U.S. Department of Transportation
Federal Transit Administration

FTA-PA-26-0008-95-1

THE RAIL TRANSIT ENERGY MANAGEMENT PROGRAM

FINAL REPORT FOR 1993-94 CALENDAR YEAR EFFORT

VOLUME I

MARCH 1995

Prepared by:

Richard A. Uher

Rail Systems Center
Carnegie Mellon University
700 Technology Drive
P.O. Box 2950
Pittsburgh, Pennsylvania 15230-2950

FTA TECHNICAL ASSISTANCE PROGRAM

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NOTICE

Technical Report Documentation Page

1. Report No.
FTA-PA-26-0008-95-1

2. Government Accession No.
(NTIS)

3. Recipient's Catalog No.
UMTRIS/Section

4. Title and Subtitle
THE RAIL TRANSIT ENERGY MANAGEMENT PROGRAM
FINAL REPORT FOR 1993-94 CALENDAR YEAR EFFORT
VOLUME I

5. Report Date
March 1995

6. Performing Organization Code

7. Author(s)
Uher, Richard A.

8. Performing Organization Report No.

9. Performing Organization Name and Address
Rail Systems Center
Carnegie Mellon Research Institute
700 Technology Drive, P.O. Box 2950
Pittsburgh, Pennsylvania 15230-2950

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
PA-26-0008

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Transit Administration
400 7th St. S.W.
Washington, D.C. 20590

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code
TTS-20

15. Supplementary Notes

16. Abstract

To meet the challenge of continuously rising energy costs for rail transit in North America, the Rail Systems Center (RSC) at Carnegie Mellon University has established the Rail Transit Energy Management Program. This program is a private-public partnership of rail transit authorities, the electric utilities which supply them energy and suppliers to both the transit and the electric utility industry. The long range goal of the program is to reduce rail transit energy costs by 10% or $46 million, annually. The program is built upon an already successful effort of energy cost reduction among several rail transit authorities and the RSC.

This report describes the effort expended on the program during the calendar years 1993-94.

17. Key Words
Energy database
Rail transit
Energy management

18. Distribution Statement
Report Available from:
National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161
(703) 487-4650

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	84	

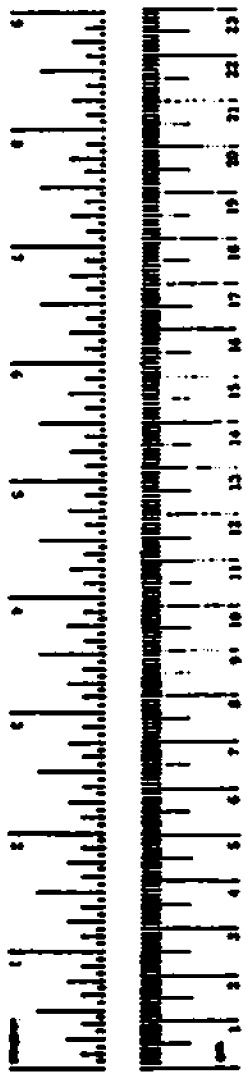
Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

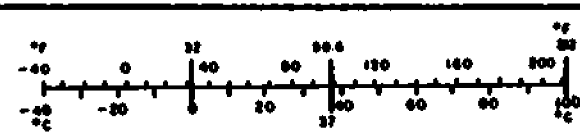
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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



ACKNOWLEDGEMENTS

This report was generated under a grant from the Federal Transit Administration (FTA) to the Rail Systems Center of Carnegie Mellon Research Institute, a division of Carnegie Mellon University.

The authors acknowledge the help and guidance of Mr. Ronald Kangas and Mr. Jeffrey G. Mora of the Office of Technical Assistance, who provided valuable support and assistance throughout the project.

The participating transit authorities are also acknowledged for their support and assistance in carrying out this work. These are Mr. Onkar Sharma and Mr. Fady Bassily of the Washington Metropolitan Area Transit Authority, Mr. John Brach of the Metropolitan Atlanta Rapid Transit Authority, and Mr. Richard Bogovich and Mr. William Millar of the Port Authority of Allegheny County.

While acknowledging all of this assistance and support, the authors retain responsibility for the materials, analysis, and opinions in this report.

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EXECUTIVE SUMMARY

Rail transit energy costs in the United States have continued to spiral upward rising 32% in constant dollars during the decade of the 1980's. This rise in energy cost increases total operating costs, which are less likely in the future to be federally supported.

For nearly 20 years the Rail Systems Center (RSC) at Carnegie Mellon University has been instrumental in the development and application of energy management methodologies to rail transit. The RSC's first work in this area began in 1976 with funding from the U.S. Department of Transportation, Urban Mass Transportation Administration (UMTA), to develop and test a series of computer codes which enabled simulation of an electrified transit system. The RSC was also funded in 1983 by UMTA to develop a set of guidelines for transit energy management. The RSC has subsequently utilized these tools to perform energy studies for a number of transit systems nationwide.

As a continuation of this effort, the RSC was awarded a grant by the Federal Transit Administration in 1990 with the goal of conceiving and evaluating innovative ways for rail transit systems to reduce electrical energy costs. The initial phase of this program addressed opportunities associated with alternative energy sources.

This first phase began by establishing a framework for cost reductions through a review of energy costs, usage patterns, rate structures and energy cost reduction strategy results for five representative transit authorities: Washington Metropolitan Area Transit Authority (WMATA), Metropolitan Atlanta Rapid Transit Authority (MARTA), Maryland Mass Transit Administration (MTA), Port Authority of Allegheny County (PAT, Pittsburgh), and Metro-Dade Transit Agency (MIAMI).

It was found that energy cost reductions on WMATA and MARTA, due principally to their aggressive implementation of energy cost reduction strategies identified in energy management studies, amounted to 43% and 24% respectively, again in constant dollars.

During the course of this initial phase, it was also found that rail transit authorities require a certain degree of sophistication in dealing with energy cost reduction issues before they can even consider alternative energy sources. A sound and detailed knowledge of how energy is used on their systems and how that use relates to energy cost through the power rate structures of the serving electric utilities would be required. Certain energy intensive data relating to operation, rolling stock and infrastructure is necessary to deal with energy cost reduction.

At the same time, the federal government was pursuing a policy toward more private initiatives in the transit industry, increased competition among suppliers to transit authorities and private enterprise approaches to secure better transit management. These efforts would reduce cost while providing better service and attracting more riders.

It was this combination of energy use sophistication and the encouragement of private-public partnerships that led to this innovative approach toward rail transit energy cost reduction; namely, the Rail Transportation Energy Management Program (EMP).

Under a grant from the Federal Transit Administration (FTA), the RSC established the EMP. This program is a cooperative effort among the rail transit industry, the electric power industry and suppliers to both industries. The objective of the EMP is to reduce energy costs to rail transit authorities across the U.S. by 10%, with an annual savings of $46 million/year after the program had been in effect for six years. Funding for the EMP would be provided by the FTA, as well as the private sector through membership fees. Rail transit authorities would pay no fee, but contribute in-kind services. In-kind services would also be provided by other member organizations.

Funding for the EMP was not provided for the second year of the program. As a consequence, organization of the program was inhibited and the first year program was stretched to two years in order to keep it alive.

This report summarizes the first two years of the EMP. A plan has been developed for the remaining five years. Four task areas are addressed.

- Program Organization
- Rail Transit Energy Database
- Alternative Energy Sources
- Five Year Plan for the EMP

<u>Program Organization</u>

The EMP consists of PARTNERS who are rail transit authorities; ASSOCIATES who are electric utilities which serve the rail transit authorities and AFFILIATES who are suppliers to the transit and electric utility industries. The EMP is primarily funded by the FTA. As PARTNERS, the rail transit authority membership has no direct cost associated with it. Canadian PARTNERS are required to pay an annual membership fee of $4500. ASSOCIATE and AFFILIATE memberships carry an annual fee of $4500. All members of the EMP are required to sign a Memorandum of Understanding which differs with the class of membership.

As of the writing of this report, three PARTNERS have executed the MOU and five PARTNERS are in the process of executing the MOU. Several ASSOCIATES and AFFILIATES have expressed their desire to join the EMP as soon as a core of PARTNER members is established.

Rail Transit Energy Database

The Energy Database (EDB) was set up under the program. The purpose of the EDB is to provide information to the members of the program. This information includes rail transit energy and energy cost data and the results of implementation of energy cost reduction strategies. The EDB also includes a means for timely exchange of information among transit authorities as well as methods for monitoring the overall cost reduction and efficiency improvement associated with energy management.

The database is presently set up on a personal computer and is accessed by the users via an 800 phone line. The software chosen to operate the EDB is the Major Bulletin Board System (BBS) by GALACTICOMM. This software is registered to the RSC. The EDB is fully transferrable to other PCs as it grows and requires more storage and memory.

The EDB became operational in October, 1994, and is expected to increase in activity as more users come on line.

Alternative Energy Sources

Previous work on alternative energy sources for rail transit indicated that battery energy storage on some rail transit systems may be economically attractive and reduce overall energy costs. The work also concluded that battery energy storage on WMATA and PAT may be economically sound. The report concluded that computer simulation tools be developed which would enable economic assessment of energy storage schemes on rail transit.

During this phase of the work, a computer model was developed to simulate the operation of a Battery Energy Storage System (BESS) at any rail transit system. The model was built in such a way that it could easily be expanded to include other storage technologies (including flywheels, superconducting magnetic fluid, etc.) should they become economically competitive with batteries.

Using the BESS computer model with conventional discharge methods (i.e. BESS constant discharge for set times), both PAT and WMATA did not show economic attractiveness for BESS. For both rail transit systems, payback periods were substantially longer than the 3-4 years which would be acceptable for the investment.

However, the capital cost of the BESS can be reduced by eliminating costly power conditioning equipment and allowing the battery to be connected directly to the third rail or trolley wire (of course, with appropriate circuit protection). The Electric Power Research Institute (EPRI) funded a program to study this innovation. This research would be contributed to next year's effort under the EMP by EPRI.

<u>Five Year Plan for the EMP</u>

The EMP would continue to be a private/public partnership consisting of rail transit authorities as partners, electric utilities as associates and suppliers to the transit and electric utility industries as affiliates. The long range objective of the program remains the same; namely, to reduce the annual energy cost for U.S. rail transit authorities by 10%.

To accomplish the objectives of the EMP, the following tasks would be initiated or continued:

- Continued organization of the program
- Maintaining the rail transit energy management database
- Continued work toward a battery energy storage demonstration
- Development of more sophisticated energy management computer tools including a train operation model
- Development of capital equipment requirements under energy reduction strategies
- Updating of the rail transit energy management guidelines manual
- Conduct educational activities in energy management for the industry through workshops and conferences

The main focus of the 1995 Program will be the preliminary development of a Train Operations Model (TOM) for use in assessing and evaluating advanced train control systems. This model will be able to determine schedule, capacity and energy performance of advanced train control technologies, based on either fixed block or moving block principles.

The TOM has already been partially developed based on earlier work by the RSC. Originally developed for main line railroads in preparation for Advanced Train Control Systems (ATCS) technologies, this model was applied to the Sacramento Light Rail Transit System. (The model also has the capability for application to manually signalled systems.)

A program for next year's activities was also defined which began or continued work in the task areas just mentioned.

Conclusion

The EMP is a solid program for reducing operating cost for rail transit. Relatively small investments can yield large returns through energy savings. It is a program which is based on a past history of similar success.

1.0 INTRODUCTION

Since the early 1970s, energy conservation has become an objective of federal, state and local governments. Electrical energy costs for rail transit systems continue to grow. After labor costs, the cost of electrical energy is the largest item in the annual operating budget. In 1993, the cost of electricity for rail transit systems in the United States was over $460 million. This cost will continue to rise in the future putting heavier burdens on rail transit operating budgets.

The Rail Systems Center (RSC) of Carnegie Mellon Research Institute, a division of Carnegie Mellon University, has been involved with rail transit energy management since 1976. The past work has addressed the subjects of energy conservation and power rate structure modification for eleven (11) rail transit authorities in the United States. It has developed a unified procedure for effecting energy cost reduction.

The RSC also completed a grant funded by the FTA to investigate the feasibility of alternative energy sources in order to reduce energy cost[1]. An alternative energy source means purchasing energy at a time different from when it will be used (storage) and/or from a source which is not the local utility (bypass).

Five rail transit authorities participated in the alternative energy source study:

- Metropolitan Atlanta Rapid Transit Authority (MARTA)
- Washington Metropolitan Area Transit Authority (WMATA)
- Mass Transit Administration of Maryland (MTAMD) (Baltimore)
- Port Authority of Allegheny County (PAT) (Pittsburgh)
- Metro-Dade Transit Agency (MIAMI)

The study represented a pioneering effort for rail transit management, especially with the trend to deregulation of the utility industry.

A review of the historical power cost and operation of four of the five rail transit authorities who participated in the project indicated that energy management efforts have reduced power costs substantially. Two of the authorities (WMATA and MARTA) who are fully implementing energy cost reduction on their systems have reduced their energy cost by 43% and 28%, respectively.

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[1] *Alternative Electric Energy Sources for Rail Transit, Final Report, Phase I,* August 1993, Uher, Richard A. and Howard, John; Rail Systems Center, Carnegie Mellon Research Institute, Carnegie Mellon University, 4400 Fifth Avenue, Pittsburgh, Pennsylvania 15213.

During the course of the program, it was found that rail transit authorities require a certain degree of sophistication in dealing with energy cost reduction issues before they can even consider alternative energy sources. This sophistication required a sound and detailed knowledge of how energy is used by the authority and how that use relates to energy cost through the power rate structure of the serving utilities. Certain energy intensive data relating to operation, equipment, and infrastructure would be required.

At the same time, the federal government was pursuing a policy toward more private initiatives in the transit industry, increased competition among suppliers to transit authorities and private enterprise approaches to secure better transit management (thus reducing operating costs while providing better service and attracting riders).

It was the combination of energy sophistication and the encouragement of private-public partnerships that led to an innovative approach toward rail transit energy cost reduction; namely, the Rail Transportation Energy Management Program (EMP).

The EMP is operated by the RSC. This program is a cooperative effort among the rail transit industry, the electric power industry and suppliers to both industries. The objective of the program is to reduce energy costs to transit authorities by 10%, with an annual savings of $46M per year after the program has been in effect for six years.

Funding for the EMP would be provided by the FTA, as well as the private sector through membership fees. Rail transit authorities would pay no fee, but would contribute in-kind service.

This report summarizes the first year's effort. This effort was divided into four major task areas:

<u>Organization of the Program</u>

The philosophy and progress for organizing the program is discussed in Section 2.0.

<u>Rail Transit Energy Database</u>

An energy database was assembled as part of the program. This database is designed to hold information on any energy and energy cost related data for rail transit authorities. A short description of this database is presented in Section 3.0, as well as its present status. Volume II of this report presents the database in more detail.

Alternative Energy Source Work

One of the major development areas for this year's work in the EMP was to continue the development of the work associated with alternative energy sources. This work would consider both energy storage and bypass. The results are reported in Section 4.0. Volume III of this report presents the storage assessment model in more detail.

Development of Five Year Plan for the EMP

A five year plan was developed for the EMP. This plan is presented in Section 5.0.

A general summary of the first year EMP is presented in Section 6.0.

