, rates are also set to provide an effective instrument for the marketing of the electric service.

Although cost of providing service is the generally accepted standard for establishing rates for customer classes, practicability and non-cost considerations may also play a role. Rate schedules are statements of differential prices over a wide range of requirements of existing and prospective users of electric service. A comprehensive list of rate design considerations are:

1. Contribution of the class to the peak demand of the utility.
2. Diversity of the peak load of the customer classes.
3. Historical development of rate patterns.
4. Economic efficiency.
5. Long term incremental cost.
6. Relative rate of return.
7. Relative contribution to system revenue.
8. Stability of and ability to meet annual revenue requirements.
9. Social goals of the region which the utility serves (employment, humanitarian acts, etc.).
10. Conservation of scarce resources.
11. Equity or fairness among customers.

12. Utility growth considerations.

13. Administrative ease.

2.5.3. Cost of Service Study Methodology

Coincidental Peak: The Coincidental Peak Method or Peak Responsibility Method allocates peak demand-related costs in accordance with each classes' coincident demand at the time of the system peak. By using each classes' demands calculated from actual metered demands (adjusted for line losses), load research statistics, and billing data, the proportion of the system peak load of each customer class is developed. The capacity costs are then allocated to each rate class on the basis of these derived percentages. The single peak version of this method utilizes each customer classes' contribution to the annual peak as the cost defining characteristic. Off-peak users are assessed on demand costs.

One drawback of the Coincidental Peak Method is that diversity benefits are inequitably distributed among the classes. Although the overall system peak is an important cost consideration to the system, there are also savings to be had from diversity. In large electric systems, the times of the class peaks do not necessarily coincide with each other or the system peak, and this is beneficial to the utility. Another weakness of the Coincident Peak Method is that, even though all users on an electrical system can use the service any time, off-peak users are allocated zero demand costs. An additional limitation of this method is that it does not consider that off-peak demand may conflict with necessary maintenance, resulting in additional capacity to permit maintenance scheduling.

Another drawback of this method is the effect that the change in time of peak may have on the cost responsibility. If the load pattern at the time of system peak is typical, then the shift of load changes the allocation of costs among the classes completely. Therefore, the Peak Responsibility Cost Allocation Method may not meet the criterion of equity.

Multiple Peak Responsibility Method: Several forms of peak responsibility demand allocation have been developed that allocate demand on the basis of multiple peaks to recognize customer diversity. One approach is to use various weighted and unweighted constibutions to the monthly maximum coincident demand. This demand allocation method apportions more expenses to consistently high use customers, rather than to those who only peak with the system.

An advantage of the Multiple Peak Responsibility Method is that it overcomes the instability of the single coincident peak approach. The Multiple Peak Responsibility Method can be calculated by constructing a normal distribution of peak demands and by giving each possible demand a probability of occurrence. Then, the weighted average of the probable demand is developed. However, this requires all customer classes to be monitored for a long period to determine what the class peaks are, and what their relationships are to the system peaks. The unavailability of this type of load-research data may be a problem for some utilities. However, it has been suggested that in the absence of such data, a company could use the mean contributions to the system peak demand over several system peak demand days as the basis for assignment.

Non-Coincident Peak Demand Allocation: The Non-Coincident Peak Method (NCP), also called the Sum of the Peak Method, is based on assigning demands to each customer class on the basis of the class' maximum demand, rather than their contribution to the system peak. The various class peaks are summed, regardless of when they occurred, and each class is allocated capacity costs by the ratio of the class peak to the sum of the class peaks.

One problem of the Non-Coincident Method is that the method disregards the economics of electric supply. A production plant system is designed to meet the maximum system coincident and not the non-coincident peak.

Another problem of the NCP Method is that is does not recognize load diversity. Since the Non-Coincident Method apportions demand costs on the basis of the proportion of the class peaks without regard to coincident peaks, the method does not recognize diversity for low and high factor customers. However, operational economics analyst Constantine Bary has postulated that this demand allocation method may meet the requirements of the Second Law of Load Diversity, referred to as the Bary Curve. The Bary Curve is a family of curves which express the relationship between load factor and coincidence factor. Coincidence factor reflects diversity, since it is the reciprocal of the diversity factor. This relationship between a customer's load factor, within a class, and their coincidence with the system peak. The Bary Curve indicates that the diversity factor is unchanging over a wide range of load factors from 30 to 70 percent. Magnitudes of class load factors usually fall within this range, that is, where the diversity factor is unchanged; therefore, the Coincident Peak Method does indirectly recognize diversity.

Average and Excess Demand Methodology: So far, this discussion of production demand allocation methodologies has been limited to cost allocation methodologies that only consider demand. The Average and Excess Demand Method bases capacity allocations on both demand and energy consumption. Two kinds of demand measurements are used to allocate demand in this method. A distinction is made between the cost of facilities to serve the average load and the cost of facilities to serve the excess load. The fraction of capacity equal to the system load factor is then allocated on the basis of the average demands. The excess demand is then allocated on the basis of the difference of the maximum class demands and their average demands.

The Average and Excess Demand Method considers the importance of the customer class load factor. Accordingly, the use of the Average and Excess Method results in a situation where system facilities are allocated in proportion to their relative uses. In addition, the opportunity for diversity is recognized as a linear relationship which decreases with increasing load factor. The effect is to assign less of the diversity benefits to high load factor customers, and more to the low load factor customers. As the system load factor increases under the Average and Excess Demand Method, the low load factor customer pays proportionately less than under the Non-Coincident Peak Method. Using the Average and Excess Method, a customer operating at a 100 percent load factor receives no diversity benefits, while a customer operating at the system load factor receives benefits equal to those assigned to the group under the NCP Method. Like the Non-Coincident Peak Method, the Average and Excess Method produces some degree of stability, since a small shift in system load patterns does not change the relationships. Proponents of the Average and Excess Method also argue that the method recognizes the differences in the types of production plants and that no customers are given a free ride for off-peak consumption.

One problem with the Average and Excess Method is that the capital costs of the mix of base load, intermediate, and peaking units are not accurately assigned. Like the Non-Coincident Peak Method, the Average and Excess Method does not consider the time element of the system load. Another problem of the Average and Excess Method is the use of the non-coincident peak to assign the excess portion of capacity costs. However, this problem can be alleviated by the use of the coincidental peak.

Average and Excess, Using Coincident Peaks: Like the traditional average and excess methodology, the system average load is allocated on the basis of the average demands of the classes. However, in this methodology, the system excess is allocated on the basis of the class excess, defined as the difference between the class average demand and the class contribution to the system peak (as opposed to the class non-coincident peak, as used in the traditional average and excess allocation). The off-peak classes have no excess demands, while the on-peak customers share in the reduction of excess demand resulting from the average demand allocation assigned to off-peak classes. The method avoids the problem of the traditional form of average and excess allocation which places an overproportionate burden on the off-peak user. In addition, the average and excess allocation using coincidental peaks "fits" the system's seasonal peak, as well as allocating to all customers some portion of the demand-related costs (since they all use the energy output of these facilities at some time).

2.6. CASE STUDY RESULTS

The principles which have just been discussed have recently been applied to various rail transit systems in their negotiations and interventions, pursuant to rate cases. Each of these cases are summarized in the following material.

2.6.1. Washington Metropolitan Area Transit Authority (WMATA)

In 1976, when Metro rail service began, electric service for D.C. operations was billed by the Potomac Electric Power Company (PEPCO) under Commercial/Industrial (C&S) Tariff. Pursuant to a negotiated agreement, PEPCO has developed and implemented a Separate Rapid Transit (RT) tariff for WMATA, based on an actual cost of service study and load data. A similar procedure was followed for WMATA's Metrorail operations in Maryland. By intervention in PEPCO's rate cases before D.C. and Maryland Public Service Commissions, WMATA has been successful in modifying the initial perpetual demand ratchet to a two (2) month billing demand ratchet. WMATA's active participation in PEPCO's rate proceedings has also resulted in less than the average authorized rate increases for Metro. In PEPCO's Virginia Service territory, Metro's negotiated separate RT rate has resulted in virtually no rate increase to Metro in the last two years. WMATA is currently negotiating with the Virginia Power Company for an appropriate rate based on cost of providing service.

Because of WMATA's opposition to time of use rate for Metro in the most recently concluded proceedings, the D.C. Public Service Commission has rejected PEPCO's proposal to charge Metro based on the time of use pricing structure.

WMATA is agressively pursuing load management and energy conservation strategies, e.g. acquisition of chopper control railcars, coasting, top speed reduction, monthly load and bill monitoring, and careful scheduling to supplement its rate intervention work[3].

2.6.2. Chicago Transit Authority (CTA)

Pursuant to a negotiated contract, CTA is served under a contract rate. Through active participation in Commonwealth Edison's rate proceedings, the CTA has been successful in the elimination of the ratcheted billing demand provision, reducing the point of supply charge, and convincing the Illinois Commerce Commission to authorize a less than average rate increase for the CTA, and direct implementation of seasonal differential in the energy component of the tariff.

2.6.3. SOUTHEASTERN PENNSYLVANIA TRANSPORTATION AUTHORITY (SEPTA/AMTRAK)

SEPTA has been trying to establish a separate rate based on cost of providing service to the railroads. In the three rate cases of Philadelphia Electric Company (PECO), the Pennsylvania Public Utility Commission rejected SEPTA's position. In the last base rate proceedings of PECO, the Commission directed PECO to develop a cost of service study and a separate rate for the railroads. In the rate proceeding of PECO, currently pending before the Pennsylvania Public Utilities Commission, PECO has proposed separate rates for SEPTA and AMTRAK based on the results of the Commission-directed cost of service study. In view of the lower cost of providing service to SEPTA and AMTRAK than PECO's industrial customers, PECO is now seeking less than an average rate increase for SEPTA and AMTRAK.

2.6.4. Metro - Dade County Miami

Pursuant to a negotiated agreement, Florida Power and Light Company (FPL) has developed and implemented a separate tariff for electric service to Metro. In approving one separate rate classification of Metro, the Florida Public Service Commission specifically relied upon one unique load, customer and cost causation characteristic of electric service to rapid rail transit systems. The tariff contains separately stated demand, energy, and customer charges. It has no billing demand ratchet provision. The ability of this tariff to accurately track demand and energy cost causation is likely to become an issue in the next rate proceedings of FPL.

TABLE 2-1

Serving Electric Utilities and Regulatory Jurisdictions

TRANSIT SYSTEM	ELECTRIC UTILITY	JURISDICTION
BART	Pacific Gas and Electric Company	California Public Utility Commission
CTA	Commonwealth Edison Company	Illinois Commerce Commission
GRCTA	Cleveland Electric Illuminating Company	Ohio Public Utilities Commission
MARTA	Georgia Power Company	Georgia Power Service Commission
MBTA	Boston Edison Company(77%)	Massachusetts Department of Public Utilities
	Massachusetts Electric Company(19%)	Massachusetts Department of Public Utilities
	Braintree Light Department(3%)	Massachusetts Department of Public Utilities
	Cambridge Electric Light Company(1%)	Massachusetts Department of Public Utilities
MIAMI	Florida Power and Light Company	Florida Public Utilities Commission
NYCTA	Power Authority State of New York	New York Public Service Commission Federal Energy Regulatory Commission Power Authority State of New York
	Consolidated Edison Company*	New York Public Service Commission
PATCO	Public Service Electric and Gas Company (68%)	New Jersey Board of Public Utilities
	Atlantic City Electric Company(17%)	New Jersey Board of Public Utilities
	SEPTA(15%)**	
PATH	Public Service Electric and Gas Company	New Jersey Board of Public Utilities
SEPTA	Philadelphia Electric Company	Pennsylvania Public Utilities Commission
WMATA	Potomac Electric Power Company	District of Columbia Public Service Commission Maryland Public Service Commission Virginia State Agency
	Virginia Electric Power Company	Virginia State Agency

* For the purpose of transmission only

** SEPTA resells power purchased from Philadelphia Electric Company to PATCO in the city of Philadelphia.

TABLE 2-2
GROUPING OF UTILITY RATE STRUCTURES FOR RAIL TRANSIT BY CLASSIFICATION

UTILITY/TRANSIT SYSTEM RATE STRUCTURE	CLASSIFICATION
Atlantic City Electric Co./PATCO	Separate
Boston Edison Co./MBTA	Modified High Voltage Industrial
Braintree Light Dept./MBTA	Modified High Voltage Industrial
Cambridge Electric Light Co./MBTA	Modified High Voltage Industrial
Cleveland Electric Illuminating Co./GRCTA	Modified High Voltage Industrial
Commonwealth Edison Co./CTA	Separate
Consolidated Edison Co./NYCTA	Modified High Voltage Industrial
Florida Power and Light Co./MIAMI	Separate
Georgia Power Co./MARTA	Modified High Voltage Industrial
Massachussets Electric Co./MBTA	Modified High Voltage Industrial
Pacific Gas and Electric Co./BART	Separate
Philadelphia Electric Co./SEPTA	Separate(pending)
Potomac Electric Power Co.(DC)/WMATA	Separate
Potomac Electric Power Co.(MD)/WMATA	Separate
Potomac Electric Power Co.(VA)/WMATA	Separate
Power Authority State of New York/NYCTA	Modified High Voltage Industrial
Public Service Electric and Gas Co./PATCO	Modified High Voltage Industrial
Public Service Electric and Gas Co./PATH	Modified High Voltage Industrial
Virginia Electric Power Co./WMATA	Government

TABLE 2-3
DEMAND ASPECTS OF RAIL TRANSIT POWER RATE STRUCTURES

ELECTRIC UTILITY/RAIL TRANSIT SYSTEM	DEMAND INTERVAL(min)	DEMAND CONSOLIDATION	MONTHLY DEMAND	DEMAND RATCHET
Atlantic City Electric Co./PATCO	15	coincdnt	max/mo	yes
Boston Edison Co./MBTA	30	noncoincdnt	max/mo	yes
Braintree Light Dept./MBTA	15	noncoincdnt	max/mo	yes
Cambridge Electric Light Co./MBTA	30	noncoincdnt	max/mo	yes
Cleveland Electric Illuminating Co./GRCTA	60	noncoincdnt	max/mo	no
Commonwealth Edison Co./CTA	60	coincdnt	(1)	yes
Florida Power and Light Co./MIAMI	30	coincdnt	max/mo	no
Georgia Power Co./MARTA	60	coincdnt	max/mo(5)	yes
Massachussets Electric Co./MBTA	15	noncoincdnt	max/mo	yes
Pacific Gas and Electric Co./BART	30	noncoincdnt	max/mo	yes
Philadelphia Electric Co./SEPTA	30	coincdnt(6)	max/mo	yes
Potomac Electric Power Co.(DC)/WMATA	30	coincdnt	max/mo	yes
Potomac Electric Power Co.(MD)/WMATA	30	coincdnt	max/mo	yes
Potomac Electric Power Co.(VA)/WMATA	30	coincdnt	max/mo	yes
Power Authority State of New York/NYCTA	30	coincdnt	max/mo	yes
Public Service Electric and Gas Co./PATCO	15	coincdnt	(2)	no
Public Service Electric and Gas Co./PATH	15	coincdnt	(3)	no
Virginia Electric Power Co./WMATA		(4)		

NOTES:

(1) Average of 3 highest demands / month
(2) Average of 4 highest daily maximum demands
(3) Average of 2 highest daily maximum demands or 75% of highest daily demand, whichever is higher
(4) No demand charge
(5) In months Jun - Sept max/mo, in months Oct - May 60%*max/mo
(6) SEPTA DC transit demand is coincident, the AC commuter lines served through Wayne Junction has a separate demand

TABLE 2-4
NONCOINCIDENT AND COINCIDENT PEAK POWER DEMAND
FOR TRACTION METERS ON THE WMATA RED LINE

METER NAME	VALUE (KW)	PEAK DEMAND TIME OF OCCURENCE
FARRAGUT NORTH	2399	17:00 - 17:30
GALLERY PLACE	2441	17:00 - 17:30
UNION STATION	1741	17:30 - 18:00
NEW YORK AVENUE	1831	16:45 - 17:15
RHODE ISLAND AVENUE	2200	17:45 - 18:15
BROOKLAND AVENUE	2961	17:45 - 18:15
NEW HAMPSHIRE AVENUE	2506	17:15 - 17:45
TAKOMA PARK	2252	17:30 - 18:00
SILVER SPRING	3542	9:15 - 9:45
TOTAL NON-COINCIDENT	21873	
COINCIDENT	16572	8:15 - 8:45

TABLE 2-5 VOLTAGE VARIATION INFLUENCES ON POWER

METER NAME	AVERAGE POWER (KW) NORMAL	 INCREASED VOLTAGE	% CHANGE
FARRAGUT NORTH	648	641	-1
GALLERY PLACE	232	206	-11
UNION STATION	259	187	-28
NEW YORK AVENUE	644	896	+39
RHODE ISLAND AVENUE	1236	1126	-9
BROOKLAND AVENUE	347	328	-5
NEW HAMPSHIRE AVENUE	85	81	-5
TAKOMA PARK	107	106	-1
SILVER SPRING	173	173	0
COINCIDENT	3731	3743	+.3

TABLE 2-6
DESCRIPTION OF TYPICAL TRANSIT DEMAND RATCHETS

ELECTRIC UTILITY/RAIL TRANSIT SYSTEM	DESCRIPTION OF RATCHET
Atlantic City Electric Co./PATCO	75% of average monthly demand in past 12 months, or 75% of original contract capacity, or 1000 kW, whichever is greatest
Boston Edison Co./MBTA	2/3 of highest monthly demand in past 11 months or 5000 kW
Braintree Light Dept./MBTA	80% of highest montly demand or 75 kW
Cambridge Electric Light Co./MBTA	95% of highest monthly demand less 1000 kW
Cleveland Electric Illuminating Co./GRCTA	None
Commonwealth Edison Co./CTA	Highest monthly demand in past 11 months
Florida Power and Light Co./MIAMI	None
Georgia Power Co./MARTA	Seasonally differentiated for preceding 11 months
	June - Sept:
	95% of highest monthly demand in previous summer months, or
	60% of highest monthly demand in previous winter months
	Oct - May:
	95% of highest monthly demand in previous summer months, or
	60% of highest monthly demand in previous winter months
	For all months no less than 50% of contract capacity, or 5000 kW, whichever is greater
Massachussets Electric Co./MBTA	80% of highest monthly demand in past 11 months
Pacific Gas and Electric Co./BART	12 month rolling average of monthly demand
Philadelphia Electric Co./SEPTA	Seasonally differentiated
	Oct - May:
	80% of highest monthly demand in previous June - Sept, or
	40% of maximum demand specified in contract
	June - Sept:
	None
Potomac Electric Power Co.(DC)/WMATA	Highest monthly demand in past two months
Potomac Electric Power Co.(MD)/WMATA	Highest monthly demand in past two months
Potomac Electric Power Co.(VA)/WMATA	Highest monthly demand in past two months
Power Authority State of New York/NYCTA	None
Public Service Electric and Gas Co./PATCO	None
Public Service Electric and Gas Co./PATH	None
Virginia Electric Power Co./WMATA	None

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TABLE 2-7 1983/1984/1985
ELECTRIC TRACTION ANNUAL POWER COSTS

TRANSIT AUTHORITY/UTILITY	1983 MWH	1984 MWH	1985 MWH	Total Costs 1983 $	1984 $	1985 $
AMTRAK						
PHILADELPHIA ELECTRIC COMPANY	388,910	423,337	444,874	24,769,810	30,496,875	32,769,963
PENNSYLVANIA POWER AND LIGHT COMPANY	24,643	22,489	20,707	1,375,093	1,420,391	1,639,306
BALTIMORE GAS AND ELECTRIC COMPANY	79,015	84,037	89,562	3,820,727	4,511,424	5,003,278
BART						
PACIFIC GAS & ELECTRIC COMPANY	232,301	238,667	243,592	14,070,796	15,512,278	19,048,644
CTA/ICG						
COMMONWEALTH EDISON COMPANY	352,318	365,964	395,940	21,282,681	23,907,024	25,860,801
MARTA						
GEORGIA POWER COMPANY	84,697	92,318	130,574	3,565,679	4,264,358	5,774,166
PATCO						
ATLANTIC CITY ELECTRIC COMPANY	5,275	5,372	5,340	325,682	357,064	362,576
RTA CLEVELAND						
THE CLEVELAND ELECTRIC ILLUMINATING COMPANY	35,115	37,213	40,149	2,748,312	2,772,567	3,044,796
SEPTA						
PHILADELPHIA ELECTRIC POWER CO.	246,918	267,361	273,583	16,163,168	19,345,569	21,562,024
WMATA						
POTOMAC ELECTRIC POWER COMPANY	270,144	302,102	358,776	17,513,247	19,933,577	24,668,671
VIRGINIA ELECTRIC POWER COMPANY (EXCLUDING FACILITIES CHARGE)	65,000	73,000	85,000	2,793,589	2,932,512	3,652,000

3. LOAD MANAGEMENT

3.1. INTRODUCTION

Load management is a term which refers to the control of the power demand component of the electric bill. Control can be accomplished in two ways. The first method is to provide an operational response to predicted values of high demand. The second method is to assure that high demand does not occur.

The first method involves monitoring, predicting and controlling peak power demand. It requires a monitoring system which can observe power demand in real time. The results of the observation are then used to predicted peak demand in the given demand interval. An appropriate operational response such as performance modification affecting traction power or reduction of support power is then initiated.

The second approach is assurance that demand will not exceed a given value. Various energy conservation strategies, which have already been discussed, do reduce peak demand. Since on most rail transit systems, peak demand will occur during peak transit operation (AM and PM rush hours), any strategy which reduces energy consumption during this period will reduce peak demand.

Another strategy which can be considered in the assurance category (rather than monitoring, prediction and control) is load leveling through energy storage. The basic strategy uses energy storage devices to absorb power during off-peak times and release power to the rail system during peak periods.

The cost effectiveness of load management strategies is particularly sensitive to the demand charge and method of computing billing demand. With no demand charge (just an energy charge), load management is not cost effective. A system which levels load through energy storage can hinge its cost-effectiveness on the energy rate of the power rate structure as well, since losses in the storage system use extra energy.

The reduction of peak power demand through load management may be negated by an increase in the demand rate as a response of the electric utilities, in order to maintain their rate of return on the investment allocated to the transit agency. In order to avoid this situation, the transit authority must maintain a knowledgable representation at rate case hearings.

3.2. POWER DEMAND MONITORING

Three forms of power demand monitoring are possible: real time, batch process and electric bill. Real time monitoring is most appropriate when a load managment system is installed to provide an operational response to predicted values of high demand. Batch process and electric bill monitoring are more appropriate in energy audits, where causes for high demand are investigated after the fact.

3.2.1. Real Time Monitoring

Power demand monitoring in real time means a system whose objective is to observe the demand trend over the early portions of the demand interval and predict the demand level for the interval. If it appears that the demand will exceed some set limit, a warning is issued so that precautions may be taken to reduce the demand. The precautions may be part of an automatic or manual response scenario.

A generic demand monitoring system is shown in Figure 3-1. The power consumption and supply voltage are monitored near each metering point. It may be possible, upon agreement with the electric utility, to use the potential and current transformers associated with their meters, to monitor demand. In the event that this is not possible, one or two potential and current transformers will be required per metering point. It is important that the monitoring point be as electrically close to the utility metering point as practical, since the monitoring system can also be used to determine billing components to verify electric bills and disagreements are more likely to be real if the condition of closeness is met. The ideal monitoring point is on the same feed point as the utility meter, with zero inpedance between the monitoring point and the electric meter. An even better situation is joint monitoring by both the utility and the transit authority.

The outputs of the potential and current transformers are fed to the inputs of a multi-element power transducer which produces output proportional to input. The output of one of the potential transformers is fed through a voltage transducer to produce a signal proportional to the supply voltage.

The outputs of the transducers are connected to the inputs of the remote transmitting units (RTU) (Figure 3-1) which convert them into frequency domain, multiplexed FM signals suitable for transmission over voice grade telephone lines. Each RTU transmits data along a single dedicated telephone line to the Central Office Equipment (COE) located at the data collection facility.

The COE separates and demodulates the two channels coming from the RTU. Each signal is processed and filtered to give the time average of its value (power or voltage) over some short, past time interval (typically 30-60 seconds). The COE contains a microprocessor that is programmed to sample power and voltage at each short time interval and pass the digitized results to the main Data Collection Computer (DCC), on command, via a serial link.

In the main DCC, the data from each meter are processed separately. The appropriate meter consolidation is made by summing the individual meter powers into appropriately consolidated meter curves. The slope and area under the power curve, together with other appropriate information, are evaluated over the early portion of the demand interval to predict the demand for the interval. The other appropriate information may be data from a train control computer, which allows a computation of car-miles to be made and ambient temperature. Both car-miles and ambient temperature can be used as peak demand predictors.

If a critical value of final demand is predicted, an alarm will sound, and those meters which are contributing the most to peak demand are displayed. In the case of an Automatic Train Control (ATC) system, a capability would exist for passing the warning to that unit for further processing. If the response would be initiated by a Support Power Control Unit, the warning would be passed to that unit. Since some experience will be required to develop some of the control algorithms, it is expected that initially the load would be shaved manually.

All of the data for a given demand interval is stored in a non-volatile memory to prevent loss in the event of a power fluctuation at the data collection facility. At the end of each day, data from memory are archived, so that historical information can be summoned for electric bill audits, rate case developments and investigation of unusual events.

A real time demand monitoring system will require proper maintenance. Many of the newer transit authorities now have parts of such systems which are not working because of lack of maintenance as well as poor reliability. Regular calibration of the transducers is a necessity.

The load monitoring system should be able to function under most common failure circumstances. Failure to predict demand levels can result in two problems:

1. Prediction of demand levels higher than actual, resulting in unnecessary reduction of transit system performance.
2. Prediction of demand levels lower than actual, meaning higher electric bills, which reduces the return on the investment in the load management system.

3.2.2. Batch Process Monitoring

Some Electric utilities record metering information on magnetic tape for subsequent processing into electric bills. In the case where real time monitoring is not economically viable and where metering information is recorded, batch process monitoring may be desirable. This type of monitoring consists of certain types of analyses of these metering records designed to understand the nature of peak demand.

The detailed analyses which are possible using batch monitoring of metering records are described in Sections 5.2 and 5.3 under the energy audit material. Batch process monitoring is actually a partial energy audit.

3.2.3. Electric Bill Monitoring

For those transit agencies which cannot use batch process monitoring because they do not have access to detailed metering records, monitoring of electric bills is possible. Because the value of peak demand, but not necessarily the time of peak demand, is usually presented on the electric bill, it is necessary only to keep records of car-miles/hour and any abnormal traction or support operation to determine how this peak demand was achieved.

Regression analysis using ambient temperature can be conducted, but only on the basis of average monthly temperature. Likewise, regression analysis to determine monthly energy consumption as it relates to car-miles/month can be carried out to determine the average monthly background power and the energy per car-mile.

3.3. POWER DEMAND REDUCTION OPPORTUNITIES

There are two classes of strategies which can be used to reduce power demand in response to a real time prediction of high power demand in a given demand interval. These strategy classes are traction performance modification and support power reduction. Both classes of strategies fall into the category of energy conservation as well.

Load leveling through energy storage can also be considered a power reduction strategy. It would not be used as part of a real time load management system (as a response to a real time prediction of high power demand), but on an everyday basis to keep the power demand component of the electric bill low.

3.3.1. Traction Performance Modification

Since peak traction power demand will occur at most of the traction power meters during peak transit operating times, traction performance modification would be a particularly useful response, especially when the train operating performance is critical to maintaining system capacity. Thus, under most conditions, when predictions of peak demand do not exceed the specified limit, traction performance would remain high in order to maintain system capacity. However, during the unusual circumstances of a prediction of demand exceeding the limit, transit capacity would be allowed to deteriorate to maintain the demand below some prescribed limit.

It is important to recognize that performance modification would only be initiated in response to high demand prediction, only when capacity reduction would be traded off for reduced peak demand. If capacity would not suffer under conditions of performance modification, then the strategy should always be used during the peak period, saving both demand and energy, without the need for monitoring.

Speed reduction, coasting and optimum performance modification could be used as the response strategy. If on of these strategies is being used during the off-peak transit operating periods, and not used during the peak periods because of the problem of transit capacity reduction, this strategy would be a good candidate. In some cases, selective application of the strategy would be adequate to limit power demand. For example, a small reduction of traction performance across the board as opposed to a larger reduction in certain regions of the system may be appropriate. In all cases, the criteria is always the minimum response to limit demand with the minimum effect on system capacity.

3.3.2. Support Power Reduction

Just as traction performance modification could mean reducing the traction power, support performance modification can result in support power reduction. If support power reduction is the choice of response to limit peak power demand, then the same logic applies as in the case of traction performance modification, namely, application of the strategy must be traded off for support function deterioration. Again, if no support function deterioration occurs as a result of the response, then the application of the strategy should be made a permanent part of normal operation, saving energy dollars without the need for real time load monitoring.

Since the reduction of the support function must occur during the peak transit operating time, very few support function responses can be accomodated. Generally, reduction of heating, air conditioning and ventilation make the best response candidates. One definite requirement is that operating the support function contributes enough to peak demand so that its reduction will bring peak demand under the required limit. The support functions of signalling, communications, train control, lighting, escalators and elevators are generally necessary during peak transit operating time.

As in the case of traction performance modification, the minimum support power reduction response to limit peak demand is all that is required.

3.3.3. Load Leveling Using Energy Storage

A power demand reduction opportunity, which does not require a real time, or any other kind of monitoring system is load leveling using energy storage devices. Recently, much attention has been given to such systems where the energy storage device is a large complex of batteries.

The energy storage devices are charged during off-peak periods, when power demand is low. They are used as power sources during the peak periods when power demand is high, to supplement power being provided by the electric utility. The concept is shown with the help of Figure 3-2. In the figure, a typical double-peaked daily load curve is shown. Charging of the energy storage devices occur during the off-peak periods. The utility power supply is supplemented from the storage devices during the peak period, "shaving" the load required to be served by the utility. Since energy storage devices are not 100% efficient, some energy is lost in the charge, discharge and natural decay of the energy storage device.

No deterioration of transit operating performance occurs because of peak load shaving using energy storage. Equipment is needed to store energy and to control charging and discharging. Additional energy use will be required because of the less than 100% efficiency of the energy storage devices and control apparatus.

3.4. COST AND BENEFIT

3.4.1. Load Management with Demand Monitoring

As used in this context, load management will involve power demand monitoring and the ability to respond to a projected high peak demand by changing operating procedures. The power demand monitoring may be on a real time basis, batch processing of metering information, and/or analysis of electric bills, while changing operating procedures could mean exercising performance modification or support power reduction strategies during the peak transit operating period. In each case there is a cost and benefit involved. The benefit is measured as the savings in the demand component of the electric bill. The costs will involve both an initial investment (capital) and recurring costs (operating).

3.4.1.1. Cost Information

Budgetary estimates were made for the three classes of monitoring methods. These estimates are presented in Table 3-1. The high voltage equipment mentioned in the Table are the current transformers (CT) and potential transformers (PT) needed to monitor the high voltage lines. If the electric utility allows the use of their CT and PT's, then the cost is much less as shown in Table 3-1.

Batch process and electric bill monitoring are much less expensive than real time monitoring.

3.4.1.2. Benefit

The main benefit achieved from load management is the reduction of the demand component of the electric bill. In a real time demand monitoring situation, the savings (and thus the payback period and return on investment) depends on how much time into the demand interval is allowed to pass before the response is initiated.

The load management concept of real time demand monitoring, prediction and control was investigated on both WMATA and MARTA rail systems. The same method of monitoring and prediction was utilized; namely, that illustrated conceptually in Figure 3-1. The demand control method used on each system is different.

Because the demand interval at WMATA is 30 minutes, peak demand reduction was estimated for reactions at 10, 15 and 20 minutes into the demand interval. The control reaction in this case was to initiate coasting.

Table 3-2 shows the basic cost components of the monitoring equipment. Table 3-3 lists the details of the energy cost savings affected by the load management system. Table 3-4 summarizes the cost/effectiveness of demand control, using coasting as the control option.

On the MARTA rail system, the control approach used for load management was different. In this case, shutting down the chiller load (support power reduction) would be the control reaction.

Because the demand interval at MARTA is one hour, operation of the control strategy was assumed to begin at 20, 30 and 40 minutes into the demand interval. The range over which load was shed was varied from 1000-5000kW.

Table 3-4 shows the basic cost components of the load monitoring and prediction portion of the system. Table 3-5 presents the cost/effectiveness of the load management system. Although payback periods are within acceptable limits at MARTA, it was difficult to find even 1000kW of load to shed under present operating conditions.

