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First Year Annual Report

Center for Transit Research and Management Development
University of Michigan Transportation Research Institute
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FINAL REPORT

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16. Abstract

The Center for Transit Research and Management Development conducted six activities during the first year of its operation that are part of a long-term transit research and training program. The six activities reported here are:

1) development of bus purchase decision making methods (including a computer program),
2) development of computer programs to assist transit personnel in traffic engineering analyses,
3) development of maintenance and breakdown-related data to determine the need for failure-detection instrumentation,
4) the development of such instrumentation,
5) development of working files of the UMTA Section 15 data, with particular emphasis on vehicle-related information, and
6) presentation of a course on traffic engineering for transit managers.

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1. INTRODUCTION

The Center for Transit Research and Management Development at Michigan is a unit within the University's Institute for Science and Technology (IST), and is located physically in the University of Michigan Transportation Research Institute (UMTRI). During the first year, the project director was Dr. George Gamota, Professor of Physics and Director of IST. The program coordinator was James O'Day, Interim Director of UMTRI. Research investigators resided in the Engineering College and in UMTRI.

This document is the final report of the program for the first year of operation (1983-1984). The body of the report consists of this introduction, a summary of each of the research projects and a description of an extension course offered by the Center.

Plans for the First Year

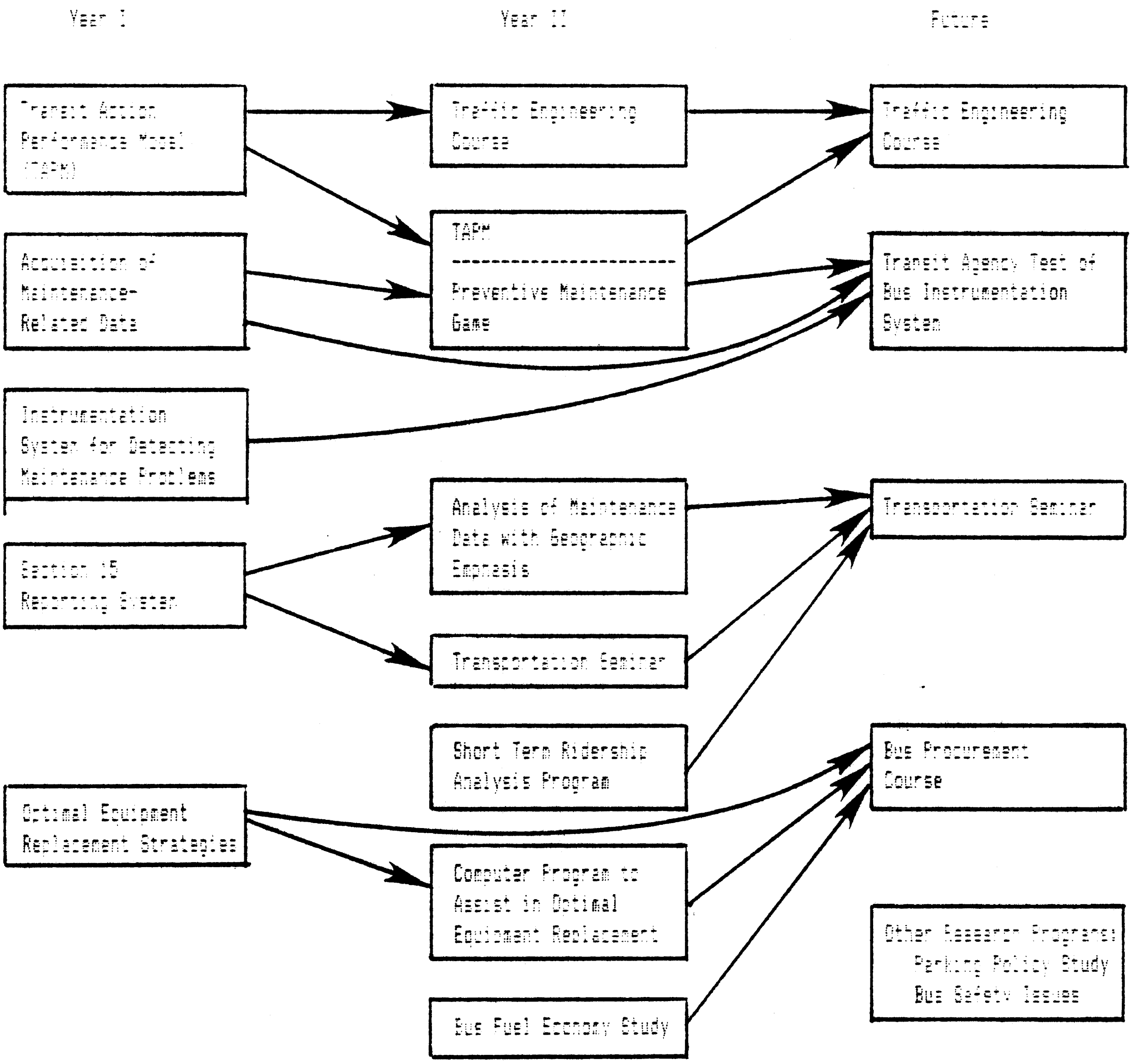
During the first year, the Michigan program was intentionally oriented toward the engineering and hardware aspects of transit operations. This came about partly because of our proximity to the vehicle manufacturing industry, and partly because Center personnel are strongly associated with a technical institute and with the engineering college. The first short course developed by this center was given in September, 1984, and was concerned primarily with traffic engineering and bus street service planning for transit managers.