2.0 ORGANIZATION OF THE PROGRAM

The Rail Transportation Energy Management Program (EMP) is a private-public partnership among the rail transit industry, the electric utility industry and the suppliers to both industries. It consists of the following types of members:

- PARTNERS - Rail transit authorities in the U.S. and Canada
- ASSOCIATES - Electric utilities which serve the rail transit authorities
- AFFILIATES - Suppliers to the transit and electric utility industry

The EMP is, in part, funded by the FTA. As PARTNERS, the rail transit authority membership has no cost associated with it. Canadian PARTNERS are required to pay a fee of $4500. ASSOCIATE and AFFILIATE membership carries an annual fee of $4500. All members are required to sign a Memorandum of Understanding (MOU). The MOU is different for each class of membership.

The program is administered by the RSC at the Carnegie Mellon Research Institute, a division of Carnegie Mellon University.

2.1 Program PARTNERS

The program PARTNERS are the rail transit authorities. A list of potential PARTNERS is shown in Table 2.1.

The basic MOU, appropriate to PARTNERS, is shown in Figure 2.1.

MOU's which have already been executed by specific rail transit authorities are contained in Appendix A. These may be slightly different than the basic MOU.

2.2 Program ASSOCIATES

The program ASSOCIATES are the electric utilities, and in particular, electric utilities which provide service to the rail transit authorities.

The basic MOU, appropriate to ASSOCIATES, is presented in Figure 2.2.

TABLE 2.1

LIST OF POTENTIAL

RAIL TRANSIT AUTHORITY PARTNERS

Transportation Authority	Acronym	City	State or Prov.
Bi-State Development Agency	BIDA	St. Louis	MO
British Columbia Rapid Trans. Co.	BC TRANSIT	Vancouver	BC
Calgary Transit	CTCT	Calgary	AL
Chicago Transit Authority	CTA	Chicago	IL
City of Detroit Dept. of Transp.	DDOT	Detroit	MI
Dallas Area Rapid Transit	DART	Dallas	TX
Edmonton Transit	ET	Edmonton	AB
Government of Ontario Transit	GO TRANSIT	Toronto	On
Gr. Cleveland Reg. Trans. Auth.	GCRTA	Cleveland	OH
Long Island Rail Road	LIRR	New York	NY
Los Angeles Co. Metropolitan Transp. Authority	LACMTA	Los Angeles	CA
MA Bay Transportation Auth.	MBTA	Boston	MA
Mass Transit Administration of MD	MTAMD	Baltimore	MD
Metro-Dade Transit Agency	MDTA	Miami	FL
Metro-North Commuter Rail Road	MNCR	New York	NY
Metro. Atlanta Rapid Trans. Auth.	MARTA	Atlanta	GA
Metro. Trans. Auth. of Harris Co.	MTA-HARR	Houston	TX
Metropolitan Rail	METRA	Chicago	IL
Miami Valley Reg. Transit Auth.	MVRTA	Dayton	OH
Montreal Urban Comm. Trans. Corp.	MUCTC	Montreal	PO
Municipality of Metro. Seattle	MMS	Seattle	WA
N. IN Commuter Transp. District	NICTD	Chicago	IN
New Jersey Transit Corporation	NJT	Newark	NJ
New York City Transit Authority	NYCTA	New York	NY
Niagra Frontier Transp. Auth.	NFTA	Buffalo	NY
Port Auth. Trans-Hudson Corp.	PATH	New York	NY
Port Authority of Allegheny Co.	PAT	Pittsburgh	PA
Port Authority Transit Corp.	PATCO	Lindenwold	NJ
Regional Transit Authority	NORTA	New Orleans	LA
Regional Transportation District	DRTD	Denver	CO
S.E. PA Transportation Auth.	SEPTA	Philadelphia	PA
Sacramento Reg. Transit District	SRTD	Sacramento	CA
San Diego Trolley, Inc.	SDTI	San Diego	CA
San Francisco Municipal Railway	MUNI	San Francisco	CA
San Francisco Bay Area Rapid Trans.	BART	San Francisco	CA
Santa Clara Co. Transp. Agency	SCCTA	San Jose	CA
The Hamilton Street Railway Co.	HSRC	Hamilton	ON
Toronto Transit Commission	TTC	Toronto	ON
Tri-Co. Met. Transp. Distr. of OR	TRI-MET	Portland	OR
Wash Metro. Area Trans. Auth.	WMATA	Washington	DC

FIGURE 2.1

PARTNER MOU template

MEMORANDUM OF UNDERSTANDING

BETWEEN: [redacted]

(hereinafter known as "the Partner")

AND: **THE ENERGY MANAGEMENT PROGRAM**

(hereinafter known as "the Program")

This Agreement is entered into by and between [redacted] as a Partner, and the Energy Management Program, operated by the Rail Systems Center (RSC) of Carnegie Mellon Research Institute, a division of Carnegie Mellon University of Pittsburgh, Pennsylvania, this ____ day of __________, 1993.

WITNESSETH

WHEREAS, the Federal Transit Administration (FTA) is committed to support the Partner's energy conservation and load management initiatives to reduce operating cost;

AND WHEREAS, the Partner is committed to evaluating and implementing cost effective power cost reduction initiatives;

AND WHEREAS, FTA has entered into a Cooperative Agreement with CMU (RSC) as of March 30, 1993, wherein FTA is providing federal funds to CMU (RSC) to inter alia invite all U.S. electrically powered rail transit systems to participate in a research program at CMU designed to foster energy management power cost reduction techniques.

AND WHEREAS, the parties wish to set forth common principles and their respective commitments to the Energy Management Program in the Memorandum of Understanding ("MOU");

NOW THEREFORE, in consideration of the mutual promises, covenants and conditions contained herein, the parties agree as follows:

1. That the primary purpose of the Energy Management Program is to evaluate and implement energy management initiatives to reduce operating costs.

2. That reduction in end use energy consumption will reduce

combustion related pollution.

3. That demand side energy management initiatives combined with alternative supply sources promote efficient use of energy at a least cost option for the society, and enhance national energy security.

4. That the active participation of equipment manufacturers, distributors, financial institutions and private enterprises is critical to achieving the goals and objectives of the Energy Management Program.

5. That existing programs and initiatives of the Partner shall become an integral part of the Energy Management Program.

6. Partner's Responsibilities:

   The Partner shall:

   a) Develop an energy management plan, which shall include:

      - An energy management study, which conducts an energy audit of all facilities, evaluates the power rate structure and identifies energy cost reduction opportunities and objectives.

      - An implementation plan, which identifies those cost reduction opportunities to be pursued, the organization within the management structure responsible, a schedule for implementation and resources to be committed.

   b) Participate in the Program sponsored seminars and workshops.

   c) Formulate energy cost reduction goals:

      Traction: 5-25%
      Non-Traction: 10-20%
      - Lighting - passenger stations, buildings and parking lots
      - Heating/ventilation/air conditioning (HVAC)
      - Elevators and escalators
      - Shop machinery
      - Others

   d) Develop a structured implementation which

- is based upon payback, cost/effectiveness and organizational priorities

- documents improvements, benefits and corrective measures to meet the goals

- undertakes an energy efficiency review of all facilities under design and construction to ascertain that they meet or exceed energy efficiency standards

- periodically reaudits energy use and re-evaluates the power rate structure

- undertakes employee awareness and training to promote energy efficiency awareness

e) Develop and pursue power rate reduction and alternative rate structures through electric utility negotiation and intervention in rate proceedings.

f) Pursue alternative energy sources when it is in the best interest of the Partner to do so.

7. Program Responsibilities:

The Program responsibilities shall be carried out by the RSC and shall include:

a) Providing guidelines, guidance and assistance to the Partners in developing and implementing cost effective and site specific energy cost reduction.

b) Seeking cooperation with governmental agencies and institutions to remove regulatory barriers that artificially restrict energy management initiatives.

c) Promoting and expanding the Program by enrolling more Partners and private sector Associates (electric utilities) and Affiliates (suppliers and service organizations).

d) Providing technical services to the Partners on a limited basis.

e) Building and maintaining a rail transit energy data base, to which the Partners, Associates and Affiliates will have access.

f) Making available to Partners, Associates and Affiliates, analysis tools for estimating energy reduction cost effectiveness (some of these tools would require formal licenses with third parties).

g) Developing new analysis tools as required which would be made available to the Partners, Associates and Affiliates as they are developed. No licenses would be required here unless the tool were provided by a third party.

h) Updating the "Energy Management Guidelines for Rail Transit" as new information and techniques become available.

i) Participating in publicity programs identifying specific facilities that have benefited from the program and participants who have contributed to its success.

j) Developing innovative financing techniques for the Program.

8. All information provided to the Partner under the terms of par. 7 is provided on an "as is" basis. The information so provided is the product of research by the RSC and the RSC disclaims any warranties of any kind, either express or implied as to the use of this information by a Partner or any third party to whom the Partner has given access to the information.

No party to this Agreement shall be liable to either or both of the other parties for any special, direct, indirect or consequential damages or any damages whatsoever resulting from the use of the aforementioned information by the user in its "as is" condition. Any user who allows a party other than a party to this Agreement to use the above information indemnifies and saves harmless the other parties from any damages, cost or charges, including attorneys' fees and court costs from any claim, suit, cause of action or judgment arising from the use of said information by the party.

9. This is a voluntary agreement between the parties. No modification, amendment or revision of this agreement shall be valid unless it is in writing and consented to by all the parties.

COMPLETE DOCUMENT MUST BE RETURNED.

As representatives of the Energy Management Program and the Partner, we, the undersigned, do hereby execute this Memorandum of Understanding on the latter of the dates indicated below.

By:______________________________

Partner [redacted]

Date:______________________________

By:______________________________

Richard A. Uher, Director
Rail Systems Center
Carnegie Mellon Research Institute
Carnegie Mellon University

Date:______________________________

By:______________________________

Dr. William M. Kaufman, Director
Carnegie Mellon Research Institute
Carnegie Mellon University

Date:______________________________

By:______________________________

Susan B. Dunkle, Associate Provost
Research & Academic Administration
Carnegie Mellon University

Date:______________________________

FIGURE 2.2

ASSOCIATE MOU template

MEMORANDUM OF UNDERSTANDING BETWEEN:

(hereinafter known as "The Program Associate Utility" "the Utility")

AND: THE ENERGY MANAGEMENT PROGRAM

(hereinafter known as "the Program)

This Agreement is entered into by and between ______________________________ as a Utility, and the Energy Management Program, operated by the Rail Systems Center (RSC) of Carnegie Mellon Research Institute, a division of Carnegie Mellon University of Pittsburgh, Pennsylvania, this _____ day of _____________, 1993.

WITNESSETH

WHEREAS, the Federal Transit Administration (FTA) is committed to support energy conservation and load management initiatives to reduce operating cost;

AND WHEREAS, the Utility is committed to evaluating and implementing cost effective demand side energy management initiatives for rapid rail transit systems;

AND WHEREAS, FTA has entered into a Cooperative Agreement with CMU (RSC) as of March 30, 1993, wherein FTA is providing federal funds to CMU (RSC) to inter alia invite all U.S. electrically powered rail transit systems (rapid rail transit systems) to participate in a research program at CMU designed to foster energy management and power cost reduction techniques.

AND WHEREAS, the parties wish to set forth common principles and their respective commitment to the Energy Management Program in the Memorandum of Understanding ("MOU");

NOW THEREFORE, in consideration of the mutual promises, covenants and conditions contained herein, the parties agree as follows:

1. That the primary purpose of the Energy Management Program is to evaluate and implement energy management initiatives to reduce operating costs.

2. That demand side energy management initiatives combined with alternative supply sources promote efficient use of energy at a least cost option for the utility, and enhance national energy security.

3. That the active participation of equipment manufacturers, distributors, financial institutions and private enterprises is critical to achieving the goals and objectives of the Energy Management Program.

4. That existing demand side energy management programs and initiatives of the Utility shall become an integral part of the Energy Management Program.

5. Utility's Responsibilities:

   The Utility shall:

   a) Identify energy cost reduction opportunities for rapid rail transit systems by undertaking

      - An energy management study, which conducts an energy audit of all facilities, evaluates the power rate structure and identifies energy cost reduction opportunities and objectives of the transit system served by the Utility.

      - An implementation plan, which identifies those cost reduction opportunities to be pursued, the organization within the management structure responsible, a schedule for implementation and resources to be committed.

   b) Participate in the program sponsored seminars, workshops, and pilot projects.

   c) Formulate energy and demand reduction goals by end use for the transit system served by the Utility.

   d) Develop a structured implementation which

      - Is based upon payback, cost/effectiveness and organizational priorities.

      - Documents improvements, benefits and corrective measures to meet the goals.

- Undertakes an energy efficiency review of all facilities under design and construction of the transit system it serves to ascertain that they meet or exceed energy efficiency standards.

- Periodically reaudits energy use and re-evaluates the power rate structure.

- Undertakes employee awareness and training to promote energy efficiency awareness.

e) Develop and pursue alternative structures to meet emerging competition in the utility industry.

6. Program Responsibilities:

The Program responsibilities shall be carried out by the RSC and shall include:

a) Providing guidelines, guidance and assistance to the Utility in developing and implementing cost effective and site specific energy cost reduction.

b) Seeking cooperation with governmental agencies and institutions to remove regulatory barriers that artificially restrict energy management initiatives.

c) Promoting and expanding the Program by enrolling more Utilities and private sector Associates and Affiliates (suppliers and service organizations).

d) Providing technical services to the Organization on a limited basis.

e) Building and maintaining a rail transit energy data base, to which the Utility will have access.

f) Making available to the Utility, and Program Associates and Affiliates, analysis tools for estimating energy reduction cost effectiveness (some of these tools would require formal licenses with third parties).

g) Developing new analysis tools as required which would be made available to the Program Associates and Affiliates as they are developed. No licenses would be required here unless the tool were provided by a third party.

h) Updating the "Energy Management Guidelines for Rail Transit" as new information and techniques become available.

i) Participating in publicity programs identifying specific facilities that have benefited from the program and participants who have contributed to its success.

j) Developing innovative financing techniques for the Program.

7. ALL INFORMATION PROVIDED TO THE UTILITY UNDER THE TERMS OF PAR. 7 IS PROVIDED ON AN "AS IS" BASIS. THE INFORMATION SO PROVIDED IS THE PRODUCT OF RESEARCH BY THE RSC AND THE RSC DISCLAIMS ANY WARRANTIES OF ANY KIND, EITHER EXPRESSED OR IMPLIED AS TO THE USE OF THIS INFORMATION BY A UTILITY OR ANY THIRD PARTY TO WHOM THE UTILITY HAS GIVEN ACCESS TO THE INFORMATION.

   No party to this Agreement shall be liable to either or both of the other parties for any special, direct, indirect or consequential damages or any damages whatsoever resulting from the use of the aforementioned information by the user in its "as is" condition. Any user who allows a party other than a party to this Agreement to use the above information indemnifies and save harmless the other parties from any damages, claims, costs or charges, including attorneys' fees, court costs and damages, from any claim, suit, cause of action or judgement arising from the use of said information by the party, including but not limited to claims of active and/or passive negligence.

8. This is a voluntary agreement between the parties. No modification, amendment or revision of this agreement shall be valid unless it is in writing and consented to by all parties.

COMPLETE DOCUMENT MUST BE RETURNED.

As representatives of the Energy Management Program and the Associate, we, the undersigned, do hereby execute this Memorandum of Understanding on the latter of the dates indicated below.