The biggest payback at MARTA occurs because of the summer ratchet, which means paying 95% of the summer demand charge all year round. Removal of the ratchet by the the Georgia Power Company could negate the effectiveness of the load management system.

3.4.2. Load Leveling Through Energy Storage

Load leveling systems which use energy storage are based on batteries as the storage device. Bechtal Inc. has done several studies in this area for transit as well as other applications. The concept is to charge a large battery system during off peak hours and use that energy during peak hours to reduce peak demand.

3.4.2.1. Cost Information

Load leveling system costs include both capital and operating costs. The capital costs represent the investment which includes procurement and installation of batteries and power control devices and installation of the plant. The initial investment is broken down into three categories: the cost of the batteries, the power converter and the balance of the plant. The initial investment is made in the initial year.

Since batteries have limited life, usually based on charge-discharge cycles and depth of discharge, it is necessary to replace them periodically. Batteries are usually accredited with an eight year lifetime in this type of service.

Investments for each of the three parts are usually determined by the formula

$$C = C_B + C_C + C_P$$

where C is the total cost,

$$C_B = C_{B0} + C_{B1} \bullet (KWH)$$

is the battery cost. The converter cost is

$$C_C = C_{C0} + C_{C1} (KW)$$

The fixed plant cost is

$$C_P = C_{P0} + C_{P1} (KWH)$$

Table 3-7 provides a listing of these cost coefficients[2] for Lead-Acid and Zinc-Chloride Batteries. These costs were obtained by Bechtel through discussions with manufacturers.

The $400K fixed cost in the converter unit covers anticipated development and engineering costs. The $100K in fixed plant costs purchases a computerized control unit which automatically puts the system on line at appropriate times.

The operating savings of a load leveling system based on battery energy storage is the reduction of the demand component of the electric bill less the operating and maintenance expenses of the system.

The reduction in peak demand related to peak load shaving may not be directly translatable to reduction in the demand component of the electric bill. Existence of ratchets will generally complicate the estimate.

3.4.2.2. Benefit

The benefit of peak load shaving is reduction of the demand charge which is offset by additional energy cost incurred because of load leveling system inefficiency and auxiliary power required to operate the system.

Table 3-8 presents the energy cost savings, payback period and annual cas flow achievable for different battery system sizes.

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[2] "Economic Analysis of Storage Battery Systems for Demand-Peak Shaving"

No ratchet effects have been included. Ratchets tend to make payback periods longer. Payback periods of less than three years are difficult to achieve unless demand charges are very high.

3.5. LOAD MANAGEMENT AND THE POWER RATE STRUCTURE

The cost-effectiveness of load management systems depends upon the demand charge of the electric utilities. If the load management system contains an energy storage device such as in a peak load shaving operation, then the energy charge will also play a part in the cost-effectiveness.

The demand charge depends upon the billing demand and the demand rate. As was mentioned previously, the billing demand is usually a formula which is based on several basic elements including the demand interval, the method of demand consolidation, the monthly demand and the ratchet. A change in any of the elements of billing demand or the demand rate will change the payback period of the load management system.

The uncertainty in the future of the demand charges by the electric utility presents a long term risk in the investment of a load management system. Since the basic objective for the investment into such a system is to save money on the electric bill, a short payback period is appropriate. A payback period no longer than three years would mean that electric bill savings would be realized in the fourth year after the system began operation.

Reduction of peak demand will shift the burden of rate increase toward other customer classes serviced by the utility. The degree to which this shift occurs depends on many factors, in addition to the degree of peak demand reduction attainable.

1. The fraction of peak demand attributable to the transit system as a member of his customer class.

2. The fraction of peak demand attributable to the customer class of which the transit system is a member.

3. The relation of the time of peak demand of the agency to utility peak demand.

4. Facilities set aside for exclusive use of transit.

5. The ratio of peak demand to energy plus customer components in cost categories.

One strong argument for initiating load management is that other customer classes of the utility will manage their loads, shifting the cost burden to the transit system. Under these circumstances, load management would become a purely defensive measure.

Load management is particularly useful, without any repercussions from the utility in the form of a rate increase, whenever service (car-miles/hour) is increased. If demand can be held at the preexpanded service level, the utility has no basis for initiating a rate increase.

The cost effectiveness of load management is dependent on the ratio of the demand/energy use component of the electric bill. As the electric bill becomes more demand determined, load management is more desirable.

TABLE 3-1 POWER DEMAND MONITORING COST COMPONENTS (1986 DOLLARS)

REAL TIME MONITORING

INITIAL INVESTMENT	
	$28,250/metering point ($13,450/metering point less high voltage equipment)
RECURRING COST	
Telephone Lines	$40/month/metering point
Monitoring Technician (Independent of number of meters monitored)	$65,000/man-year

The initial investment is based on a sixteen metering point system:

Hardware Cost (Less High Voltage Equipment)	$123,000
High Voltage Equipment	$237,000
Engineering Labor (1 man year)	$42,000
Total	$452,000

BATCH PROCESS MONITORING

INITIAL INVESTMENT	
Computer Programs	$30,000
RECURRING COST	
Computer Time	$700/month
Engineering Time (1/4 MY/Y)	$1920/month

ELECTRIC BILL MONITORING

NO INITIAL INVESTMENT	
RECURRING COST	
Engineering Time (1/10 MY/Y)	$770/month

TABLE 3-2 COST OF DEMAND MONITORING EQUIPMENT FOR WMATA (1983 DOLLARS)

INITIAL INVESTMENT (72 METERING POINTS) ($M)	
With high voltage equipment *	1.77
Without high voltage equipment *	0.84
Coasting Modification to fleet **	0.04
RECURRING COST ($K/month)	
Telephone lines ***	2.3
Monitoring Technician	4.2

* Based on initial investment of $24,560/metering point ($11,690 for monitor plus high voltage potential and current transformers)

** Initial coasting investment of $32,000 in 1981 escalated to 1983 dollars.

*** Estimated at $32/month/metering point.

TABLE 3-3
ENERGY COST SAVINGS OF LOAD MANAGEMENT ON WMATA USING COASTING (1983 DOLLARS)

	DEMAND RATE	BASE DEMAND SAVINGS (KW)	MONTHLY DEMAND SAVINGS(KW) COASTING INITIATED AFTER: 10 MIN	15 MIN	20 MIN	ENERGY COST SAVINGS $K/MONTH 10 MIN	15 MIN	20 MIN
PEPCO DC	11.70	2300	1533	1150	767	17.9	13.5	9.0
PEPCO MD	9.85	670	447	335	223	4.4	3.3	2.2
PEPCO VA	7.85	150	100	75	50	0.8	0.6	0.4
TOTAL		3120	2080	1560	1040	23.1	17.3	11.6

TABLE 3-4
COST/EFFECTIVENESS OF LOAD MANAGEMENT AT WMATA (1983 DOLLARS)

	WITH*	WITHOUT*
INITIAL INVESTMENT($M)	1.81	0.84
RECURRING MONTHLY COST($K)	6.5	6.5
MONTHLY SAVINGS($K)		
10 MIN**	23.1	23.1
15 MIN	17.3	17.3
20 MIN	11.6	11.6
PAYBACK PERIOD(YRS) +		
10 MIN**	6.2	3.4
15 MIN	8.2	4.8
20 MIN	12.7	8.2

* High Voltage Equipment
** Time of demand interval when coasting is initialized
+ Based on 12%/year cost of money

TABLE 3-5 COST DETAILS OF REAL TIME POWER DEMAND MONITORING SYSTEM ON MARTA (1985 DOLLARS)

A. Initial Cost	
Hardware Cost	$191K
High Voltage Equipment	$368K
Engineering Labor (1 MY $90K)	$90K
Total w/o high voltage equipment	$281K
w high voltage equipment	$649K
B. Recurring Cost	
Telephone Lines $38/Month/Mtrg Pnt)	$11.9K
Technician ($60K/yr)	$60.0K
TOTAL	$71.9K

TABLE 3-6
COST/EFFECTIVENESS OF LOAD MANAGEMENT ON MARTA (1985 DOLLARS)

	WITH*	WITHOUT*			
INITIAL COST($K)	281.0	649.0			
RECURRING COST($K/MONTH)	6.0	6.0			
DEMAND RATE($/KW)			11.62		
BASE DEMAND LEVEL(KW)	1000	2000	3000	4000	5000
DEMAND SAVINGS(KW)					
20 MIN**	667	1333	2000	2667	3333
30 MIN	500	1000	1500	2000	2500
40 MIN	333	667	1000	1333	1667
DEMAND SAVINGS($K/MONTH)					
20 MIN**	7.7	15.5	23.2	31.0	38.7
30 MIN	5.8	11.6	17.4	23.2	29.1
40 MIN	3.9	7.7	11.6	15.5	19.4
PAYBACK PERIOD(YRS)(WITHOUT HV EQUIPENT)+					
20 MIN**	NP	2.2	1.3	0.9	0.7
30 MIN	NP	3.4	1.8	1.3	1.0
40 MIN	NP	NP	3.4	2.2	1.6
PAYBACK PERIOD(YRS)(WITH HV EQUIPMENT)+					
20 MIN**	NP	4.4	2.7	2.0	1.5
30 MIN	NP	NP	3.8	2.7	2.1
40 MIN	NP	NP	NP	4.4	3.3

* High Voltage Equipment
** Time into Demand Interval for Load Shedding
\+ Cost of money at 12%/year
NP No Payback

TABLE 3-7 COST COEFFICIENTS FOR
BATTERY STORAGE SYSTEM (1985 DOLLARS)

SYSTEM		BATTERY COST		CONVERTER COST		PLANT COST	
TYPE	SIZE (MWh)	FIXED C_{B0} ($K)	UNIT C_{B1} ($/KWH)	FIXED C_{C0} ($K)	UNIT C_{C1} ($/KW)	FIXED C_P ($K)	UNIT C_{P0} ($/KWH)
Lead-Acid	1.00	0.00	150.20	400.00	370.00	100.00	295.20
Lead Acid	2.00	0.00	146.10	400.00	250.45	100.00	187.85
Lead Acid	4.00	0.00	142.00	400.00	198.30	100.00	155.83
Lead Acid	6.00	0.00	139.62	400.00	196.48	100.00	146.98
Lead Acid	8.00	0.00	137.94	400.00	168.63	100.00	135.84
Zinc-Chloride	6.00	0.00	581.45	400.00	196.48	100.00	262.70

Table 3-8 Summary of Peak Load Shaving Effectiveness

System size MW	Initial Invsmnt K$	Total Capital Invsmnt K$	Demand Charge $/KW	Payout Time YRS	Avg. annual Net Savings K$	Avg. annual Cash Flow K$
2.	1,703	2,285	5.00	>25	-	-69.
			10.00	>25	-	-7.
(1 MW shaved)			15.00	13.21	146.	55.
			20.00	9.25	209.	117.
4.	2,502	3,628	5.00	>25	-	-78.
			10.00	15.68	191.	46.
(2 MW shaved)			15.00	7.85	315.	170.
			20.00	5.64	439.	294.
6.	3,300	4,970	5.00	>25	-	-87.
			10.00	13.52	298.	99.
(3 MW shaved)			15.00	6.77	484.	285.
			20.00	4.89	670.	471.
10.	4,896	7,655	5.00	>25	-	-105.
			10.00	11.92	511.	205.
(5 MW shaved)			15.00	5.93	821.	515.
			20.00	4.31	1131.	825.
14.	6,492	10,340	5.00	>25	-	-124.
			7.50	19.73	507.	94.
			10.00	11.26	724	311.
(7 MW shaved)			15.00	5.58	1159.	745.
			20.00	4.07	1593.	1179.

Notes: Assumed 2 cycles per day
each cycle 2 hours long.
Therefore, for example, if the demand is shaved by 1 MW, then the battery delivers 2 MWH per cycle, and this has to be the size of the battery/system.

Have taken 2 cycles per day, 20 days per month every month of the year, for a total of 480 cycles per year.

POWER DEMAND MONITORING

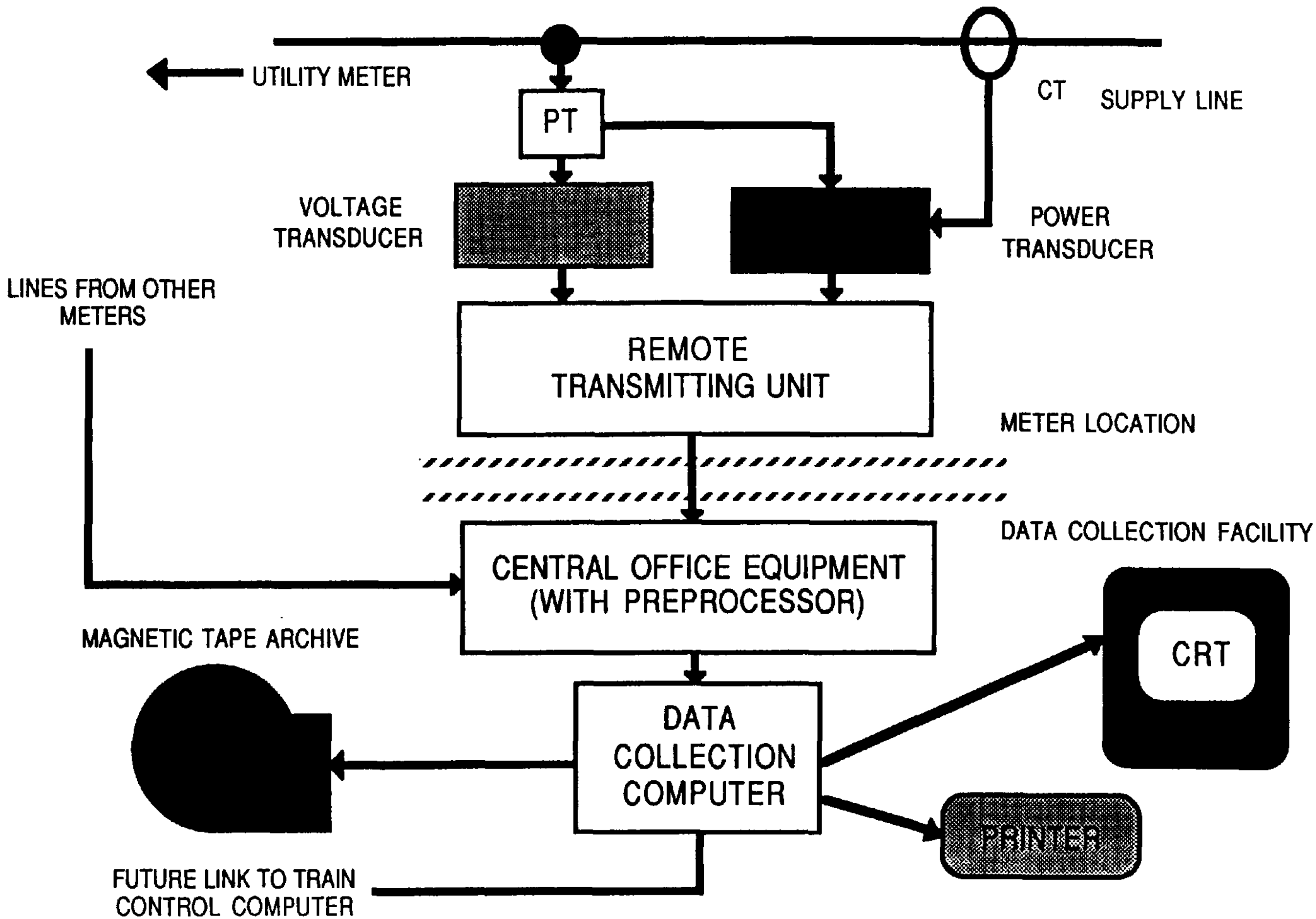


FIGURE 3-1

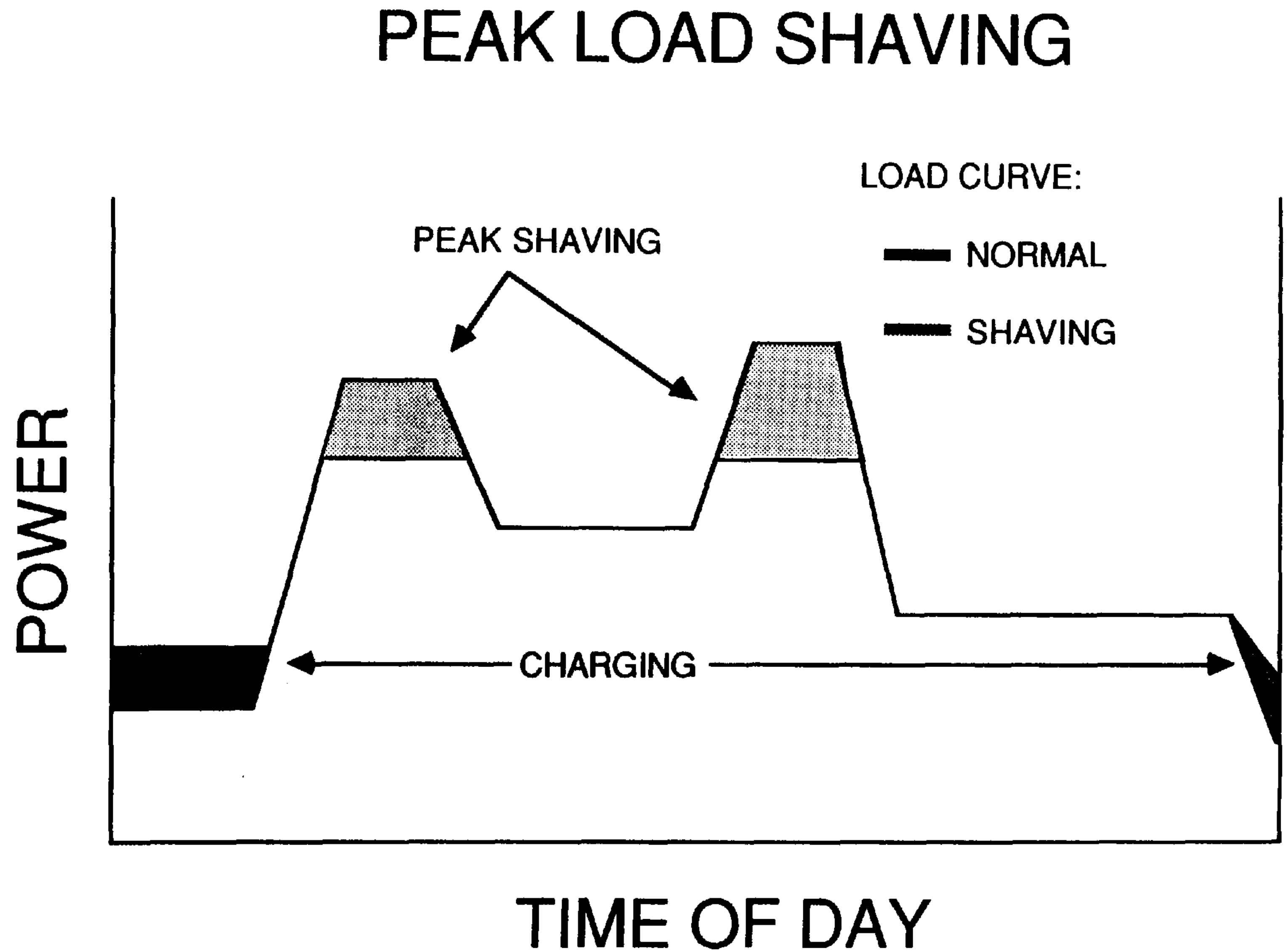

PEAK LOAD SHAVING
LOAD CURVE:
PEAK SHAVING
NORMAL
SHAVING
POWER
CHARGING
TIME OF DAY

FIGURE 3-2

4. RAIL TRACTION ENERGY MANAGEMENT MODEL

4.1. INTRODUCTION

The rail transit energy management model (EMM) is a group of computer programs which can be used to study the traction power costs on rail transit systems and electrified commuter railroads.The EMM consists of two major simulators and several computer programs which service these simulators both on the input and output side. The two major simulators are the Train Performance Simulator (TPS) and the Electric Network Simulator (ENS). Both work together to simulate schedule performance and energy consumption under normal and abnormal operation and under the application of energy conservation strategies to the transit system. Although originally designed for application to electric powered transportation systems, a fuel consumption routine has been added to the TPS and allows simulation of energy consumption on non-electrified systems.

The next section presents a brief description of the EMM and its capabilities. The next two sections describe the TPS and ENS, respectively, their input requirements and output capabilities, and the methodologies used in simulation.

4.2. BRIEF DESCRIPTION OF THE ENERGY MANAGEMENT MODEL

4.2.1. Objectives

The package of computer programs which constitute the EMM has been designed to meet certain functional and architectural objectives.

4.2.1.1. Functional Objectives

The functional objectives define what the package is expected to accomplish. They are:

1. To realistically simulate power and energy use of existing and future electric powered transportation systems.

2. To separate the system's energy consumption into its important end uses and to provide the means to identify cause-effect relationships between the end uses and equipment design and operating practices.

3. To provide the means to develop, refine and test energy conservation strategies before they are tested and implemented on the real system.

4.2.1.2. Architectural Objectives

The architectural objectives define how the package is built. They are:

1. To be modular at all levels so that any module can be developed, tested and verified, independently and can be inserted or replaced in the package without a major retrofit, which affects the package integrity.

2. To have a maximum of hardware independence and to be written in a widely used language. (In practice, no large package can come close to being machine independent, but steps can be taken to minimize the effort required to move the package from one computer to another.)

3. To have enough flexibility in structure to accommodate new models, new energy conserving strategies and new technology.

4.2.2. Approach

The approach to simulating an electric powered transportation system; i.e., to determine its schedule performance, power flows and energy consumption, and other pertinent information, involves the following steps:

1. For each train in the system, assemble raw data on its physical and performance characteristics, the route and schedule it is to follow, and the physical characteristics of the route it is to follow.

2. Assemble raw data on the electrical configuration and component characteristics of the network supplying power to the trains.

3. The raw data assembled in steps 1 and 2 are processed and put into a form which is acceptable to the simulators.

4. Treating each train separately, calculate tables of its speed, position and power draw against time (hereafter called a power profile); and, from these tables, assemble a master table, which for selected time instants which span the period under investigation, contains information on the locations and electric power draw of every train on the system.

5. At each of the selected time instants, calculate the voltages, currents and real and reactive power flows for all salient points in the electrical network.

6. Integrate the power flows over all of the time instants in the simulation period to give energies and wattless flow.

In steps 1-6, the transportation system's energy consumption is synthesized from its end uses (examples of these end uses are energy consumed by on-board auxiliaries, losses in propulsion equipment, third rail losses, etc.). Thus, the simulation provides a means to identify the end uses, calculate the overall consumption and test sensitivities of both end uses and consumption to changes in design and operation of the system.

The EMM is designed to be run by competent engineers who have electrical, computer and transportation system experience. Recognizing this, allowances are made for knowledgeable professionals to interact with the package at two levels:

1. Through identification and creation of strategies that are systematic enough to be automated and consequently can become permanent package features; and,

2. Through direct interaction with the package in a time shared mode so that knowledgeable trial-and-error can be used to find solutions.

The overall package is assembled from the principal modules shown in Figure 1. Each of the programs within the modules is an independent entity developed, tested, verified and used, separately. All programs are written exclusively in FORTRAN 77. Each principal program is modular in structure to facilitate continued development, maintenance and upgrading. At every level, each module is defined with respect to its function, input and output.

4.2.3. Principal Modules

The EMM consists of five principal components: a Train Performance Simulator, an Electric Network Simulator, an Energy Cost Module, an input File Construction Module, and a File Manipulation Module. The deployment of the principal and support components of the package is shown in the figure.

4.2.3.1. Train Performance Simulator (TPS)

The TPS accepts as input, vehicle parameters such as weight, propulsion system characteristics (tractive effort and efficiencies vs. speed and tractive effort), train resistance, numbers and types of vehicles in train, auxiliary electric loads, and passenger load factors; wayside parameters such as power distribution system type (DC, single phase AC or three phase AC), voltage and right-of-way profile (grade, curve and speed restriction as a function of location); and system operational characteristics such as acceleration and braking rates, maximum speed and station dwell times. The program simulates the operation of a single train under the input conditions. Outputs include power profiles (real power for DC distribution and real and reactive power for AC distribution as a function of location). The program will accept trains with dynamic braking capability and the energy can be fed into storage devices aboard the vehicle (batteries or flywheels), dissipative devices aboard the vehicle (resistors), or other trains external to the train (regeneration) using the power distribution system.

Various forms of coasting (running trains with a power off condition) can be accommodated.

There are many other programs that can perform some or all of these functions. This program is unusual, not in terms of its functions, but its structure. First, it is modular and therefore can continue to easily grow. For instance, if new propulsion system models, or more accurate train resistance formulae are needed, the existing modules in which these are contained can easily be augmented or replaced.

4.2.3.2. Electric Network Simulator (ENS)

This program accepts as input single train power and time profiles as a function of location along the right-of-way, timetables for movement of multiple trains, power rail, catenary or trolley impedances, running rail impedances, substation locations and characteristics, operating voltage both nominal, maximum and minimum, characteristics of the distribution network, the substations, and metering point locations. This program simulates the movement of the trains by taking snapshots of the entire system at fixed intervals of time. The calculated output of this program is a complete electrical picture of the system including power flows, voltages, currents and losses at all salient points. In particular, power through metering points (forward and reverse), power distribution system and substation losses are computed. Capability for regeneration to other trains and/or through regenerative substations (even though metering points) is also included.

4.2.3.3. Energy Cost Module (ECM)

The Energy Cost Module (ECM) consists of two computer programs which use the output of the ENS to compute such things as power demand at meters, coincident power demand and energy consumption. It does not compute energy costs directly, but rather provides the basis for a simple manual computation of these costs. This approach was taken since power rate structures vary greatly among transportation authorities.

The two programs which constitute the ECM are the Appended and Consolidated Load Curve (APL) program and the Energy-Demand Consolidation (EDC) program.

The APL uses as input, meter load curves which have been generated by the ENS. It appends these load curves and consolidates them by only selecting those meters which are designated for consolidation (i.e., they belong to the same power company or some other reason for consolidation). The time span of the resulting appended coincident load curve is the union of the set of time spans from the individual load curves.

The EDC uses as input a set of coincident meter load curves and summarizes the meter readings over the stated demand intervals.

4.2.3.4. File Construction Module (FILCMD)

The FILCMD is a series of computer programs, which interact with the user to transform raw transit system and vehicle data to files which are acceptable input to the ENS and TPS. A brief description of each of these programs is given here.

AMF - Current Position File Construction ¦ The positions along the track where instantaneous and RMS third rail or trolley current(amps) is to be calculated and displayed as output from ENS are specified using this program. The resulting file is used as input to the ENS. It requires a successive entry input file created by the user, either manually, or by using the program SUC, to be described later.

CLF - Control File Construction ¦ Control and system type parameters, such as displays desired, train movement direction, maximum speed, acceleration and deceleration, and coasting parameters are developed using this process. The resulting file is used as input to the TPS.

NFC - Network File Construction ¦ The electric network, in which the transit system operates and from which it obtains power, is specified using this program. The resulting file is used as input to the ENS.

OPF - Operating File Construction ¦ This program constructs the operating file, which is used as input to the ENS. The file contains the time range over which the simulation is to run, and the time interval between snapshots of the power flows in the electric network.

STF - Station File Construction ¦ This program constructs the station file, from an input file which was created by the user, either manually or using the program SUC, described next. The station file contains the position and names of the passenger stations and stops as well as dwell times and expected passenger loadings.

SUC - General File Construction ¦ This program is a general file construction process which uses an input format file to prompt the user to create a file consisting of records whose lengths are one entry. The successive records in the file follow the format and may be repeated indefinitely. The resulting output is an intermediate file which is used as input to other FILCMD programs, which create the final ENS and TPS acceptable files. Intermediate files created in this manner are station, grade, curve, speed restrictions, route and current position.

TLF - Train Location File Construction ¦ The specification of the method (headway, position, timetable) for locating trains on the electric network and the subsequent construction of the train location file is achieved using this program. The resulting file is used as input to ENS.

TNF - Train File Construction ¦ This process is used to create the train file, which is input to the TPS. The TNF uses a propulsion model which calls on actual manufacturer's data to determine propulsion system efficiencies in power and brake modes. It can accommodate cam or chopper control with series or separately excited motors.

TRF - Profile Construction ¦ This program is used to create a file in a format acceptable as input to TPS, given an intermediate file of successive entry records, containing the data. The intermediate file is either generated manually or by using the program SUC.

4.2.3.5. File Manipulation Module

There are several utility programs which manipulate the output files from the ENS and TPS. These programs are described below.

CMB - Power Profile Appender ¦ This process appends several power profiles, which are output from the TPS and combines them into one power profile. This utility is exercised when it is convenient to run train performance on several connected track segments separately, and later combine the results for input into the ENS or other programs.

EXP - Load Curve Projector ¦ This process is useful to expand meter load curve cycles over time, when it is known that the original load curve is cyclic in nature. Such would be the case for a transit system operating with constant headway between identical trains.

PAV - Power Profile Averager ¦ This program develops an average power profile given two or more power profiles(TPS Output) from different trains. For example, a train made up of mixed chopper and cam control cars with identical performance characteristics could be simulated by running two trains, one of them with all chopper cars and the other with all cam control cars. Using PAV, the mixed train power profile is developed from the other two power profiles.

4.3. TRAIN PERFORMANCE SIMULATOR

The TPS is a program which accepts input data describing the characteristics of a train and information about stations, grade, curvature and speed restriction profiles of a corridor. These data are used to simulate the motion of the train along the corridor in order to obtain the trajectory of the train (speed and time vs. distance along the corridor) as well as its power profile in a format acceptable to the ENS.

4.3.1. Input

Input data for the TPS are divided into four major categories: file definition, simulation or control parameters, train data and right of way data. The first category includes the names of files to be used as input data to the TPS and the names of files for output data. The second category includes selections for output display, input/output controls and general transportation system parameters such as acceleration, deceleration, top speed and starting position. The third category includes train makeup, on-board energy storage capability, propulsion and braking characteristics. The fourth category includes station mileposts, dwell times and load factors, speed restrictions, grade and alignment profiles and routing information.

4.3.1.1. File Definition

The File of Filenames contains the names of the input and output files which will be used in the TPS run.

The first seven records are input filenames: The first record contains the name of the control file which contains the system and control parameters. The second record is the name of the train file, which contains information on the makeup of the train, including the propulsion and braking system. The next five records contain the names of the station, grade, curve, speed restriction and route files, all of which comprise the corridor data.

The last three records of the File of Filenames contain the output filenames: The first record contains the name of the power profiles; the second, the name of the detailed output file and; the third, the name of the summary output file.

The user has the option of entering the names of these ten files, manually, in which case the File of Filenames would not be required as input.

4.3.1.2. Simulation and Control Parameters

The simulation and train control parameters are set in the Control File. Five graph choices and ten tabular displays for detailed output can be chosen from thirty nine parameters. Train control parameters are also set in this file. These include acceleration and deceleration rates, maximum speed, coasting and direction of train movement.

4.3.1.3. Train Data

Most of the data relative to the characteristics reside in the Train File. The variables are grouped in four sections:

- Section 1 provides weight and dimensional type information, train resistance data and control information which key other inputs for the Train File.

- Section 2 provides data on any on board storage devices. These data include maximum input and output power, maximum and minimum energy storage, decay rates, and input and output efficiencies.

- Section 3 contains the information on converting mechanical power at the rail to electric power at the third rail, catenary or trolley or to fuel consumption. One of four choices can be made:

    - Use of an internal electric propulsion model

    - Use of efficiency arrays in both power and electrical braking, in which the efficiencies are a function of tractive or electrical braking effort and speed.

    - Use of direct conversion of rail horsepower to fuel rate.

    - Use of fuel consumption curves.

- Section 4 contains the maximum tractive, electrical braking and mechanical braking curves as a function of speed. The nominal tractive and braking efforts are set in the Control File.

4.3.1.4. Right of Way Data

The description of the corridor is shared among the Station, Grade, Curve, Speed Restriction, and Route Files, which are read by the TPS in that order. In each file, an integer variable indicates the number of records in the file. The principal purpose of routing is to distinguish between tracks on different routes that a train may take through a complex network.

4.3.2. The Main Program Description

The TPS uses discreet, adjustable time steps to integrate the equations of motion to obtain speed and position as a function of time. Electric power consumption is determined using propulsion system models which outputs electric power as a function of tractive and dynamic braking effort and speed. The models do not reside within the TPS, but the results of the models are part of the train file, which is input data. Using this method is efficient, since the TPS is not burdened with the recalculations necessary with a sophisticated propulsion model for every tractive effort-speed point in the trajectory.