Research activities for the first year included four areas: (1) The development of purchase decision making methods (and associated computer programs), (2) the development of traffic engineering computer programs (a continuation of a previous UMTA research program), (3) the development of maintenance and breakdown-related data to determine the need for failure-detection instrumentation, and (4) the development of such instrumentation. A fifth activity, referred to as "information transfer" in the grant application was the development of working files of the UMTA Section 15 data, with particular emphasis on vehicle-related information.

These research projects were scaled down from plans presented in the original proposal to UMTA. Each activity was a pilot study which can be seen as an initial effort leading to larger-scale research programs. Projects underway in the second year and in future Center operations reflect the basis developed during first year activities. Table 1 illustrates the relationship of first year activities to future research programs.

Figure 1

Center Program Development



The Transit Action Performance Model (TAPM) work is continuing in the second year and was an important part of the traffic engineering course reported in this document. We expect to offer this course again in the future. The activities related to acquiring and analyzing maintenance data will be used to develop a preventive maintenance game to help teach maintenance strategies. The data will also be used to help develop strategies to use the instrumentation to detect maintenance problems most efficiently. During the first year, this instrumentation was developed enough to propose implementing its use in revenue service in a local transit agency.

During the first year, vehicle-related Section 15 data were put into structured files that are currently being used in a second year research project to analyze maintenance data with a geographic emphasis. The files are also being used by students in a transportation seminar for course research projects. The experience gained in these uses helps to further refine the structure of the data base.

Research to develop optimal equipment replacement strategies during the first year led to the ability to produce software useful to transit agency personnel in making bus purchase decisions. This work will also be included in the curriculum for a future course planned to cover issues in bus procurement.

Report Structure

The remaining sections of this report are devoted to individual descriptions of the course and the various projects. Section 2 contains a report on the development of TAPM (Transit Action Performance Model), particularly the adaptation of the Apple Pascal computer programs to IBM. Section 3 provides a description of the purchase decision-making model. Section 4 contains a report on an analysis of maintenance data records from one transit property. Section 5 describes first year activities related to the development of instrumentation to detect bus maintenance problems. Section 6 describes current efforts with the UMTA Section 15 data. Section 7 describes the course entitled "Essentials of Traffic Engineering for Transit Managers.