The Program Associate Utility:

By:______________________________

Date:____________________________

By:______________________________
Richard A. Uher, Director
Rail Systems Center
Carnegie Mellon Research Institute
Carnegie Mellon University

Date:____________________________

By:______________________________
Dr. William M. Kaufman, Director
Carnegie Mellon Research Institute
Carnegie Mellon University

Date:____________________________

By:______________________________
Susan B. Dunkle, Associate Provost
Research & Academic Administration
Carnegie Mellon University

Date:____________________________

2.3 Program AFFILIATES

The program AFFILIATES are the suppliers to the rail transit and electric utility industry. Classes of suppliers who are potential AFFILIATES are:

- Vehicle propulsion equipment
- Power distribution and transmission equipment
- Signalling and train control equipment
- Lighting equipment
- HVAC equipment
- Energy management equipment
- Software
- Service organizations

The basic MOU for the AFFILIATE member is presented in Figure 2.3.

2.4 Membership Status

The original strategy for signing up members to the EMP was to sign up a core number of rail transit authorities as PARTNERS. Once the core program was established, ASSOCIATES and AFFILIATES would be invited to join.

Funding for the second year of the program was not available from the FTA for FY 94. This uncertainty in funding forced the RSC to stop work on the organization of the program and shift the resources to the other task areas.

PARTNER Membership

The status of PARTNER membership is listed in Table 2.2.

FIGURE 2.3

AFFILIATE MOU template

MEMORANDUM OF UNDERSTANDING BETWEEN:

(hereinafter known as "The Program Associate Manufacturer" or "the Manufacturer")

AND: THE ENERGY MANAGEMENT PROGRAM

(hereinafter known as "the Program")

This Agreement is entered into by and between ______________________________ as a Program Associate Manufacturer or the Manufacturer, and the Energy Management Program, operated by the Rail Systems Center (RSC) of Carnegie Mellon Research Institute, a division of Carnegie Mellon University of Pittsburgh, Pennsylvania, this _____ day of _______________, 1993.

WITNESSETH

WHEREAS, the Federal Transit Administration (FTA) is committed to support energy conservation and load management initiatives to reduce operating cost;

AND WHEREAS, the Manufacturer is committed to manufacturing, developing, evaluating and implementing energy efficient technologies and products for rapid rail transit systems;

AND WHEREAS, FTA has entered into a Cooperative Agreement with CMU (RSC) as of March 30, 1993, wherein FTA is providing federal funds to CMU (RSC) to inter alia invite all U.S. electrically powered rail transit systems (rapid rail transit systems) to participate in a research program at CMU designed to foster energy management and power cost reduction techniques.

AND WHEREAS, the parties wish to set forth common principles and their respective commitment to the Energy Management Program in the Memorandum of Understanding ("MOU");

NOW THEREFORE, in consideration of the mutual promises, covenants and conditions contained herein, the parties agree as follows:

1. That the primary purpose of the Energy Management Program is to evaluate and implement energy management initiatives to reduce operating costs.

2. That commercial application of energy efficient technologies promote efficient use of energy at a least cost option for the society, and enhance national energy security.

3. That the active participation of equipment manufacturers, distributors, financial institutions and private enterprises is critical to achieving the goals and objectives of the Energy Management Program.

4. That existing products and technologies and initiatives of the manufacturer shall become an integral part of the Energy Management Program.

5. Manufacturer's Responsibilities:

   The Manufacturer shall:

   a) Produce, manufacture, deploy and offer energy efficient equipment and technology that meets current and future requirements of Program Partners and Associates.

      - Participate in energy audits.

      - Evaluate commercialization of energy efficient technologies.

   b) Participate in the Program sponsored seminars, workshops and pilot projects.

      - Participate in pilot programs sponsored by the Energy Management Program.

      - Document improvements, benefits and corrective measures to meet the goals.

      - Undertake an energy efficiency review of all equipment required for facilities under design and construction to ascertain that they meet or exceed energy efficiency standards.

      - Undertake employee awareness and training to promote energy efficiency awareness.

6. Program Responsibilities:

   The Program responsibilities shall be carried out by the RSC and shall include:

a) Providing guidelines, guidance and assistance to the Manufacturer in developing and implementing cost effective and site specific energy cost reduction.

b) Seeking cooperation with governmental agencies and institutions to remove regulatory barriers that artificially restrict energy management initiatives.

c) Promoting and expanding the Program by enrolling more manufacturers and private sector Associates (electric utilities) and Affiliates (suppliers and service organizations).

d) Providing technical services to the Manufacturer on a limited basis.

e) Building and maintaining a rail transit energy data base, to which the Manufacturer will have access.

f) Making available to Manufacturers and the Program Associates and Affiliates, analysis tools for estimating energy reduction cost effectiveness (some of these tools would require formal licenses with third parties).

g) Developing new analysis tools as required which would be made available to the Program Associates and Affiliates as they are developed. No licenses would be required here unless the tool were provided by a third party.

h) Updating the "Energy Management Guidelines for Rail Transit" as new information and techniques become available.

i) Participating in publicity programs identifying specific facilities that have benefited from the program and participants who have contributed to its success.

j) Developing innovative financing techniques for the Program.

7. ALL INFORMATION PROVIDED TO THE MANUFACTURER UNDER THE TERMS OF PAR. 7 IS PROVIDED ON AN "AS IS" BASIS. THE INFORMATION SO PROVIDED IS THE PRODUCT OF RESEARCH BY THE RSC, AND THE RSC DISCLAIMS ANY WARRANTIES OF ANY KIND, EITHER EXPRESSED OR IMPLIED AS TO THE USE OF THIS INFORMATION BY A MANUFACTURER OR ANY THIRD PARTY TO WHOM THE MANUFACTURER HAS GIVEN ACCESS TO THE INFORMATION.

No party to this Agreement shall be liable to either or both of the other parties for any special, direct, indirect or consequential damages or any damages whatsoever resulting from the use of the aforementioned information by the user in its "as is" condition. Any user who allows a party, other than a party to this Agreement, to use the above information indemnifies and save harmless the other parties from any damages, claims, costs or charges, including attorneys' fees, court costs and damages from any claim, suit, cause of action or judgement arising from the use of said information by the party, including but not limited to claims of active and/or passive negligence.

8. This is a voluntary agreement between the parties. No modification, amendment or revision of this agreement shall be valid unless it is in writing and consented to by all parties.

COMPLETE DOCUMENT MUST BE RETURNED.

As representatives of the Energy Management Program and the Program Associate Manufacturer, we, the undersigned, do hereby execute this Memorandum of Understanding on the latter of the dates indicated below.

The Program Associate Manufacturer:

By:__________________________

Date:__________________________

By:__________________________
Richard A. Uher, Director
Rail Systems Center
Carnegie Mellon Research Institute
Carnegie Mellon University

Date:__________________________

By:__________________________
Dr. William M. Kaufman, Director
Carnegie Mellon Research Institute
Carnegie Mellon University

Date:__________________________

By:__________________________
Susan B. Dunkle, Associate Provost
Research & Academic Administration
Carnegie Mellon University

Date:__________________________

TABLE 2.2

STATUS OF PARTNER MEMBERSHIP

Rail Transit Authority	Status
Mass Transit Administration of Maryland (Baltimore)	Execution of MOU
San Francisco Bay Area Rapid Transit	Execution of MOU
Greater Cleveland Regional Transit Authority	Execution of MOU
Metropolitan Atlanta Rapid Transit Authority	PARTNER
National Railroad Passenger Corporation	Execution of MOU
New Jersey Transit	Execution of MOU
Port Authority of Allegheny County (Pittsburgh)	PARTNER
Washington Metropolitan Area Transportation Authority	PARTNER

3.0 RAIL TRANSIT ENERGY DATABASE

3.1 Background

As part of the Rail Transit Energy Management Program (EMP), a database has been established at the Rail Systems Center (RSC) at Carnegie Mellon University.

The database is part of a bulletin board system (BBS) which will contain the following information:

- Energy related rail transportation system parameters for North American systems.
- Energy management related materials and reports for transportation and other industrial applications.
- Related Electric Power Research Institute (EPRI) research results.
- Descriptions of rail transportation energy management computer tools, as well as computer tools for related applications.

Since the membership of the EMP will have access to the BBS, provisions were made to have both on-line forums and electronic mail, through which parties could discuss energy related matters.

3.2 Description of Database Structure and Contents

The purpose of the database is to provide information to the members of the Rail Transit Energy Management Program. This information includes rail transit energy and energy cost data, the results of implementation of energy cost reduction strategies and timely exchange of information concerning energy cost reduction among transit authorities. The database has been set up to expedite these objectives.

3.2.1 Hardware

The database is presently set up on a Gateway 2000 386/33C. This PC has a hard disk with 85MB and an extended RAM of 16MB in addition to conventional memory of 640KB.

The communications channel is through a Supra Fax Modem via a serial port on the computer.

3.2.2 Software

The software chosen for the database is the Major Bulletin Board System (BBS) by GALACTICOMM, Version 6.12. This software is registered to the Rail Systems Center of Carnegie Mellon University.

The EMP database is fully transferable to other PCs as it grows and requires more hard disk space and RAM.

3.2.3 Contents

Table 3.1 shows the principal (TOP) menu of the EMP database. The "page" references in this menu are also shown in the table.

A page can be one of three types: MENU, MODULE or FILE.

> A MENU page displays a menu to the user with choices that lead to either other menu pages, module pages or file pages.
>
> A MODULE page invokes a service which is resident within the database. Electronic mail and forums are examples of MODULE pages.
>
> A FILE page displays a text file to the user.

A MENU TREE is a collection of pages. Each page is either a MENU, a MODULE or a FILE.

The TOP page, which is a MENU, is the base of the tree. Only MENU pages have branches which point to other pages.

Each of the pages of the main menu, shown in Table 3.1, are discussed.

<u>Page INFO (I - Information Center)</u>

As presently configured, INFO is a MENU page which points to three other pages. These are shown in Table 3.2.

Each of the pages which branch from the INFO page are FILE pages.

- The EMPDB page (File: EMPDB.TXT) describes the operator of the DB, the DB and its purposes and how to contact the operator.

- The SHORTCUTS page (File: GALGIC.TXT) describes shortcut methods for accessing pages in the database. These shortcuts bypass the menu/tree route for accessing sections of the database.

TABLE 3.1

PRINCIPAL MENU OF EMP DATABASE

Page - TOP

Menu	Page Name	Page Type
I - Information Center	INFO	MENU
N - Energy News	NEWS	FILE
D - Energy Database	EDBASE	MENU
E - Electronic Mail	MAILBOX	MODULE
F - Forums	FORUMS	MODULE
A - Account Display/Edit	ACCOUNT	MODULE
R - Registry of Users	REGISTRY	MODULE
S - System Manager	REMOTE	MODULE
X - Exit System (Logoff)	EXIT	MODULE

TABLE 3.2

MENU OF INFO PAGE

Page - INFO

Menu	Page Name	Page Type
A - About the Database	EMPDB	FILE
S - Shortcut Commands	SHORTCUTS	FILE
H - Help (EDBUSER.DOC)	HELP	FILE

- The HELP page (File: EDBUSER.DOC) is the User's Manual for the database, which is, in its entirety, Volume III of this report.

Page - NEWS (N - Energy News)

This is a FILE page (NEWS.TXT) on the database which communicates general news items from the system operator (SYSOP) to all members. News items are kept for two months and then removed.

Page - EDBASE (D - Energy Database)

As presently configured, EDBASE is a MENU page which points to three other pages. These pages are listed in Table 3.3.

A brief description of each of the pages which branch from the EDBASE page are briefly discussed.

- The MEMBERS is a FILE page (MEMBERS.TXT) which lists the members of the Rail Transit Energy Management Program. These are divided by Partners (transit authorities), Associates (electric utilities which serve transit authorities) and Affiliates (the transit supply industry).

- The TED page is a MENU page which contains the rail transit authority energy and energy cost data, as well as energy management activities and results. These are separated by specific transit authority. More detail is available in Volume III of this report.

- The RINDEX is a MODULE page which contains a search capability of all energy and power related reports in the RSC library.

Page - MAILBOX (E - Electronic Mail)

The MAILBOX is a MODULE page which provides the E-mail service to the database. It has the following menu items which can be accessed by the user:

R - Read Messages
W - Write Messages
M - Modify a Message
E - Erase a Message
S - Special Functions
X - Exit E-mail

TABLE 3.3

MENU OF EDBASE

Page - EDBASE

Menu	Page Name	Page Type
M - EMP Membership List	MEMBERS	FILE
T - Transit Energy Data	TED	MENU
R - Report Index	RINDEX	MODULE

Details on how to use the E-mail functions are discussed in the User's Manual in Volume III.

Page - FORUMS (F- Forums)

The FORUMS is a MODULE page which provides a forum service on the database. It has the following menu items which can be accessed by the user:

R - Read Messages
W - Write Messages
Q - Quickscan Menu
F - Filescan
S - Select a New Forum

In addition, there are FORUMS menu items which can only be accessed by the SYSOP:

M - Modify a Message
E - Erase a Message
A - Approve Files
C - Configure Users
O - Operations Menu

More detail on all FORUMS functions appear in the User's Manual of Volume III.

Page - ACCOUNT (A-Account Display/Edit)

The ACCOUNT is a MODULE page that allows the user to view and change information in his account. It consists of the following menu items:

S - Display statistics on your account

A - Display or edit account information (address/phone/password)

More detail on the ACCOUNT function is given in the User's Manual of Volume III.

Page - REGISTRY (R-Registry of Users)

The REGISTRY is a MODULE page which allows users to say something about themselves to other users. The menu items in this module are:

G - General Information
D - Directory of Users in Registry ("DA" to start at beginning)
Y - Edit your entry
L - Lookup another user's entry
X - Exit from the Registry Area

Page - REMOTE (S - System Management)

The REMOTE is a MODULE page which allows the SYSOP to manage the database remotely.

Table 3.4 lists the commands which can be used for remote operation by the system operator.

TABLE 3.4

REMOTE OPERATOR MENU

SENDALL	- Send Message to All	SYSTATS	- View Overall Statistics
SEND	- Send Message to User-ID	MODSTATS	- View Module Usage
LOGON	- Edit BBS Log-on Message	DEMSTATS	- View System Demographics
		CLSSTATS	- View Class Statistics
ACCOUNT	- Accounting functions		
DETAIL	- Detail Info on User-ID	EMULATE	- Emulate a channel
AUDIT	- Display the Audit Trail	MONITOR	- Monitor All mode
USERS	- Stats of Users Online	INPUT	- Monitor Input mode
SEARCH	- Account Database Search	CHANGE	- Change Channel Status
HANGUP	- Disconnect a User-ID	TYPE	- DOS TYPE command
SUSPEND	- Suspend/Unsuspend a User-ID	COPY	- DOS COPY command
PROTECT	- Exempt/Unexempt a User-ID	RENAME	- DOS RENAME command
DELETE	- Delete a User-ID	DIR	- DOS DIR command
SHUTDOWN	- Shutdown the System	MD	- DOS MD command
CLEANUP	- Force Cleanup or Event	RD	- DOS RD command
TRANSFER	- Transfer files	DEL	- DOS DELETE command
SYSOP	- Edit a User-ID's Access		

4.0 ALTERNATIVE ENERGY SOURCES

An alternative electrical energy source is an energy storage device and/or a supplier which is not the native (local) utility company. It refers to the purchase of electricity which may be used at a time different from the purchase time and/or from an alternative supplier. If the electricity is purchased from an alternative supplier, the process is termed bypass.