A simplified flow diagram for the TPS is shown in Figure 2. In addition to the usual bookkeeping in such programs, the core of the program is contained in the forward and backward trajectory calculations. In the forward calculations, the equations of motion are integrated in the direction of positive time flow, while in the backward calculations, they are integrated in the direction of negative time flow. An example of the trajectory calculations is illustrated with the help of Figure 3.

To move from point A to B in the figure, the following steps would be taken if a minimum time trajectory were taken:

1. A forward trajectory would be developed from A to C by using maximum acceleration followed by maintaining the speed determined by the speed limit until the lower speed limit at C was encountered.

2. A backward trajectory calculation would then follow using maximum deceleration from C to F using negative time steps. The point F is determined by the intersection of the backward trajectory with the forward trajectory.

3. A forward trajectory is continued from to C to D, the point at which a higher speed limit is encountered.

4. A forward trajectory is developed from D to B by using maximum acceleration until the lower speed limit at B was encountered.

5. A backward trajectory using maximum deceleration from B to E using negative time steps. The point E is determined by the intersection of the backward trajectory with the forward trajectory.

6. Adjustments are made in the time increments to bring the forward and backward trajectories into synchronization.

Train length is accounted for in obeying speed restrictions; namely, the speed of the train is less than or equal to the speed limit when the head of the train enters the restricted zone and the same condition is true when the tail leaves the zone.

Train resistance is computed from data in the train file. The algorithms used in these calculations allow measured values to be closely approximated.

4.3.3. Output

There are three separately selectable outputs from the TPS. These are the Detailed, Summary, and Power Profile outputs.

4.3.3.1. Detailed Output

The Detailed Output has six parts. The first part summarizes the input data concerning the train. Information concerning the number of vehicles, (powered and unpowered), vehicle empty and full weights as well as passenger load factor to start and train weight; number of motors, vehicle lengths and cross sectional areas; wheel diameter, and operating voltage are printed out when selected. Four character plots are also supplied. These graphs show acceleration versus speed and braking force (both electrical and mechanical) versus speed.

The second part lists the track profile and station information. All grades, curves, speed restrictions, and route segments are displayed versus distance. Station names, mileposts, dwell times and passenger load factors are all displayed.

The third part allows the user to select up to ten variables to be printed out at selected time increments during the calculation. There are thirty-nine variables from which to choose including speed, distance, acceleration, all of the various power variables, and all of the associated energy variables. Time is always displayed.

The fourth part allows the user to specify up to five variables to be plotted against distance in a character plot. These five variables can be selected from the thirty-nine mentioned above. The plot is completely self-scaling; however, the user may specify the horizontal scale.

The fifth part summarizes the on-board energy storage information.

The program summarizes the energy usage and power demand of the train for the entire run in the Detailed Output. Some information concerning the train make-up is repeated for clarity. Overall figures on kilowatt hours per car mile and watt hours per trailing ton mile are computed and displayed. Total distance, run time, average speed, and other summary information is also displayed. The actual energy consumption is also displayed as are all of its constituent parts such as energy going to rolling friction losses, etc. An energy flow diagram can be developed from this section of the output which graphically shows how much energy is lost to the environment and where these losses occur.

4.3.3.2. Summary Output

The Summary Output provides a station-by-station summary of the run. The station-to-station names, distances, time(including dwell), average speeds, energies and energies per car mile are displayed as well as a summary of these same quantities for the entire run.

4.3.3.3. Power Profile Output

The program creates a Power Profile containing information for the ENS. This file lists the train position, speed, routing real and reactive power demand, acceleration and tractive effort as a function of time. The user specifies the time increment between successive points in this output.

4.4. METHODOLOGY

The TPS generates a speed, distance, routing, real and reactive power table as a function of time. It uses discrete time steps to integrate the equations of motion. Speed and distance are determined by integrating the equation of motion. Real and reactive power are determined by either using a propulsion system model to determine them as a function of tractive effort and speed of the propulsion unit or by converting mechanical power at the rail to real and reactive electrical power at the line using conversion efficiencies which are also functions of tractive effort and speed.

4.4.1. Equations of Motion

The equation of motions are shown in Figure 4. The grade and curve resistance are also shown in the same figure.

The train resistance used in the computation follows the Davis type formulae. The actual formulae used are shown in Figure 4. Selection of the coefficients allow a close approximation to measured values.

The acceleration term in Figure 4 is written in the form:

$$M_E * dv/dt = 100. * W * a \qquad \text{where:}$$

a is the acceleration(mphps)

W is the weight(tons).

This method of expressing the acceleration term includes an effect of approximately 10% for equivalent rotational weight. Changes in equivalent rotational weight can easily be made with a text editor in the program itself.

4.4.1.1. Integration Formulae

Acceleration is integrated using Euler's Method to find speed

$$V_{n+1} = V_n + dt * A_n$$

at each step in time, in the forward calculation. In the backward calculation a reverse Euler's Method is employed as the index is being decremented (for negative time step).

$$V_n = V_{n+1} - dt * A_{n+1}$$

The trapezoidal rule is employed to integrate speed and determine distance. This method yields identical results for the forward and backward calculations though the form is slightly different.

$$S_{n+1} = S_n + dt * (V_n + V_{n+1})/2 \qquad \text{Forward}$$

$$S_n = S_{n+1} - dt * (V_n + V_{n+1})/2 \qquad \text{Backward}$$

When calculating energy from the instantaneous values of power, Euler's Method is again used.

$$E_{n+1} = E_n + dt * P_n$$

There is no need to have a forward and a backward calculation at this point since the entire integration is in the forward direction using Euler's Method.

4.4.2. Real and Reactive Power Estimates

It has been found by experience that a better way to input the propulsion system is to use propulsion efficiency and power factor curves for traction and electrical braking. Both efficiency and power factor are functions of both tractive effort and speed. This method is advantageous in that it allows the model calculations to be done before running the TPS, which is efficient in terms of running time. A simple linear interpolation scheme is used to obtain the actual efficiency and power factor (for AC distribution systems) in the power mode and the efficiency in the electrical braking mode.

4.5. ELECTRIC NETWORK SIMULATOR

The Electric Network Simulator (ENS) is a computer program which determines the overall power flow in an electrified transportation system under the dynamic conditions of train movement.

4.5.1. Input

Input data for the ENS are divided into six basic areas: file definition, electric network description, operating parameters, train location, current calculation designation, and train performance power profiles.

The first area includes the names of files to be used as input data to the ENS and the names of files to capture the generated output. The second area provides a description of the electric network which is feeding the moving trains. The third category provides the operating parameters for simulation. The fourth area deals with the specification of the location of trains and their movement in time. The fifth defines positions along the corridor where instantaneous and RMS values of third rail or trolley current will be computed. And finally, the sixth category includes a sequence of power profiles which have been generated by the TPS for each type train running on the system.

4.5.1.1. File of Filenames

The first four records are the input filenames. The first record contains the name of the network description file, the second record contains the name of the operating time file, the third record has the name of the train locator file, and the fourth record shows the name of the current position file.

The next three records in the file are output files which the user may or may not specify. These files include the detailed output file, the meter load curve file, and the current measurement output file. This latter file can only be requested when a current position input file is named.

The remaining records in the file specify the names of the power profiles for each of the trains which will be running on the system.

4.5.1.2. Electric Network Description File

The electric network description consists of a general portion, definition of the AC part of the network, definition of the DC part of the network, and definition of the converter portion, which is the interface between AC and DC sections.

There are several points worth noting on the input format to the network description file.

1. Two titles of eighty characters each can be used to describe the electric network. These titles will appear on both the summary and detailed output.

2. In general the electric rail transit in North America have both an AC and DC part to the network. In many cases the AC portion consists of just a meter node and an AC converter node for each substation. There are cases, however, where more extensive AC distribution and transmission does occur.

3. The meter node is considered an infinite bus, and as such the voltage will remain fixed. for all other nodes in the system the voltage will vary according to the solution of the network equations.

4.5.1.3. Operating Time File

The Operating Time File controls both the time interval over which the simulation takes place plus the snapshot interval, or the time between snapshots.

4.5.1.4. Train Locator File

The method for locating trains on the electric network and the parameters for execution of that method are determined using the train locator file. The user may specify both AC or DC trains, that is, trains which obtain their power from a line which carries AC or DC, and the method for locating the trains which may be by POSITION, TIMETABLE, or HEADWAY AND OFFSET.

Locating trains by specifying their POSITION means that the trains are placed on the network at particular locations. As the simulation advances in time, the trains will move according to their power profiles, and eventually will move from the network as they reach their terminating points. No new trains are added to the system after the beginning of the simulation. This method for locating the trains is useful when only a few snapshots of the system are taken at special positions to determine instantaneous currents and voltage drop.

The TIMETABLE method for train location is the usual way to effect the process. A schedule is specified, and the ENS places the trains on the network following that schedule. Departure times are considered the beginning point of the power profile. as the simulation proceeds trains are added and removed from the network as specified by the schedule.

The HEADWAY AND OFFSET method for locating trains is used in limited circumstances. The condition for specifying the method is a double track system between two terminus points with a regular schedule. The headway, which is the separation between trains running on the same track, is given as a time interval (seconds). The offset, which is the difference in the time when the trains leave one terminal relative to the second terminal, is also input as a time interval (seconds).

The offset can vary between zero, in which the trains leave each of the terminals simultaneously, to one second less than one headway.

4.5.1.5. Current Position File

This file specifies the position at which line current will be computed and displayed, for each snapshot and in summary form as an RMS current. The position is specified as both a milepost and track number. The actual current calculated at that position will be flowing through the third rail, or alternatively, the trolley or catenary.

4.5.1.6. Train Power Profiles

The train power profile is a direct output from the TPS. It is the specification of how a particular train will run through the network as the simulation advances in time. The actual power used or regenerated by the train is also contained in the records of this file.

4.5.1.7. Main Program Description

This program accepts as input, single train power and time profiles as functions of location along the right of way, timetables for movement of multiple trains, power rail, catenary or trolley impedances, running rail impedances, substation locations and characteristics, operating voltages-nominal, maximum and minimum, characteristics of the distribution network, the substation feeders, and metering point locations and simulates the movement of the trains by taking snapshots of the entire system at fixed intervals in time. The output gives a complete electrical picture of the system including power flows, voltages, currents and losses at all salient points. In particular, power through metering points (forward and reverse), third rail propulsion system and substation losses and energy given to the environment (train resistance, auxiliary loads, friction or dissipative braking) are computed. Capability for regeneration to other trains and/or through regenerative substations (even through metering points), is also included.

The flow diagram for the ENS is shown in Figure 5.

The electric network in which the trains run is first set up without the trains. This means that all of the nodes are identified and all of the impedances of the connecting lines are computed.

In each snapshot (calculational time), the trains are placed in their proper positions as determined from the timetable and the power profiles of the trains which were computed by the TPS. The new electric network is set up which includes new lines between trains and all line impedances are calculated. Both the DC and AC parts of the network are converted to an interconnected AC network with the DC substation lines and train nodes treated specially. The admittance matrix is calculated and the network is solved.

In the case of trains which are taking DC power and are capable of regenerating, if power tries to flow in the reverse direction through the substation lines, the substation impedance is increased substantially and the network is resolved. Likewise, if maximum voltage at any train is exceeded because of regeneration, the regenerated power is reduced and the network is resolved.

4.5.2. Output

The output, all of which is user selectable, consists of three files: detailed output, meter load curves, and current measurement.

4.5.2.1. Detailed Output

The detailed output consists of a title page, a description of the input parameters and a detailed output of the voltages at each node and other data concerning the run at each snapshot.

4.5.2.2. Meter Load Curves

Meter load curves for each meter are output one point per snapshot. The file contains this information as well as the number of snapshots, time interval between snapshots, and beginning and end time. This file is used as an input to the energy - demand consolidation program which is used to predict demand and energy.

4.5.2.3. Current Measurement Output

This file contains a detailed output of all voltages at all of the nodes, currents flowing through the converters and currents at selected points along the right of way (third rail, catenary or trolley). These points are selected by specifying a current position file as input. The information just described is output every snapshot and is summarized at the end for the whole simulation period.

4.5.3. Methodology

4.5.3.1. Load Flow

The load flow calculation uses the Gauss-Seidel iterative method. This module differs from conventional load flow calculations. It has the capability to handle either AC, DC or composite networks.

The basic steps are:

1. Convert the system to an all AC network keeping a record of the DC part and the converters.

2. Perform the load flow calculation on the AC network.

3. Check the current flows through all the converters. If the converter is an inverter, the current can flow both ways. If the converter is a rectifier and current tries to flow in the blocked direction, increase the impedance of the rectifier in a sizable step. If the current is flowing in the unblocked direction set the rectifier impedance in accordance with the rectifier model.

4. Repeat procedure 2 and 3 until convergence is obtained.

5. After convergence is obtained, the voltage for each vehicle is checked in the system. If there is any vehicle with its voltage exceeding maximum allowable then its regeneration power is reduced by 25%.

6. Repeat procedure 4 and 5 until convergence is obtained.

7. Continue with the next snapshot, go to procedure 1.

8. When snapshots are finished formalize output.

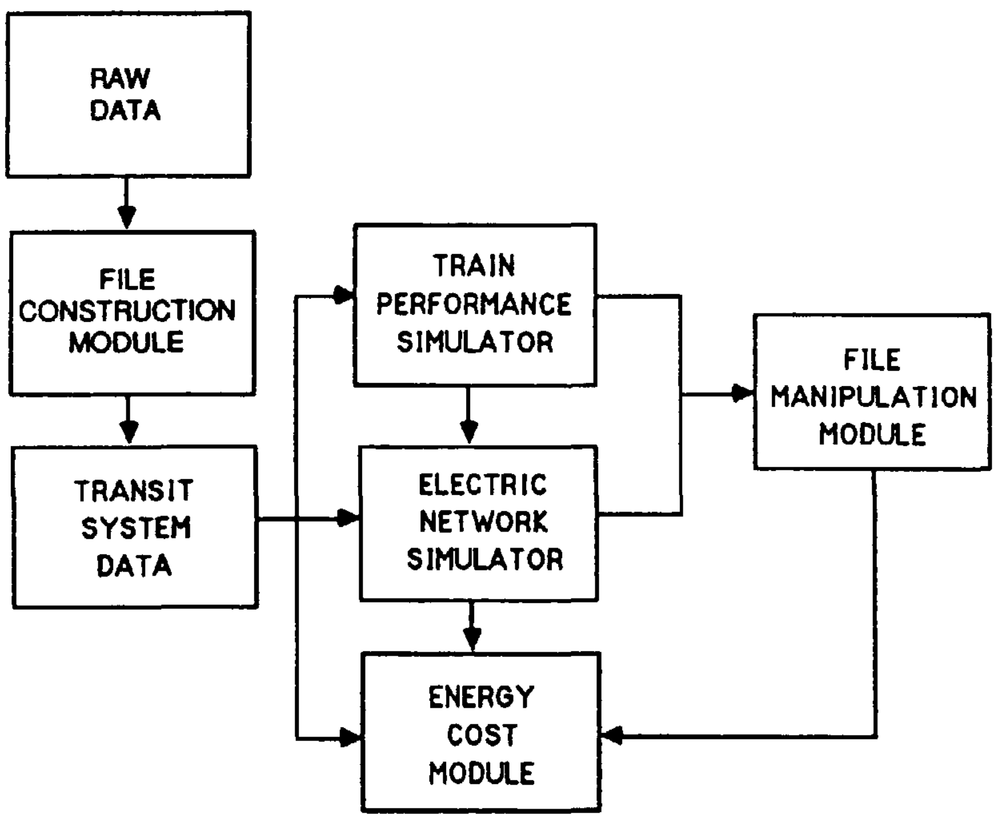


Figure 1 Energy Management Model Block Diagram

TRAIN PERFORMANCE SIMULATOR FLOWCHART

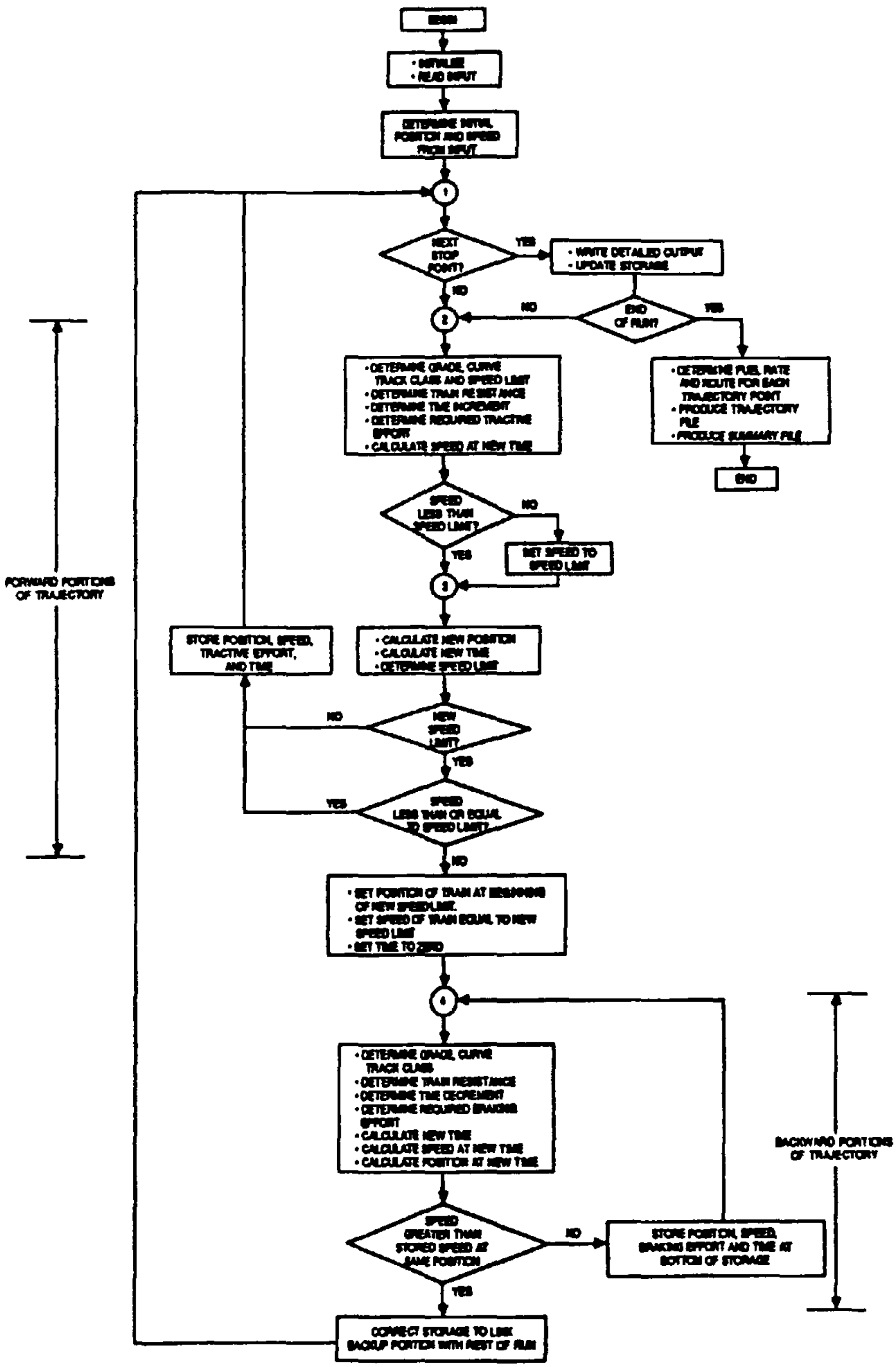


Figure 2

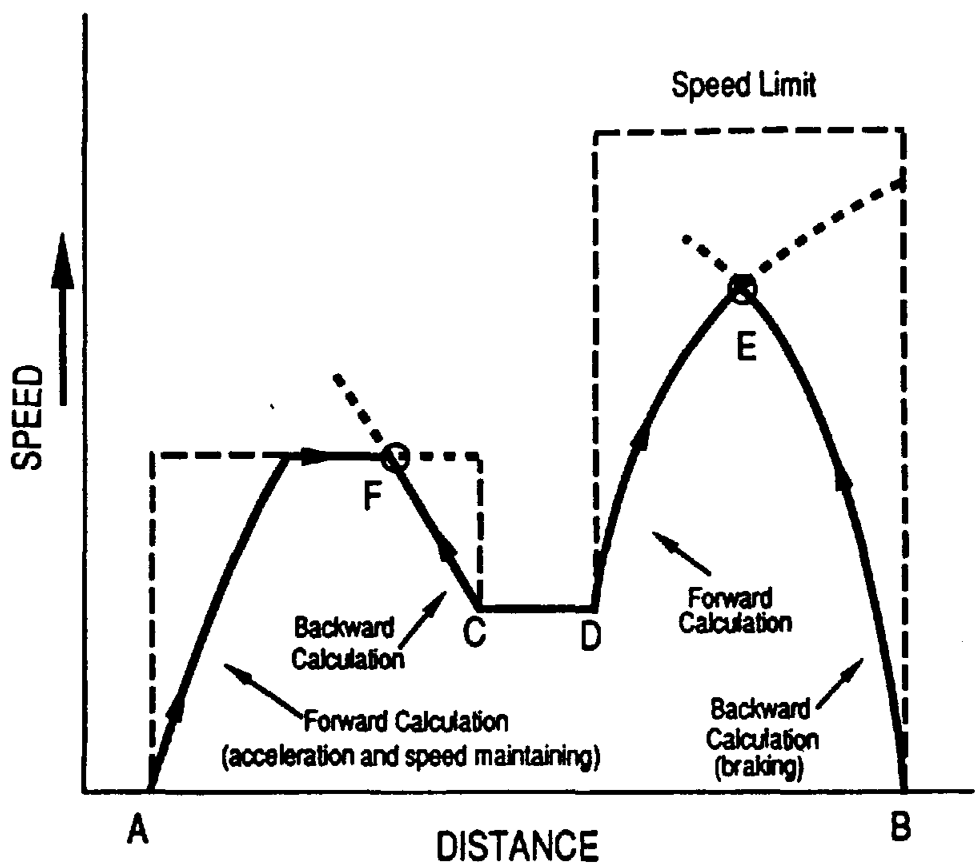
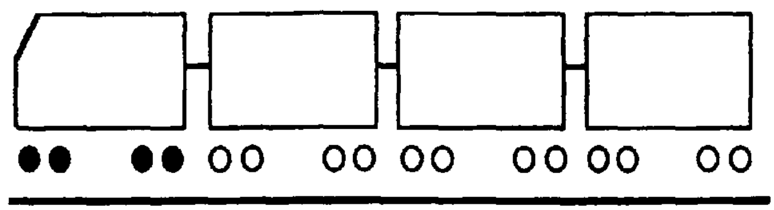


Figure 3 TPS Trajectory Calculation Methodology



EQUATION OF MOTION

$F_A - T_{RR} - T_{RA} - G - C = M_E \cdot dV/dT$

DEFINITION OF QUANITITIES:

F_A	Tractive effort (positive) of Braking effort (negative)
T_{RR}	Rolling portion of train resistance
T_{RA}	Aerodynamic portion of train resistance.
C	Curve resistance [0.8 LBS/TON °CURVATURE]
G	Grade resistance [20 LBS/TON/%GRADE]
M_E	Equivalent mass to include rotational inertia effects
dV/dT	Acceleration or deceleration

● - driver wheel
○ - non-driver wheel

Figure 4 Equations of Motion

ELECTRIC NETWORK SIMULATOR FLOWCHART

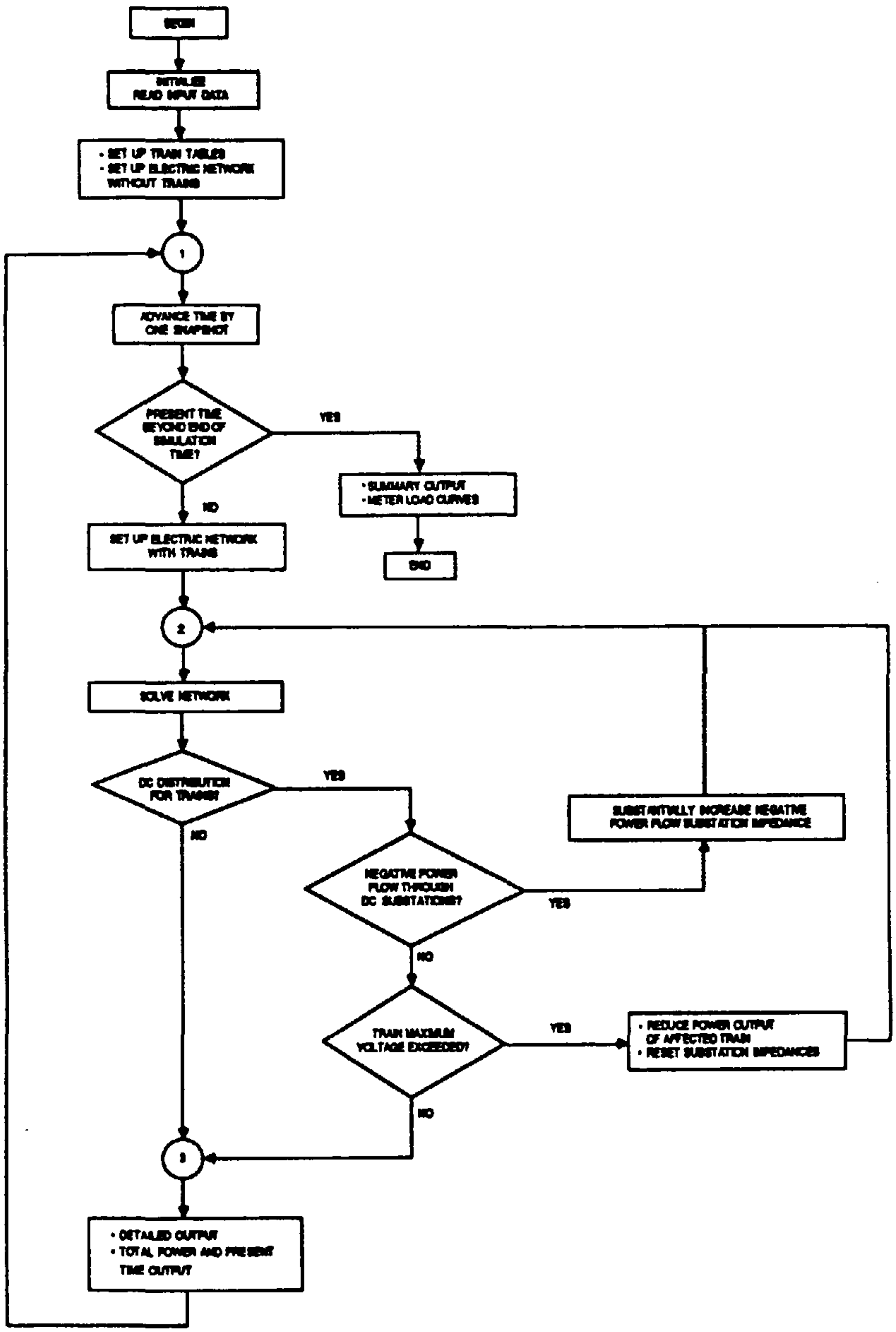


Figure 5

5. ENERGY AUDIT

5.1. INTRODUCTION

The purpose of the energy audit is to determine the energy use pattern and its relation to the operating rail system. This can be done by studying the metered power and its end uses as a function of time and relating this study to variations in the pattern of operation.

Since the energy use pattern should be related to energy cost, it is important that the metering information required for the audit be obtained from electric utility metering records. This information is sometimes available on magnetic tape. The smallest time interval available for the audit is the smallest interval for which metering data are available.

For those transit agencies which are served by electric utilities which do not keep detailed metering records, analysis of electric bills may be possible. In this case, just the value of peak demand is known and total monthly energy use. Under these circumstances, only very gross characteristics of the energy use pattern can be determined.

There are two principal analyses which can be carried out using metering records. The first analysis relates the metering data to the operating characteristics which are driving energy use, and these are car-miles per unit time and ambient temperature (heating and cooling). The second analysis provides statistical summaries of the data. These summaries, which include such things as average values, standard deviations, maxima and minima, can sometimes be related to abnormal operating conditions, the usual cause of high peak demand.

5.2. ENERGY AUDIT OF THE MARTA RAIL SYSTEM

The energy audit of the MARTA rail system was conducted by analyzing power metering data supplied by Georgia Power Co. (GP), for the period beginning December 1, 1982 through August 31, 1984, a time interval of twenty-one months. This period was selected because the rail system operational timetable remained relatively constant during this time.

5.2.1. Description of the Power Metering Data

During the time period selected for the audit, GP metered the rail system through twenty to twenty-six feed points. The names of the metering points, their circuit numbers and identification codes are listed in Table 5-1. Observation of this table shows that each of the metered feeds to the rail system supplies both traction and support power. Traction power is supplied through the traction substations, and its primary end uses are the running of the trains and auxiliary functions aboard the cars. Support power is used for support operations along the wayside. Its end uses include heating, air conditioning and ventilation, lighting, escalators and elevators, and train control. The meters do not distinguish between the energy delivered to traction and support functions.

The demand interval for electric power service to the rail system is one hour. Demand is measured on a coincident basis, which means that in any one hour clock interval (beginning on the hour), the average power is the sum of the power recorded at each of the meters. The resulting sum of the average powers is the demand for the one hour time interval. The monthly demand is the highest of the demands recorded during a monthly billing period, which typically runs from the twentieth of the month to the twentieth of the next month.

GP provided a magnetic tape, which contained the hourly demands for each of the twenty-six meters for the twenty-one months. These data provided the basis for the energy audit.

During the time period selected for the energy audit (12/82 - 8/84), there were three minor changes in the rail operations, which affected energy consumption. On December 18, 1982, service was extended on the NS line. On October 12, 1983, auxiliary load was added to Peachtree Center station. In January, 1984, the headway on the EW line was shortened from ten to six minutes and the number of cars per train during the weekday AM and PM peak periods was decreased fom six to four.

5.2.2. Regression Analyses

Data readily available at MARTA allowed regression analyses using daily energy as the dependent variable and daily car-miles (CM) and ambient temperature effects as the independent variables. A list of daily car-miles was obtained from the Authority and a list of daily average ambient temperatures was obtained from the U.S. Weather Bureau for the audit time period (12/82 - 8/84).

Three models were used to test the existing energy data dependence on car-miles and daily average temperature effects. All of the models used the concept of heating and cooling degree-days, but in each of the models heating and cooling degree-days were defined differently to reflect the behavior of the heating and cooling facilities in the rail system with the help of Figure 5-1.

In model #1, the heating (HDD) and cooling (CDD) degree days are defined in the standard manner. The number of heating degree days in a particular day is just the difference between 65°F and the average temperature of the day. If the average temperature of the day is 65° or higher, then HDD = 0. Likewise, the number of cooling degree days in a particular day is just the difference between the average temperature of the day and 65°F. If the average temperature of the day is 65°F or less, then CDD = 0.

In model #2, a base temperature is defined for both the definition of the heating and cooling degree day. Thus the number of heating degree days in a particular day is just the difference between the heating degree day base temperature (T_H) and the average temperature of the day. If the average temperature of the day is higher than T_H, then HDD = 0. This model reflects the fact that heating facilities begin to operate when the temperature falls below T_H. Likewise, the number of cooling degree days in a particular day is just the difference between the cooling degree day base temperature (T_C) and the average temperature of the day. If the average temperature of the day is lower than T_C, then CDD = 0. Again, this model reflects the fact that cooling facilities begin to operate once the temperature rises above T_C. The temperatures T_H and T_C are selected by the optimum fit of the data to the regression equation.

Finally, model #3 is an extension of model #2, where the effect of saturation of heating and cooling facilities is added. The temperatures T_H and T_C have the same meaning as in model #2, however the following modifications are made to the meaning of heating and cooling degree days. When the average daily temperature is below the heating degree day saturation temperature (T_{HS}), the number of heating degree days remains constant, at a value (T_H - T_{HS}). When the average daily temperature is higher than the cooling degree day saturation temperature (T_{CS}), the number of cooling degree days remains constant, at a value of (T_{CS} - T_C). In addition to including the "turning on" effect at different base temperatures of the heating and cooling facilities of model #2, model #3 also includes the effects of these facilities operating all of the time once saturation temperatures are reached.