2. TRANSIT ACTION PERFORMANCE MODEL

The participants in this project were Donald E. Cleveland, Lidia P. Kostyniuk and Gary Waissi of the Department of Civil Engineering (CE).

The Transit Action Performance Model (TAPM) is a system of user-friendly programs designed to help a transit planner, city traffic engineer or a consultant evaluate the impacts of actions intended to improve the movement of people on urban streets. The original formulation of TAPM was developed for UMTA under Grant MI-06-0027. It is intended to accompany the still unpublished manual of Traffic Engineering for Transit drafted under that grant. The TAPM-software package was originally designed and developed for Apple II microcomputer using APPLE-Pascal. As part of the work carried out under this grant, the TAPM package is being extended to include more models and is being prepared to run on the IBM and other microcomputers.

This report first describes the programs presently on TAPM and then details the progress that has been made in the translation of TAPM for the IBM microcomputer.

Although considerable progress in the development of the TAPM models occurred during the first year, they are not yet ready for general distribution. It is expected that, by the end of the second year, the programs will be completed and a technical report documenting the programs will be published. The existence of the program package will also be advertised in UMTA's catalogue of microcomputer software with transit applications. During the year TAPM has been made available to UMTA-authorized transit properties and has been used extensively by students in University of Michigan CE courses. This report contains a description of the training course given in September in which students received training in the use of TAPM and other models developed under UMTA support.

TAPM Models

At the present time TAPM contains models capable of calculating the effects of the following actions:

1. Bus signal preemption
2. Isolated intersection signal setting
3. Bus stop spacing

<u>TAPM Signal Preemption Model (Program Preempt)</u>. The signal preemption model employed in TAPM was developed by Radwan and Hurley in 1982.[1] This macroscopic model applies a stochastic

1. Radwan, A.E. and Hurley, J.W., Jr., "A Macroscopic Traffic Delay Model of Bus Preemption," <u>Transportation Research Record</u>, 881, 1982, pp. 59-65.

procedure to evaluate different bus preemption signal strategies at an isolated intersection. The model permits the user to evaluate certain operational strategies for both main street and cross-street bus traffic. It is assumed that the signal controller has green extension and red truncation capabilities. Webster's delay formula is used in the delay calculations.

The basic concept of the model is to investigate all possible cases in which any bus detection event may result in signal preemption, either green extension or red truncation. The probabilities of these preemption events and the corresponding signal cycle lengths and signal splits are listed. The cycle lengths, proportions of the cycle which are effectively green, degree of saturation, and flow rates are substituted in Webster's delay formula to determine the average delays per approaching vehicle for individual cases. These average delays and their probabilities are used to determine the expected delay for each vehicle.

The program internally calculates the total delays for passenger cars and busses under the preemption and non-preemption strategies, and provides the total delay saving (or losses) attributable to the signal preemption. The output includes: optimal cycle length and main-street green/cycle ratio, total person delay without preemption, person time saved for cars and for busses, person time saved for the main street and for the cross street, and total person time saved with preemption.

<u>TAPM Optimal Signal Time Model (Program BEAST)</u>. This is an interactive program for finding a fixed-cycle length which minimizes total personal delay at individual intersections. The delay formula of Miller[2,3], is used for calculating the average delay for each vehicle on each approach, which is stated as follows:

$$d = (c-g/2c(1-y) \{(2x-1/q(1-x) \ I + (c-g) + (I-1-y/s)\}$$

where:

d = the average delay per vehicle on one approach (sec/vehicle)

c = cycle time (sec)

g = effective green on one approach (sec)

I = dispersion index, variance/mean ratio of counts of arrivals per cycle on one approach (Poisson=1.0)

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2. Miller, A.J., "Settings for Fixed-Cycle Traffic Signals," <u>Operational Research Quarterly</u>, 14:4 (December 1963), 373-386.
3. Miller, A.J., "Settings for Fixed-Cycle Traffic Signals," <u>Proceedings of Australian Road Research Board</u>, Vol. 2, Part 1, 1964, pp. 342-365.