4.1 Energy Storage

Energy storage systems are designed to enable purchase of energy during low cost purchase times, to store that energy, and to use it during high cost purchase times. Energy storage can be used for load shifting, improving regeneration receptivity and providing backup energy for emergency or abnormal conditions. Load shifting is primarily used for peak demand reduction. Energy is purchased during periods of low demand and used at periods of high demand. This process is known as peak shaving. For a rail transit authority with time-of-day power rates, load shifting can be used to offset energy, as well as demand based costs.

A second and sometimes overlooked use for energy storage systems is for improvement of regeneration receptivity. In this circumstance, the stationary energy storage system functions as a load or generator on the system. When the receptivity is low, the energy storage system functions as a load increasing the receptivity of the system. When the receptivity is high, it can function as a generator supplying power to the trains. In contrast to the situation where energy storage is used as a load shifter, here the transfer times of the energy are on the order of seconds rather than hours. However, the effect is the same; namely, energy cost is reduced through both demand and energy components.

Several energy storage technologies have been examined including battery, fluid, flywheel and superconducting[2]. Energy storage system costs are dependent on both peak power input and output (kW component) and the amount of stored energy (kWh component). Typical rail transit energy storage requirements can range between 300 kWh-5000 kWh, with associated input and output power ranges between 1000 kW and 7000 kW.

A review of the cited report[2] indicates that lead-acid battery based energy storage systems are the most economical for this type of application. Flywheels, which probably fall into second place in the economic tier, may improve as new materials are developed to withstand the large centrifugal stresses developed. Superconducting Magnetic Energy Storage (SMES) is still not the state of the art and is projected to cost 1-2 orders of magnitude

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[2] *Characterization of Energy Storage for Transportation*, Stolte, W.J., EPRI, RP 2415-31, May 1993.

more than lead-acid batteries for installations in the range of powers and energies for rail transit.

Although several battery storage systems have been built for several other applications, only one has been prototyped in the U.S. San Diego Gas and Electric, the San Diego Trolley, and the San Diego Metropolitan Transit Development Board cooperated in building a $1.4 million Battery Energy Storage System prototype. The facility is used for reducing peak demand. It was estimated that the battery system would pay for itself in eight to ten years.

Previous work[3] indicated that energy storage for PAT and WMATA may be economically feasible because of the high demand rate charged by the local utility. One of the recommendations of this report was that computer simulation tools be developed which would enable economic assessment of energy storage schemes.

As a result, for this effort, a computer model, which would simulate the operation of a BESS at a transit system, was developed. Additionally, the results of the BESS model were utilized to establish the economic feasibility of implementing a BESS at two separate transit systems: PAT and WMATA.

4.1.1 BESS Computer Program Description

The BESS model is to simulate operation of a BESS based on one year's worth of metering load curves. These load curves are generally available from the electric utility which services the rail transit system. The model estimates the annual power bill from the load curves without a BESS in place. It then simulates operation of a BESS modifying the load curves to reflect the use of the BESS. A power bill is then calculated using these modified load curves. An economic model then considers the BESS cost and savings, and provides the user with the BESS Internal Rate of Return, Net Present Value and Payback Period. These parameters provide the user with the information necessary to establish whether use of the BESS is economically sound.

For the purposes of this report, a BESS is a bank of batteries electrically connected through a power conditioning unit to the electrical distribution subsystem of the rail transit system. The BESS provides power to the transit system during its peak-load times, and is recharged during off-peak hours. In this way, the BESS is able to reduce the monthly power requirements from the utility, thus reducing the monthly demand charges (commonly referred to as peak-shaving). For the BESS to be considered economically feasible, the demand savings associated with BESS operation

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[3] *Alternative Electric Energy Sources for Rail Transit, Final Report, Phase I*, August 1993, Uher, R.A., Howard, J.; Rail Systems Center, Carnegie Mellon University, Pittsburgh, PA 15213.

must exceed the sum of the construction finance costs and the operation and maintenance costs.

From discussions with battery manufacturers and from reviewing recent literature, the valve regulated, lead-acid (VRLA) battery was the most attractive from both a cost and performance perspective. Therefore, the BESS model reflects application of a VRLA battery.

The energy capacity of a lead-acid battery varies depending on the rate at which the energy is removed from it. The faster the energy is removed, the lower the amount of energy that can be obtained from the battery for that cycle. The simulation of this phenomena within the BESS model was accomplished through the use of a relationship known as Peukert's equation. This equation, which relates the discharge current to the time the battery will last at the given current, enables the simulator to estimate the capacity for any possible discharge rate history.

Another phenomena modeled within the BESS model is energy recovery, whereby capacity that was lost due to high discharge rates is partially recovered when the battery is idle. The BESS model takes into account a number of other battery characteristics, including its maximum allowable depth-of-discharge, recharge efficiency, battery life and increased battery voltage. The model's handling of each of these battery parameters enables a more realistic simulation of the BESS.

The BESS model simulates the control of battery discharge in two ways. The first, more conventional method allows discharge of the BESS at a set rate for a specified amount of time, regardless of the demand. The second approach allows discharge of the BESS only when the demand rises above a user-specified value.

Cost estimates were obtained from battery manufacturers and from application studies. The BESS model can use these costs, or case-specific costs can be entered.

The BESS model accepts utility rate structures based on demand and energy charges. The PAT and WMATA rate structures are internally coded into the program, but can easily be replaced by other rate structures. More details are contained in Volume III.

4.1.2 BESS Application to PAT and WMATA

One year's worth of metering load curves was obtained for both the PAT and WMATA systems, and the BESS computer program utilized this information to determine the economic feasibility of a BESS application at these facilities.

Using the BESS computer program with the conventional discharge method (i.e. BESS constant discharge for set times), both the PAT and the WMATA systems were not economically feasible. For both systems, the payback period was more than 3-4 years, which is considered reasonable.

However, considering a discharge methodology, whereby the BESS is utilized only when the demand exceeds a set value, the payback period results are over 14 and 10 years for WMATA and PAT, respectively. Both of these payback periods are marginal. With the uncertainty or risk associated with implementing a BESS at these authorities, it is doubtful whether transit management would be inclined to make such an investment.

4.2 Bypass

The second class of alternative energy sources falls under the general category of bypass. Bypass options include non-native utility generation, non-utility generation and self generation.

Energy storage is presently in limited use as well as being researched by the Electric Power Research Institute (EPRI - the research agency for the electric power industry). While energy storage is generally not opposed by the electric power industry, bypass by retail customers is discouraged and opposed by the industry. There are technical, regulatory and institutional issues involved with this opposition. In general, in order to effect bypass, the transit authority must obtain generation access and transmission access. There are coordination issues to be considered, and cooperation of both the native electric utility and the regulatory agencies will be necessary.

The previous study[3] concluded:

> "Retail wheeling, which is power transmission to a customer which is not a utility, is strongly opposed by the utilities, legislators and regulators. This opposition will certainly limit most types of retail wheeling transactions."

During most of the 1980's and beginning of the 1990's, the electric power industry commissioned EPRI to conduct a series of investigations into improving demand side management. The philosophy was to cooperate with their customers to achieve higher energy efficiency and thus reduce the customer's cost.

EPRI has also indicated their support for the EMP. A copy of a letter from them is shown in Appendix B. It is clear from the sixth paragraph in this letter that neither EPRI nor the utilities would support the "bypass" option. Thus, for the time being, demonstration of a bypass project has been postponed in favor of reducing energy costs through energy management, energy storage and utility cooperation with rail transit authorities.

5.0 FIVE YEAR PLAN

As originally conceived, the EMP was set up as a six year program. Although two calendar years have passed since the EMP was established, lack of federal funds for the second year's effort (FY 1994) has resulted in only one year's worth of work spread out over two years. It was on this basis that the five year plan for the program was developed. This plan is outlined in the next section. Following that section, a more detailed plan is worked out for next year's effort.

5.1 Overall Plan

The EMP would continue to be a private/public partnership consisting of rail transportation authorities as partners, electric utilities as associates and manufacturers, vendors and service companies as affiliates.

The long range objective of the program remains the same; namely, to reduce annual energy cost for North American rail transportation authorities by 10%. For U.S. rail transit authorities, this goal translates to a reduction of operating cost of $45 million at the end of the fifth year of the continuing program.

To accomplish the objectives of the program, the following tasks would be initiated (I) or continued (C):

- Program Organization (C)
- Energy Management Database Maintenance (C)
- Battery Energy Storage Demonstration (C)
- Energy Management Computer Tools Development, including a Train Operations Model (TOM) (I)
- Capital Equipment Cost Reduction under energy management scenarios (I)
- Energy Management Guidelines Manual Updates (I)
- Educational Activities in Energy Management for the Industry, including workshops and conferences (C)

5.1.1 Five Year Program Work Scope

The tasks in the five year program are outlined in more detail.

1. Program Organization

Organization of the program would continue during the first year of the five year plan. Partners, associates and affiliates would be solicited. Associate and affiliate members would be sought after a core of 8-10 partners have joined the program. Partners who are rail transit authorities would pay no fee, while associate and affiliate members would pay an annual membership fee. This fee would be the private contribution to the private/public partnership.

An advisory board to the program will also be established. It will have a majority representation from the partners, representation from associates and affiliates, an FTA member and other members elected at-large. A chairman and secretary will be elected annually.

2. Energy Database (EDB) Maintenance

The EDB has been established. The EDB will be expanded in the following areas:

- As new transit authorities become members of the EMP, information from them will be added to the EDB similar to that already existing for current members.
- Transit authorities who are current members will update time sensitive data as they become available.
- As the EDB grows, both E-mail and forum activity will increase. This media will provide an excellent exchange place for up-to-date energy cost reduction information.
- Other categories will be added as the membership grows. This will include electrical equipment supply, cost and cost history, energy management computer tool descriptions and availability and energy management equipment and equipment costs.
- A doorway program will be added to the EDB which will allow users to run actual computer models on line.

3. Battery Energy Storage Demonstration

Work completed by the RSC for the Electric Power Research Institute (EPRI) will be contributed to the EMP. This work, which uses an innovative approach to battery storage, has shown storage systems whose capital cost can be payed back in less than three years.

A prototype demonstration of this innovative storage system would be conducted at one of the partner's rail system.

4. Energy Management Computer Tools Development

Tools which already exist for non-traction power uses will be evaluated by the program. Recommendations would be made to the members of the program for future purchases.

The EMM would be updated and improved. These improvements would be made available to the license holders of the model, who are also members of the program. Those members who are not presently license holders of the model will have the opportunity to purchase the license at a discount price. The improvements made by the program would be given to the members at no cost (copying charges only). The improvements purchased by the program from present license holders may carry an additional fee for the improver.

The Train Operations Model (TOM) is now under development at the RSC. It was designed to test train control strategies for both energy and schedule time performance. Appendix C is a paper which describes the mainline railroad version of the model. A rail transit version is also under development and was applied to the Sacramento light rail system.

The TOM development would be completed under the program. This would include verification at one or two rail transit systems. Algorithms would be developed which would allow energy efficient operation.

Other tools defined and/or developed by the program would be made available to the members.

5. Capital Equipment Cost Reduction

Application of certain energy cost reduction technologies to rail transit reduces the requirements for electrical equipment in substations, passenger stations and on board the trains. This in turn can reduce both replacement and new capital cost.

Guidelines will be developed to determine how such capital equipment can be resized after application of energy management reduction strategies. Estimates will be made of the capital cost saving potential of the resized equipment.

6. Rail Transit Energy Management Guidelines Manual Updates

The Guidelines Manual was developed under a grant from the FTA by the RSC during 1983-86. It would be updated to reflect experience gained since that time. Two updatings are anticipated.

7. Educational Activities in Energy Management for the Industry

Existing workshops and shortcourses, which were developed at the RSC, would be offered at a discount rate to members of the program. These are shown in Appendix D. Courses and workshops developed by the program will be offered to members free of charge (limited representation from member organizations) and at a fee to non-members.

5.1.2 Five Year Plan Schedule

The schedule for the tasks to be performed in the five year plan is shown in Figure 5.1

Task 1

Organization of the program would be completed by the end of one year and six months. It is expected that 90% of the rail transit authorities would have joined the program by that time.

Task 2

The energy database would continue to be expanded and updated during the whole five year program. It would also be used as a monitoring device to assess the program's effectiveness.

Task 3

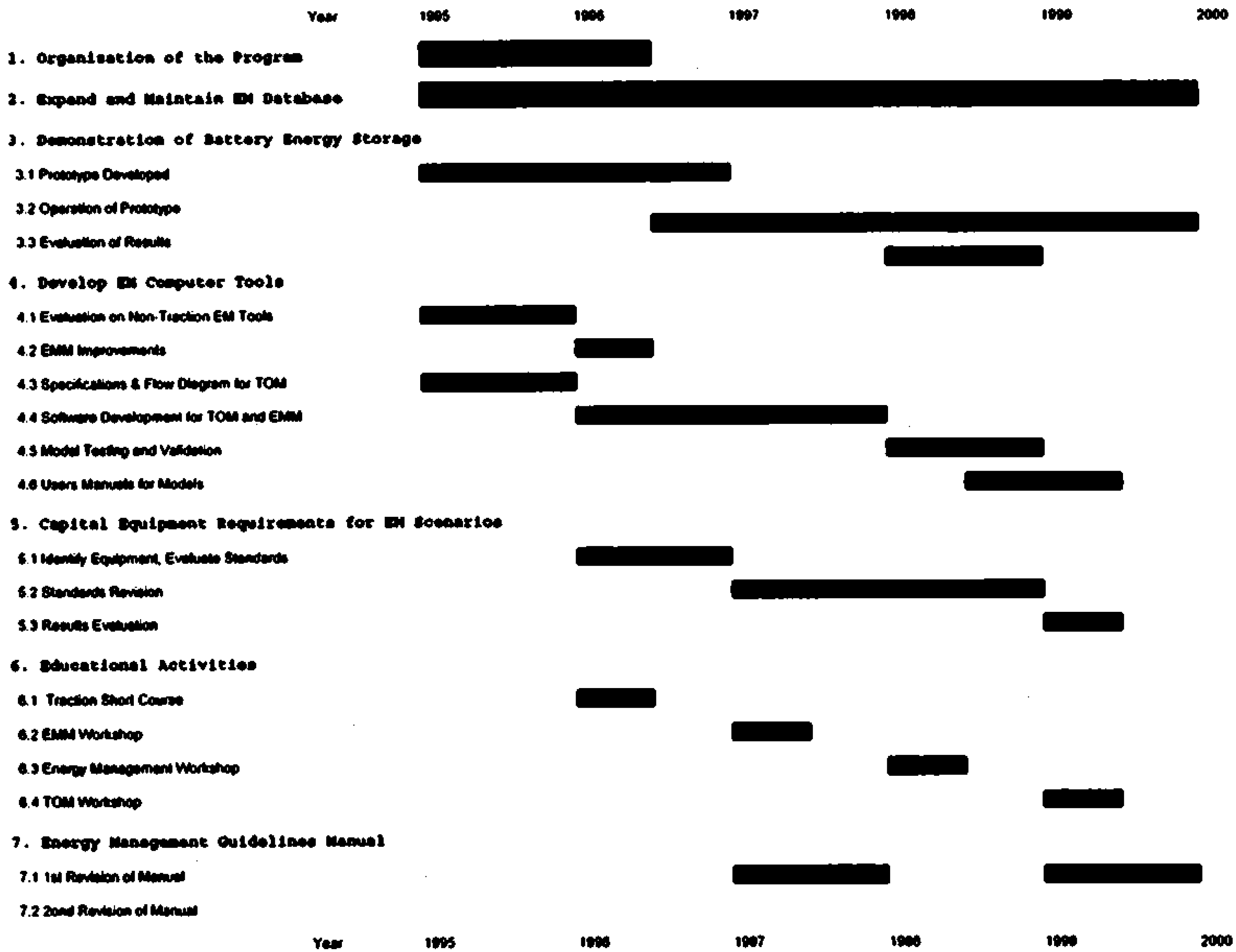
An energy storage demonstration is expected to be installed by the end of the second year of the program. Evaluation of the results of the demonstration would continue for another two years.