The regression equation was a simple linear relation between the independent variables car miles, heating degree days and cooling degree days and the dependent variable, daily energy consumption. The equation had the form:

$$E = E_O + E_{CM}*CM + E_{HDD}*HDD + E_{CDD}*CDD$$

with the following definition of symbols:

E - Daily energy use (kWh)

E_O - Background energy use (not dependent on car miles or degree days.) (kWh)

E_{CM} - Coefficient of car-mile dependent term (kWh/CM)

CM - Daily car-miles (CM)

E_{HDD} - Coefficient of heating degree day dependent term (kWh/HDD)

HDD - Number of heating degree days (HDD)

E_{CDD} - Coefficient of cooling degree day dependent term (kWh/CDD)

CDD - Number of cooling degree days (CDD)

The results of the regression analysis are summarized in Table 5-2. For all of the three models. The following remarks refer to the results shown in Table 5-2.

1. Model #3 best explains the variation of daily energy with car-miles and ambient temperature. The best fit shows that the heating facilities begin operation at 54°F and operate continuously when the daily average temperature reaches 33°F. Likewise the same model shows that cooling operations begin at 70°F and are saturated at 83°F.

2. The model #3 R^2 term, which represents the goodness of the fit (0% = no fit, 100% = ideal fit), is 87%. This is considered an excellent fit.

3. The T-ratio, which is also a measure of the goodness of the fit to each coefficient separately, is large for each of the coefficients. A value of a T-ratio greater than 2 is considered good.

The largest change in daily energy consumption took place on January 9, 1984 when the timetable on the EW line changed. The metering data were divided into several parts:

1. NS line (Jan 9, 1984 - Aug 31, 1984) [N-S (1984)]

2. EW line (Jan 9, 1984 - Aug 31, 1984) [E-W (1984)]

3. Both Lines (Jan 9, 1984 - Aug 31, 1984) [BOTH (1984)]

4. Both Lines (Jan 1, 1983 - Jan 8, 1984) [BOTH (1983)]

Because car-miles were available from the NS and EW line, separately from Jan - Aug, 1984, it was possible to conduct regression analyses on the four cases which were just outlined. The results are presented in Table 5-3 using model #3.

Observation of Table 5-3 shows that the best fits occur on the EW lines during 1984 and both lines combined during 1984. The worst R^2 occurs for the analyses of the NS line during 1984.

It is interesting to compare the contribution of each of the terms of the regression equation on a typical summer, spring and winter day at several levels of daily car-miles. The results of this comparison are shown in Table 5-4. The 23,000 car-mi/day was typical of weekday operation during the audit period, while the 10,000 car-mi/day was typical of weekend operation. Three average daily temperatures were selected, the heating

Finally, Figure 5-2 shows the observed versus predicted values of daily energy use. The prediction uses the regression equation of model #3.

5.2.3. Power Demand Statistics

Summary statistics for hourly energy use for the MARTA rail system during the energy audit are shown in Figure 5-3. This graph shows the minimum, average, average plus one standard deviation and the maximum hourly energy use. Since the energy use time interval is one hour, the power demand is equivalent to the energy use per hour. The dates, on which the minimum and maximum demand at each hour of the day occurred, are shown to the right of the bar chart in the figure. The absolute minimum and maximum demands are indicated with an asterisk.

The data, from which these summary statistics were generated, spanned a time interval which included two summer and two winter seasons. Both the peaks of average power and average power plus one standard deviation occur in the transit operating peak periods in the morning (7:00 - 8:00 AM) and the afternoon (5:00 - 6:00 PM). This is typical of rail transit power demand. The ratio of the average power demand during midday (10:00 AM - 4:00 PM) to the peak power is not typical of transit operations. At MARTA this ratio is 90%. At most other rail transit systems, it is 60 - 70%.

One reason that this ratio was so high at MARTA during the energy audit is that the same consist sizes and same headways were run throughout the day, with only minor reductions in car-mi/hr from peak to midday. A second reason is that the ratio of support power to total power (support plus traction) is large.

Figures 5-4 through 5-10 show summary statistics of hourly energy use for the months January 1983, April 1983, July 1983, Ocotber 1983, January 1984, April 1984 and July 1984, respectively. These summary statistics illustrate power demand behavior during two winter months, two summer months, two spring months and one fall month. The study of these statistics leads to the following observations:

1. Peaks during the winter months tend to occur during the AM peak period, when heating facilities are operating at their maximum, together with more lighting because of the shorter day.

2. Peak during the summer months generally occur during the PM peak, when cooling facilities are operating at their maximum.

3. In the fall and spring months, peaks can occur during either the AM or PM peak operating time.

5.3. ENERGY AUDIT OF WMATA RAIL SYSTEM

5.3.1. Traction Energy

In Metrorail operation, traction energy is the time integrated power registered by the electric meters in the traction substations. It includes energy to operate the trains during revenue service, testing and yard movement. It also includes energy for other functions which are powered through these substations, such as auxiliaries aboard the cars during layup, heating and ventilation, some air conditioning, tunnel lighting and switchpoint heating. In order to determine what fraction of the energy was used for traction, it was necessary to undertake an audit of the energy end uses.

The traction energy audit was conducted by analyzing metering information supplied by the Potomac Electric Power Company (PEPCO) for nine months of the year 1980. This method was chosen because PEPCO supplied 86% of the energy for Metrorail operations during this time period. The Virginia Electric Power Company (VEPCO) supplied the remaining 14%. Table 5-5 provides a summary of energy used in 1980 by utility and jurisdiction. A second reason for this course of action was that PEPCO had detailed metering information available while VEPCO did not.

5.3.1.1. Description of PEPCO Metering Data

The interval selected for the traction energy audit was a compromise based on the time span of the metering information provided by PEPCO and the period during which the 1980 Metrorail operating timetable remained relatively constant.

The PEPCO provided a magnetic tape which contained energy usage (pulses) for each fifteen minute interval for the twenty-six traction energy meters which were in operation during 1980. The time span was January 20, 1980, to January 19, 1981. The data from each meter were analyzed.

Of the twenty-six traction meters considered in the analysis, eighteen, five and three were in the DC, MD and VA jurisdictions, respectively. During the analysis, it was found that pulses were not provided by PEPCO for the meters at Cheverly, Landover, Beaver Dam Creek, New Carrollton Yard and Silver Spring substations, all of which were in the MD jurisdiction. Thus, precautions were taken during the audit to discount the effect of these meters.

The 1980 Metrorail operating timetable showed the same weekly pattern of train operation from February 1, 1980, to November 1, 1980, at which time service on the Blue Line was extended from the Stadium Armory station to the Addison Road station.

Because of more missing metering information from October 15, 1980, to November 1, 1980, the time span for the audit was selected from February 1, 1980, to October 15, 1980, a total of 257 days.

5.3.1.2. Regression Analyses: Daily Car-Miles and Temperature

In order to determine the dependence of traction energy usage on car-miles and daily temperature, regression analyses were conducted using the traction meter data. Each day was divided into two periods: revenue service time and non-revenue service time. Revenue service time was that part of the weekday, Saturday or Sunday, during which trains were scheduled to run according to the operating timetable. Non-revenue service time was all other time.

5.3.1.2.1 Revenue Service Time Regression Description

The regression formula was assumed to have the form:

$$P = P_0 + E_1(CM/H) + P_2(ADD)$$

where P is the average power over the revenue operating time as obtained from the meter data, P_0 is the background power in units of KW, CM/H is the average car-miles per hour over revenue service time on a daily basis, ADD is the average degree-day defined as the average temperature less 70°F. The coefficient E_1

represents the energy per car-mile (KWHPCM) and P_2 represents the average power per average degree day (KWPADD).

In order to conduct the regressions, the actual car-miles accumulated each day were obtained from Metrorail over the interval of the audit. A statistical summary of the actual car-miles on the Red, Blue and Orange Lines are shown in Figures 5-11 to 5-13. The three peaks visible in the figures are attributed to weekday, Saturday, and Sunday operation. Table 5-6 presents a summary of the average, actual, and scheduled car-miles per day for the Red Line, and Blue/Orange Line combination.

An increase in actual car-miles on the Red Line was observed to occur on May 1, 1980. Table 5-6 shows the average car-miles broken down into two periods: February 1-April 30, 1980, and May 1-October 15, 1980. The weekday and Saturday averages were significantly different for the two cases. Metro reports that four-, together with six-car trains were used during weekday evenings, Saturdays, and Sundays during the spring of 1980.

The second independent variable of the revenue service time regression was the average degree day (ADD), defined as the average daily temperature less 70°F. A statistical summary of ADD over the audit period is shown in Figure 5-14. The average value is -3.7°, which represents an average daily temperature of 66.3°F.

5.3.1.2.2 Non-Revenue Service Time Regression

During non-revenue service time, the regression formula was assumed to have the form:

$$P = P_0 + P_2(MDD)$$

where all of the variables are the same as in the revenue service time regression, and MDD is the minimum degree day, the minimum temperature less 70°F. The average value of the minimum degree day is -13°, which represents a temperature of 57°F. The minimum temperature was selected as the independent variable because non-revenue service time generally had the minimum temperature.

5.3.1.2.3 Regression Analyses Results

The results of the regression analyses for the traction energy meters are shown in Table 5-7. In addition to those completed on the individual meters, regressions were also conducted on Red Line coincident power, and Blue/Orange Line coincident power with the exception of the power metered at Cheverly, Landover, Beaver Dam Creek, and New Carrollton.

During revenue service time, a strong dependence on car-miles is obvious. The confidence limits of this dependence exceeded 99%, even for the smallest value of the coefficient (E_1) of 0.24 at the New Carrollton Yard substation meter.

Table 5-8, which is based on the results of Table 5-7, shows the degree-day coefficients (P_2) for five meter consolidations separated by heating and cooling effects. Load differences between winter (20-30°F) and summer (80-90°F) are also tabulated. For example, for non-revenue service time the summer-winter power differential is (235 KW-67 KW) 168 KW.

Car storage during revenue service time at midday and evenings on weekdays, and on Saturdays and Sundays, has its predominant effect on the meters at New York Avenue (Brentwood Yard), Silver Spring and New Carrollton Yard. The meter at New Carrollton Yard exhibits only a 30% dependence on car-miles with the background accounting nearly for the remaining amount. The background is attributed to yard car movement and car storage.

During revenue service time, the degree-day component of the traction power is small. With the exception of the power at the Shirley Highway meter, which exhibits an 8% temperature component on the average day, the remaining degree-day components are 1% or less of the total power during revenue service time.

During non-revenue service time, the temperature component is much higher because there is no car-mile component.

Several of the meters exhibit increased power with rising temperature (cooling effects dominate P_2 positive), while others exhibit increased power with falling temperature (heating effects dominate P_2 negative). The large cooling effects occur at New Hampshire Avenue, Shirley Highway, Rosslyn, Potomac Avenue, and New Carrollton Yard. The effects at Shirley Highway and Rosslyn are the result of chiller plant power being metered through the traction substation, and the effect at New Carrollton is due to air conditioning of the yard office building and tower. At the present time, there is no explanation for the effects at New Hampshire Avenue on the Red Line, and Potomac Avenue on the Blue/Orange Line.

Table 5-9 lists the average powers for the traction meters at different operating times from May 1, 1980, to October 15, 1980. This time interval was selected for the averages because six car trains were generally used on Saturdays, Sundays and weekday evenings rather than mixtures of four and six car trains as were used in the Spring of 1980. Ratios of average power of AM peak to midday, AM peak to PM peak, midday to evening, and midday to Sunday are listed.

If there were no background, the ratio of AM peak to midday peak would be 2.3 on the Red Line, and 2.0 on the Blue/Orange Line.

The ratio of AM to PM peak power is 0.93 on the Red Line, and 0.95 on the Blue/Orange Line.

The ratio of midday to evening power is 1.03 on the Red Line, and 0.97 on the Blue/Orange Line. The ratio of midday to Sunday is 1.09 on all lines, so that 9% more power is used during midday operation than on Sunday.

5.3.1.3. Selection of Metered Background Power

It is clear from the regression analyses carried out on the traction energy meter that a background of power is registered even when no trains are operated. This background exists because of:

1. no-load losses of the transformer-rectifier units in the substation,
2. operation of car auxiliaries during layup,
3. support services, such as heating and ventilation of substations and other structures, chiller plants metered through the traction meters, tunnel ventilation, lighting and switchpoint heating, and testing of trains.

This background is not simply the background of the regression analysis carried out during revenue service time, because of the intercept error. It is more appropriate to consider the non-revenue service time as the basis for the background estimate (Table 5-7).

Table 5-10 contains a summary of the background values for all the traction meters used in all of the subsequent analyses using the EMM. These backgrounds were derived using the following rules:

1. The minimum power through any traction meter is the no-load losses of the transformer-rectifier units in the substation.These are estimated at 8 KW per unit. These no-load losses are also shown in the table.
2. The average layup power used by a car is 5 KW. This number is based on a measured value.

The background power for peak and non-peak operation differ because of the layup power of the auxiliaries on board the cars which are stored during non-peak operation.

Since it was not possible to obtain a detailed analysis of the background associated with the VEPCO meter, this estimate was made by taking each VEPCO substation background the same as the average of all of PEPCO substations. Thus, the background value for the VEPCO meter was 686 KW.

5.3.1.4. Consolidation Histogram Analysis

Figures 5-15, through 5-19 show statistical summaries of traction power metered by PEPCO for the AM peak for the Red Line, Blue/Orange Line, DC, MD and VA jurisdictions of PEPCO, respectively. Figures 5-20 through 5-24 show statistical summaries for the PM peak for the same PEPCO traction meter consolidations. The time interval selected for these summaries was May 1-October 15, 1980, for which the timetable was relatively stable.

The statistical summaries show the average, standard deviation, and the maximum of the traction power over one-half hour intervals beginning each quarter hour. These values are the measured power demands.

Table 5-11 presents a comparison of the maximum power demand to the average power demand for the AM and PM peak operating periods, for four meter consolidations: Red Line, Blue/Orange Lines, DC and VA jurisdiction of PEPCO. Because of missing meter data on the MD jurisdiction meters, this consolidation was not considered. In the case of the Red and Blue/Orange Line traction meter consolidation, the percent increase of the maximum demand over the average demand is 25-31%. In the case of the DC jurisdiction, the percent increase of the maximum over the average demand was 18-19%. However, in the case of the PEPCO VA jurisdiction, the percent increase is 67-86%.

The large difference in the case of the VA jurisdiction can be attributed to the small number of meters in the consolidation (3 meters), and as a result, any variation in operating conditions over the portion of the rail network serviced through these three meters tend to be coincidental, whereas, in the case of the DC jurisdiction serviced by a large number of meters serving different portions of different lines, the operating difference effects tend to be non-coincidental.

5.3.2. Support Energy

In Metrorail operation, the support energy is the time integrated power registered by the electric meters in the passenger stations, the office building, and the repair shops. It includes energy for heating, air conditioning, ventilation, lighting, elevators, escalators, signals and communications, and power to run special equipment and machinery. As in the case of traction energy, an audit was undertaken by analyzing metering information from PEPCO for part of the year 1980.

5.3.2.1. Description of Audit

The time interval selected for the audit was the same as that for the traction energy audit.

Of the thirty-seven support meters analyzed as part of the 1980 operation, thirty were in the DC jurisdiction, four were in the MD jurisdiction, and three were in the VA jurisdiction. During the analysis, it was found that pulse data were missing from the meters at Silver Spring, Landover, Cheverly, and Minnesota Avenue. Thus, precautions were taken during the audit to discount the effects of these meters.

5.3.2.2. Regression Analyses: Temperature

In order to determine the dependence of support energy usage on daily temperature, regression analyses were conducted using the support meter data. Each day was divided into two periods: revenue service time and non-revenue service time. Revenue service time was that part of the weekday, Saturday or Sunday, during which trains were scheduled to run according to the operating timetable. Non-revenue service was all other times.

The regression formula was assumed to have the form:

$$P = P_0 + P_2(ADD)$$

during revenue service time, and:

$$P = P_0 + P_2(MDD)$$

during non-revenue service time, where P is the average power as obtained from the meter data, P_0 is the background power in units of KW, ADD is the average degree-day defined as the average temperature less 70°F, and MDD is the minimum degree-day defined as the minimum temperature less 70°F.

The results of the regression analyses are shown in Table 5-12. All stations which are above ground show a power increase with decreasing degree-days (heating), and those below grade show a power increase with increasing degree-days. For the below ground stations, this is attributed to tunnel ventilation, and for above ground stations it is attributed to heating and lighting. The lighting correlation is probably a secondary effect due to a relation between longer night hours and colder days.

The office building shows a large cooling effect because chiller plants at Gallery Place and Judiciary Square are metered here. The Garden City Shop shows a large heating effect.

Table 5-13 shows the temperature dependent coefficient of the regression analyses and load dependence on temperature for several consolidations of the support meters. The load differences can be interpreted as between winter (30°F) and summer (90°F), and the spring and fall seasons (60°-70°F).

5.3.2.3. Average PEPCO Support Power

Table 5-14 lists the average support power for the passenger stations, the office building, and repair shops for PEPCO jurisdictions during the principal operating periods. Table 5-15 lists the average support power for five PEPCO support meter consolidations which are the Red Line passenger stations, the Blue/Orange Line passenger stations, and the DC, MD and VA jurisdictions. The MD and DC jurisdictions are shown with and without office building and repair shop power.

5.3.2.4. PEPCO Support Power Model

The PEPCO support power model was developed for the passenger stations serviced by PEPCO. It includes a background power, lighting loads, and escalator loads.

5.3.2.4.1 PEPCO Passenger Station Lighting Loads

Table 5-16 shows a summary of the power used for lighting of the passenger stations serviced by PEPCO. This table was constructed using the following information from Metro:

1. Underground stations with center (side) platforms have 70 (120) KW of lighting load.
2. Stations above ground with center (side) platforms have 30 (40) KW of lighting load.
3. The Pentagon and Rosslyn stations have two levels underground, and the lighting load is 130KW.
4. Parking lot lighting loads associated with passenger stations are estimated at 30 watts/space.

Based on this information in Table 5-16, a summary of the lighting loads for Red Line, Blue/Orange Line, and DC, MD and VA jurisdiction passenger stations is presented in Table 5-17.

5.3.2.4.2 PEPCO Passenger Station Escalator Loads

It has been shown that if as many people ascend escalators as descend them in a given time period at the loading which would be experienced at Metro, the average power consumed in the time period is proportional to the sum of the heights of rise of all of the escalators. This conclusion is valid for the modular escalators supplied by Westinghouse to Metro under medium load conditions. The conversion coefficient from the height of rise to KW is 0.11 KW/ft. of rise.

In order to use this relation between height of rise and escalator power, time periods must be selected where ascending and descending load averages over the periods are relatively equal. These periods are: the AM and PM peak taken together, midday, evening, Saturday and Sunday operation. It is even more valid when considering several passenger stations, such as on the separate lines or the DC jurisdiction where all people must enter and leave the system within 30 minutes.

Using the relationship between escalator power and height of rise, a summary of average power consumed by the escalators is listed in Table 5-18. The heights of rise were calculated based on the Metro information.

The average power for all underground stations was determined for the peak revenue service periods and the non-revenue service periods on weekdays in order to verify the validity of the simple power formula for the escalators. The difference between the powers during these two weekday periods should equal the escalator power if the assumptions that all escalators are running during the peak revenue service periods and that of the passenger station loads only the escalators are turned off during the non-revenue service periods. This comparison is shown in Table 5-19. Agreement is within 2%.

5.3.2.4.3 PEPCO Support Power Model

In this study, support background power is defined as all support power less the lighting and escalator load on the average degree-day. This definition was selected in order to test lighting and escalator energy conservation strategies.

The PEPCO support background power was estimated by subtracting the escalator average power, as calculated using the simple escalator formula described in the previous section, and the full underground station lighting loads from the average support power used in the AM and PM peak revenue service periods taken together. A summary of the resulting support power background for the passenger stations of the Red Line, Blue/Orange Line, and the DC, MD and VA jurisdictions is tabulated together with the lighting and escalator loads in Table 5-20.

In the construction of Table 5-20, it was assumed that station lighting was operational for all periods, and lighting in stations above ground was used only in the evening.The latter assumption is not critical. Escalators were assumed off during non-revenue service time.

With reference to Table 5-20, the actual power and estimated power have been forced to agree during the peak periods because of the estimation method. However, the agreement during the other periods is good with the exception of that of the MD jurisdiction where the metering information was not complete.

Table 5-21 lists the metered power demand and energy use for the office building and repair shops. Since no conservation strategies will be applied to these installations in this study, this power will be considered background in the DC and MD jurisdictions.

5.3.2.5. The VEPCO Support Power Model

Since no detailed information is available on VEPCO support power, the model was patterned after that of PEPCO. The background support power was estimated using the average background of similar type passenger stations serviced by PEPCO. The types of stations considered were underground side platform, underground center platform, and above ground.

Table 5-22 presents a comprehensive listing of lighting and escalator loads (using the simple escalator power formula) in VEPCO passenger stations.

Table 5-23 presents a listing of background, lighting and escalator power for VEPCO service at passenger stations. The background support power was estimated in the same way as in PEPCO serviced passenger stations.

5.3.2.6. Algorithms for Estimating Support Power Demand and Energy Use

The models developed in Sections 5.3.2.4 and 5.3.2.5 can be applied directly to energy conservation strategies involving escalator and lighting power reduction. The following procedure is used.

Estimate of Peak Power Demand

Peak power demand is estimated by summing up the background power, the lighting power, and the escalator power during the peak demand period.

Estimate of Energy Use

Energy use is estimated by summing the background energy (background power x 24 hours/day), the lighting energy (integration of the lighting vpower over the day), and the escalator energy (integration of the escalator power over the day).

Table 5-24 shows an estimate of the support energy use and average peak power demand for normal operation on a weekly basis. The assumptions for this estimate are:

1. Lighting load of underground stations is continuous.
2. Lighting load of stations above ground is on during evening revenue service operation only (6:00PM-12:00AM).
3. Escalators operate only during revenue service.

TABLE 5-1

METERING POINTS AND POWER FEED INFORMATION

METER NAME & CIRCUIT#	CODE	END USE OF FEEDS: TRACTION	AUXILIARY	CHILLER	OTHER
	NORTH-SOUTH LINE				
West End A0708	100E	1	1		
West End A0709	100F	3	2		
Wabash A1382	100C	3	2		
Wabash A1392	100D	3	3	1	
Spring Street S7582	100A	3	2	1	
Spring Street S7592	100B	3	3		
Lindmont L1762	100H	2	2		
Lindmont L1752	100G	3	1		
Buckhead S1588	100J	3	1		
Buckhead S1598	100K	2	2		
	EAST-WEST LINE				
Hightower H0142	101L	1	1		
Hightower H0152	101M	1	1		
Northwest 808	101K	2	2		
Northwest 468	101J	2	1		
Davis Street 188	101E	2	2	1	
Davis Street 198	101F	1	1		
Davis Street 488	101H	2	2		
Davis Street 498	101G	1	1		1*
Hill Street 1612	101C	3	3		
Hill Street 1622	101D	3	4	1	
Moreland 1362	101B	3	3		1*
Moreland 1312	101A	3	4		
Decatur 592	028M	2	1		2#
Decatur 582	028L	1	1		2+
Scottdale 352	278A	1	1		2+
Scottdale 362	278B	2	1		3#

* Fan
\# Car Shop & Maintenance of Way
\+ Central Train Control, Yard Control

TABLE 5-2

REGRESSION ANALYSES RESULTS

Coefficient	Model #1	Model #2	Model #3
E_O(kWH)	144,269	150,328	151,123
E_{CM}(kWH/CM)	4.721	4.714	4.685
E_{HDD}(kWH/HDD)	2253	2554	2939
$E_{kWH/CDD}$	1018	1161	1548
Base and Saturation Temperatures (°F) [Best Fit]			
CDD Base	65	69	70
HDD Base	65	57	54
CDD Saturation	-	-	83
HDD Saturation	-	-	33
Statistical Quantities [Best Fit]			
R^2(Adjusted for Degrees of Freedom)			
	85.5%	85.9%	86.6%
T-Ratio (Coefficient/Std Deviation)			
of E_O term	85.52	97.13	101.62
of E_{CM} term	56.01	56.57	57.78
of E_{MDD} term	23.81	23.33	24.15
of E_{CDD} term	18.13	17.43	18.73

TABLE 5-3

RESULTS OF REGRESSION ANALYSES ON NORTH-SOUTH AND EAST-WEST LINES DURING DIFFERENT TIME PERIODS

Analyses ID	HDD BASE (°F)	HDD SAT (°F)	CDD BASE (°F)	CDD SAT (°F)	R^2 (%)	E_0 (KWH)	E_1 (KWHPCM)	E_{CDD} (KWHPCDD)	E_{HDD} (KWHPCDD)
1. N-S(1984)	55	34	68	76	79.2	41467	5.00	1802	405
2. E-W(1984)	56	37	69	81	94.2	120820	3.76	1123	1182
3. BOTH(1984)	54	26	68	78	93.0	162036	4.17	2918	1777
4. BOTH(1983)	55	36	73	84	82.8	145155	5.01	3935	1404

TABLE 5-4

COMPARISON OF TERMS OF REGRESSION EQUATION TO TOTAL DAILY ENERGY

Daily Car-Miles	Ambient Temp	Energy (kWH)[%] Background	Car-Mi	Amb Temp	Total
23,000	33°	151123[52]	107756[37]	32516[11]	291395[100]
	65°	151123[58]	107756[42]	0.[0]	258879[100]
	83°	151123[51]	107756[36]	38207[13]	297086[100]
10,000	33°	151123[66]	46851[20]	32516[14]	230490[100]
	65°	151123[76]	46851[24]	0[0]	197974[100]
	83°	151123[64]	46851[20]	38207[16]	236181[100]

TABLE 5-5
ENERGY CONSUMED BY METRO OPERATIONS DURING 1980

(X1000 KWH)(% of TOTAL)

	PEPCO		VEPCO
ENERGY CONSUMED BY	DC	MD & VA	
All Passenger Stations	47,721 (66%)	12,541 (17%)	12,184 (17%)
All Rail Traction Operations	107,635 (62%)	43,371 (25%)	21,819 (13%)
TOTAL	155,356 (63%)	55,912 (23%)	34,453 (14%)

Source: Testimony of Richard T. Labonski of Washington Metro before the DC Public Service Commission, Formal Case #748, April 1981.

TABLE 5-6
SUMMARY OF AVERAGE ACTUAL VS. SCHEDULED CAR-MILES FOR METRO (FEBRUARY 1, 1980-OCTOBER 15, 1980)

RED LINE	Average Actual Car-Miles	Scheduled Car-Miles
Weekdays	16,470	18,018
Saturdays	10,489	11,571
Sundays	5,487	5,964
BLUE/ORANGE LINE		
Weekdays	41,338	41,855
Saturdays	25,186	26,779
Sundays	13,977	14,053

	Average Actual Car-Miles	
RED LINE		
	February 1-April 30, 1980	May 1-October 15, 1980
Weekdays	14,876	17,372
Saturday	8,712	11,419
Sunday	5,203	5,618

TABLE 5-7
RESULTS OF REGRESSION ANALYSES FOR POWER VS. CAR-MILES AND DEGREE-DAYS

RED LINE METER NAME (SYMBOL)	REVENUE SERVICE TIME*			NON-REVENUE SERVICE TIME**	
	P_0(KW)	E_1(KWHPCM)	P_2(KWPDD)	P_0(KW)	P_2(KWPDD)
Farragut North (MA1)	222	0.90	-1.1	93	0.4
Gallery Place (MB1)	134	0.88	N	98	N
Union Station (MB2)	95	0.69	N	133	N
New York Avenue (MB3)	217	0.75	N	321	N
Rhode Island Avenue (MB4)	44	0.73	-1.6	75	-0.7
Brookland Avenue (MB5)	261	1.00	-3.3	274	-2.6
New Hampshire Avenue (MB6)	170	0.63	N	323	6.3
Takoma Park (MB7)	71	0.82	-2.9	107	-1.4
Silver Spring (MB8)	449	0.62	N	388	N
Coincident Red	1844	6.87	-11.6	1853	N
ORANGE/BLUE LINE METER NAME (SYMBOL)					
Shirley Highway (MC8)	197	.30	7.8	256	6.6
Washington Boulevard (MC6)	106	.60	0.7	81	-0.7
Rosslyn (MC5)	60	.50	3.7	220	2.6
Potomac (MC4)	43	.50	N	91	-0.7
Farragut West (MC3)	-11	.58	1.3	54	N
Metro Center (MC1)	52	.55	2.2	31	N
Smithsonian (MD2)	51	.51	0.9	36	N
Federal Center (MD4)	-57	.40	0.6	22	N
Seward Square (MD6)	64	.62	1.2	41	N
Potomac Avenue (MD7)	-82	.36	N	75	1.7
Stadium Armory (MD8)	197	.55	N	73	-0.3
Minnesota Avenue (MD9)	123	.53	N	79	0.6
Deanwood (MD10)	111	.49	1.7	79	-10.7
Cheverly (MD11)	96	.54	N	132	-1.0
Landover (MD12)	254	.31	2.8	222	-8.4
Beaver Dam Creek (MD13)	176	.39	2.2	266	N
New Carrollton Yard (MDY)	639	.24	7.8	981	6.5
Coincident Blue/Orange (Except MD11, MD12, MD13, MDY)	895	5.52	18.7	1156	N
Coincident Blue/Orange	1526	5.73	37.1	1796	8.2

*Revenue Operating Time

	Red Line	Blue/Orange Line
Weekdays	00:00-00:45; 05:15-24:00	00:00-00:45; 05:30-24:00
Saturdays	00:00-00:45; 07:30-24:00	00:00-00:45; 07:30-24:00
Sundays	09:30-18:45	09:30-18:45

**Non-Revenue Operating Time

	Red Line	Blue/Orange Line
Weekdays	00:45-05:15	00:45-05:30
Saturdays	00:45-07:30	00:45-07:30
Sundays	00:00-09:30; 18:45-24:00	00:00-09:30; 18:45-24:00

N - Not significant with 95% Confidence Limits.