q = arrival on one approach (vps)

s = saturation flow on one approach (vps)

y = q/s, the ratio of arrival to saturation flow on one approach

x = qc/sg, the ratio of arrival to capacity on one approach

When the average delay for each vehicle type is weighted by its occupancy, the result is the person delay. By varying the split for each approach to a given cycle, the optimum solution which minimizes total person delay for that cycle is obtained. The same process is repeated until a cycle length which minimizes total person delay at the intersection is obtained.

The input of the program includes auto and bus arrivals on two critical approaches, auto and bus occupancies, number of approaching lanes on two approaches, the dispersion index of arrivals on both approaches, and the saturation flow. The program output includes the optimum signal setting with total cycle length and the splits identified, total vehicle delays for cars and for busses, total bus passenger delay, and total person delay at the intersection.

TAPM Bus Stop Spacing Model (Program BUSTOP). The bus stop spacing model used in TAPM is a modification of a model developed by L.J.S. Lesley.[4]

The model considers a bus route along a straight road with bus stops spaced equally apart. Surrounding each stop is a circular catchment area with a radius of half of the bus stop spacing distance. It is assumed the land use within the catchment area is homogeneous and generates passenger origins at a constant rate per unit area per unit time. The model assumes that a grid pattern is followed in the passenger's walk to the bus stop and thus uses the Euler distance for the average walking distance from the catchment area to the bus stop.

The bus acceleration and deceleration characteristics are built into the model. A non-linear acceleration model developed from performance values of urban busses is used. A constant value of 3 mphps is used for deceleration. Passengers arrive randomly at the bus stop, and have a constant in-vehicle trip length.

The model can calculate the following outputs:

1. The average in-vehicle time of each passenger trip.

2. The average out-of-vehicle time of each trip. This includes the walking and waiting times.

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4. Lesley, L.J.S., "Optimum Bus-Stop Spacing: Part 1," Traffic Engineering and Control, October 1976, pp. 399-401.

3. The average total travel time for a passenger.

4. The average weighted travel time. This is the sum of the average in-vehicle time and the product of the out-of-vehicle time multiplied by the out-of-vehicle time factor. This is calculated for use in common modal choice analyses.

5. Base+Passenger cost per trip. This is a generalized cost of each trip. It includes the bus operating cost, the administrative cost per trip, and the value of passenger's total trip time.

6. Route fleet size.

7. Average steady state bus occupancy.

8. Overall speed of the bus.

Input variables are:

1. Bus stop spacing (ft)
2. Time headway of service (min)
3. Trips generated per sq. mile per hour
4. Maximum running speed (mph)
5. Route length (mi)
6. Door time loss at each stop (sec)
7. Boarding time per passenger (sec)
8. Administrative costs of route ($/yr)
9. Hourly bus operation cost ($/hr-bus)
10. Average annual bus operating time (hr/yr)
11. Passenger in-vehicle trip length (mi)
12. Passenger walking speed (ft/sec)
13. Value of passenger time ($/hr)
14. Out-of-vehicle time factor

Translation of TAPM for IBM and Other Microcomputers

In accordance with UMTA requirements, the original TAPM program system was formulated for the Apple II+ system using APPLE-Pascal and made extensive use of the Apple's library functions and procedures.

The task in this phase of the research was to convert the original programs into standard Pascal. This conversion includes the reprogramming of the Apple-library functions and procedures given in the USES-declaration of the original programs. With this conversion, TAPM can be easily transferred to any computer having the Pascal programming language. In this phase of the work the graphics output of the original programs is omitted because of its machine-specific features. The graphics will be incorporated into the Standard Pascal programs for each specific machine starting with the IBM PC.