Task 4

The first year of the five year plan would be used to evaluate non-traction energy management tools. Improvements to the EMM would be identified. Specifications would be developed for the Train Operations Model (TOM) together with flow diagrams for software development.

FIGURE 5.1

SCHEDULE FOR FIVE YEAR PLAN



The next two years of the program would concentrate on software development for the TOM and the EMM to meet the specifications developed in the first year. The fourth year would involve testing and experimental validation of the models developed. Guidelines manuals for using the models would also be completed during the fourth year.

Task 5

This program will begin in the second year of the five year plan. All areas for cost reduction will be identified and current standards used to specify energy sensitive equipment will be reviewed. Changes in these standards will be suggested and referred back to the originating organizations for the standards. The next two years would involve the meeting of the standards committees and changed standards development. Evaluation and estimates of new equipment capital costs would be completed during the fifth year of the five year plan.

Task 6

The Rail Transit Energy Management Guidelines Manual will be updated in year 3 of the program and then once again in year 5.

Task 7

The following activities would be conducted in parallel with the program:

- Traction shortcourse (year 2)
- Energy Management workshop (year 3)
- EMM workshop (year 4)
- TOM workshop (year 5)

5.2 Next Year (1995) Effort

The following work will be conducted during the 1995 phase of the EM Program.

1.0 Program Organization

1.1 Program Partners

Continue working with the rail transit authorities to sign the EMP Memorandum of Understanding and become partners in the program. The goal is 60% of 24 rail transit authorities.

1.2 Program Associates

Continue working with the electric utilities to become associate members in the program. A goal of 5 electric utilities has been established.

1.3 Program Affiliates

Continue working with manufacturers, vendors and service companies to become affiliate members in the program. A goal of 5 of these private sector entities has been established.

1.4 Technical Oversite Committee

Establish a core technical oversite committee. This committee would initially consist of eight members. In the following year it would be expanded to sixteen members.

2.0 Expand and Maintain the Energy Program Database

In the present work, the database was established. During the 1995 phase of the effort, the database will be expanded.

2.1 New Members

As new members join the program, contributions to the database will be solicited and accepted from them.

2.2 Present Members

Present members will be solicited to update the information on their system or equipment as it becomes available.

2.3 Continuing Literature Search

The literature will continually be scanned and items related to the Energy Management Program will be added to the database.

2.4 Data Maintenance

The database will be operated and maintained.

3.0 Specifications for Train Operations Model

The rail transit version of the Train Operations Model will be fully specified in the 1995 phase of the work.

3.1 TOM Definition

The rail transit TOM will be defined in terms of its capabilities. These capabilities shall include, but are not limited to:

- The ability to be applied to any rail transit system without program changes.

- The ability to handle manual signaling, fixed block signaling, and fixed block and moving block automatic train control.

- The ability to summarize performance measures including schedule performance, capacity performance and energy performance.

- The ability to test train control algorithms such as energy optimization of train operation, optimization of performance on recovery from system faults and optimized performance under abnormal operation.

3.2 TOM Block Diagram

A block diagram will be developed to show all of the TOM inputs, outputs and internal processes. This block diagram will be updated as the program proceeds and changes are made.

3.3 Assembly and Coding

Maximum use will be made of the programs included in the Rail Transit EMM in the assembly and development of the TOM. This will include the Train Performance Simulator (TPS), Electric Network Simulator (ENS) and input file creation programs. The following additional work would also be included:

- Development of a Train Movement Simulator (TMS) for use with rail transit and commuter rail.

- Evaluation and purchase of a graphics package which can interact with the user in a "friendly" way.

- Development of a performance summary module, which may be transit system specific, which can be used for summarizing the performance characteristics which result from simulations.

- Development of an automatic train control algorithm interface package which will allow train control algorithms to be tested on the simulator. The algorithms themselves would not be developed as part of this effort.

- Development of a "user friendly" supervisory module which can control the simulator and provide the user with on-line help for running the TOM.

4.0 Continued Implementation of an Alternative Energy Purchase Demonstration

An alternative energy purchase demonstration has been initiated in the present work. The focus of the demonstration would be battery storage. Two transit authorities, WMATA and PAT, show potential for such a demonstration. It is not expected to be complete. Progress of the purchase will be monitored and reported to the members of the program. Such things as energy cost savings, cost of purchase, etc. will be part of the report.

5.0 Energy Storage Evaluation

The following research effort will be contributed to the program by EPRI. This is the development of a generic energy storage model to be used with the EMM and applied and evaluated on three rail transit authorities including WMATA.

5.1 Generic Storage Design Model

A generic design model for a rail transit battery energy storage system was developed. Input to the model will be performance and rail transit power subsystem interface requirements. Output will be cost, size, and risk type information.

5.2 Generic Economic Assessment Model

An economic assessment model will be assembled which will use the rail traction EMM, developed previously by the University, as its base. The EMM will simulate the effect of operating the rail transit system with and without the battery energy storage system in operation. This will determine energy and capacity savings. The economic model will then use this information together with output from the generic design model to determine return on investment information.

5.3 Application to WMATA

The procedure of battery energy storage design and economic assessment will be applied to WMATA.

APPENDIX A

EXECUTED TRANSIT AUTHORITY MOUs

MEMORANDUM OF UNDERSTANDING

BETWEEN: **METROPOLITAN ATLANTA RAPID TRANSIT AUTHORITY**

(hereinafter known as "the Partner")

AND: **THE ENERGY MANAGEMENT PROGRAM**

(hereinafter known as "the Program")

This Agreement is entered into by and between Metropolitan Atlanta Rapid Transit Authority, as a Partner, and the Energy Management Program, jointly operated by the Rail Systems Center (RSC) of Carnegie Mellon Research Institute, a division of Carnegie Mellon University of Pittsburgh, Pennsylvania and the Canadian Institute for Guided Ground Transportation (CIGGT) of Queen's University, Kingston, Ontario, Canada, this 25 day of November, 1993.

WITNESSETH

WHEREAS, the Federal Transit Administration (FTA) is committed to support the Partner's energy conservation and load management initiatives to reduce operating cost;

AND WHEREAS, the Partner is committed to evaluating and implementing cost effective power cost reduction initiatives;

AND WHEREAS, FTA has entered into a Cooperative Agreement with CMU (RSC) as of March 30, 1993, wherein FTA is providing federal funds to CMU (RSC) to inter alia invite all U.S. electrically powered rail transit systems to participate in a research program at CMU designed to foster energy management power cost reduction techniques and to establish a cooperative relationship with the Canadian Institute of Guided Ground Transport at Queen's University in Canada to exchange information on energy management techniques and strategies used in Canada.

AND WHEREAS, the parties wish to set forth common principles and their respective commitments to the Energy Management Program in the Memorandum of Understanding ("MOU");

NOW THEREFORE, in consideration of the mutual promises, covenants and conditions contained herein, the parties agree as follows:

1. That the primary purpose of the Energy Management Program is to evaluate and implement energy management initiatives to reduce operating costs.

2. That reduction in end use energy consumption will reduce combustion related pollution.

3. That demand side energy management initiatives combined with alternative supply sources promote efficient use of energy at a least cost option for the society, and enhance national energy security.

4. That the active participation of equipment manufacturers, distributors, financial institutions and private enterprises is critical to achieving the goals and objectives of the Energy Management Program.

5. That existing programs and initiatives of the **Partner** shall become an integral part of the Energy Management Program.

6. **Partner's** Responsibilities:

   The **Partner** shall:

   a) Develop an energy management plan, which shall include:

      - An energy management study, which conducts an energy audit of all facilities, evaluates the power rate structure and identifies energy cost reduction opportunities and objectives.

      - An implementation plan, which identifies those cost reduction opportunities to be pursued, the organization within the management structure responsible, a schedule for implementation and resources to be committed.

   b) Participate in the Program sponsored seminars and workshops.

   c) Formulate energy cost reduction goals:

      Traction: 5-25%
      Non-Traction: 10-20%
      - Lighting - passenger stations, buildings and parking lots
      - Heating/ventilation/air conditioning (HVAC)
      - Elevators and escalators
      - Shop machinery
      - Others

d) Develop a structured implementation which

- is based upon payback, cost/effectiveness and organizational priorities

- documents improvements, benefits and corrective measures to meet the goals

- undertakes an energy efficiency review of all facilities under design and construction to ascertain that they meet or exceed energy efficiency standards

- periodically reaudits energy use and re-evaluates the power rate structure

- undertakes employee awareness and training to promote energy efficiency awareness

e) Develop and pursue power rate reduction and alternative rate structures through electric utility negotiation and intervention in rate proceedings.

f) Pursue alternative energy sources when it is in the best interest of the **Partner** to do so.

7. Program Responsibilities:

The Program responsibilities shall be carried out by the RSC and CIGGT and shall include:

a) Providing guidelines, guidance and assistance to the **Partners** in developing and implementing cost effective and site specific energy cost reduction.

b) Seeking cooperation with governmental agencies and institutions to remove regulatory barriers that artificially restrict energy management initiatives.

c) Promoting and expanding the Program by enrolling more **Partners** and private sector Associates (electric utilities) and Affiliates (suppliers and service organizations).

d) Providing technical services to the **Partners** on a limited basis.

e) Building and maintaining a rail transit energy data base, to which the Partners, Associates and Affiliates will have access.

f) Making available to Partners, Associates and Affiliates, analysis tools for estimating energy reduction cost effectiveness (some of these tools would require formal licenses with third parties).

g) Developing new analysis tools as required which would be made available to the Partners, Associates and Affiliates as they are developed. No licenses would be required here unless the tool were provided by a third party.

h) Updating the "Energy Management Guidelines for Rail Transit" as new information and techniques become available.

i) Participating in publicity programs identifying specific facilities that have benefited from the program and participants who have contributed to its success.

j) Developing innovative financing techniques for the Program.

8. All information provided to the Partner under the terms of par. 7 is provided on an "as is" basis. The information so provided is the product of research by RSC and CIGGT, and RSC and CIGGT disclaim any warranties of any kind, either express or implied as to the use of this information by a Partner or any third party to whom the Partner has given access to the information.

   No party to this Agreement shall be liable to either or both of the other parties for any special, direct, indirect or consequential damages or any damages whatsoever resulting from the use of the aforementioned information by the user in its "as is" condition. Any user who allows a party other than a party to this Agreement to use the above information indemnifies and saves harmless the other parties from any damages, cost or charges, including attorneys' fees and court costs from any claim, suit, cause of action or judgment arising from the use of said information by the party.

9. This is a voluntary agreement between the parties. No modification, amendment or revision of this agreement shall be valid unless it is in writing and consented to by all the parties.

COMPLETE DOCUMENT MUST BE RETURNED.

As representatives of the Energy Management Program and the Partner, we, the undersigned, do hereby execute this Memorandum of Understanding on the latter of the dates indicated below.

By: ______________________
Partner (Metropolitan Atlanta Rapid Transit Authority)

Date: 11-8-93

By: ______________________ 11-15-93
Richard A. Uher, Director
Rail Systems Center
Carnegie Mellon Research Institute
Carnegie Mellon University

Date: 11-15-93

By: ______________________
for Dr. William M. Kaufman, Director
Carnegie Mellon Research Institute
Carnegie Mellon University

Date: 11/16/93

By: ______________________
Susan B. Dunkle, Associate Provost
Research & Academic Administration
Carnegie Mellon University

Date: 4/25/95

MEMORANDUM OF UNDERSTANDING

BETWEEN: PORT AUTHORITY OF ALLEGHENY COUNTY
(hereinafter known as "the Partner")

AND: THE ENERGY MANAGEMENT PROGRAM
(hereinafter known as "the Program")

This Memorandum of Understanding is executed by Port Authority of Allegheny County as a Partner, and The Energy Management Program, jointly operated by the Rail Systems Center (RSC) of Carnegie Mellon Research Institute, a division of Carnegie Mellon University of Pittsburgh, Pennsylvania (CMU) and the Canadian Institute for Guided Ground Transportation (CIGGT) of Queen's University, Kingston, Ontario, Canada, as of the ____ day of ____________________, 1994.

WITNESSETH

WHEREAS, the Partner is committed to evaluating and implementing cost effective power cost reduction initiatives; and

WHEREAS, the Federal Transit Administration (FTA) is committed to support the Partner's energy conservation and load management initiatives to reduce operating costs; and

WHEREAS, FTA has entered into a Cooperative Agreement with CMU (RSC) as of March 30, 1993, wherein FTA is providing federal funds to CMU (RSC) to, inter alia, invite all U.S. electrically powered rail transit systems to participate in a research program at CMU designed to foster energy management and power cost reduction techniques and to establish a cooperative relationship with CIGGT to exchange information on energy management techniques and strategies used in Canada and the United States; and

WHEREAS, the Partner is willing to participate in the Program; and

WHEREAS, the parties wish to set forth common principles and their respective understandings with respect to the Program in this Memorandum of Understanding as follows:

1. The Partner and the Program support the following principles:

    a. That the primary purpose of the Energy Management Program is to evaluate and implement energy management initiatives to reduce operating costs for electrically powered rail transit systems.

b. That reduction in end use energy consumption will reduce combustion-related pollution.

c. That demand side energy management initiatives combined with alternative supply sources promote efficient use of energy at a least cost option for the society, and enhance national energy security.

d. That the active participation of equipment manufacturers, distributors, financial institutions and private enterprises is critical to achieving the goals and objectives of the Program.

e. That existing energy conservation programs and initiatives of the Partner shall become an integral part of the Program.

2. In order to further the purposes of the Program, the Partner shall make reasonable efforts to:

a. Develop an energy management plan, which shall include:

i. An energy management study, which conducts an energy audit of all facilities, evaluates the power rate structure and identifies energy cost reduction opportunities and objectives.

ii. An implementation plan, which identifies those cost reduction opportunities to be pursued, the person or department responsible, a schedule for implementation and resources to be committed.

b. Participate in the Program sponsored seminars and workshops.

c. Formulate energy cost reduction goals of 5-25% for traction and 10-20% for non-traction uses, including:

i. Lighting - passenger stations, buildings and parking lots;

ii. Heating/ventilation/air conditioning (HVAC);

iii. Elevators and escalators;

iv. Shop machinery; and

v. Others.

d. Develop a structured implementation which:

i. is based upon payback, cost/effectiveness and organizational priorities;

ii. documents improvements, benefits and corrective measures to meet the goals;

iii. undertakes an energy efficiency review of all facilities under design and construction to ascertain that they meet or exceed energy efficiency standards;

iv. periodically reaudits energy use and re-evaluates the power rate structure; and

v. undertakes to promote energy efficiency awareness.

e. Develop and pursue power rate reduction and alternative rate structures through electric utility negotiation and intervention in rate proceedings.

f. Pursue alternative energy sources when it is in the best interest of the Partner to do so.