Regression Equations

$P = P_0 + E_1(CM/H) + P_2(DD)$

P : Average Power (KW)
P_0: Background Power (KW)
E_1: KWHPCM (Car-Mile Component Coefficient)
CM/H: Average Car-Miles/Hour
P_2: KWHPDD (Degree-Day Component Coefficient)
DD: Degree-Day

TABLE 5-8
TEMPERATURE DEPENDENT COEFFICIENT OF REGRESSION ANALYSES AND LOAD DIFFERENCES FOR TRACTION METER CONSOLIDATION

	P_2(KWPADD) Revenue Service Time		P_2(KWPMDD) Non-Revenue Service Time	
	Negative	Positive	Negative	Positive
Red Line	8.9	0	4.7	6.7
Blue/Orange Line	0	32.9	21.8	16.3
D.C. Jurisdiction	8.9	7.9	16.4	9.0
MD Jurisdiction	0	12.8	9.4	6.5
VA Jurisdiction	0	12.2	0.7	9.2

LOAD DIFFERENCES (KW)

	P(30°)-P(70°)	P(90°)-P(70°)	P(20°)-P(70°)	P(80°)-P(70°)
Red Line	356	0	235	67
Blue/Orange Line	0	658	1090	163
D.C. Jurisdiction	356	158	820	90
MD Jurisdiction	0	256	470	65
VA Jurisdiction	0	244	35	92

TABLE 5-9
AVERAGE POWERS (KW) FOR TRACTION METERS AT DIFFERENT OPERATING TIMES (MAY 1, 1980-OCTOBER 15, 1980)

	WEEKDAY									
RED LINE METER NAME (SYMBOL)	AM PEAK 8:00-9:00	MIDDAY 12:00-13:00	PM PEAK 17:00-18:00	EVENING 20:00-21:00	SATURDAY 12:00-13:00	SUNDAY 12:00-13:00	AM PEAK / MIDDAY	AM PEAK / PM PEAK	MIDDAY / EVENING	MIDDAY / SUNDAY
Farragut North (MA1)	1759	832	1836	819	813	796	2.11	.96	1.02	1.05
Gallery Place (MB1)	1585	757	1663	713	717	671	2.09	.95	1.06	1.13
Union Station (MB2)	1116	590	1283	557	526	484	1.89	.87	1.06	1.22
New York Avenue (MB3)	1149	735	1338	784	655	622	1.56	.86	.94	1.18
Rhode Island Avenue (MB4)	1160	534	1259	505	500	437	2.17	.92	1.06	1.22
Brookland Avenue (MB5)	1764	922	1827	926	889	846	1.91	.97	1.00	1.09
New Hampshire Avenue (MB6)	970	639	1086	568	619	611	1.52	.89	1.13	1.05
Takoma Park (MB7)	1267	614	1277	593	626	606	2.06	.99	1.04	1.01
Silver Spring (MB8)	1241	854	1278	854	794	860	1.45	.97	1.00	.99
Coincident Red	12011	6476	12847	6318	6140	5933	1.85	.93	1.03	1.09

BLUE/ORANGE LINE METER NAME (SYMBOL)	AM PEAK 8:00-9:00	MIDDAY 12:00-13:00	PM PEAK 17:00-18:00	EVENING 20:00-21:00	SATURDAY 12:00-13:00	SUNDAY 12:00-13:00	AM PEAK / MIDDAY	AM PEAK / PM PEAK	MIDDAY / EVENING	MIDDAY / SUNDAY
Shirley Highway (MC8)	563	379	615	461	500	496	1.49	.92	.82	.76
Washington Boulevard (MC6)	1009	565	1055	572	523	499	1.79	.96	.99	1.13
Rosslyn (MC5)	1739	912	1841	887	832	853	1.91	.94	1.03	1.07
Potomac (MC4)	1705	918	1741	949	866	813	1.86	.98	.97	1.13
Farragut West (MC3)	1986	1017	2123	967	929	902	1.95	.94	1.05	1.13
Metro Center (MC1)	1962	1030	2016	992	986	963	1.90	.97	1.04	1.07
Smithsonian (MD2)	1800	972	1832	946	875	900	1.85	.98	1.03	1.08
Federal Center (MD4)	1248	640	1449	657	593	547	1.95	.86	.97	1.17
Seward Square (MD6)	2143	1177	2179	1144	1074	1103	1.82	.98	1.03	1.07
Potomac Avenue (MD7)	1006	537	1138	537	501	503	1.87	.88	1.00	1.07
Stadium Armory (MD8)	2031	1147	2079	1142	1100	1110	1.77	.98	1.00	1.03
Minnesota Avenue (MD9)	1036	615	1162	609	571	558	1.68	.89	1.01	1.10
Deanwood (MD10)	1023	591	1076	609	567	562	1.73	.95	.97	1.05
Cheverly (MD11)	978	625	1044	610	551	537	1.48	.94	1.02	1.16
Landover (MD12)	734	569	869	592	484	463	1.29	.85	.96	1.23
Beaver Dam Creek (MD13)	737	537	745	559	461	479	1.37	.99	.96	1.12
New Carrollton Yard (MDY)	635	747	638	1084	564	605	.85	1.00	.69	1.23
Coincident Blue/Orange	22332	12979	23600	13315	11975	11893	1.72	.95	.97	1.09
Coincident Blue/Orange	19248	10501	20304	10470	9915	9809	1.83	.95	1.00	1.07

TABLE 5-10
DERIVED BACKGROUND OF PEPCO TRACTION METERS ON RED, ORANGE AND BLUE LINES

METER NAME	LINE	LOCATION (MILEPOST)	SYMBOL	AUXILIARY RATED KW	NUMBER OF 2000 KW TRANSFORMER-RECTIFIER UNITS	NO LOAD LOSSES (KW)	NON-REVENUE SERVICE TIME POWER (KW)	CAR LAYUP POWER (KW)	MINIMUM BACKGROUND (KW) (AM+PM PEAK)	MIDDAY & EVENING BACKGROUND (KW)
Farragut North	Red	0.434	MA1	-	3	24	88		88	88
Gallery Place	Red	1.504	MB1	-	3	24	98		98	98
Union Station	Red	2.508	MB2	-	2	16	133		133	133
New York Avenue	Red	3.610	MB3	150	2	16	321	200	121	241
Rhode Island Avenue	Red	4.468	MB4	-	3	24	84		84	84
Brookland Avenue	Red	6.029	MB5	150	3	24	306		306	306
New Hampshire Avenue	Red	7.199	MB6	150	2	16	250		250	250
Takoma Park	Red	8.730	MB7	-	2	16	124		124	124
Silver Spring	Red	9.984	MB8	-	3	24	388	180	208	328
									1412	1652
Shirley Highway	Blue	1.676	MC8	1500	2	16	163		163	163
Washington Boulevard	Blue	2.795	MC6	500	2	16	90		90	90
Rosslyn	Blue/Orange	4.004	MC5	750	3	24	184		184	184
Potomac	Blue/Orange	5.225	MC4	600	2	16	100		100	100
Farragut West	Blue/Orange	6.171	MC3	-	3	24	54		54	54
Metro Center	Blue/Orange	7.036	MC1	-	3	24	31		31	31
Smithsonian	Blue/Orange	7.770	MD2	-	2	16	36		36	36
Federal Center	Blue/Orange	8.545	MD4	-	2	16	22		22	22
Seward Square	Blue/Orange	9.313	MD6	-	2	16	41		41	41
Potomac Avenue	Blue/Orange	10.748	MD7	500	3	24	52		52	52
Stadium Armory	Blue/Orange	11.387	MD8	225	2	16	77		77	77
Minnesota Avenue	Orange	12.878	MD9	-	2	16	71		71	71
Deanwood	Orange	13.891	MD10	-	2	16	213		213	213
Cheverly	Orange	15.042	MD11	-	2	16	140		140	140
Landover	Orange	16.447	MD12	112.5	2	16	287		287	287
Beaver Dam Creek	Orange	17.395	MD13	75	2	16	266		266	266
New Carrollton Yard	Orange	18.314	MDY	1500	2	16	929	600	329	599
									1134(w/o MD11, 12, 13, Y)	

CAR LAYUP INFORMATION	NUMBER OF CARS NIGHT	NUMBER OF CARS MIDDAY
Silver Spring	36	24
Brentwood Yard	40	16
New Carrollton Yard	120	54
Ballston	24	6
National Airport	36	18

TABLE 5-11
COMPARISON OF MAXIMUM POWER DEMAND TO AVERAGE
FOR SEVERAL TRACTION ENERGY METER CONSOLIDATIONS

	AM PEAK		PM PEAK	
METER CONSOLIDATION	MAXIMUM DEMAND INTERVAL	$\frac{\text{MAX-AVG}}{\text{AVG}}$ (%)	MAXIMUM DEMAND INTERVAL	$\frac{\text{MAX-AVG}}{\text{AVG}}$ (%)
Red Line	7:30-8:00	29	17:15-17:45	31
Blue/Orange Line	7:00-7:30	31	16:45-17:15	25
DC Jurisdiction	7:45-8:15	19	17:45-18:15	18
VA Jurisdiction	8:15-8:45	67	18:15-18:45	86

Note: The MD consolidation was not considered because of missing data from several of the MD meters.

TABLE 5-12
RESULTS OF TEMPERATURE REGRESSION ANALYSES FOR SUPPORT METERS

RED LINE PASSENGER STATIONS		LOCATION	JURISDICTION	REVENUE SERVICE TIME* P_0(KW)	REVENUE SERVICE TIME* P_2(KWPADD)	NON-REVENUE SERVICE TIME** P_0(KW)	NON-REVENUE SERVICE TIME** P_2(KWPMDD)
Dupont Circle	(MSA3)	U	DC	350	0.85	298	1.05
Farragut North	(MSA2)	U	DC	327	1.75	319	2.25
Metro Center	(MSA1)	U	DC	373	2.95	384	3.57
Gallery Place	(MSB1)	U	DC	214	0.55	195	0.44
Judiciary Square	(MSB2)	U	DC	246	0.39	228	0.59
Union Station	(MSB3)	U	DC	261	1.39	243	1.47
Rhode Island Ave.	(MSB4)	A	DC	103	-4.81	69	-5.11
Brookland	(MSB5)	A	DC	112	-1.55	96	-1.47
Fort Totten	(MSB6)	A	DC	100	-1.16	89	-1.18
Takoma Park	(MSB7)	A	DC	77	-0.97	62	-0.99
Silver Spring	(MSB8)	A	MD	115	N	104	-0.25
BLUE/ORANGE LINE PASSENGER STATIONS							
Pentagon	(MSC7)	U	VA	398	1.23	364	1.17
Arlington Cemetery	(MSC6)	A	VA	106	-0.36	77	-0.42
Rosslyn	(MSC5)	U	VA	370	1.20	346	1.21
Foggy Bottom	(MSC4)	U	DC	189	0.57	165	0.63
Farragut West	(MSC3)	U	DC	305	1.48	296	1.75
McPherson Square	(MSC2)	U	DC	265	0.99	260	1.21
Metro Center	(MSC1)	U	DC	290	1.59	276	1.65
Federal Triangle	(MSD1)	U	DC	183	0.98	167	0.72
Smithsonian	(MSD2)	U	DC	255	0.24	223	0.19
L'Enfant Plaza	(MSD3)	U	DC	305	1.05	279	1.15
Federal Center	(MSD4)	U	DC	196	0.73	184	0.65
Capitol South	(MSD5)	U	DC	247	1.86	242	1.91
Eastern Market	(MSD6)	U	DC	102	N	95	N
Potomac Ave.	(MSD7)	U	DC	147	0.37	142	0.39
Stadium Armory	(MSD8)	U	DC	226	0.77	197	0.84
Minnesota Ave.	(MSD9)	A	DC	110	-1.34	100	-1.30
Deanwood	(MS10)	A	DC	95	-0.70	76	-0.65
Cheverly	(MS11)	A	MD	86	-0.36	94	0.35
Landover	(MS12)	A	MD	54	N	48	-0.69
New Carrollton	(MS13)	A	MD	111	N	151	N
Gallery Place	(MSE3)	U	DC	141	0.36	146	0.35
Archives	(MSE2)	U	DC	60	1.26	72	1.29
L'Enfant Plaza	(MSE1)	U	DC	198	0.51	182	0.52
OFFICE BUILDING AND REPAIR SHOPS							
Office Building	(MOB)		DC	1972	12.16	1594	9.3
T-St. Repair Shop	(MRS)		DC	579	0.63	522	N
Garden City Shop	(MGCS)		MD	273	-11.14	181	-14.9

*Revenue Operating Time

	Red Line	Blue/Orange Line
Weekdays	00:00-00:45; 05:15-24:00	00:00-00:45; 05:30-24:00
Saturdays	00:00-00:45; 07:30-24:00	00:00-00:45; 07:30-24:00
Sundays	09:30-18:45	

**Non-Revenue Operating Time

	Red Line	Blue/Orange Line
Weekdays	00:45-05:15	00:45-05:30
Saturdays	00:45-07:30	00:45-07:30
Sundays	00:00-09:30; 18:45-24:00	00:00-09:30; 18:45-24:00

N - Not significant with 95% Confidence Limits.

Regression Equations

$P = P_0 + P_2(DD)$

P : Average Power (KW)

P_0: Background Power (KW)

P_2: KWHPDD (Degree-Day Component Coefficient)

DD: Degree-Day

TABLE 5-13
TEMPERATURE DEPENDENT COEFFICIENTS OF REGRESSION ANALYSES LOAD DIFFERENCES FOR SUPPORT METER CONSOLIDATION

	P_2(KWPADD)		P_2(KWPMDD)	
	REVENUE SERVICE TIME		NON-REVENUE SERVICE TIME	
SUPPORT METER CONSOLIDATION	NEGATIVE	POSITIVE	NEGATIVE	POSITIVE
Red Line	8.49	7.88	9.00	9.37
Blue/Orange Line	2.76	15.19	3.06	15.98
DC Jurisdiction	10.53	33.43	10.7	29.76
MD Jurisdiction	11.50	0	15.84	0.35
VA Jurisdiction	0.36	2.43	0.42	2.73

	LOAD DIFFERENCES (KW)			
	P(30°)-P(70°)	P(90°)-P(70°)	P(20°)-P(70°)	P(80°)-P(70°)
Red Line	340	158	450	94
Blue/Orange Line	110	304	153	160
DC Jurisdiction	421	669	535	298
MD Jurisdiction	460	0	794	4
VA Jurisdiction	14	49	21	27

TABLE 5-14
AVERAGE SUPPORT POWER (KW) FOR PASSENGER STATIONS, OFFICE BUILDINGS AND REPAIR SHOPS DURING PRINCIPAL DAILY OPERATIONAL PERIODS

METER	JURIS-DICTION	WEEKDAY AM PEAK	WEEKDAY MIDDAY	WEEKDAY PM PEAK	WEEKDAY EVENING	WEEKDAY NIGHT	SATURDAY OPERATION	SATURDAY NIGHT	SUNDAY OPERATION	SUNDAY EVENING	SUNDAY NIGHT
RED LINE PASSENGER STATIONS											
Dupont Circle (MSA3)	DC	369	368	380	376	317	361	314	354	309	307
Farragut North (MSA2)	DC	360	357	359	354	318	336	312	341	318	313
Metro Center (MSA1)	DC	411	405	410	408	389	403	370	398	376	377
Gallery Place (MSB1)	DC	216	217	220	218	196	220	297	205	187	185
Judiciary Square (MSB2)	DC	257	255	256	251	229	240	225	236	223	223
Union Station (MSB3)	DC	278	283	280	273	244	270	242	267	242	242
Rhode Island Avenue (MSB4)	DC	70	63	63	94	89	76	84	61	83	76
Brookland (MSB5)	DC	102	92	104	109	100	104	101	97	98	96
Fort Totten (MSB6)	DC	86	83	83	104	93	88	90	83	88	87
Takoma Park (MSB7)	DC	77	72	70	86	70	76	69	70	77	67
Silver Spring (MSB8)	MD	117	109	108	125	106	110	107	105	113	105
BLUE/ORANGE LINE PASSENGER STATIONS											
Pentagon (MSC7)	VA	417	401	411	415	368	397	364	392	378	365
Arlington Cemetery (MSC6)	VA	106	95	107	104	79	100	82	98	93	81
Rosslyn (MSC5)	VA	388	385	391	384	352	376	343	358	332	330
Foggy Bottom (MSC4)	DC	195	188	189	186	168	185	165	185	170	168
Farragut West (MSC3)	DC	330	324	325	327	300	309	285	316	296	283
McPherson Square (MSC2)	DC	288	291	293	285	254	269	254	270	254	256
Metro Center (MSC1)	DC	309	309	309	306	277	309	279	308	280	279
Federal Triangle (MSD1)	DC	194	192	198	195	180	190	167	187	176	161
Smithsonian (MSD2)	DC	268	261	257	249	225	257	224	258	221	219
L'Enfant Plaza (MSD3)	DC	332	324	327	324	283	304	286	303	283	282
Federal Center (MSD4)	DC	208	203	209	203	182	200	180	201	183	181
Capitol South (MSD5)	DC	264	261	266	262	239	259	241	263	246	243
Eastern Market (MSD6)	DC	88	88	88	88	85	101	97	90	88	92
Potomac Avenue (MSD7)	DC	147	147	152	146	135	145	129	148	136	132
Stadium Armory (MSD8)	DC	229	231	236	233	202	230	200	227	203	196
Minnesota Avenue (MSD9)	DC	96	94	96	114	100	106	103	100	107	101
Deanwood (MS10)	DC	88	82	82	100	80	87	78	80	83	75
Cheverly (MS11)	MD	88	78	77	108	94	92	97	79	96	87
Landover (MS12)	MD	54	49	53	61	51	54	53	43	47	48
New Carrollton (MS13)	MD	146	125	124	215	216	155	200	121	191	179
Gallery Place (MSE3)	DC	148	145	144	145	146	144	148	143	144	145
Archives (MSE2)	DC	72	72	73	73	72	73	73	71	71	71
L'Enfant Plaza (MSE1)	DC	208	209	209	204	183	201	184	201	185	183
OFFICE BUILDING AND REPAIR SHOPS											
Total Office and Shop		3197	3382	3202	2806	2377	2427	2260	2085	2130	2085
Office Building (MOB)	DC	2382	2516	2380	1969	1651	1689	1459	1471	1419	1311
T-St. Repair Shop (MRS)	DC	557	640	606	603	510	533	533	411	507	515
Garden City Shop (MGCS)	MD	258	226	216	234	216	205	268	203	204	259

TABLE 5-15
AVERAGE SUPPORT POWER FOR METER CONSOLIDATIONS AT VARIOUS OPERATING PERIODS

	WEEKDAY					SATURDAY		SUNDAY		
	AM PEAK	MIDDAY	PM PEAK	EVENING	NIGHT	OPERATION	NIGHT	OPERATION	EVENING	NIGHT
PASSENGER STATION (KW)										
Red Line	2343	2304	2333	2398	2151	2284	2111	2217	2114	2078
Blue/Orange Line	4663	4554	4616	4728	4271	4543	4232	4442	4263	4157
DC Jurisdiction	5690	5616	5678	5714	5156	5543	5097	5463	5127	5040
MD Jurisdiction	405	361	362	509	467	411	457	348	447	419
VA Jurisdiction	911	881	909	903	799	873	789	848	803	776
ALL SUPPORT METERS INCLUDING OFFICE BUILDING AND REPAIR FACILITIES (KW)										
DC Jurisdiction	8629	8772	8664	8286	7317	7765	7089	7345	7053	6866
MD Jurisdiction	663	587	578	743	683	616	725	551	651	678

TABLE 5-16
SUMMARY OF LIGHTING LOADS BY PASSENGER STATION

STATION (METER SYMBOL)	JURIS-DICTION	STATION LOCATION	STATION TYPE	NUMBER OF PARKING SPACES	STATION LIGHTING (KW)	PARKING LOT LIGHTING (KW)***	TOTAL LIGHTING (KW)
RED LINE STATIONS							
Dupont Circle (MSA3)	DC	U	S		120		120
Farragut North (MSA2)	DC	U	C		70		70
Metro Center (MSA1)	DC	U	S		120		120
Gallery Place (MSB1)	DC	U	S		120		120
Judiciary Square (MSB2)	DC	U	C		120		120
Union Station (MSB3)	DC	U	C		70		70
Rhode Island Avenue (MSB4)	DC	A	C	300	30	9	39
Brookland (MSB5)	DC	A	C		30		30
Fort Totten (MSB6)	DC	A	C	300	30	9	39
Takoma Park (MSB7)	DC	A	C	1000	30	30	60
Silver Spring (MSB8)	MD	A	C		30		30
BLUE/ORANGE LINE STATIONS							
Pentagon (MSC7)	VA	U	S**		130		130
Arlington Cemetery (MSC6)	VA	A	S		40		40
Rosslyn (MSC5)	VA	U	S**		130		130
Foggy Bottom (MSC4)	DC	U	C		70		70
Farragut West (MSC3)	DC	U	S		120		120
McPherson Square (MSC2)	DC	U	S		120		120
Metro Center (MSC1)	DC	U	C		70		70
Federal Triangle (MSD1)	DC	U	C		70		70
Smithsonian (MSD2)	DC	U	S		120		120
L'Enfant Plaza (MSD3)	DC	U	C		70		70
Federal Center (MSD4)	DC	U	C		70		70
Capitol South (MSD5)	DC	U	C		70		70
Eastern Market (MSD6)	DC	U	C		70		70
Potomac Avenue (MSD7)	DC	U	C		70		70
Stadium Armory (MSD8)	DC	U	C		70		70
Minnesota Avenue (MSD9)	DC	A	C	250	30	7	37
Deanwood (MS10)	DC	A	C	220	30	7	37
Cheverly (MS11)	MD	A	S	500	40	15	55
Landover (MS12)	MD	A	C	1000	30	30	60
New Carrollton (MS13)	MD	A	C	1900	30	56	86
Gallery Place (MSE3)*	DC	U	C		70		70
Archives (MSE2)*	DC	U	C		70		70
L'Enfant Plaza (MSE1)*	DC	U	S		120		120

Note: U - underground A - above ground S - side platform C - center platform
*Green/Yellow Line
**two level
***based on 30 watts per space

TABLE 5-17
SUMMARY OF LIGHTING LOADS BY METER CONSOLIDATIONS

SUPPORT METER CONSOLIDATIONS	PARKING LIGHTING	(KW) STATION LIGHTING	TOTAL LIGHTING
Red Line Passenger Stations	48	770	818
Blue/Orange Passenger Stations*	115	1830	1945
DC Passenger Stations	62	2050	2112
MD Passenger Stations	101	130	231
VA Passenger Stations	0	300	300

*Includes three Green/Yellow Line stations which were on during 1980: L'Enfant Plaza, Gallery Place and Archives.

TABLE 5-18
PASSENGER STATION AVERAGE DAILY POWER OF ESCALATORS

PASSENGER STATION (METER)	JURISDICTION	TOTAL ESCALATOR RISE (FT)	DAILY KW***
RED LINE PASSENGER STATION			
Dupont Circle (MSA3)	DC	540	59
Farragut North (MSA2)	DC	307	34
Metro Center (MSA1)	DC	576	63
Gallery Place (MSB1)	DC	99	11
Judiciary Square (MSB2)	DC	187	21
Union Station (MSB3)	DC	159	17
Rhode Island Avenue (MSB4)	DC	64	7
Brookland (MSB5)	DC	89	10
Fort Totten (MSB6)	DC	85	9
Takoma Park (MSB7)	DC	76	8
Silver Spring (MSB8)	MD	116	13
BLUE/ORANGE LINE PASSENGER STATIONS			
Pentagon (MSC7)	DC	481	53
Arlington Cemetery (MSC6)	VA	219	24
Rosslyn (MSC5)	VA	483	53
Foggy Bottom (MSC4)	DC	134	15
Farragut West (MSC3)	DC	229	25
McPherson Square (MSC2)	DC	266	29
Metro Center (MSC1)	DC	*	*
Federal Triangle (MSD1)	DC	106	12
Smithsonian (MSD2)	DC	237	26
L'Enfant Plaza (MSD3)	DC	720	79
Federal Center (MSD4)	DC	152	17
Capitol South (MSD5)	DC	166	18
Eastern Market (MSD6)	DC	139	15
Potomac Avenue (MSD7)	DC	156	17
Stadium Armory (MSD8)	DC	279	31
Minnesota Avenue (MSD9)	DC	86	9
Deanwood (MS10)	DC	67	7
Cheverly (MS11)	MD	117	13
Landover (MS12)	MD	43	5
New Carrollton (MS13)+	MD	71	8
Gallery Place (MSE3)	DC	**	**
Archives (MSE2)	DC	**	**
L'Enfant Plaza (MSE1)+	DC	**	**

*Included with MSA1 Metro Center.
**Escalators not on in 1980.
***Calculated on basis of 0.11 kw/ft.
+These escalators to lower levels were not in service in 1980.

TABLE 5-19
COMPARISON OF PREDICTED DAILY AVERAGE ESCALATOR POWER WITH OBSERVATION USING SIMPLE ESCALATOR POWER FORMULA

SUPPORT METER CONSOLIDATION	KW(PEAK)	KW(NIGHT)	KW(PEAK)- KW(NIGHT)*	KW(ESC.)*
Underground Stations	5552	4943	609	595

*Based on the assumption that all escalators operate during the peak periods and that only the escalators in underground stations are turned off at non-revenue service time, the value 595KW computed using the simple escalator formula compares well with the actual measured power of 609KW.

TABLE 5-20
SUMMARY OF BACKGROUND, LIGHTING AND ESCALATOR POWER (KW)
FOR SUPPORT METERS AT PASSENGER STATIONS

	PEAK**	MIDDAY**	EVENING	NON-REVENUE
RED LINE				
Background*	1470	1470	1470	1470
Lighting	620	620	820	620
Escalators	250	250	250	0
Total	2340	2340	2540	2090
Actual Total	2340	2300	2400	2130
BLUE/ORANGE LINE				
Background*	2555	2555	2555	2555
Lighting	1630	1630	1945	1630
Escalators	455	455	455	0
Total	4640	4640	4955	4185
Actual Total	4640	4550	4730	4270
DC JURISDICTION				
Background*	3275	3275	3275	3275
Lighting	1870	1870	1945	1870
Escalators	540	540	540	0
Total	5685	5685	5760	5145
Actual Total	5685	5615	5715	5160
MD JURISDICTION				
Background*	340	340	340	340
Lighting	0	0	230	0
Escalators	40	40	40	0
Total	380	380	510	340
Actual Total	380	360	510	465
VA JURISDICTION				
Background*	520	520	520	520
Lighting	260	260	300	260
Escalators	130	130	130	0
Total	910	910	950	780
Actual Total	910	880	900	800

*The background is determined by subtracting the underground station lighting load and escalator load from the average support power during peak periods.
**Only underground station lighting is on during these periods.

TABLE 5-21
AVERAGE POWER DEMAND DURING PEAK PERIODS AND DAILY ENERGY CONSUMPTION OF OFFICE BUILDINGS AND REPAIR SHOP

	OFFICE BUILDING (DC) (MOB)	T-ST. REPAIR SHOP (DC) (MRS)	GARDEN CITY SHOP (MD) (MGCS)
POWER DEMAND (KW)			
AM Peak (8:00-9:00AM)	2280	610	290
PM Peak (16:00-17:00PM)	2205	590	235
ENERGY CONSUMPTION (KWH)			
Weekday	47510	13835	6865
Saturday	37375	12525	6570
Sunday	32025	11795	5410
ANNUAL ENERGY USE (MWH)	16000	4900	2400

TABLE 5-22
PASSENGER STATION LIGHTING AND ESCALATOR LOADS
PROVIDED BY VEPCO

PASSENGER STATION	LOCATION	TYPE	LIGHTING LOAD (KW)	ESCALATOR RISE (ft)	AVERAGE ESCALATOR POWER (KW)(0.11/ft rise)
National Airport	A	C&S	70*	84	9
Crystal City	U	S	120	191	21
Pentagon City	U	S	120	169	19
Courthouse	U	C	70	219	24
Clarendon	U	S	120	114	13
Virginia Square	U	S	120	144	16
Ballston	U	S	120	168	18
TOTAL			740		120

A - above ground

U - underground

C - center platform

S - side platform

TABLE 5-23
SUMMARY OF BACKGROUND, LIGHTING AND ESCALATOR SUPPORT POWER (KW) FURNISHED BY VEPCO

	PEAK	MIDDAY	EVENING	NON-REVENUE
Background	1065	1065	1065	1065
Lighting	670	670	740	670
Escalator	120	120	120	0
TOTAL	1855	1855	1925	1735

AVERAGE DATA ON THE PEPCO SERVICED PASSENGER STATIONS USED IN DETERMINING BACKGROUND

LOCATION	TYPE	AVERAGE BACKGROUND (KW)	
U	C	147	
U	S	167	
A	C	84	} Average 81
A	S	77	

TABLE 5-24

ESTIMATE OF SUPPORT ENERGY USE AND AVERAGE PEAK POWER DEMAND BY UTILITY/JURISDICTION

		P E P C O			VEPCO
ANNUAL SUPPORT ENERGY (MWH)	HRS/WEEK	DC	MD	VA	
Background	168	49400(72)	5400(90)	4500(58)	9300(58)
Lighting					
Underground	168	16300	0	2300	5900
Above Ground	36	100	400	100	100
Total		16400(24)	400(7)	2400(32)	6000(38)
Escalators	114	3200(4)	200(3)	800(10)	700(4)
TOTAL		69000(100)	6000(100)	7700(100)	16000(100)

( ) indicates % of total support energy.

	DC	MD	VA	VEPCO
SUPPORT PEAK POWER DEMAND (KW)				
Station Background	3275	340	520	1065
Office and Repair Shop Background	2890	290	0	0
Station Lighting	1870	0	260	670
Station Escalators	540	40	130	120
TOTAL	8575	670	910	1855
AVERAGE POWER (KW) USED FOR ENERGY COMPUTATION				
Station Lighting				
Underground	1870	0	260	670
Above Ground	75	230	40	70
Station Escalators	540	40	130	120

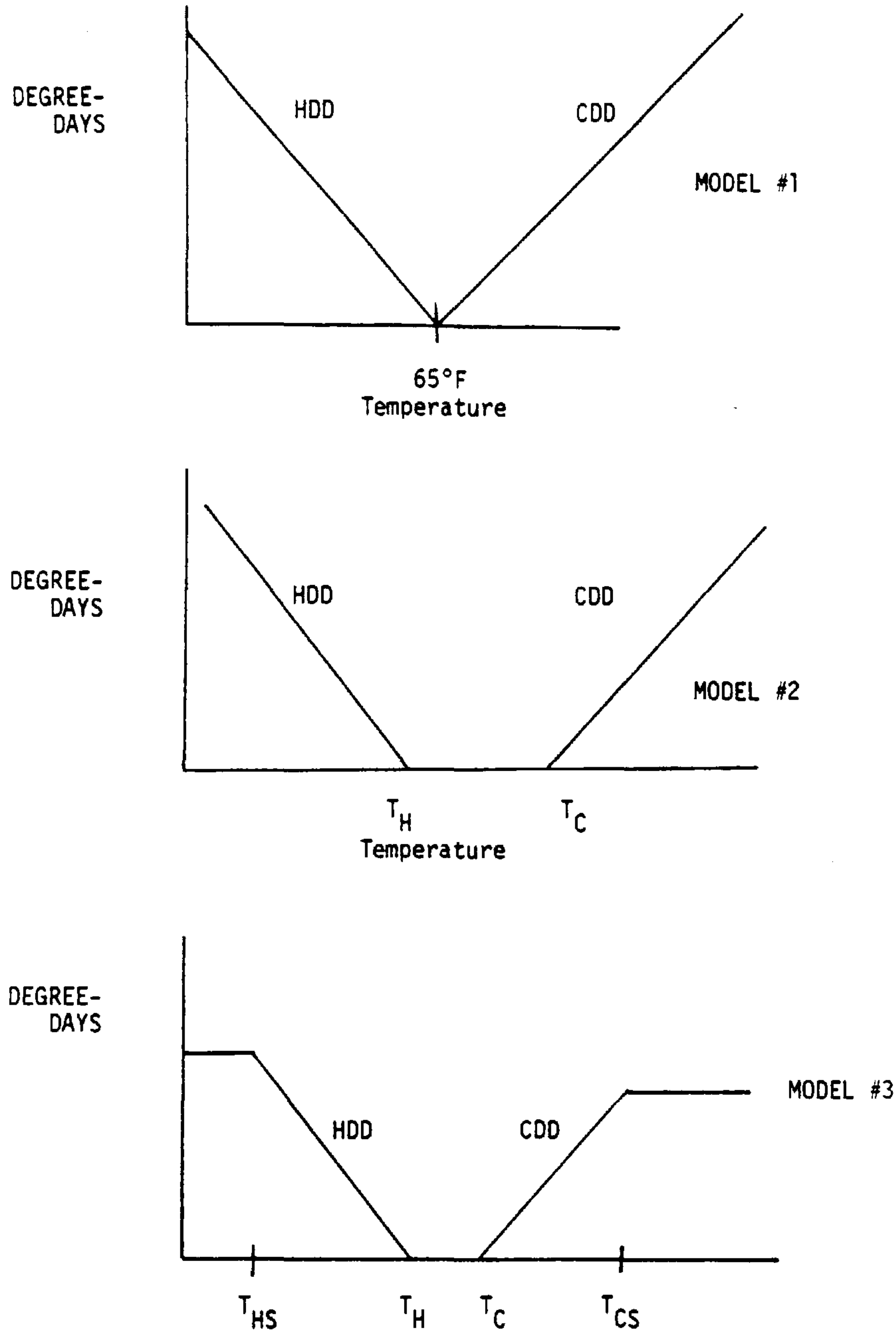

DEGREE-DAYS
HDD
CDD
MODEL #1
65°F
Temperature
DEGREE-DAYS
HDD
CDD
MODEL #2
T_H
T_C
Temperature
DEGREE-DAYS
HDD
CDD
MODEL #3
T_{HS}
T_H
T_C
T_{CS}

FIGURE 5-1

OBSERVED VS PREDICTED DAILY ENERGY USE
(KWH)