The programs and subprograms converted to Standard Pascal during the first year include the following program TAPM sections:

TAPM:	The main program structure.
TEXPL:	The subroutine explaining the program usage to the user, general
WELCOME:	The subroutine including the general welcome-session and introduction to the user.
BUSTOP:	The program for "Optimum bus stop spacing."
BEXPL1:	The subroutine of the program BUSTOP explaining to the user how to use the program.
BLIB1:	Functions and procedures of program BUSTOP.
BLIB2:	Functions and procedures of program BUSTOP.

The conversion has also included the Apple-Pascal library units TRANSCEND, SCRNSTUFF, REALSTUFF, and PRINTSTUFF used by the original programs as well as preliminary testing of the Standard Pascal programs. The conversion of the programs PREEMPT and BEAST and their library routines is to be completed during year two.

3. LONG-TERM OPTIMAL EQUIPMENT REPLACEMENT STRATEGIES

The participants in this project are James C. Bean, Jack R. Lohmann, and Robert L. Smith of the Department of Industrial and Operations Engineering.

The first year of funding of this project covered the period June 1983 through March 1984. The objectives of this project, contained in the proposal, were "to develop analytical methods for planning replacement of existing transit fleets and to develop usable computer programs which can assist in the process." Considerable progress was made in developing the algorithm for analyzing bus replacement options. The computer program using this algorithm has been written. However, at the end of the first year, both the algorithm and the computer program were incomplete. However, by the end of the second year, enough progress will have occurred to warrant a technical report outlining the methodology and explaining how to use the computer program. In addition to the objectives stated in the proposal, the participation of Ann Arbor Transportation Authority personnel in a graduate course in the Department of Industrial and Operations Engineering resulted in students working on the problem of optimum vehicle assignment and bus driver scheduling. Following is a description of the accomplishments during the first year.

Algorithm Development

The problems of when to replace equipment and the choice of what to replace it with are well known to public agencies and private firms. The choices may include the replacement with the same equipment or replacement with one of several versions of models that incorporate new advances in technology. On the other hand, there is always the chance that some new innovation that will revolutionize the industry is just over the horizon that will make previous choices obsolete or very costly.

The inherent uncertainty that accompanies these equipment replacement problems makes it difficult to handle them practically as well as to solve analytically. Searches of the literature reveal that there is no existing analytical technique that can handle this problem adequately.

The transit agency is very familiar with this problem. They expect to operate indefinitely into the future, must replace equipment periodically, and are entrusted by the public to make wise decisions in their purchases.

We have had several meetings with the Assistant General Manager of the Ann Arbor Transportation Authority and the head of bus maintenance at Chicago Transit Authority (CTA). These discussions were very valuable in understanding the practices, goals, and viewpoints of transit managers and in verifying our beliefs that the techniques we are developing are applicable to the problems of bus replacement facing transit properties.

We found that the recent experiments with lifecycle costing have clearly done much to damage the credibility of any forward-looking analytical techniques for solving equipment replacement problems. However, these negative opinions appear to be a reaction to the sources of data in such analyses (the suppliers) rather than the techniques themselves.

As part of ongoing research and as part of the work undertaken in this research problem an algorithm which optimizes the equipment replacement decision was developed. The methodology was developed in general for any equipment replacement problem. The methodology uses concepts of dynamic programming and infinite horizon (i.e. long and indefinite time frame) optimization. The potential effects of future changes in bus design and cost are included in the bus replacement decision making.

A technical paper summarizing this methodology was submitted to and will appear in The Engineering Economist.

Computer Software

The computer program code is the first version of a computer program which is intended to help transit agencies in their equipment replacement decisions. It is an application of the general optimal equipment strategy algorithm which was described in the previous section. Members of the research team acquired data and information about the issues involved in equipment purchases from the Ann Arbor Transportation Authority and worked these into their general equipment replacement algorithm.

Thus, the computer program is a specific application of the theoretical model to the bus replacement problem. The program is intended to be user-friendly and to be easily used by transit agency personnel. It is being developed for the IBM PC in the BASIC language. The program is still in its prototype state and is not yet user-friendly. Work is expected to continue and it is anticipated that the program will be completed during the second year of funding.