3. The Program responsibilities shall be carried out by the RSC and CIGGT and shall include:

a. Providing guidelines, guidance and assistance to the Partners in developing and implementing cost effective and site specific energy cost reduction.

b. Seeking cooperation with governmental agencies and institutions to remove regulatory barriers that artificially restrict energy management initiatives.

c. Promoting and expanding the Program by enrolling more Partners and private sector Associates (electric utilities) and Affiliates (suppliers and service organizations).

d. Providing technical services to the Partners on a limited basis.

e. Building and maintaining a rail transit energy data base, to which the Partners, Associates and Affiliates will have access.

f. Making available to Partners, Associates and Affiliates, analysis tools for estimating energy reduction cost effectiveness. (Some of these tools would require formal licenses with third parties.)

g. Developing new analysis tools as required which would be make available to the Partners, Associates and Affiliates as they are developed. (No licenses would be required unless the tool is provided by a third party.)

h. Updating the "Energy Management Guidelines for Rail Transit" as new information and techniques become available.

i. Participating in publicity programs identifying specific facilities that have benefited from the Program and participants who have contributed to its success.

j. Developing innovative financing techniques for the Program.

4. All information provided by any party to another is provided on an "as is" basis. RSC and CIGGT disclaim any warranties of any kind, either express or implied as to the use of this information by a Partner or any third party to whom the Partner has given access to the information, and Partner disclaims any warranties of any kind, either express or implied as to the use of this information by Program or any third party to whom the Program has given access to the information.

5. No party to this Memorandum shall be liable to any other party for any special, direct, indirect or consequential damages or any damages whatsoever resulting from the use of the aforementioned information by the user in its "as is" condition. Each party hereby releases the others from any and all costs, claims, expenses and damages that may be incurred by such party acting in reliance on any information received under this Memorandum.

6. The Partner may withdraw from its participation in the Program at any time by giving written notice thereof to the Program at the following address: Rail Systems Center, Carnegie Mellon Research Institute, Carnegie Mellon University, 4400 Fifth Avenue, Pittsburgh, PA 15213-2683 Attention: Mr. Richard A. Uher. RSC and CIGGT may elect to terminate the Program at any time by giving written notice thereof to the Partner at the following address: 2235 Beaver Avenue, Pittsburgh, PA 15233-1080 Attention: H. Scott Baker.

7. Each party shall make its personnel available for consultations with personnel of the other only to the extent the time constraints placed on such personnel in connection with their regular duties may otherwise permit and, unless otherwise

agreed, to the extent such consultation may be performed without cost to either party. Neither party shall be required to make its personnel available for any fixed or predetermined period of time, such availability to be determined by the parties in their sole discretion.

8. This Memorandum is not intended to create, and shall not be construed to create, a relationship of partnership or an association between the parties hereto or to render the parties liable as partners.

COMPLETE DOCUMENT MUST BE RETURNED

As representatives of the Energy Management Program and the Partner, we, the undersigned, do hereby execute this Memorandum of Understanding on the dates indicated below.

PORT AUTHORITY OF ALLEGHENY COUNTY

By: ________________________

Title: ________________________

Date: 12/27/93

RAIL SYSTEMS CENTER
Carnegie Mellon Research Institute
Carnegie Mellon University

By: ________________________
Richard A. Uher, Director

Date: 1-10-94

CARNEGIE MELLON RESEARCH INSTITUTE
Carnegie Mellon University

By: ________________________
Dr. William M. Kaufman, Director

Date: 1-12-94

CARNEGIE MELLON UNIVERSITY

By: ________________________
Susan B. Dunkle, Associate Provost,
Research & Academic Administration

Date: 31 Jan 94

MEMORANDUM OF UNDERSTANDING

BETWEEN: **WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY**

(hereinafter known as "the Partner")

AND: **THE ENERGY MANAGEMENT PROGRAM**

(hereinafter known as "the Program")

This Agreement is entered into by and between Washington Metropolitan Area Transit Authority as a Partner, and the Energy Management Program, jointly operated by the Rail Systems Center (RSC) of Carnegie Mellon Research Institute, a division of Carnegie Mellon University of Pittsburgh, Pennsylvania and the Canadian Institute for Guided Ground Transportation (CIGGT) of Queen's University, Kingston, Ontario, Canada, this _____ day of ___________, 1993.

WITNESSETH

WHEREAS, the Federal Transit Administration (FTA) is committed to support the Partner's energy conservation and load management initiatives to reduce operating cost;

AND WHEREAS, the Partner is committed to evaluating and implementing cost effective power cost reduction initiatives;

AND WHEREAS, FTA has entered into a Cooperative Agreement with CMU (RSC) as of March 30, 1993, wherein FTA is providing federal funds to CMU (RSC) to inter alia invite all U.S. electrically powered rail transit systems to participate in a research program at CMU designed to foster energy management power cost reduction techniques and to establish a cooperative relationship with the Canadian Institute of Guided Ground Transport at Queen's University in Canada to exchange information on energy management techniques and strategies used in Canada.

AND WHEREAS, the parties wish to set forth common principles and their respective commitments to the Energy Management Program in the Memorandum of Understanding ("MOU");

NOW THEREFORE, in consideration of the mutual promises, covenants and conditions contained herein, the parties agree as follows:

1. That the primary purpose of the Energy Management Program is to evaluate and implement energy management initiatives to reduce operating costs.

3. That demand side energy management initiatives combined with alternative supply sources promote efficient use of energy at a least cost option for the society, and enhance national energy security.

4. That the active participation of equipment manufacturers, distributors, financial institutions and private enterprises is critical to achieving the goals and objectives of the Energy Management Program.

5. That existing programs and initiatives of the Partner shall become an integral part of the Energy Management Program.

6. Partner's Responsibilities:

   The Partner shall:

   a) Develop an energy management plan, which shall include:

      - An energy management study, which conducts an energy audit of all facilities, evaluates the power rate structure and identifies energy cost reduction opportunities and objectives.

      - An implementation plan, which identifies those cost reduction opportunities to be pursued, the organization within the management structure responsible, a schedule for implementation and resources to be committed.

   b) Participate in the Program sponsored seminars and workshops.

   c) Formulate energy cost reduction goals:

      Traction: 5-25%
      Non-Traction: 10-20%
      - Lighting - passenger stations, buildings and parking lots
      - Heating/ventilation/air conditioning (HVAC)
      - Elevators and escalators
      - Shop machinery
      - Others

   d) Develop a structured implementation which

      - is based upon payback, cost/effectiveness and organizational priorities

- documents improvements, benefits and corrective measures to meet the goals

- undertakes an energy efficiency review of all facilities under design and construction to ascertain that they meet or exceed energy efficiency standards

- periodically reaudits energy use and re-evaluates the power rate structure

- undertakes employee awareness and training to promote energy efficiency awareness

e) Develop and pursue power rate reduction and alternative rate structures through electric utility negotiation and intervention in rate proceedings.

f) Pursue alternative energy sources when it is in the best interest of the Partner to do so.

7. Program Responsibilities:

The Program responsibilities shall be carried out by the RSC and CIGGT and shall include:

a) Providing guidelines, guidance and assistance to the Partners in developing and implementing cost effective and site specific energy cost reduction.

b) Seeking cooperation with governmental agencies and institutions to remove regulatory barriers that artificially restrict energy management initiatives.

c) Promoting and expanding the Program by enrolling more Partners and private sector Associates (electric utilities) and Affiliates (suppliers and service organizations).

d) Providing technical services to the Partners on a limited basis.

e) Building and maintaining a rail transit energy data base, to which the Partners, Associates and Affiliates will have access.

f) Making available to Partners, Associates and Affiliates, analysis tools for estimating energy reduction cost effectiveness (some of these tools would require formal licenses with third parties).

g) Developing new analysis tools as required which would be made available to the Partners, Associates and Affiliates as they are developed. No licenses would be required here unless the tool were provided by a third party.

h) Updating the "Energy Management Guidelines for Rail Transit" as new information and techniques become available.

i) Participating in publicity programs identifying specific facilities that have benefited from the program and participants who have contributed to its success.

j) Developing innovative financing techniques for the Program.

8. All information provided to the Partner under the terms of par. 7 is provided on an "as is" basis. The information so provided is the product of research by RSC and CIGGT, and RSC and CIGGT disclaim any warranties of any kind, either express or implied as to the use of this information by a Partner or any third party to whom the Partner has given access to the information.

No party to this Agreement shall be liable to either or both of the other parties for any special, direct, indirect or consequential damages or any damages whatsoever resulting from the use of the aforementioned information by the user in its "as is" condition. Any user who allows a party other than a party to this Agreement to use the above information indemnifies and saves harmless the other parties from any damages, cost or charges, including attorneys' fees and court costs from any claim, suit, cause of action or judgment arising from the use of said information by the party.

9. This is a voluntary agreement between the parties. No modification, amendment or revision of this agreement shall be valid unless it is in writing and consented to by all the parties.

COMPLETE DOCUMENT MUST BE RETURNED.

As representatives of the Energy Management Program and the Partner, we, the undersigned, do hereby execute this Memorandum of Understanding on the latter of the dates indicated below.

By: ______________________
Washington Metropolitan Area
Transit Authority
Robert F. Bearinger
Date: August 18, 1993

By: ______________________
Richard A. Uher, Director
Rail Systems Center
Carnegie Mellon Research Institute
Carnegie Mellon University

Date: 8/26/93

By: ______________________
Dr. William M. Kaufman, Director
Carnegie Mellon Research Institute
Carnegie Mellon University

Date: 8/26/93

By: ______________________
Susan B. Dunkle, Associate Provost
Research & Academic Administration
Carnegie Mellon University

Date: 8/30/93

EPRI
Electric Power Research Institute — *Leadership in Science and Technology*

Monday, January 17, 1994

Dr. Richard Uher
Rail Systems Center
Carnegie Mellon Research Institute
4400 5th Avenue
Pittsburgh, PA 15213

Dear Dr. Uher:

I am writing to express the support of the Electric Power Research Institute (EPRI), and in particular, the Public Transportation Projects I manage for EPRI, for the urban rail electricity Energy Management Program you run at RSC.

EPRI already funds part of the Energy Management work, as part of RP 3025, and plans to continue to do so in 1994. I know that you are seeking additional funding from FTA, and we hope, at least informally, that we can be considered co-funders, with FTA, of your project. The fact that we fund part of the Energy Management Program is, I believe, a strong indication of the support we have for your work in this area.

Electric utilities already supply approximately 5 billion kilowatt hours (BkWh) of electricity for rail systems, and collect revenues of almost $500 million for providing this service. At EPRI, we believe that planned expansions, new starts, and increased ridership could add as much as 3 BkWh to the amount supplied before 2010. However, such an increase in electricity sales will probably not come about unless this fuel can be economically competitive with other alternatives available. Your Energy Management Program addresses, in part, means for the unit costs of electricity for urban rail to be reduced. In particular, your project seeks to conserve energy and to shift peak demand so as to reduce both energy and demand charges.

Superimposed on this potential reduction in electric fuel cost per passenger mile traveled (PMT) we project a large increase in the total number of PMTs by 2010. It is this increase in PMTs, coupled with conservation of 20%, that leads us to believe that 8 BkWh will be required by 2010. Electric utilities, and therefore, EPRI, have a great stake in this activity, of course. If the load management is implemented with the cooperation of the supplying electric utility, there is clearly a much better chance for electric unit costs to be

Headquarters: 3412 Hillview Avenue, Post Office Box 10412, Palo Alto, CA 94303, USA • (415) 855-2000 • Telex: 82977 EPRI UF • Fax: (415) 855-2954
Washington Office: 2000 L Street, NW, Suite 805, Washington, DC 20036, USA • (202) 872-9222 • Fax: (202) 296-6040

lowered. For example, if the electric urban rail peak that is coincident with the local peak of the supplying utility can be lowered, then the utility has an opportunity to increase utilization of generation, transmission and distribution assets, and thus to reduce unit costs.

There are other reasons why utilities are interested in the CMRI Project. The potential for increased sales, with the possibility that cent/kWh costs can be held in line for all customers, is obvious. However, there is another very important reason, I believe. There is much synergy between the activities of urban utilities and transit agencies. (I am enclosing an EPRI brochure that addresses this synergy). As a result, the local utility supplier has a vested interest in trying to help assure that transit agencies can provide the best possible service. As a result of this, and because of the potential for increased asset utilization, particularly in the utility distribution system, it is <u>local</u> utilities that have the greatest interest in your Energy Management Program. However, neither utilities or EPRI have an interest in supporting work on "Utility Bypass," since this does not allow the local utility to optimize its operations and thus minimize its costs. The "Bypass" approach will not, in my opinion, lead ultimately to minimum costs per PMT. We thus will focus our funding on the other approaches being taken in your project, which I think reduce "inherent" costs. I believe that the probability that electric utilities will support your project will be greatly enhanced if the "Utility Bypass" approach is <u>not</u> part of it.

I hope in this letter I have been able to express the enthusiasm I feel for your Energy Management Program at RSC/CMRI. EPRI is supporting your work because we think it will lead to electric urban rail systems that will be more attractive than the alternatives to both operators and riders, and that electric utilities will thereby be more profitable.

I look forward to continuing to work with you, and hope that through co-funding your project, EPRI personnel can further develop their relationships with their counterparts at FTA and RSC.

Sincerely,

Philip C. Symons
Senior Project Manager
Transportation Program

PCS:sap.9994.94.L

APPENDIX C

(Presented at Comprail '87 International Conference - Computer Aided Design, Manufacture and Operation in the Railway and Other Advanced Mass Transit Systems), July 7-9, 1987, Frankfurt.

A TRAIN OPERATIONS COMPUTER MODEL

Richard A. Uher Daniel R. Disk

Rail Systems Center, Carnegie Mellon University, Pittsburgh, PA, 15213 USA; Union Switch & Signal Company, American Standard Inc., Pittsburgh, PA 15230 USA

INTRODUCTION AND BACKGROUND

Competition from other modes of transportation, especially trucks, pipelines, and inland waterways, has resulted in a substantial decrease in the freight market share for U.S. railroads. Over the past 35 years, the freight market share declined from 56% to 38%. (Railroad Facts[1])

Concern with the increasing competition and declining profits has prompted the U.S. railroads to embark on measures which will enhance their market position and improve their profit picture. Among such measures are mergers and acquisitions, divestitures and abandonments, and campaigns to increase productivity (more ton-miles per dollar spent on labor, materials and resources).

New concepts, which are generally high technology oriented, have been proposed as a solution to productivity improvement. Two concepts which are now being promoted in the United States and Canada are, Advanced Train Control and the High Productivity Integral Train (Railroad Productivity[2]). These concepts for improving productivity, have created the need for new central traffic control systems, which can function more efficiently and cost effectively.