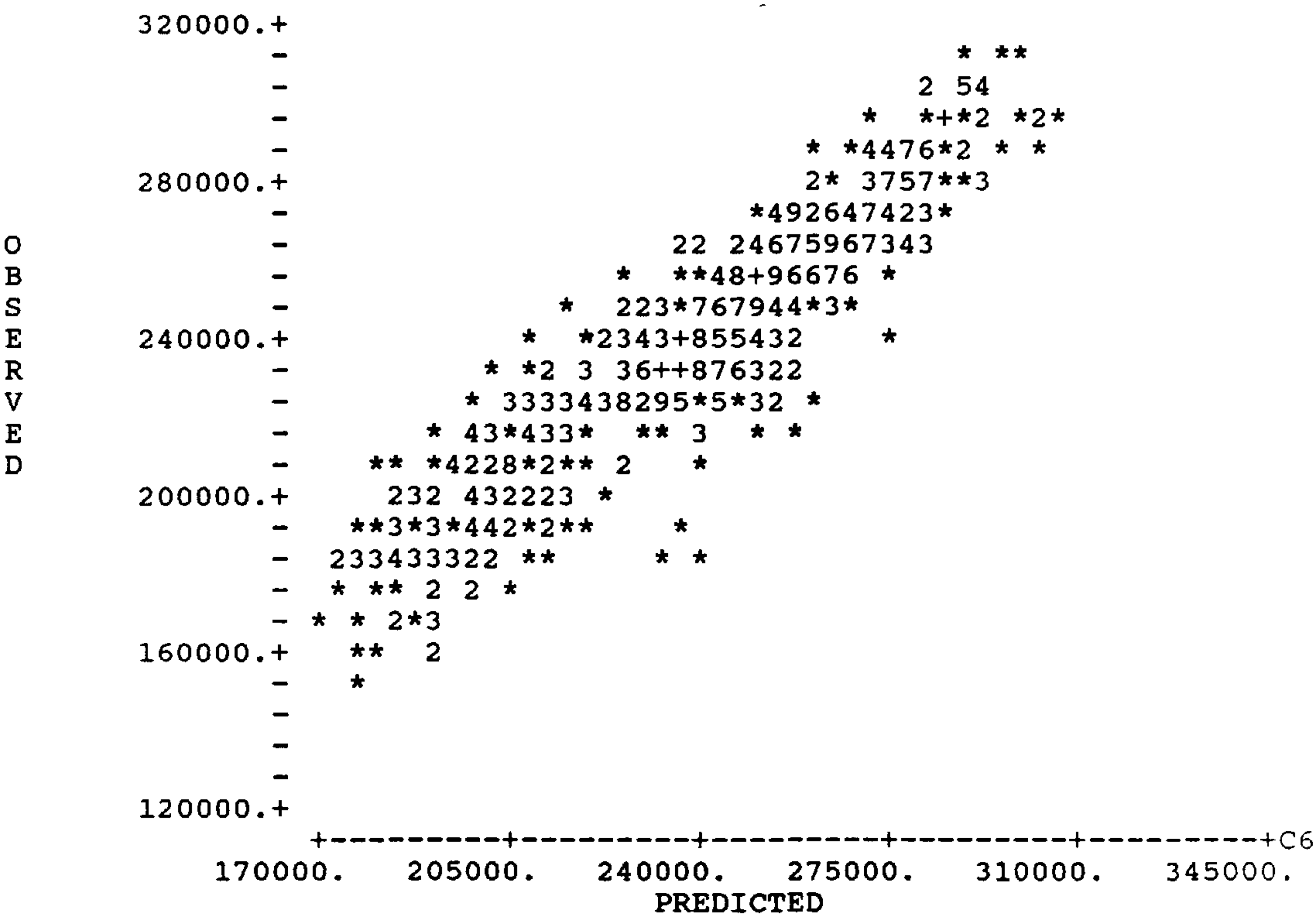
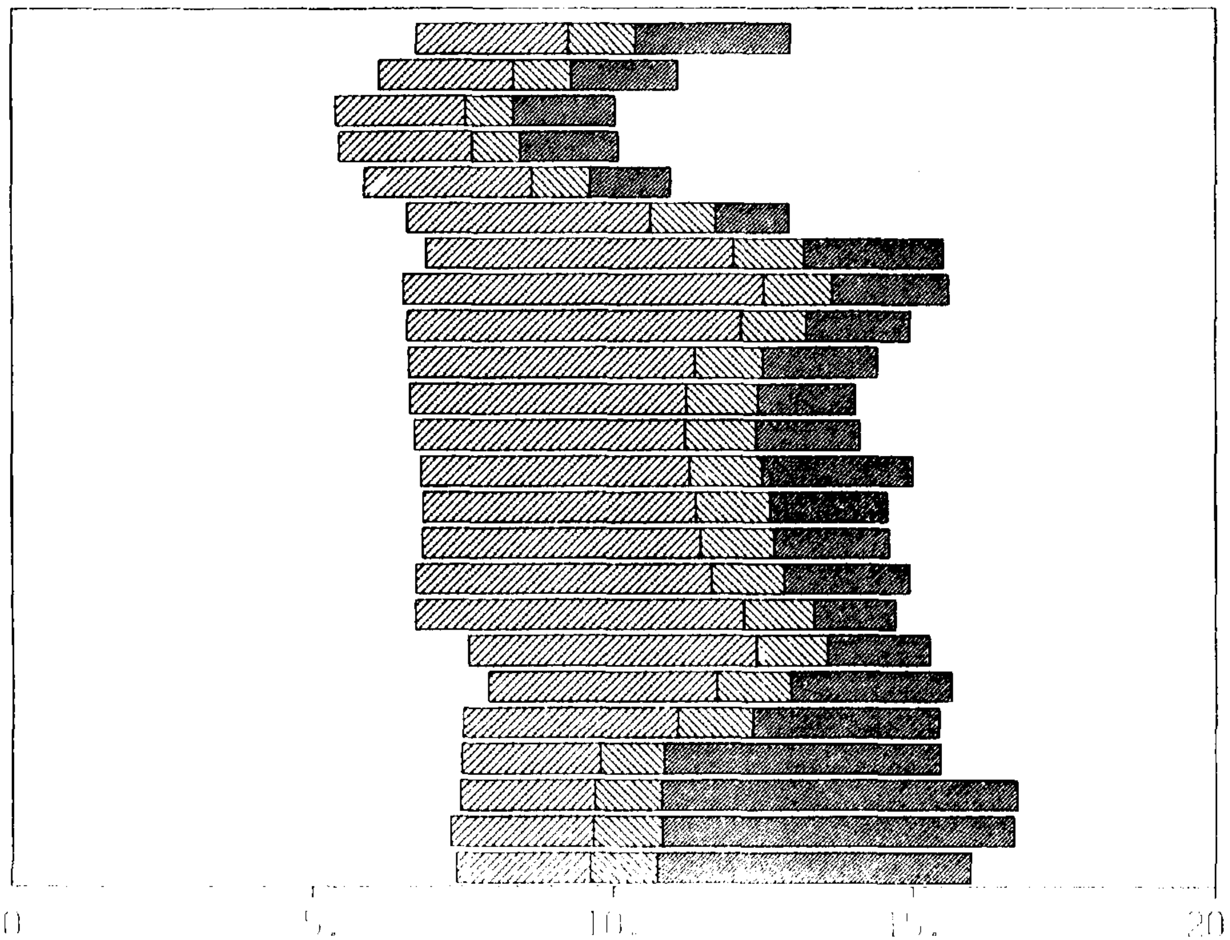


FIGURE 5-2

MARTA METER SUMMARY STATISTICS

ALL COINCIDENT ALL DAYS

MIN, AVE, AVE+STD, MAX



HR	DATE-MIN	DATE-MAX
1	5-30-83	3- 1-84
2	11-28-83	3- 1-84
3	12-22-83*	2- 7-84
4	12-21-83	1-18-83
5	11-24-83	5- 9-84
6	5-30-83	2- 8-84
7	5-30-83	2- 7-84
8	5-30-83	1-20-84
9	11-24-83	2- 7-84
10	11-24-83	2- 7-84
11	11-24-83	1-20-84
12	11-24-83	7-27-84
13	11-24-83	2-17-83
14	11-24-83	7-25-84
15	11-24-83	7-25-84
16	11-24-83	7-25-84
17	11-24-83	7-24-84
18	11-24-83	6-29-84
19	5-28-84	6-29-84
20	4-25-83	6-29-84
21	5- 4-83	6-29-84
22	5- 4-83	6-29-84*
23	5- 9-83	6-29-84
24	12-22-83	6-29-84

* ABSOLUTE MAX OR MIN

FIGURE 5-3

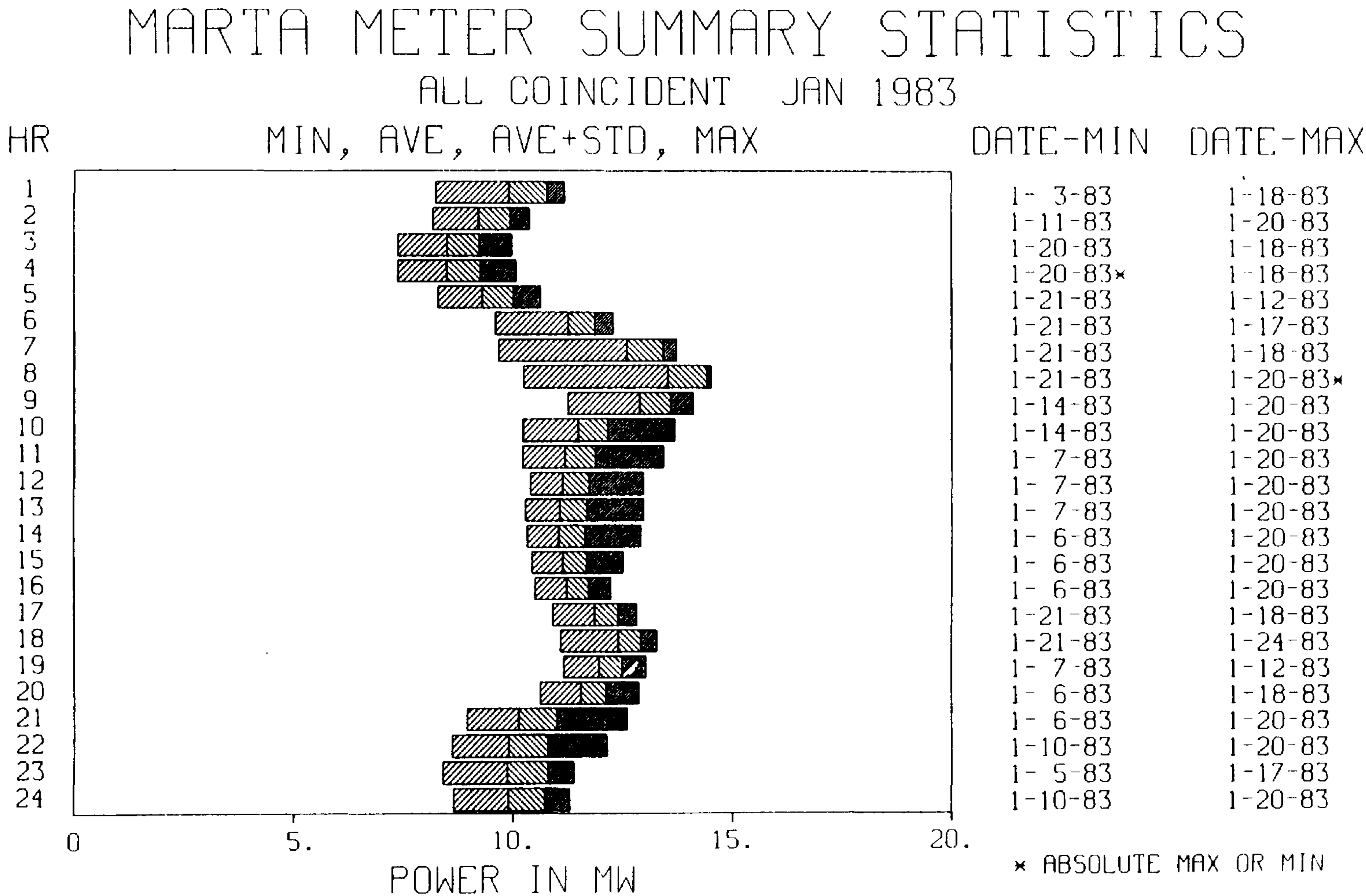
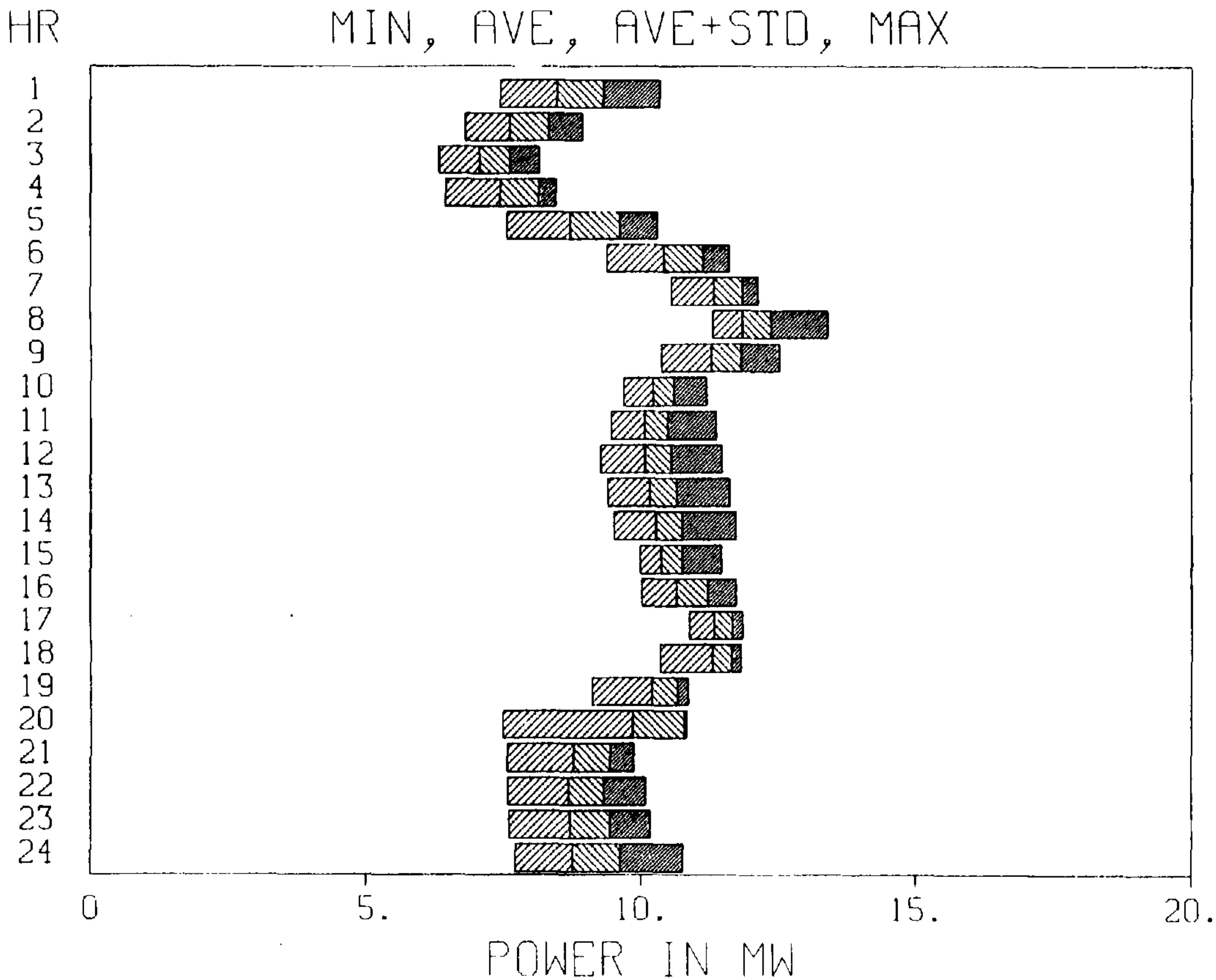

MARTA METER SUMMARY STATISTICS
ALL COINCIDENT JAN 1983
HR
MIN, AVE, AVE+STD, MAX
DATE-MIN DATE-MAX
1 1- 3-83 1-18-83
2 1-11-83 1-20-83
3 1-20-83 1-18-83
4 1-20-83* 1-18-83
5 1-21-83 1-12-83
6 1-21-83 1-17-83
7 1-21-83 1-18-83
8 1-21-83 1-20-83*
9 1-14-83 1-20-83
10 1-14-83 1-20-83
11 1- 7-83 1-20-83
12 1- 7-83 1-20-83
13 1- 7-83 1-20-83
14 1- 6-83 1-20-83
15 1- 6-83 1-20-83
16 1- 6-83 1-20-83
17 1-21-83 1-18-83
18 1-21-83 1-24-83
19 1- 7-83 1-12-83
20 1- 6-83 1-18-83
21 1- 6-83 1-20-83
22 1-10-83 1-20-83
23 1- 5-83 1-17-83
24 1-10-83 1-20-83
0
5.
10.
15.
20.
POWER IN MW
* ABSOLUTE MAX OR MIN

FIGURE 5-4

MARTA METER SUMMARY STATISTICS

ALL COINCIDENT APR 1983



HR	DATE-MIN	DATE-MAX
1	4-25-83	4-21-83
2	4-29-83	4-21-83
3	4- 8-83*	4-22-83
4	4- 8-83	4-26-83
5	4- 8-83	4-26-83
6	4- 8-83	4-25-83
7	4-13-83	4-25-83
8	4-28-83	4-20-83*
9	4-29-83	4-20-83
10	4-14-83	4-27-83
11	4- 8-83	4-27-83
12	4- 8-83	4-27-83
13	4- 8-83	4-27-83
14	4- 8-83	4-27-83
15	4- 7-83	4-27-83
16	4- 8-83	4-27-83
17	4-22-83	4-19-83
18	4-25-83	4-18-83
19	4-25-83	4-18-83
20	4-25-83	4-20-83
21	4-29-83	4-20-83
22	4-29-83	4-20-83
23	4-29-83	4-21-83
24	4-29-83	4-21-83

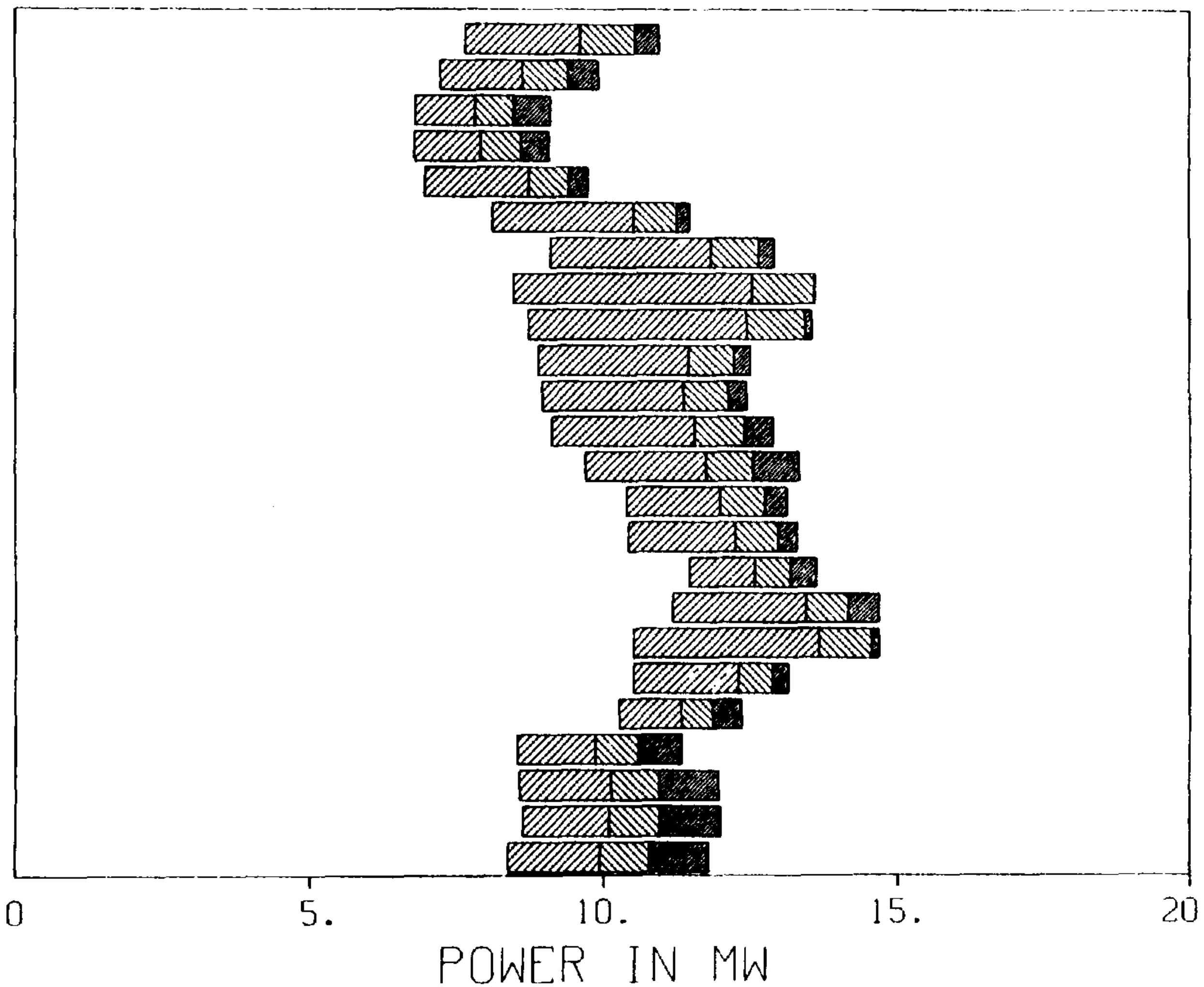
* ABSOLUTE MAX OR MIN

FIGURE 5-5

MARTA METER SUMMARY STATISTICS

ALL COINCIDENT JUL 1983

MIN, AVE, AVE+STD, MAX



HR	DATE-MIN	DATE-MAX
1	7-25-83	7-20-83
2	7- 4-83	7-22-83
3	7- 4-83	7-22-83
4	7- 4-83*	7-15-83
5	7- 4-83	7-29-83
6	7- 4-83	7-15-83
7	7- 4-83	7-15-83
8	7- 4-83	7-14-83
9	7- 4-83	7-13-83
10	7- 4-83	7-13-83
11	7- 4-83	7-13-83
12	7- 4-83	7-22-83
13	7- 4-83	7-20-83
14	7- 4-83	7-20-83
15	7- 4-83	7-22-83
16	7- 4-83	7-22-83
17	7- 4-83	7-22-83
18	7- 4-83	7-27-83*
19	7- 4-83	7-27-83
20	7-25-83	7-21-83
21	7-25-83	7-22-83
22	7- 7-83	7-21-83
23	7- 7-83	7-22-83
24	7- 7-83	7-22-83

* ABSOLUTE MAX OR MIN

FIGURE 5-6

MARTA METER SUMMARY STATISTICS

ALL COINCIDENT OCT 1983

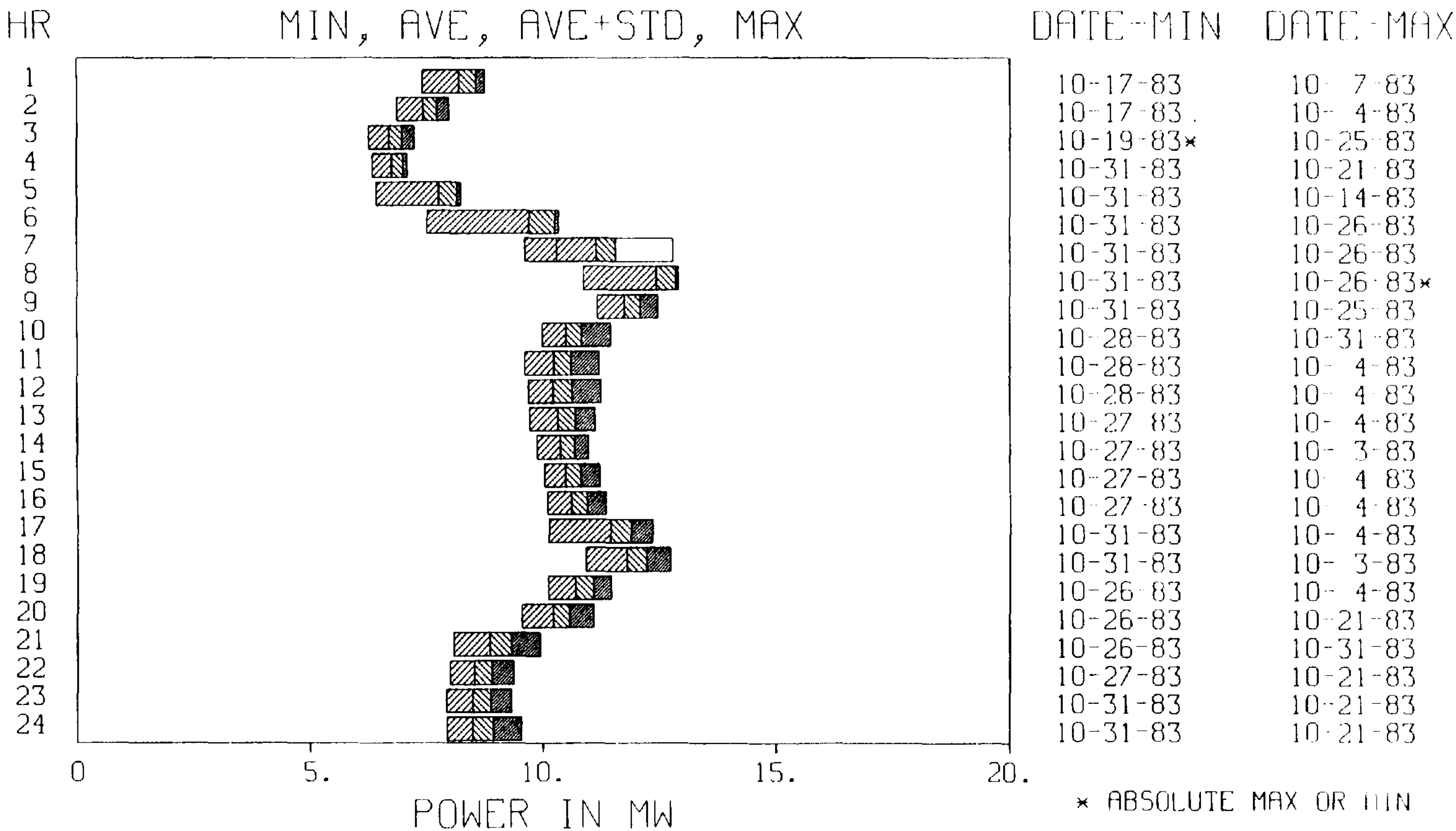


FIGURE 5-7

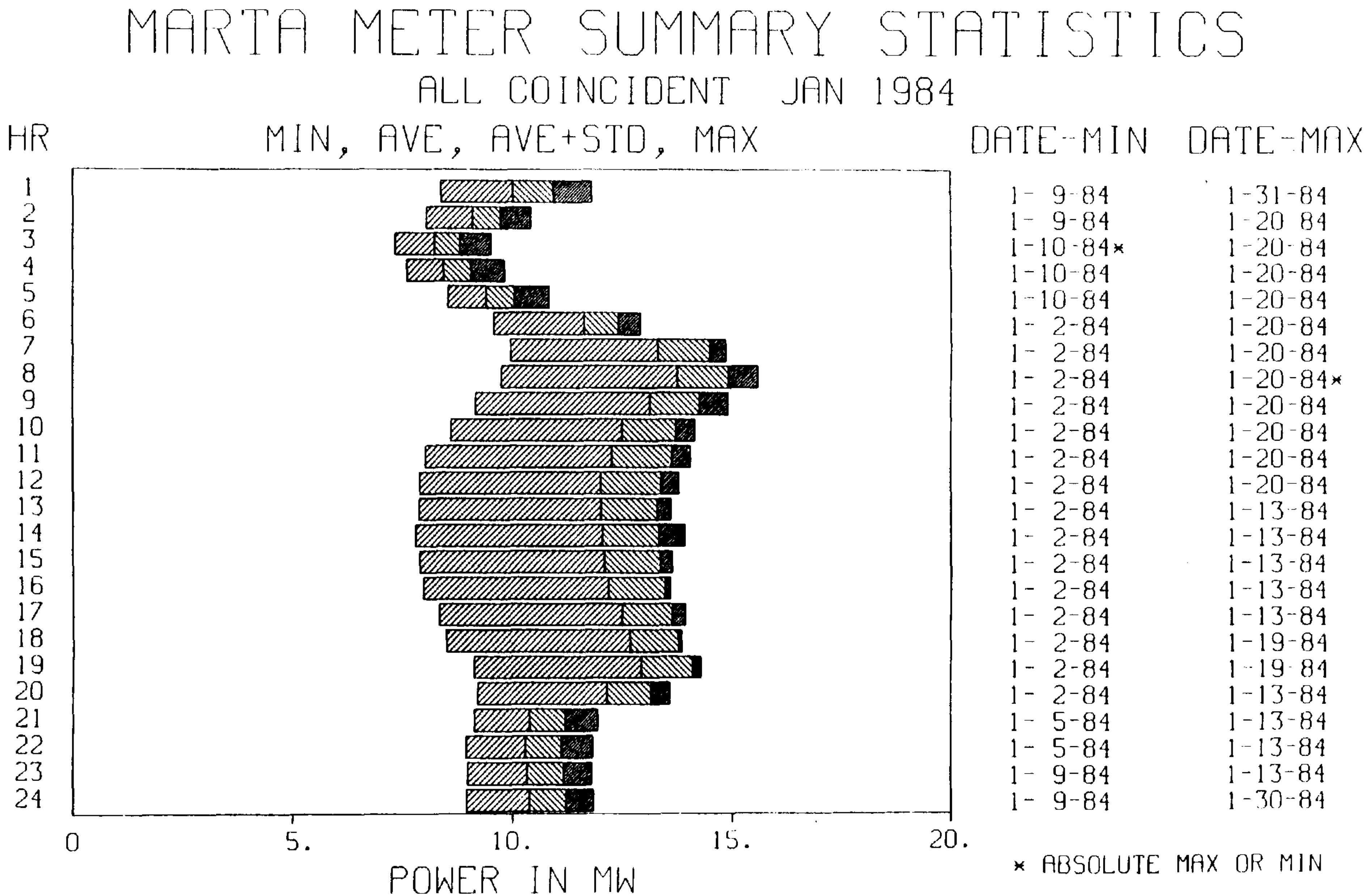

MARTA METER SUMMARY STATISTICS
ALL COINCIDENT JAN 1984
HR
MIN, AVE, AVE+STD, MAX
DATE-MIN DATE-MAX
1 1- 9-84 1-31-84
2 1- 9-84 1-20-84
3 1-10-84* 1-20-84
4 1-10-84 1-20-84
5 1-10-84 1-20-84
6 1- 2-84 1-20-84
7 1- 2-84 1-20-84
8 1- 2-84 1-20-84*
9 1- 2-84 1-20-84
10 1- 2-84 1-20-84
11 1- 2-84 1-20-84
12 1- 2-84 1-20-84
13 1- 2-84 1-13-84
14 1- 2-84 1-13-84
15 1- 2-84 1-13-84
16 1- 2-84 1-13-84
17 1- 2-84 1-13-84
18 1- 2-84 1-19-84
19 1- 2-84 1-19-84
20 1- 2-84 1-13-84
21 1- 5-84 1-13-84
22 1- 5-84 1-13-84
23 1- 9-84 1-13-84
24 1- 9-84 1-30-84
0
5.
10.
15.
20.
POWER IN MW
* ABSOLUTE MAX OR MIN