Vehicle Assignment and Operator Scheduling - Algorithm and Program

Operational planning of transit service requires the determination of routes, frequency of service along routes, assignment of vehicles, and operator scheduling. Each agency tries to optimize this procedure such that a desirable level of service is maintained and the costs are minimized. This is a large scale systems problem and is quite formidable in the general case.

The discussions with Ann Arbor Transportation Authority led to their participation in Industrial and Operations Engineering 640, "Mathematical Modeling of Large Scale Systems." In this course graduate students became familiar with technical problems facing AATA and currently available software for solving them. The students worked with AATA personnel to address one of these problems by developing an algorithm for optimum vehicle assignment and bus driver scheduling for the Ann Arbor Transportation Authority .

The fleet of vehicles, routes, and frequency of service were taken as given and the optimization of the vehicle assignment and driver scheduling was formulated as a linear programming problem. The routes were assigned for shortest mileage including minimizing dead heading. The operator scheduling incorporates relief time, formation of shifts, and minimizes the number of trippers (part-time drivers or overtime). At the end of the algorithm, work schedules for all regular operators are be generated. Based on their seniority the operators could then bid for the schedule of their choice. The "trippers" remaining in the final solution would be assigned to part-time operators.

It is unlikely that this model would generate the optimal assignment and operator schedule in the first pass. There are undoubtedly latent constraints better known to the scheduler. Furthermore, some of the constraints built into the model might in reality be soft and permit marginal violation in practice. The model itself is seen as a tool which the transit authority could use in an interactive environment where the scheduler's experience could augment the computer optimization.

This project led to a final report which was forwarded to AATA and to UMTA for review and comment.

Future Funding

In order to run a credible research effort on problems of this type we believed that funding in addition to UMTA monies was necessary. As a result, a good deal of our efforts during 1983-1984 were aimed at developing this additional funding. We have been very successful to date. IBM has awarded us a grant of $58,000 to study similar problems. Further, the National Science Foundation has awarded Professor Jack Lohmann $62,500 which will be used to a great extent on this project.

Combined with the $30,000 budget proposed for the second year of this UMTA grant, we now have a substantial research effort in this area. We believe this combined funding will enhance our work on the bus replacement problem due to economies of scale in the research effort.

4. ANALYSIS OF BUS MAINTENANCE DATA

Introduction

In serving the public safely and comfortably transit properties must maintain the condition of their fleet. Providing such maintenance efficiently is a continuing challenge. An understanding of how the various component systems of vehicles perform (as measured by failure rates, replacement costs, lost service time, etc.) is useful to management in directing an efficient operation.

Even in a small property, collecting data on and analyzing such maintenance details manually has been a tedious and laborious procedure. Consequently, it has seldom been done in a complete or satisfactory manner. The availability of computers and development of more sophisticated record-keeping software has made it practical to maintain more detailed records.

One part of the University of Michigan's UMTA-sponsored research program is directed toward the development of instrumentation to permit early detection of bus component and subsystem failures. The expectation is that such detection will lead to fewer breakdowns, road calls, and service interruptions. In connection with that development, we have acquired a set of computerized maintenance information which provides estimates of current breakdown frequency. The Ann Arbor Transportation Authority (AATA) computerized most of its maintenance records beginning in October 1982. The computer package used by AATA, the Vehicle Service Account or V.I.S.A., was originally obtained from Des Moines, Iowa. Shortcomings of this data system, for our purposes, include the absence of road call information and the program's inability to accurately cumulate data from year to year. However, as a means of familiarizing our data and research analysts with maintenance data file building and filtering, it was decided to use the AATA information to determine repair frequency of major bus system components for the AATA.