Because of the relatively large cost involved to take advanced train control concepts to a practical application, the need exists for a computer-based model which can test some of these ideas through simulation of various segments of a railway. This must be accomplished early enough in the conceptual design phase to estimate feasibility and effectiveness. Testing can be used to eliminate those concepts which have little or no merit and are not cost-effective. Use of this approach can save a great deal of the development costs and time associated with decisions involving the addition of track or control equipment on the railway.

A computer-based model must be able to fully emulate the railway system operation. Such a model will be referred to in this paper, as a Train Operations Model (TOM).

Future Centralized Traffic Control (CTC) systems are expected to be heavily computer oriented with the principal goal of increased productivity. It is also expected that a CTC system will control larger and larger territories, and ultimately all transportation (not only the railway) operations of a company (not necessarily a railway company) will be handled from a single central office location. Economics will provide the motivation for the use of energy management and dis - patching systems which will permit the more efficient rail operations to effectively compete with other modes of transportation. (F.Young, D. Disk[3])

With reference to CTC, increased productivity means minimized train delay, minimized fuel consumption and lower initial and operating costs. A Train Operations Model must be able to accurately estimate train delay and fuel consumption under realistic simulated operating conditions with any type of train control system and any number of trains running on the railway. This paper will describe a TOM developed and refined as a joint cooperative effort of the Carnegie Mellon Rail Systems Center and Union Switch and Signal (WABCO Westinghouse), which can meet the requirements of most railway systems.

OVERVIEW OF THE TRAIN OPERATIONS MODEL AND ITS APPLICATIONS

The TOM realistically simulates train movement on a rail network in accordance with timetables, train orders, block restrictions and switch positions. Its outputs are the location of each train on the system, the status of the signals and the cost variations of operating the railway, which result from train delay time and fuel consumption. Within its own framework, the TOM is not able to resolve meet/pass conflicts, however, it has an interface, which permits manual, adaptive, and/or automatic train dispatching techniques to be used or evaluated. In simplest terms, it is a simulation of railway operations, that can be easily tailored to any railway.

In addition to testing out Advanced Train Control and High Productivity Integral Train conceptual designs, the TOM has other uses:

1. A realistic simulation tool, which can be used during the development and design of a train control or CTC system based on a specific railway or track configuration.

2. A tool which will aid in the development of automatic and semi-automatic adaptive (expert systems) train dispatching methods. This tool permits fuel consumption and delay time to be used as cost variables in determining the effects of a dispatch decision or method.

3. A prediction tool to be used with a manual dispatching system. It has the ability to look ahead in time to determine the cost of dispatch decisions. This means that the TOM must run faster than real time operations.

4. A training aid for dispatchers.

5. A tool for evaluating the effects on line capacity, delay time, and fuel consumption under particular operating conditions for proposed changes to the track network; such as adding sidings or changing double track to single track territory, etc. These evaluations can be accomplished using the actual dispatching system either presently used by the railway (including manual dispatching) or a new or planned dispatching system.

As is illustrated in Figure 1, the TOM consists of two major simulation programs: the Train Performance Simulator (TPS) and the Train Movement Simulator (TMS).

The TPS, is one of the most sophisticated of its kind. It takes as its input, routing information, grade profile, curve alignment, speed restrictions, information on the cars and rolling resistance as well as the motive power which makes up the train.

The TPS was developed from a rapid transit version which has been tested and verified in detail on several rail transit systems (R. Uher[4]).

The output of the TPS is a detailed profile of speed, position, and fuel or the electrical power consumption as a function of time. The initial output is based under conditions of no traffic interference. This profile is generated for each train on the system.

The TMS is the heart of the TOM. It requires the track network layout, including block and switch positions, signal aspects, train schedules and orders, and the detailed profiles produced by TPS as input. Its function is to run the trains on the railway obeying the signals (or commands). These signals or commands can be determined either by the interaction of the trains with the signal system, by a dispatcher making manual dispatch decisions or by a computer program using adaptive or automatic dispatching techniques. Fuel consumption and delay time is accumulated for each train as part of the output of the TMS.

The Train Operations Model also contains an economic impact module. This module is a computer program which uses the information obtained from the TMS; namely, delay time and fuel consumption. Delay time results in additional operational cost. These costs are extremely railway specific, but include such things as extra crew and labor, train priorities because of freight carried, non-available service time of cars and locomotives and customer or late fees. In addition, an economic model peculiar to the specific railway, is used to determine the cost of operating the simulated railway. Because of the speed at which simulation occurs, costs of several dispatch decision alternatives can be compared, so that a dispatcher can select the more favorable decisions.

The File Construct Module consists of the interface programs which convert the raw data obtained from track and signal layouts, timetables and train orders, physical descriptions of freight cars and motive power (including fuel consumption curves) into an input form which is acceptable by the TPS and TMS.

All of the modules were written in FORTRAN-77. The model has been adapted to run on either a personal computer or a main frame computer.

TRAIN OPERATIONS MODEL DESCRIPTION

The two simulators which constitute the Train Operation Model are the Train Performance Simulator (TPS) and the Train Movement Simulator (TMS). A detailed description of each follows.

Train Performance Simulator

The TPS accepts input data which describes the track and operating characteristics over which the train will be operated. This includes information about stopping points, grade, curvature and speed restriction profiles, routing instructions, and locomotive driving methods.

These data elements are then used to simulate the motion of the train along the railway, in order to obtain the trajectory of the train (speed, time, power or fuel consumption as a function of distance). This trajectory is referred to as the "normal" trajectory of the train. It is important to realize that the "normal" trajectory can be any trajectory, including those which contain delays in anticipation of meets/passes or other scheduled stops.

Input The input data are divided into three major categories: simulation and control parameters, train related information, and right-of-way related information.

Simulation and control parameters The simulation and control parameters are contained in one file called the control file. This file contains such things such as the display choices for output, train driving information including acceleration and braking rates, and the top speed limits which may be different from the imposed speed restrictions of a particular territory on the track network.

Train related information The train related information resides in a single input file. This file contains the train identification or ID and a description of the consist of the train including the number and types of locomotives and cars. These data are characterized by the number of loads and empties, motive power number and type, train resistance information, tractive and braking effort curves as well as fuel or electric power consumption data.

A car library is included among the train related information. The car library contains data on all of the different freight car types in the railway inventory. The car data include such things as length, empty and full weight and maximum braking force, which the car is capable of applying to retard its motion. The TPS is unique in that the car data may also include information on train resistance which is a function of class of track. The formula for train resistance is expressed as:

$$R = R_A + R_B/W + R_C \cdot V + (R_D/W) \cdot V^2 \qquad (1)$$

where R_A, R_B, R_C, R_D are coefficients of train rolling resistance which depend on the class of track, car suspension system parameters and wheel type; W is the weight of the car; and V is the speed. (See Reference 5 for determination of these coefficients.)

The coefficients of rolling resistance are functions of the class of track because the tolerances of misalignment of the track in the vertical, horizontal, cross level and gauge difference for each track class (1-6). Generally, class 6 has the tightest tolerances, followed by 5, 4, etc. The classes of track are input in the right of way related information.

Right-of-way related information The right-of-way information consists of the following files: curve, grade, speed restriction and track data. Each file has the same format; namely, (curve, grade, speed restriction and track data) as a function of position (or distance from some fixed point). The track data is characterized into one of six classes of track and is used in the computation of the train resistance.

A file is developed for each of the tracks along the right-of-way including sidings. The right-of-way related information also contains a stop file which identifies the position and names of any stopping points and the associated dwell time at any desired location.

A route file contains data on which track the train will be on at any given position along the right-of-way. This is basically the definition of the "normal" trajectory of the train. Different trains may follow different routes, so that many route files may be required.

It is the particular combination of control, train, grade, curve, speed restriction, class of track, route and stop files that constitute the "normal" train performance input for a particular train.

Output The TPS has three output files: summary, detailed and trajectory. The summary output presents the time, average speed, and fuel or power consumed between the stopping points. The detailed output presents the input data and presents a table of ten (out of forty) selectable output parameters as a function of time. Typical data may include tractive effort, speed, mechanical power output through the wheels, grade, curvature, power losses in various components, etc. The inherent accuracy of the calculation depends on the time step. If calculations are repeated every 0.1 second, accuracy will be better than if repeated every second. However, program execution time increases by a factor of ten.

The trajectory output file contains technical information on the train and the time, speed, route and fuel or power consumption rate as a function of position along the right of way. The trajectory file is used as input to the TMS.

Methodology The Train Performance Simulator uses discreet, adjustable time steps to integrate the equations of motion to obtain speed and train position as a function of time. Fuel or electric power consumption is determined using propulsion system models which produce fuel rate or 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 used as input data. In the case of diesel railways, fuel rate is expressed based on the fuel consumption curves of the particular locomotive type to be simulated. In the case of electric railways, the efficiencies of the conversion of mechanical power at the rail, to line power at the pantograph/catenary interface is input as a function of the tracive or braking effort and speed. Using this method is extremely efficient because the TPS is not burdened with having to do the re-calculations necessary for a sophisticated propulsion model on every tractive effort-speed point in the trajectory. In this manner the results can be readily obtained at any time during the simulation run.

A simplified flow diagram for the TPS is shown in Figure 2. In addition to the usual housekeeping 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.

Referencing Figure 3, To move from point A to B the following steps would be taken if a minimum time trajectory were used for the simulation. It should be noted that this is not the most efficient means of train operation, but is merely used to illustrate the concept of the forward and backward calculation methods.

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 is developed using maximum deceleration from B to E using negative time steps. 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.

All of the external forces on the train are computed taking the train length into account. Grade forces, curve resistance and the class of track portion of train resistance are averaged over the train length. However, no account is taken of the internal motions of the train (about the center of mass). Train length is also accounted for in obeying speed restrictions. 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.

If the cars included in the train are all contained in the car library which is used as an input file to the TPS, the train resistance is computed using the coefficients from this library. These coefficients are also a function of the class of track on which the train is running. If the cars in the train are not in the library, train resistance is computed from data in the train file.

Train Movement Simulator

The Train Movement Simulator (TMS) accepts input data describing the track network on which the trains run. This includes the normal trajectories for each train on the network (trajectories which were calculated by the TPS), and schedules for train movement. These input data are used to move each train on the system in accordance with the signalling rules, system specifications, network description and dispatching model.

Initially, all trains move according to their "normal" trajectory. Traffic interference or commands from the dispatcher, which disrupt the "normal" trajectory cause the TMS to compute an "abnormal" trajectory, which the train follows until it returns to the "normal" trajectory or receives another command.

Input. The input data are divided into three major categories: track network, train trajectories and schedules.

Track network The track network file describes the track layout. It contains information on location and length of blocks, switch location and position, parallel track connections, entry points into the network, grades, curves, speed limits and class of track data for all blocks. A description of signalling and control logic may also be included.

Train trajectories The train trajectory files are generated by the TPS and contain two types of information. The first section contains sufficient data on the nature of the train so that the TMS can calculate an "abnormal" trajectory should interference with the "normal" trajectory occur. The second portion of the file has speed, position, time, route and fuel rate or power records of the "normal" movement of the train from its origin to destination. A train trajectory file is required for each train on the system.

Train schedule The train schedule file contains information on the initial position, speed and time for each individual train's entry into the track network. The train schedule file contains information on the initial position, speed and time for each train's entry into the track network.

Output Output from the TMS is the position, speed, route and fuel rate or electric power usage of each train on the system as a function of time. The status of all switches and blocks are also output as a function of time. Time progresses in discreet programmable steps and at the end of each step a snapshot of the track network with the position of each train is recorded.

At any given snapshot, delay time and fuel consumption or electrical energy can be computed by integrating the detailed outputs. Delay time for each train is computed by subtracting the actual time taken for the train to complete its run from the time it would have taken if it remained on its normal trajectory. Energy use is obtained by integrating the fuel rate or electric power usage of the train over time based on the actual trajectory.

All of the outputs can also be displayed in graphical form. The graphics interface can display position of each train and block and switch status at any snapshot time.

Methodology The flow diagram for the Train Movement Simulator is presented in Figure 4. A historical file is used to record the results of each time increment of simulation. Two kinds of records are produced for each time increment. The first contains the position, speed, route designation (track #), average fuel rate or electric power and normality ("normal" or "abnormal") for each train on the system at that particular time instant. The second record contains the status of all signals, blocks and switches. As the simulation proceeds, the historical file is always updated so that the top records (network status, train status) on the stack reflect the last value of the simulation time.

Three times are identified in the flow diagram; namely, display time, present time, and simulation time. Display time is set by the user as an input and refers to the time when the display is to be updated. Present time refers to the system time as seen by the computer as it is executing the simulation program. When working in the simulation mode (below 4 in the flow diagram of Figure 4) the present time is the current simulation time. When working from the historical file, the present time is the display time. Simulation time is the point to which the simulation has progressed. Simulation time is always the point when the last records were written to the historical file.

The use of this methodology allows the user to rapidly move forward and backward in time, within the simulation time window. When moving backward in time however if the user makes changes to the system either by adding trains, setting switches or giving other commands, the historical file beyond the present time will be written over. If desired however, this data can be saved for future reference by selecting path "U" on the flow chart (see Figure 4).

At the start of the simulation run all trains are placed on their "normal" trajectories. As the simulation progresses in time, with unanticipated traffic interference, "abnormal" trajectories will develop. When the traffic interference subsides, trains will tend to revert back on their "normal" trajectories. "Abnormal" trajectories are calculated inside the TMS in the same manner as they are calculated in the TPS. Since the "abnormal" trajectories are developed as required though, additional processing time is necessary to complete these calculations.

If the user is able to estimate traffic interference in his determination of "normal" trajectories, then the computer time used will be less. Both "normal" and "abnormal" (once they are calculated) trajectories are stored in tables and are extracted by pointers (rather than table lookup). Thus, program running is extremely fast.

APPLICATION DETAIL

<u>Tool for design of CTC</u>
Any railway which plans on implementing a new or modified traffic control system will find the TOM invaluable as a tool in designing, constructing and testing the signalling system. During the design phase, the TOM can be used to test and evaluate different signalling configurations and concepts. These evaluations can be conducted under projected traffic conditions and can also contain an economic basis for selecting the most cost effective and efficient system. During the construction phase, the TOM can be used as the railway. A system-wide test can be conducted, interfaced to the simulator instead of the railway. This can provide a laboratory debugging phase before actual installation.

<u>Automatic and adaptive dispatching development</u>
Computer programs have been developed which are capable of making dispatch decisions, automatically. The TOM can be used to evaluate these programs, in terms of their overall economic benefits. The TOM can accurately predict fuel consumption, crew costs and delay time based on a particular set of dispatching decisions. This energy cost dimension can be added to automatic dispatching algorithms as a part of their evaluation and/or implementation.

Many railways have found that automatic dispatching decisions are often overridden by the dispatcher, because of other factors that cannot be accounted for in present automatic dispatching algorithms. The TOM can be used as an excellent tool in the development of adaptive dispatching using an expert system approach. In an adaptive dispatching setting, a computer learns from the expert dispatcher. The learning process could take place initially in a simpler operating environment by using the TOM, instead of the actual railway.

<u>Prediction tool</u>
The TOM can also be used in a dispatch office as a prediction tool for determining the cost of dispatch decisions. In this scenario, the model would be calibrated to the railway's condition at the present time. The model would then be used to predict the future for several decision alternatives. This is possible since the simulation can be run faster than real time operation. Under

this type of operation, the dispatcher could make the most favorable decision and evaluate the economic impact of a decision before it is actually implemented. The economics of train delay, crew costs and fuel consumption can also be considered in the selection of alternative dispatch decisions.