FIGURE 5-8

MARTA METER SUMMARY STATISTICS

ALL COINCIDENT APR 1984

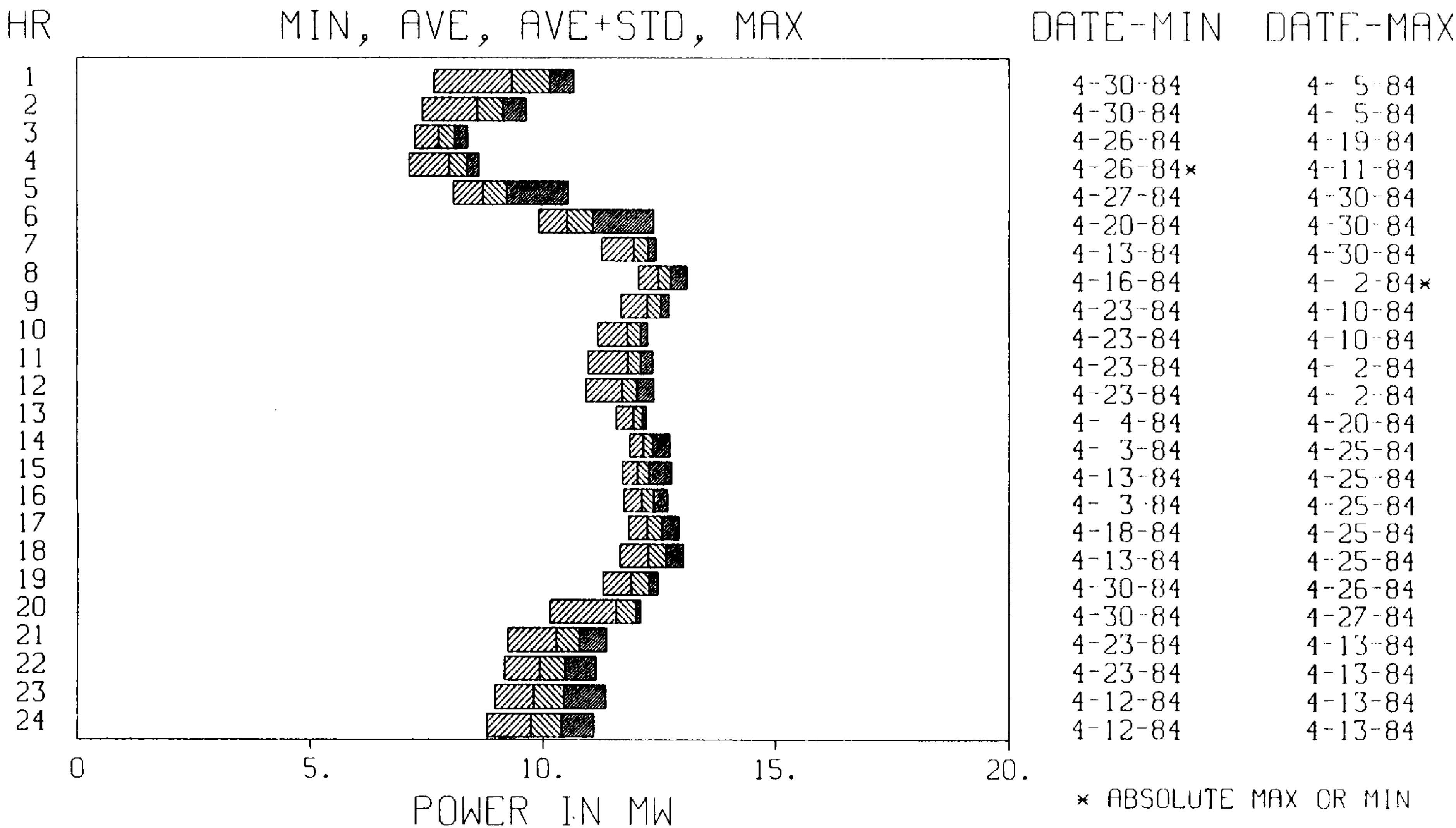
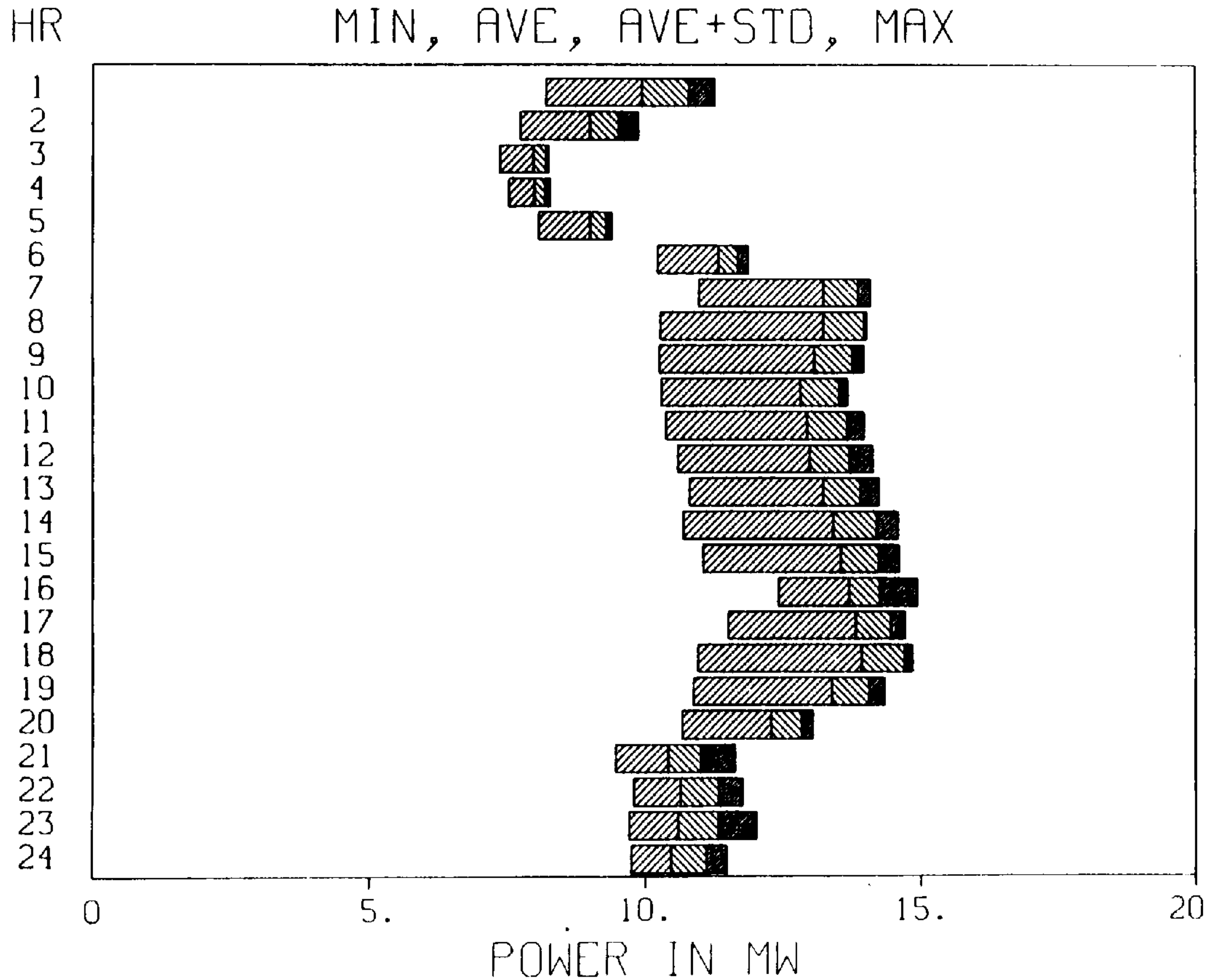


FIGURE 5-9

MARTA METER SUMMARY STATISTICS

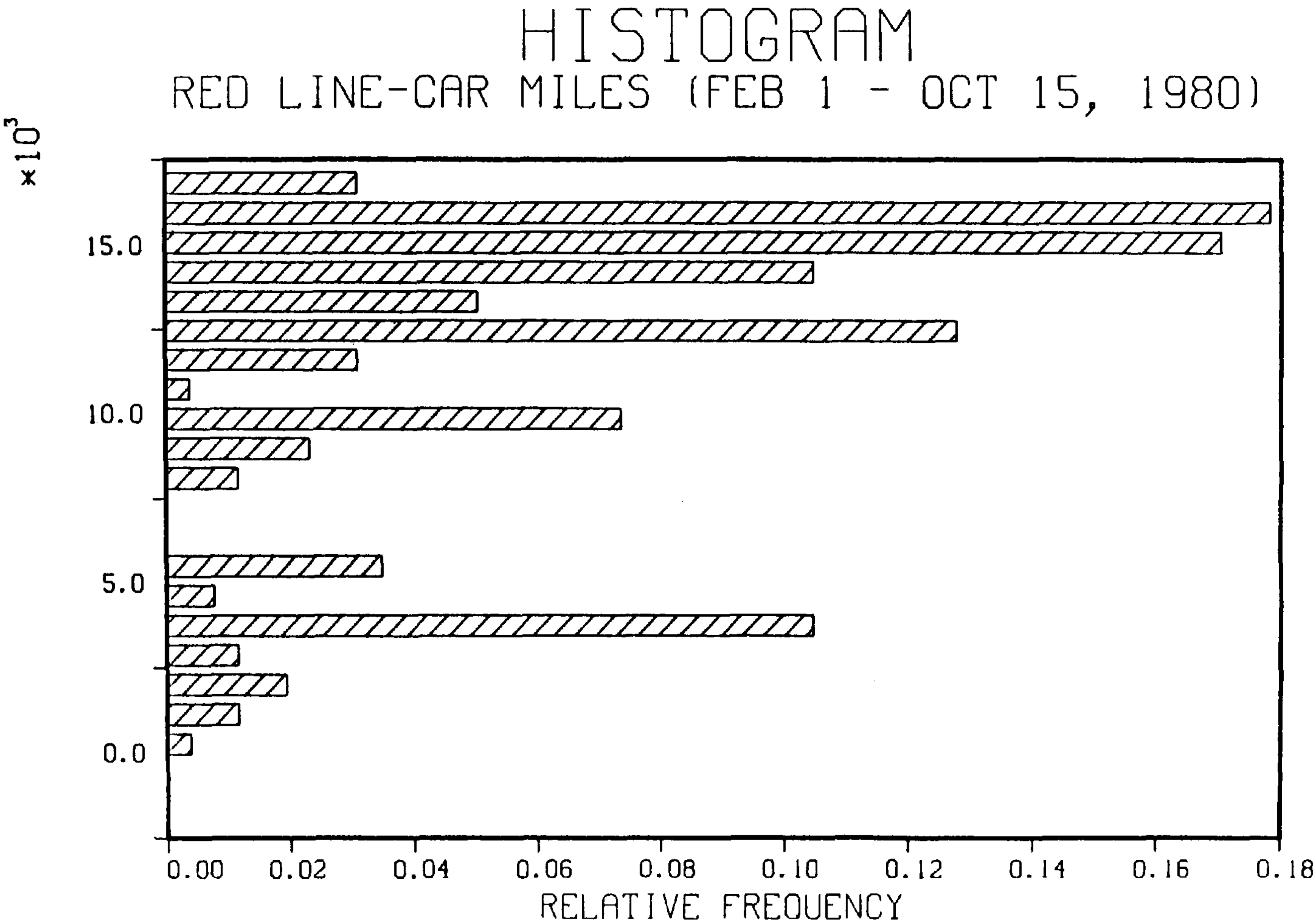
ALL COINCIDENT JUL 1984



HR	DATE-MIN	DATE-MAX
1	7-23-84	7-13-84
2	7-23-84	7-13-84
3	7-23-84*	7-25-84
4	7-23-84	7-13-84
5	7- 4-84	7-31-84
6	7- 4-84	7-27-84
7	7- 4-84	7-25-84
8	7- 4-84	7-25-84
9	7- 4-84	7-25-84
10	7- 4-84	7-25-84
11	7- 4-84	7-12-84
12	7- 4-84	7-27-84
13	7- 4-84	7-27-84
14	7- 4-84	7-25-84
15	7- 4-84	7-25-84
16	7- 4-84	7-25-84*
17	7- 4-84	7-24-84
18	7- 4-84	7-25-84
19	7- 4-84	7-24-84
20	7- 4-84	7-13-84
21	7-17-84	7-10-84
22	7-18-84	7-10-84
23	7-16-84	7-13-84
24	7-16-84	7-12-84

* ABSOLUTE MAX OR MIN

FIGURE 5-10



HISTOGRAM
RED LINE-CAR MILES (FEB 1 - OCT 15, 1980)
*10^3
15.0
10.0
5.0
0.0
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
RELATIVE FREQUENCY

FIGURE 5-11

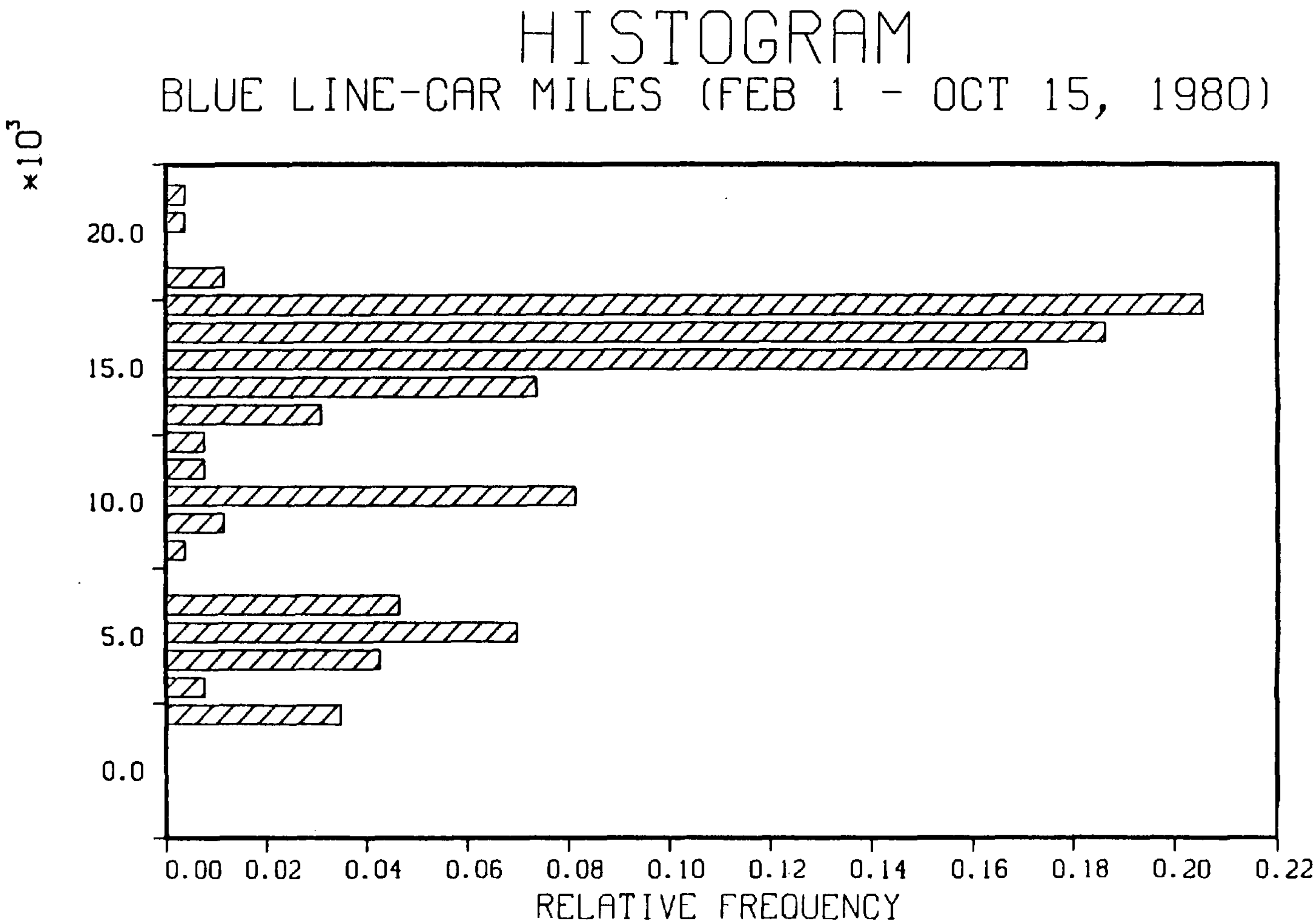

HISTOGRAM
BLUE LINE-CAR MILES (FEB 1 - OCT 15, 1980)
*10³
20.0
15.0
10.0
5.0
0.0
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
RELATIVE FREQUENCY

FIGURE 5-12

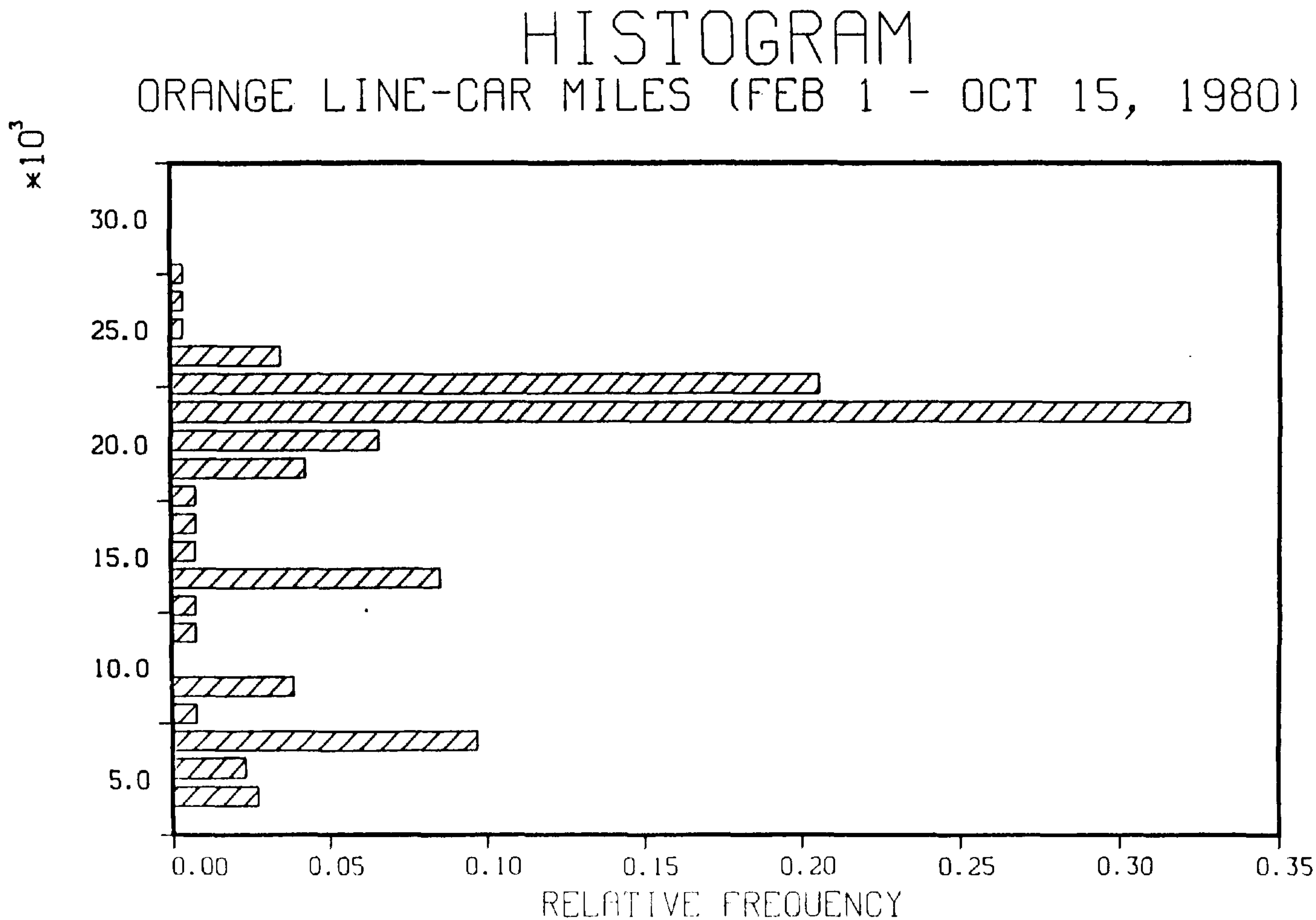

HISTOGRAM
ORANGE LINE-CAR MILES (FEB 1 - OCT 15, 1980)
*10^3
30.0
25.0
20.0
15.0
10.0
5.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
RELATIVE FREQUENCY

FIGURE 5-13

HISTOGRAM
AVERAGE DEGREE DAY (FEB 1 - OCT 15, 1980)

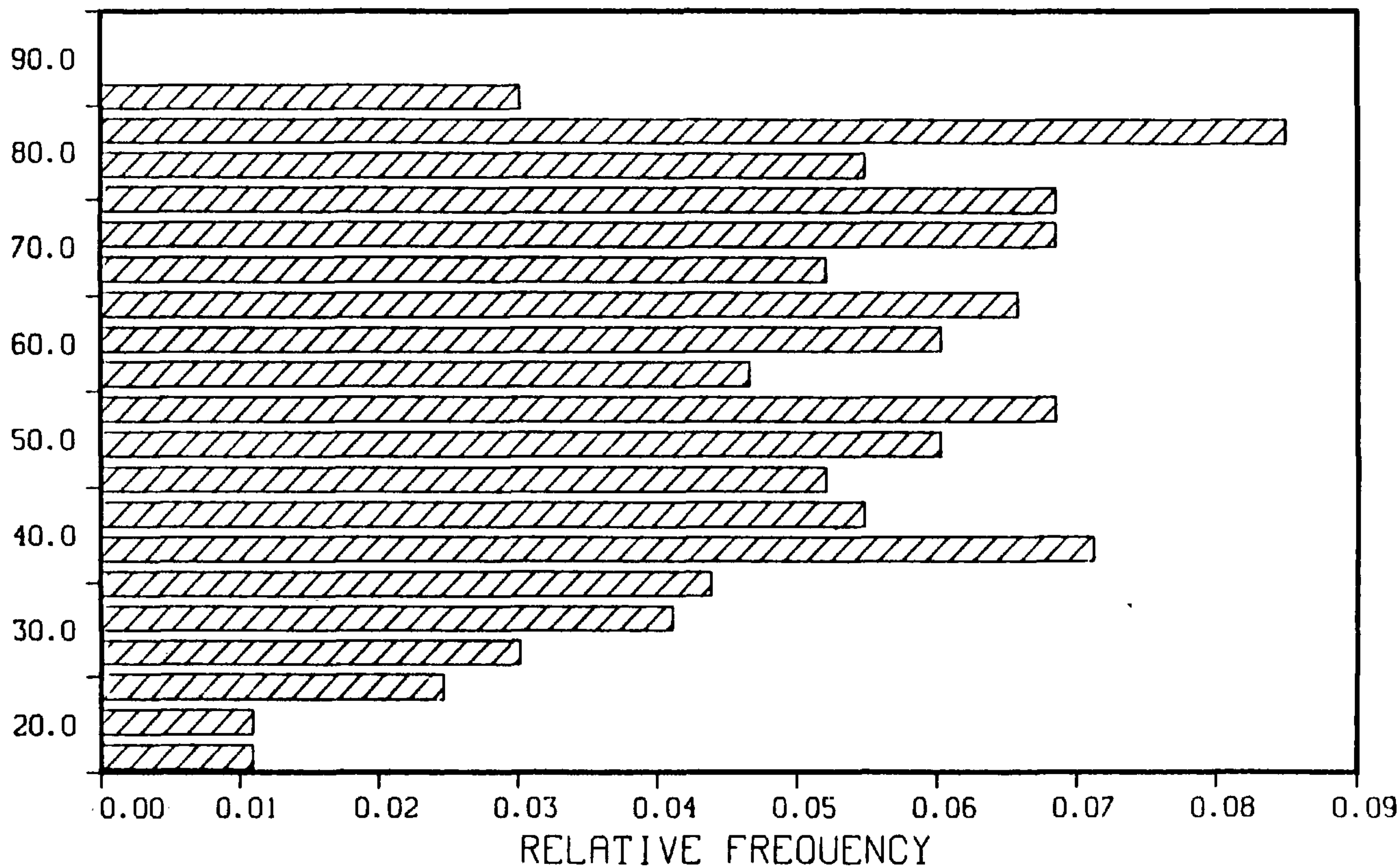


FIGURE 5-14

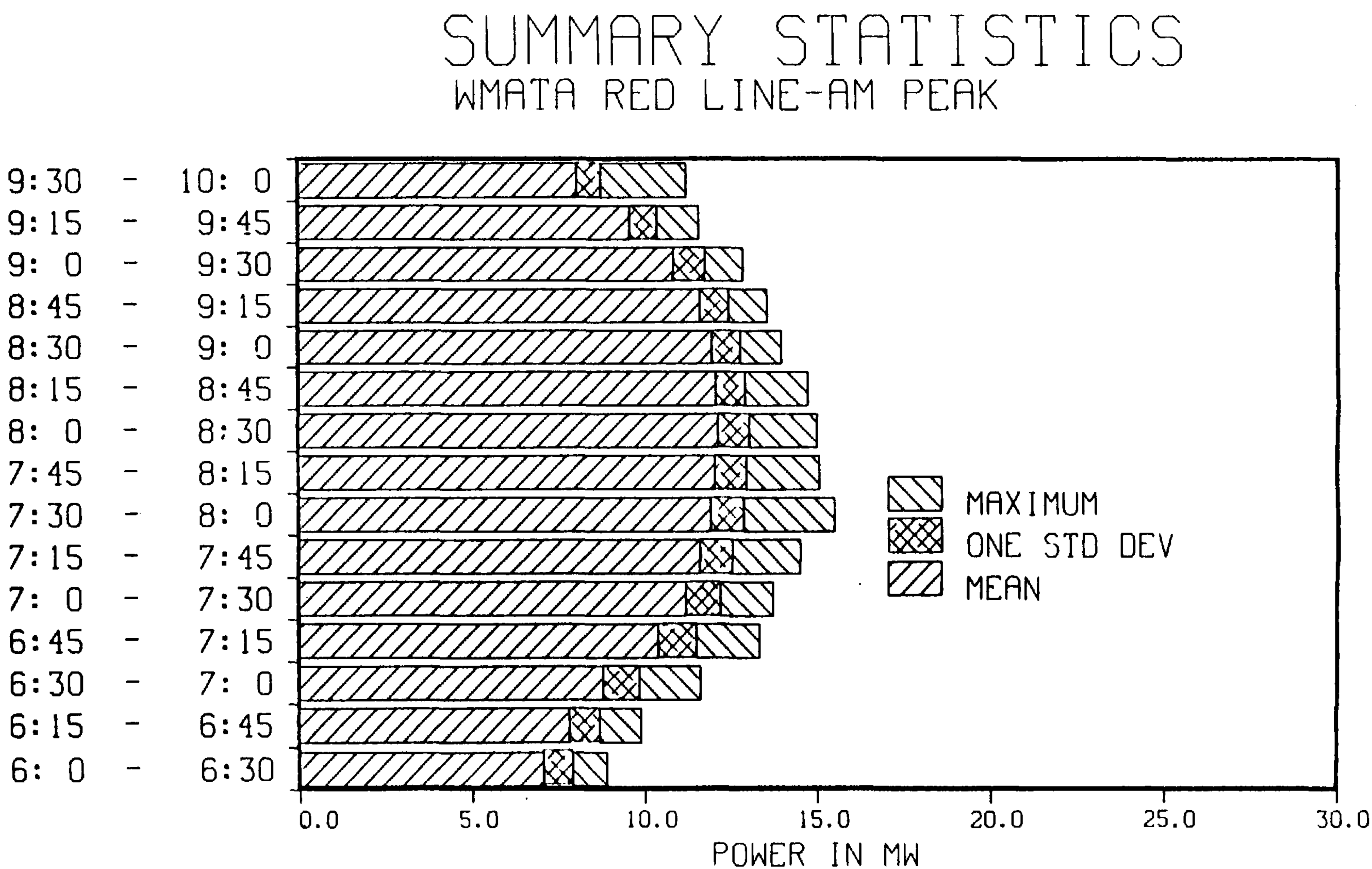

SUMMARY STATISTICS
WMATA RED LINE-AM PEAK
9:30 - 10: 0
9:15 - 9:45
9: 0 - 9:30
8:45 - 9:15
8:30 - 9: 0
8:15 - 8:45
8: 0 - 8:30
7:45 - 8:15
7:30 - 8: 0
7:15 - 7:45
7: 0 - 7:30
6:45 - 7:15
6:30 - 7: 0
6:15 - 6:45
6: 0 - 6:30
MAXIMUM
ONE STD DEV
MEAN
0.0
5.0
10.0
15.0
20.0
25.0
30.0
POWER IN MW

FIGURE 5-15

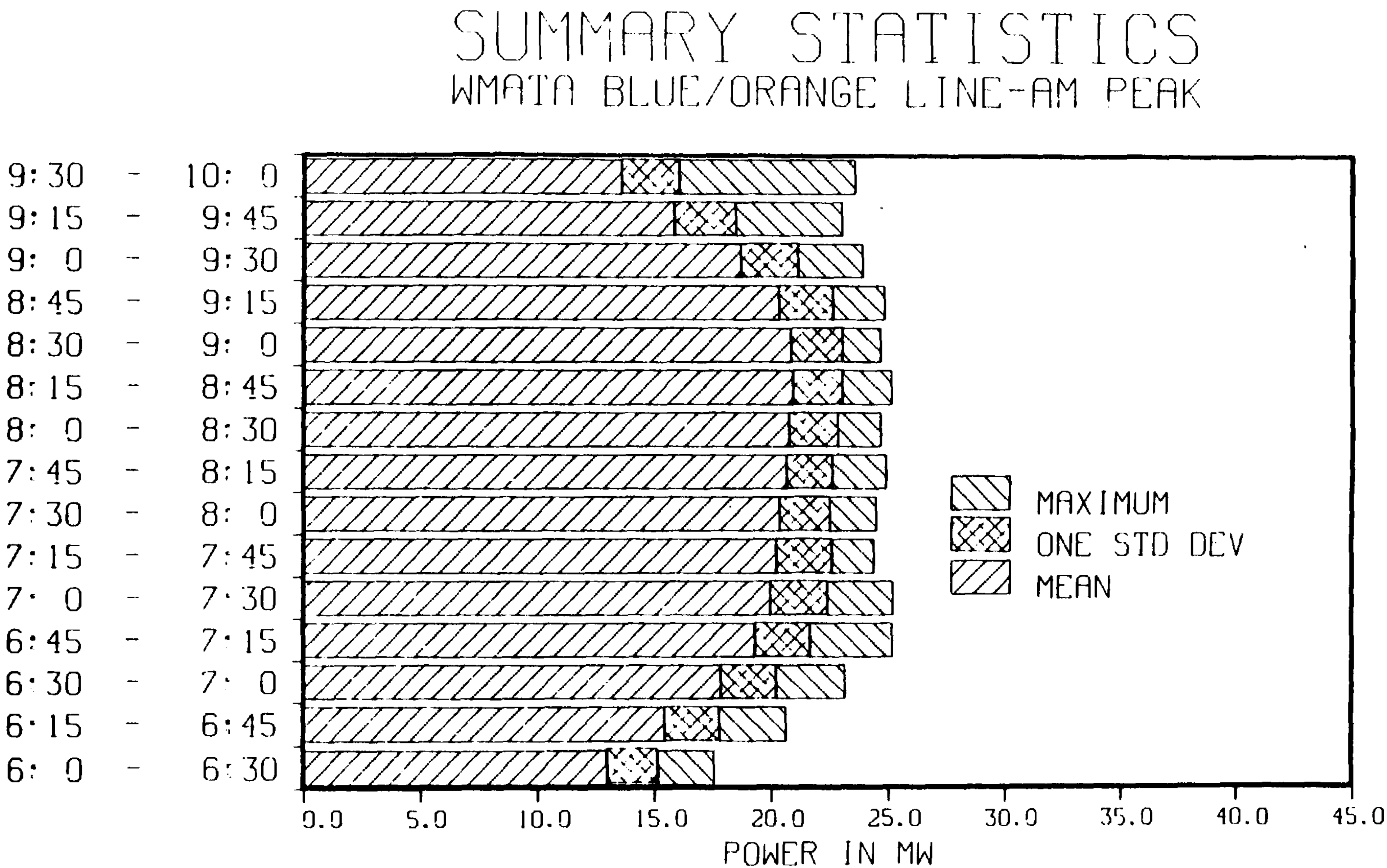

SUMMARY STATISTICS
WMATA BLUE/ORANGE LINE-AM PEAK
9:30 - 10: 0
9:15 - 9:45
9: 0 - 9:30
8:45 - 9:15
8:30 - 9: 0
8:15 - 8:45
8: 0 - 8:30
7:45 - 8:15
7:30 - 8: 0
7:15 - 7:45
7: 0 - 7:30
6:45 - 7:15
6:30 - 7: 0
6:15 - 6:45
6: 0 - 6:30
MAXIMUM
ONE STD DEV
MEAN
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
POWER IN MW