In the following sections, some of the results of our analysis are presented. While some further analysis will be necessary, these results will be used when we test the instrumentation for detecting incipient maintenance problems in our future research program. We have also obtained a larger data set from Seattle Metro. We expect to use that in addition to the AATA data in the development of the preventative maintenance game during future Center activities. While the results reported here are of limited use in themselves, they will be useful in future comparisons.

AATA Fleet Data

The AATA fleet consists of 64 operating vehicles, 49 coaches with seating capacity ranging from 33 to 53 persons and 15 vans, each with a capacity for 12 people. The average age of vehicles in the fleet was 5.3 years as of December 1983. Thirty-seven of the AATA coach vehicles were manufactured by GMC and twelve by Grumman/Flxible. The fifteen vans are produced by Dodge and Chevrolet.

The AATA vehicle maintenance files recorded under a work order format include odometer reading, problem part number and name, vehicle age, system repair, and operating cost data for replacement parts and maintenance labor. Using these data, the frequency of repair of major component systems were determined for vehicles classified by vehicle use and by manufacturer.

We now present an analysis of the frequency of the component system repairs for the entire AATA fleet for 1983. The five component systems repaired most frequently within the fleet, in decreasing frequency order are: (1) electrical, (2) brake, (3) engine, (4) body repair, and (5) transmission. Work on these five systems constitute more than 70 percent of the work orders the AATA garage completed in 1983. Table 2 presents the average

Table 2

Mean Miles between Repair (MBR) and Average Number of Work Orders Per Year (WPY) by System Repaired

Vehicle Type	Vehicle Component/System: Electrical	Brake	Engine	Body Repair	Trans
Work orders	601	432	297	265	147
Coach					
MBR	19,076	27,197	26,847	22,964	23,095
WPY	7.1	6.3	4.0	4.0	3.4
Van					
MBR	29,400	19,805	25,210	12,414	67,088
WPY	9.9	5.5	4.3	3.5	2.0

number of miles between repairs (MBR) and the average number of visits for the these repair systems, along with the number of work orders recorded for each of the top ranking components.

The following sections examine the frequency and cost of system repair by vehicle manufacturer and vehicle type. We look mainly at coach vehicles manufactured by General Motors and the Dodge vans.

GMC Coach Data

There are three age groups of GMC vehicles used in daily service. The two largest groups in active service are the eleven 1974 and three 1976 GMC New Look models. Fourteen vehicles are 1981 GMC advanced design buses. The average number of repair orders by system was determined for each group along with the average number of miles driven between repairs. An 11-month cumulative cost total for replacement parts and labor to keep a given system operational was also obtained. Next, a cost-per-mile (CPM) total for parts and labor for each component was developed. Finally, the most frequently replaced parts are listed. These values are presented in Tables 3 and 4, with the replacement parts

Table 3

Summary Repair Statistics:
1974 GMC Coaches in AATA Fleet

Component	Avg. Visits (11 mo.)	Avg. Mi. Between Repairs	Avg. Cost per mile Parts	Labor
Electrical	8.6	9,411	.0057	.0108
Brakes	10.3	14,400	.0067	.0270
Inspections	5.0	3,970	.0049	.0228
Body Repair	3.3	23,900	.0024	.0098
Transmission	5.1	6,555	.0053	.0196

Table 4

Summary Repair Statistics
1981 GMC Coaches in AATA Fleet

Component	Avg. Visits (11 mo.)	Avg. Mi. Between Repairs	Avg. Cost per mile Parts	Labor
Electrical	8.2	8,645	.0025	.0069
Brake	4.4	12,094	.0085	.0140
Inspections	6.5	4,227	.0099	.0153
Body Repair	4.2	13,582	.0030	.0073
Transmission	2.0	4,876	.0040	.0040

summarized in Table 5. It can be seen that brake repairs on the older coaches occur much more frequently than on the trans busses. The MBR for engine and body repairs on the new busses are much less.