Training aid
The railway can use the TOM as a training aid for new dispatchers. If the economic model is selected to reflect the true cost of railway operation, retraining of seasoned dispatchers may also prove beneficial for fine tuning of dispatch decisions.

Evaluation of modified networks
As railway markets change, there are continuing requirements for changing the configuration of the track network. The addition of sidings, or the changing of single track territory into double track are among such changes. The TOM can be an invaluable tool for evaluating proposed track changes. The effect on railway economics and line haul capacity can be readily determined under practical operating conditions, using the TOM, rather than the so called "ideal", theoretical conditions which are used in most line haul capacity models. In this manner several alternative track network changes can be evaluated, before a final decision is made.

Applications
The model is relatively new and has not been applied extensively. It was developed using a portion of the Union Pacific Railroad.

The first application of the model was on the Sacramento Light Rail Passenger System. The configuration on this system is much like that of a freight railway, i.e., single track with passing sidings. The model was successfully used in this application to investigate scenarios which would improve line haul capacity.

SUMMARY

A Train Operations Model, which can simulate any railway, has been developed. The model can be used for any of the following applications:

1. To test Advanced Train Control and High Productivity Integral Train conceptual designs.

2. A realistic simulation of a railway, while a CTC system is being designed, constructed and tested.

3. A tool to aid in the development of automatic and adaptive (expert system) train dispatching, which may also use reduction of fuel consumption as an objective.

4. A prediction tool for manual or semi-automatic dispatching.

5. A training aid for dispatchers.

6. A tool to evaluate the effects on line capacity, delay time and fuel consumption under realistic operating conditions for proposed changes to the track network.

The program was built and tested using a portion of the Union Pacific Railroad, and was applied to the Sacramento Light Rail Project to study improvement of line haul capacity. The model will not be ready for commercial use until it is verified on an actual railway. Future plans are to work directly with a U.S. railroad in simulating actual territory and verifying the model as compared to recorded train sheet and train graph data.

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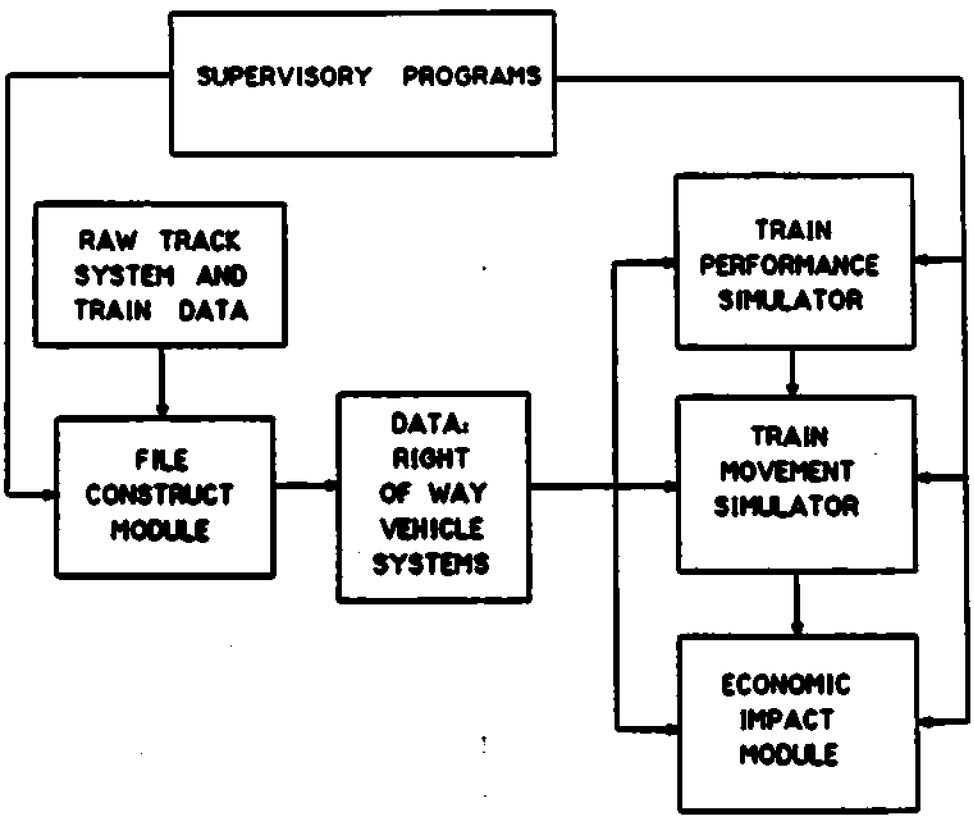

Figure 1 Train Operations Model Block Diagram

TRAIN PERFORMANCE SIMULATOR FLOWCHART

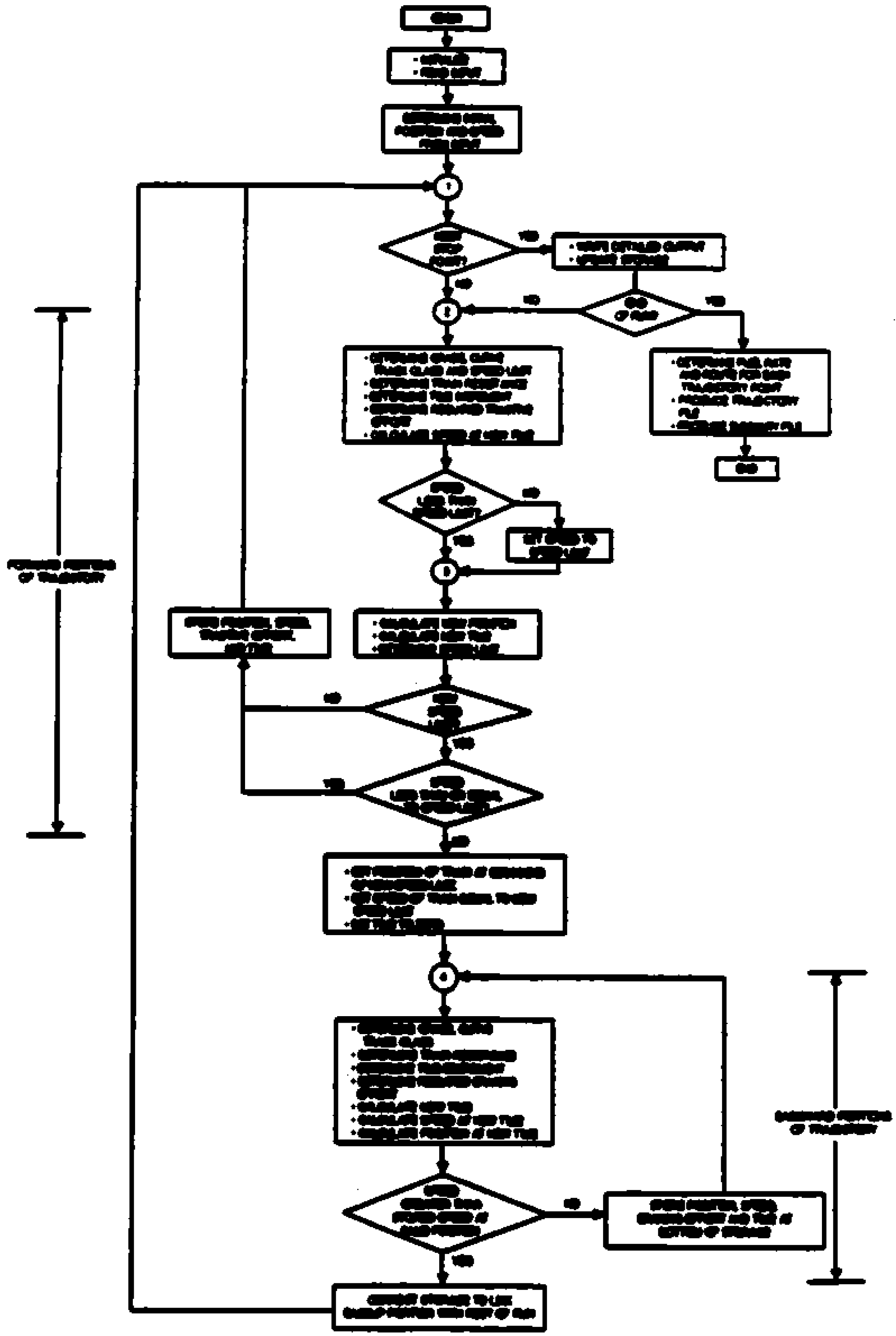

Figure 2

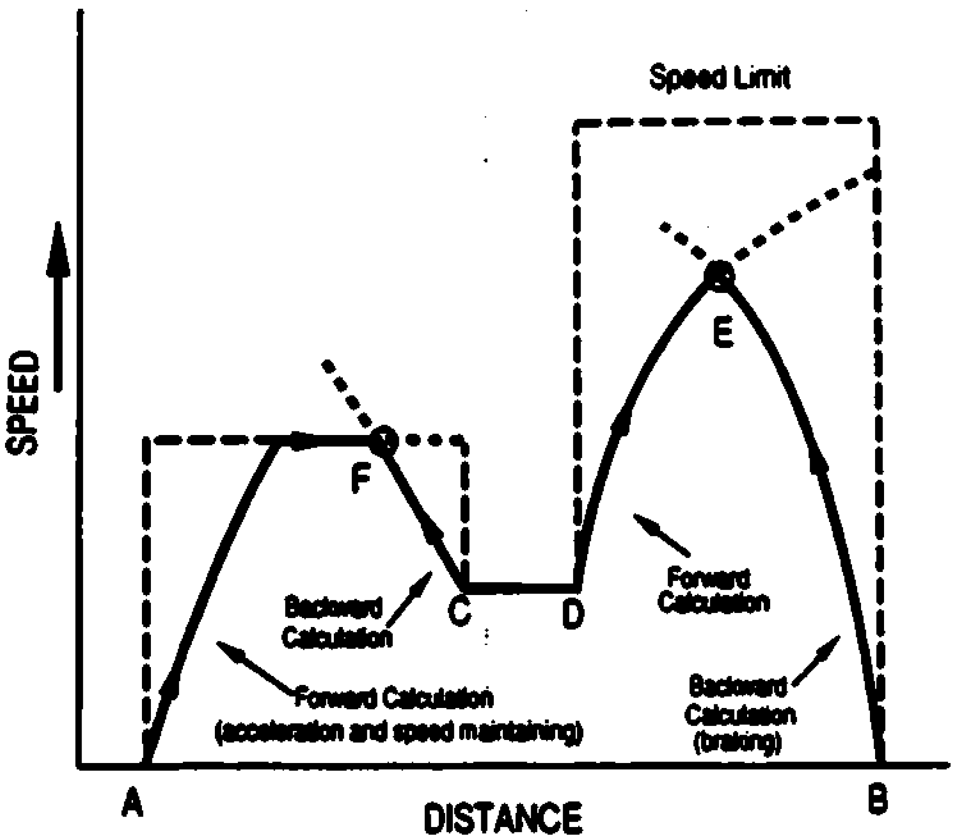

Figure 3 TPS Trajectory Calculation Methodology

TRAIN MOVEMENT SIMULATOR
FLOWCHART

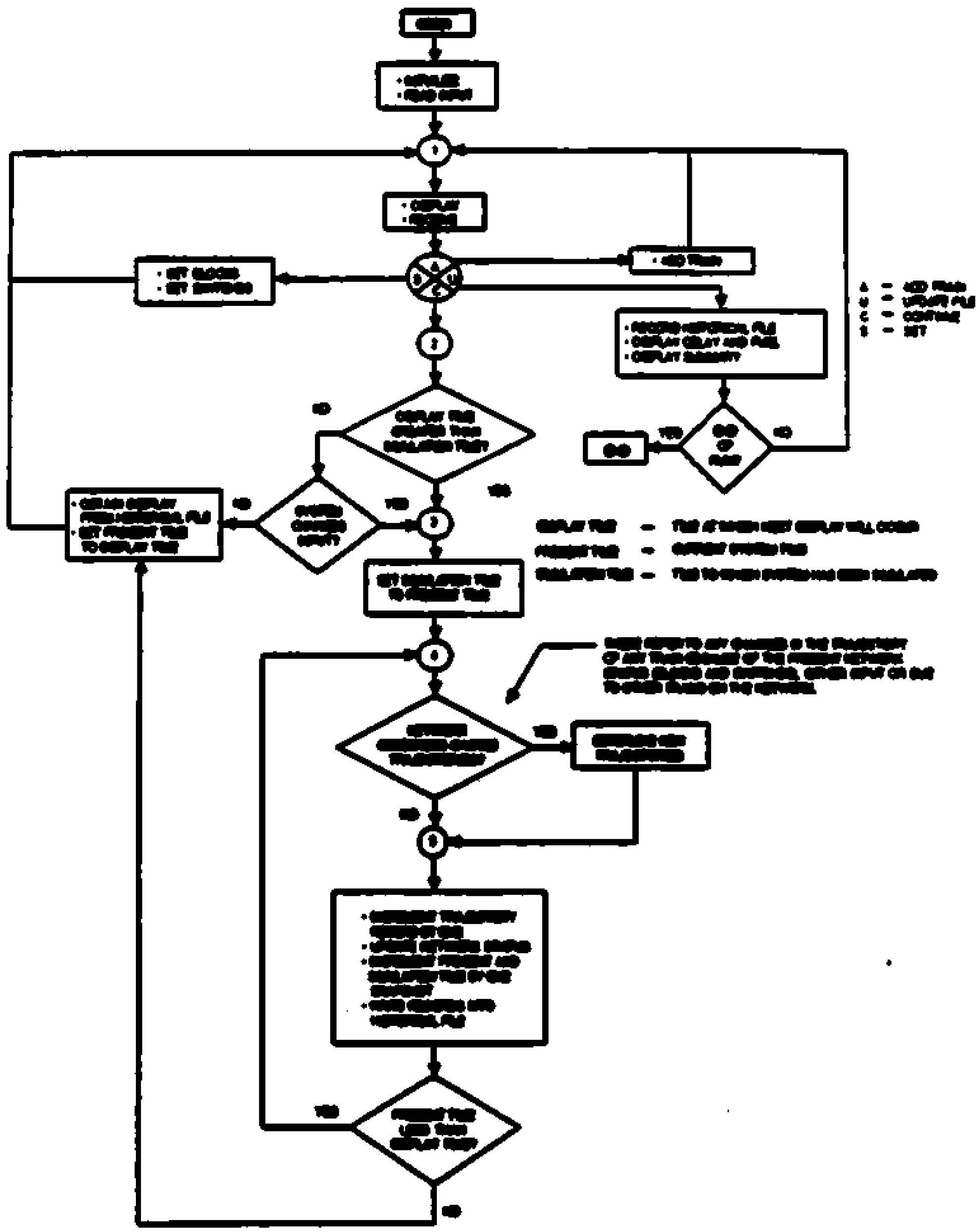

Figure 4

APPENDIX D

WORKSHOPS & SHORT COURSES

- Energy Management Guidelines for Rail Transit .... April 1986
- Microprocessors in Rail Transit .... Sept. 1987
- Energy Management for Rail Transit .... April 1988
- Electric Traction Systems for Rail Transit .... Dec. 1988
- Electric Traction Systems for Rail Transit (to be given) ... Mar. 1996