FIGURE 5-16

SUMMARY STATISTICS
DC JURISDICTION-AM PEAK

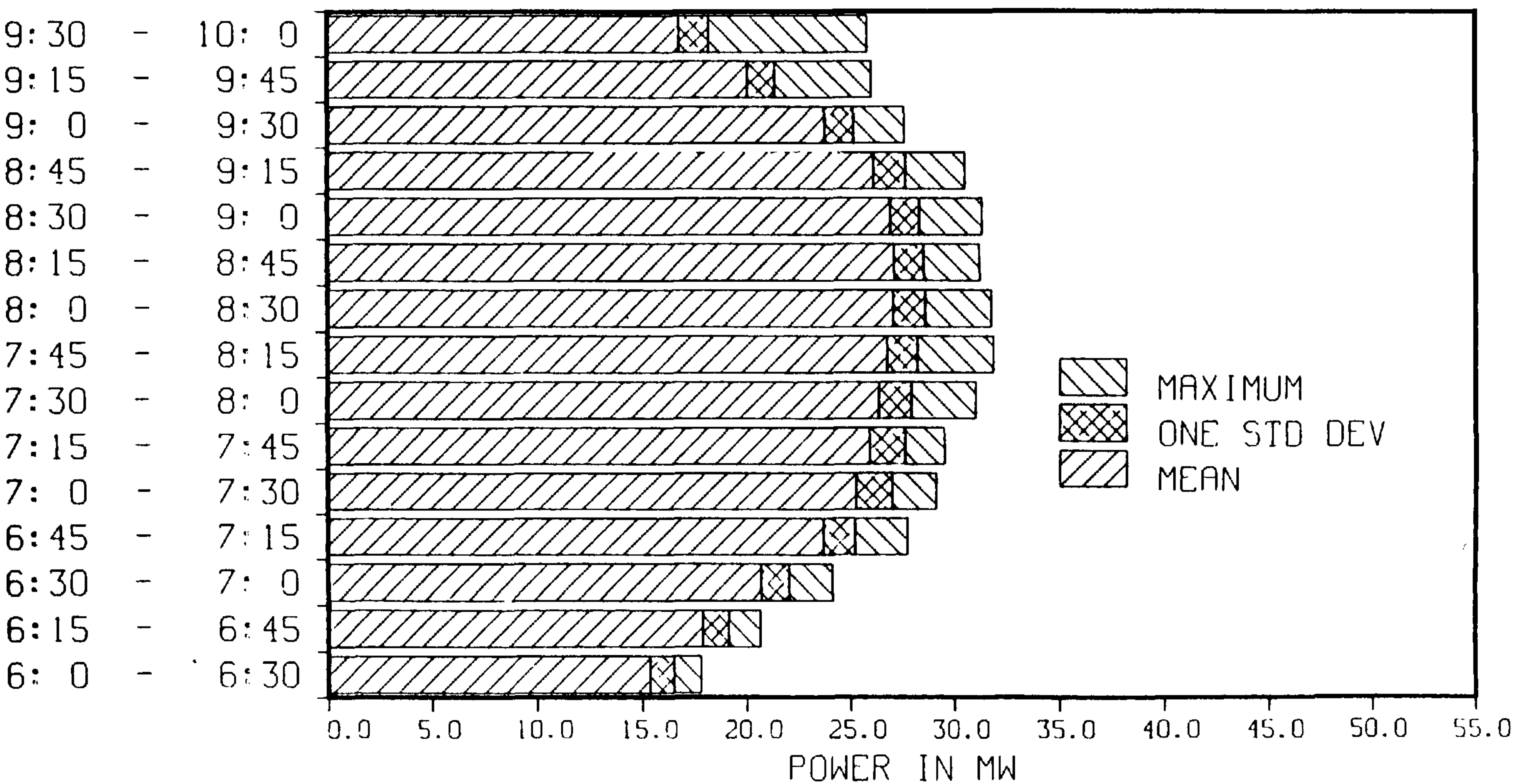


FIGURE 5-17

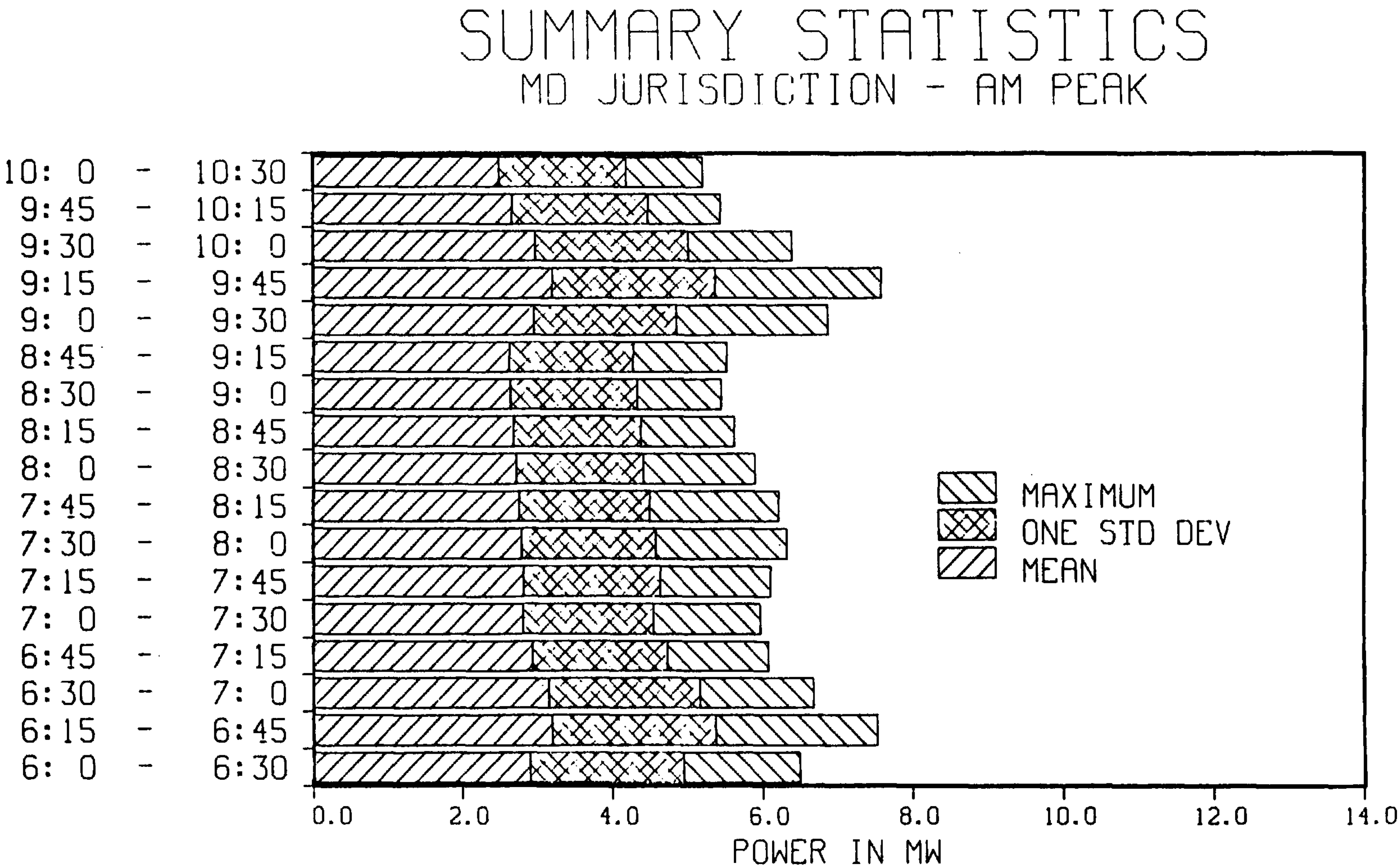

SUMMARY STATISTICS
MD JURISDICTION - AM PEAK
10: 0 - 10:30
9:45 - 10:15
9:30 - 10: 0
9:15 - 9:45
9: 0 - 9:30
8:45 - 9:15
8:30 - 9: 0
8:15 - 8:45
8: 0 - 8:30
7:45 - 8:15
7:30 - 8: 0
7:15 - 7:45
7: 0 - 7:30
6:45 - 7:15
6:30 - 7: 0
6:15 - 6:45
6: 0 - 6:30
MAXIMUM
ONE STD DEV
MEAN
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
POWER IN MW

FIGURE 5-18

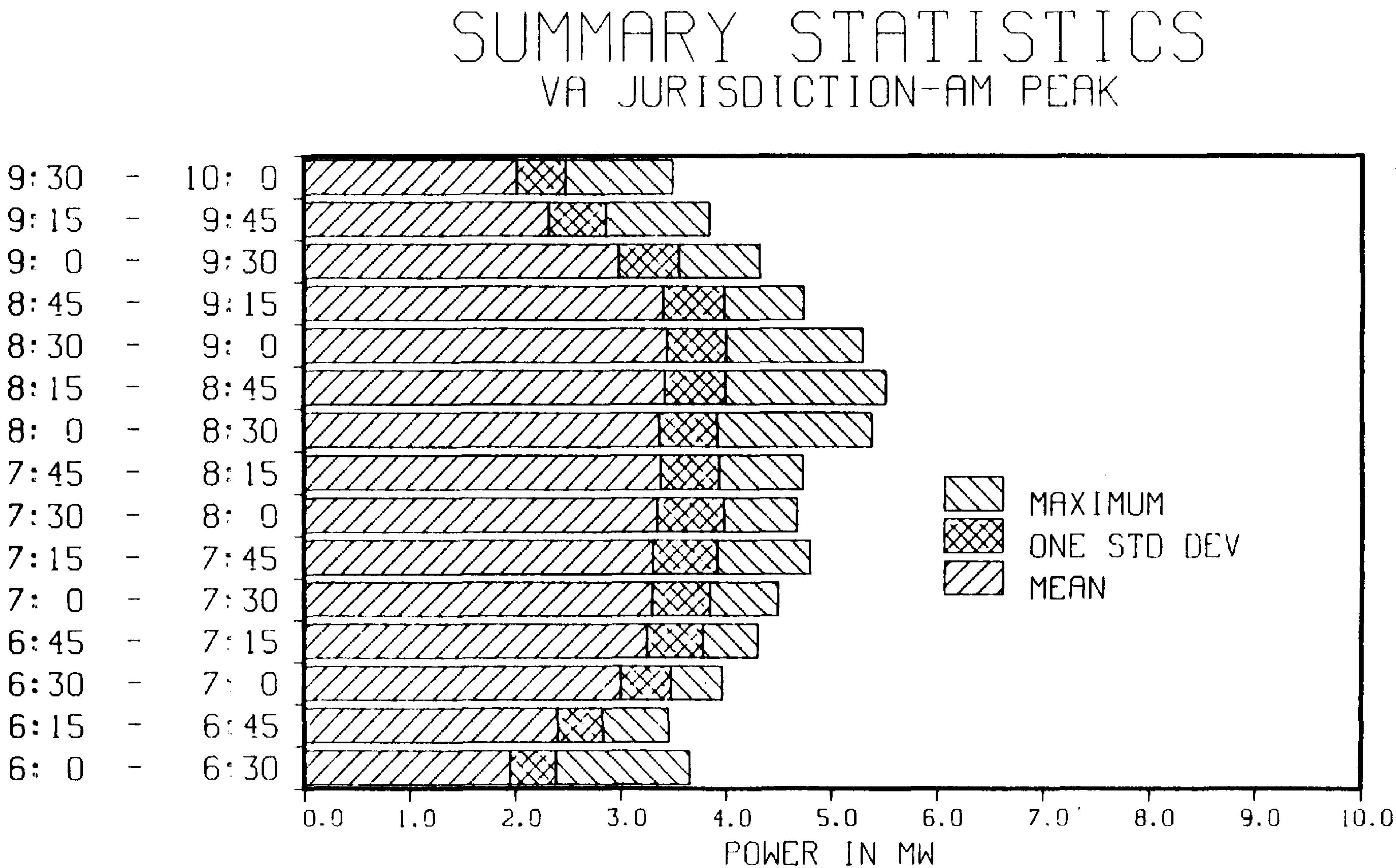

SUMMARY STATISTICS
VA JURISDICTION-AM PEAK
9:30 - 10: 0
9:15 - 9:45
9: 0 - 9:30
8:45 - 9:15
8:30 - 9: 0
8:15 - 8:45
8: 0 - 8:30
7:45 - 8:15
7:30 - 8: 0
7:15 - 7:45
7: 0 - 7:30
6:45 - 7:15
6:30 - 7: 0
6:15 - 6:45
6: 0 - 6:30
MAXIMUM
ONE STD DEV
MEAN
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
POWER IN MW

FIGURE 5-19

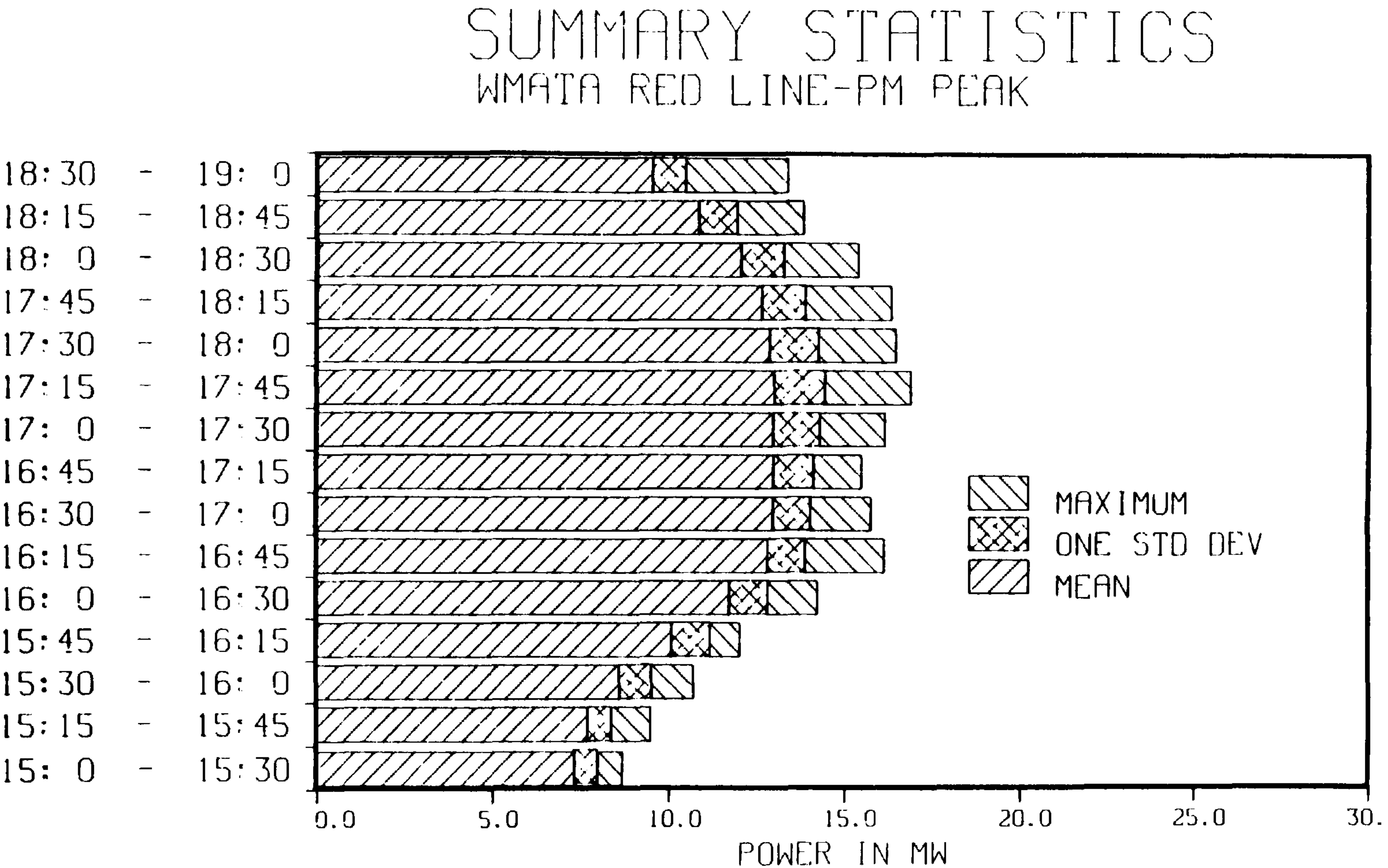

SUMMARY STATISTICS
WMATA RED LINE-PM PEAK
18:30 - 19: 0
18:15 - 18:45
18: 0 - 18:30
17:45 - 18:15
17:30 - 18: 0
17:15 - 17:45
17: 0 - 17:30
16:45 - 17:15
16:30 - 17: 0
16:15 - 16:45
16: 0 - 16:30
15:45 - 16:15
15:30 - 16: 0
15:15 - 15:45
15: 0 - 15:30
MAXIMUM
ONE STD DEV
MEAN
0.0
5.0
10.0
15.0
20.0
25.0
30.0
POWER IN MW

FIGURE 5-20

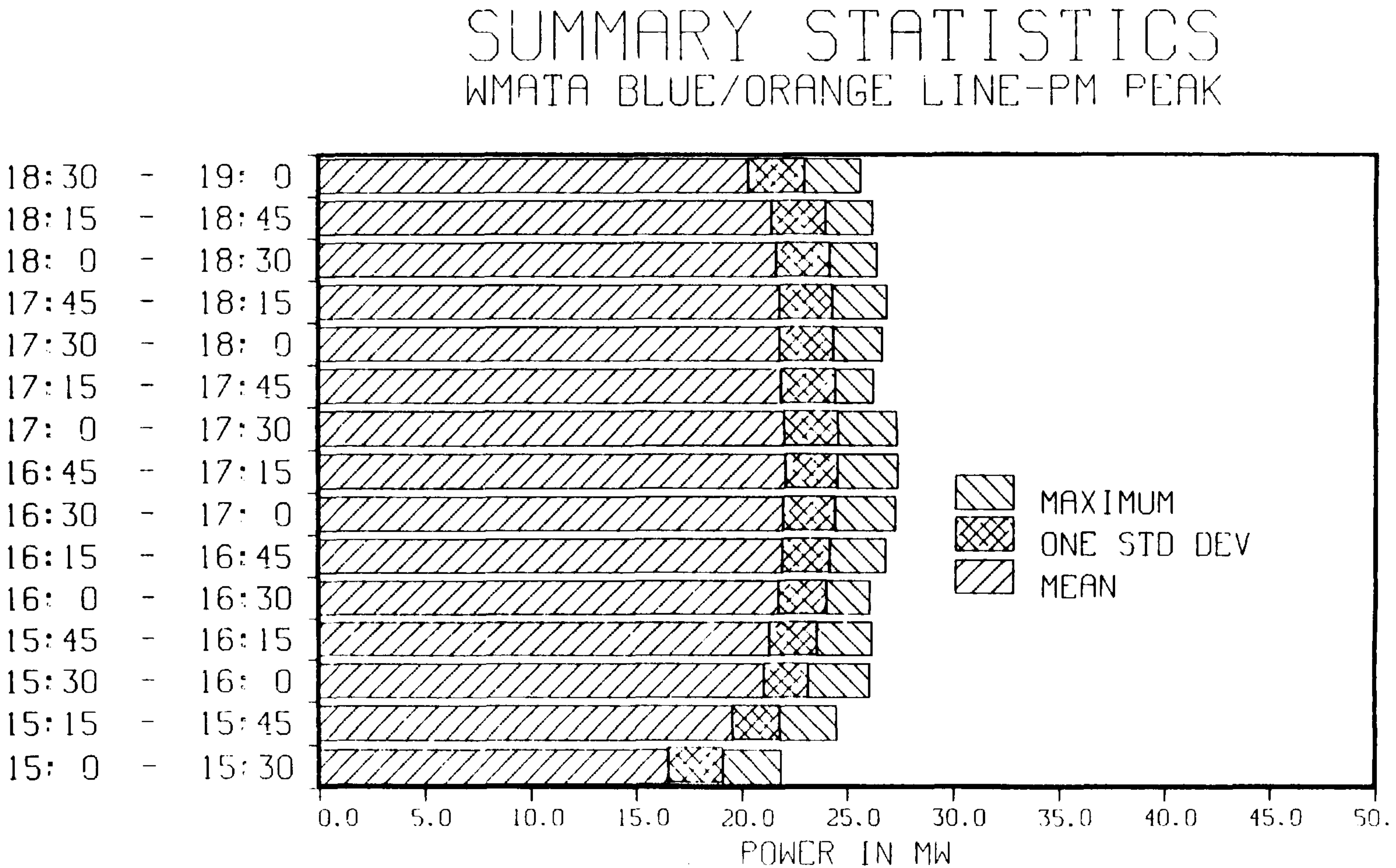

SUMMARY STATISTICS
WMATA BLUE/ORANGE LINE-PM PEAK
18:30 - 19: 0
18:15 - 18:45
18: 0 - 18:30
17:45 - 18:15
17:30 - 18: 0
17:15 - 17:45
17: 0 - 17:30
16:45 - 17:15
16:30 - 17: 0
16:15 - 16:45
16: 0 - 16:30
15:45 - 16:15
15:30 - 16: 0
15:15 - 15:45
15: 0 - 15:30
MAXIMUM
ONE STD DEV
MEAN
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
POWER IN MW

FIGURE 5-21

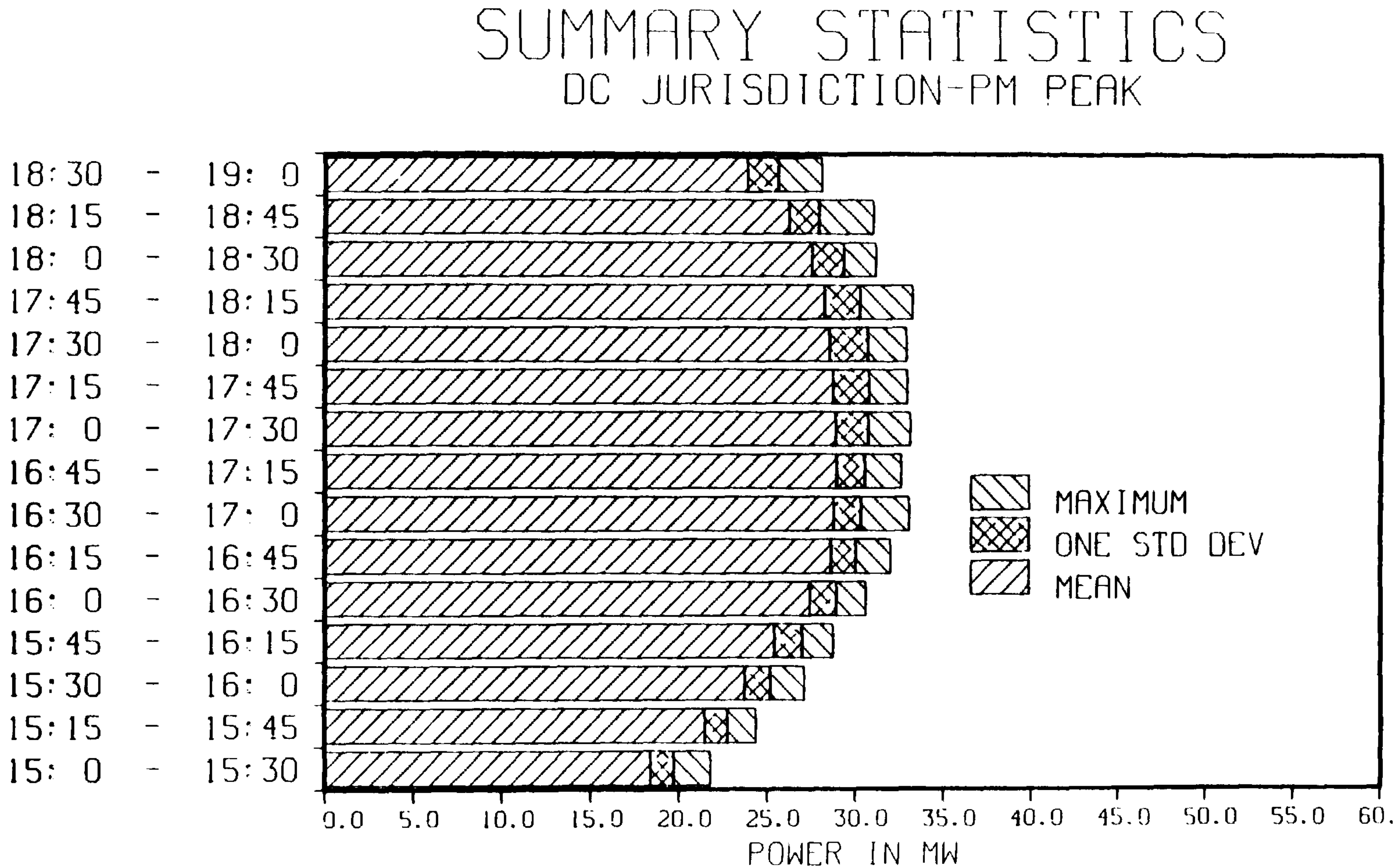

SUMMARY STATISTICS
DC JURISDICTION-PM PEAK
18:30 - 19: 0
18:15 - 18:45
18: 0 - 18:30
17:45 - 18:15
17:30 - 18: 0
17:15 - 17:45
17: 0 - 17:30
16:45 - 17:15
16:30 - 17: 0
16:15 - 16:45
16: 0 - 16:30
15:45 - 16:15
15:30 - 16: 0
15:15 - 15:45
15: 0 - 15:30
MAXIMUM
ONE STD DEV
MEAN
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
POWER IN MW

FIGURE 5-22

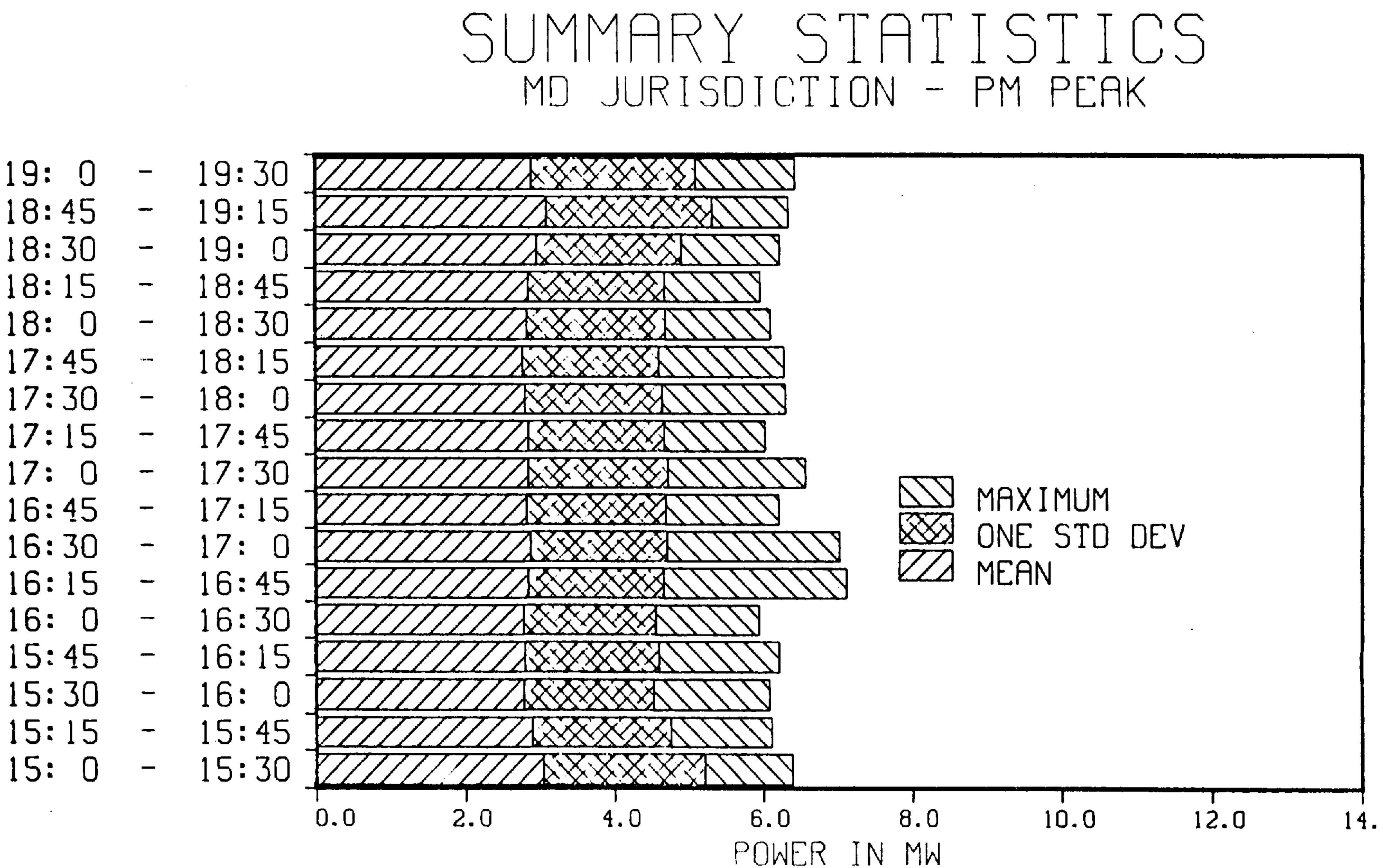

SUMMARY STATISTICS
MD JURISDICTION - PM PEAK
19: 0 - 19:30
18:45 - 19:15
18:30 - 19: 0
18:15 - 18:45
18: 0 - 18:30
17:45 - 18:15
17:30 - 18: 0
17:15 - 17:45
17: 0 - 17:30
16:45 - 17:15
16:30 - 17: 0
16:15 - 16:45
16: 0 - 16:30
15:45 - 16:15
15:30 - 16: 0
15:15 - 15:45
15: 0 - 15:30
MAXIMUM
ONE STD DEV
MEAN
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
POWER IN MW

FIGURE 5-23

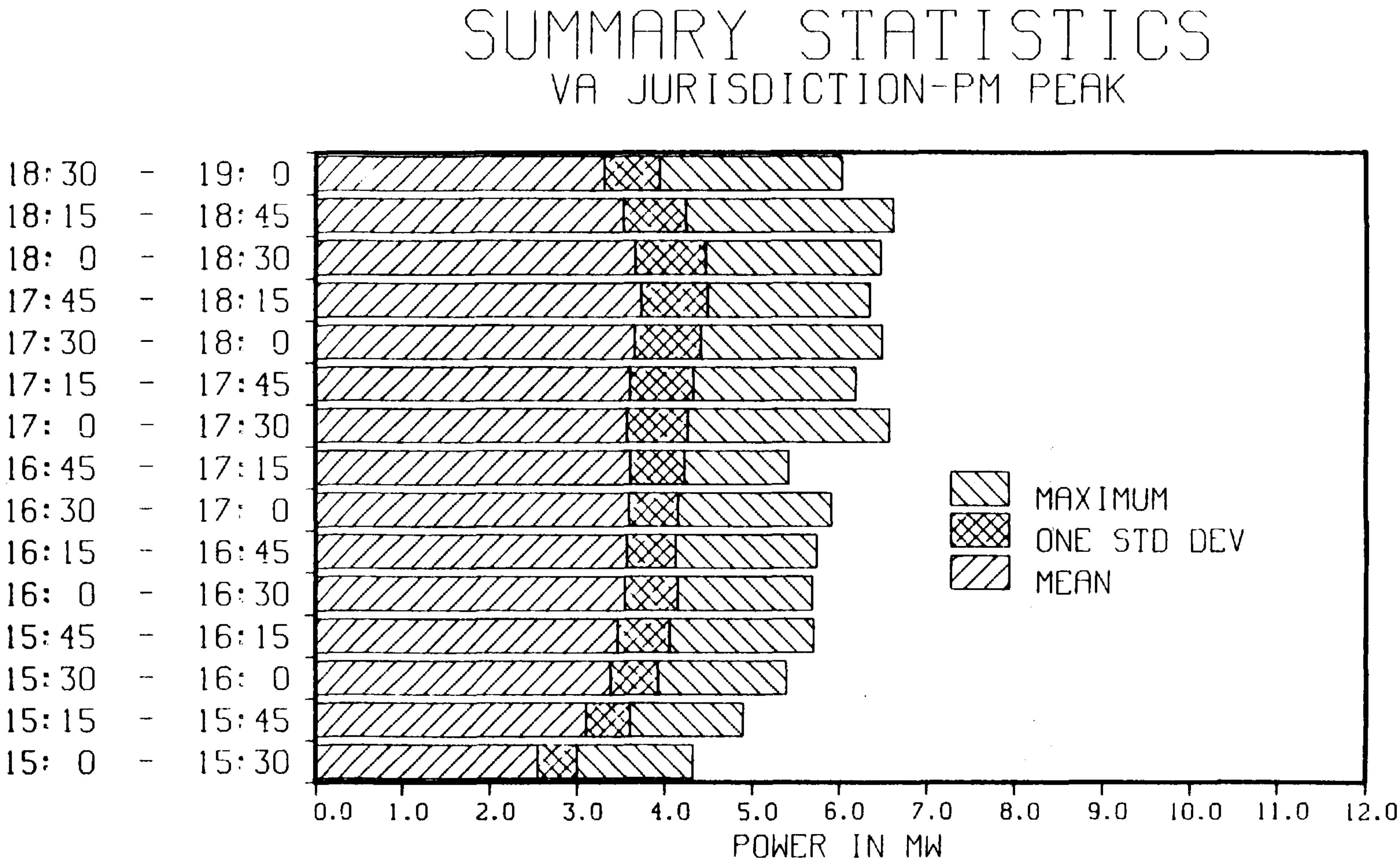

SUMMARY STATISTICS
VA JURISDICTION-PM PEAK
18:30 - 19: 0
18:15 - 18:45
18: 0 - 18:30
17:45 - 18:15
17:30 - 18: 0
17:15 - 17:45
17: 0 - 17:30
16:45 - 17:15
16:30 - 17: 0
16:15 - 16:45
16: 0 - 16:30
15:45 - 16:15
15:30 - 16: 0
15:15 - 15:45
15: 0 - 15:30
MAXIMUM
ONE STD DEV
MEAN
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
POWER IN MW

FIGURE 5-24