Table 5

Most Frequent Replacement Parts for GMC Coaches: AATA (1983)

Electrical		Brake	
Part	Qty.	Part	Qty.
Flasher (SF55a)	77	Dessicant Filter	75
Sealed Beam (4000)	33	Front/rear brakes	53
Sealed Beam (4652)	45	Oil Seal (2010807)	51
Power Supply 24V	24	Seal Assembly (2010065)	50
Relay (684198)	16	Spring (2377712)	36
Light Socket (8907701)	16	Roller (235611)	32
Engine		**Body Repair**	
Gasket (5139450)	19	Fisheye Mirror (E375)	22
Fuel Tube (5126336)	15	Mirror Assembly	13
Water Pump (5101802)	11		
Transmission			
Gasket (677504)	20		

Dodge Van Analysis

The Dodge 12-passenger dial-a-ride van fleet contains two vehicle age groups, five from 1975 and eight from 1981. Tables 6 and 7 show the ranking of component systems for each of the Dodge van age groups. Large differences in repairs to the various systems for the two models are apparent.

Table 6

Summary Repair Statistics:
1975 Dodge Vans in AATA Fleet

Component	Avg. Visits (11 mo.)	Avg. Mi. Between Repairs	Avg. Cost per mile Parts	Avg. Cost per mile Labor
Electrical	3.5	22,072	.0055	.0444
Brakes	1.7	1,133	.0060	.0249
Engine	2.8	19,638	.1632	.0306
Body Repair	2.5	21,237	.0047	.0039
Transmission	-	-	.0041	.0255

Table 7

Summary Repair Statistics:
1981 Dodge Vans in AATA Fleet

Component	Avg. Visits (11 mo.)	Avg. Mi. Between Repairs	Avg. Cost per mile	
			Parts	Labor
Electrical	14.3	3,524	.0051	.0492
Brakes	7.4	18,703	.0044	.0429
Engine	4.9	15,892	.0101	.0280
Body Repair	3.1	6,253	.0027	.0360
Transmission	2.0	10,786	.0015	.0120

Work Order Frequency by System

An analysis of work order frequency for both coaches and vans was made using a two-way cross tabulation of manufacturer vs. component repair type. Table 8 presents the total number of work orders by component for each manufacturer. The analysis was carried out to determine whether the relative amount of repairs required for a particular component differed by vehicle type and make.

Examining Table 8, and focusing first on the coach manufacturers, there are major differences in repair frequencies by system. Particularly large differences in relative electrical and transmission repairs can be seen. For vans, the differences between the two makes is not great. Looking at vehicle type, electrical repairs are needed more often in the vans than on the coaches in the fleet.

Summary

The information shown above is part of a pilot study and is of limited value by itself. However, we have shown that it is possible to use computerized maintenance information to produce data which will be useful in future research endeavors. We have also established the groundwork to examine other transit fleet maintenance data bases. Such analyses will be used in developing optimal maintenance schedules using the instrumentation to detect incipient maintenance problems described elsewhere in this report. These data and others will also be used to develop a preventative maintenance game to be used as a training tool for transit maintenance personnel.

Table 8

Vehicle Component Repair Work Orders
by Vehicle Type and Make

Total Work Orders	No. Work Orders	Coaches GMC	Coaches GRUMMAN	Vans DODGE	Vans CHEV
TOTAL	3737	2388	556	643	150
Brake	1427	966	199	220	42
Expected	-	912	212	246	57
Col%	38.2	40.5	35.8	34.2	28.0
Electrical	786	398	142	206	40
Expected	-	502	117	135	32
Col%	21.0	16.7	25.5	32.0	26.7
Engine	615	368	109	103	35
Expected	-	393	92	106	25
Col%	16.5	15.4	19.6	16.0	23.3
Transmission	478	401	19	53	5
Expected	-	305	71	82	19
Col%	12.8	16.8	3.4	8.2	3.3
Body Repair	431	255	87	61	28
Expected	-	275	64	74	17
Col%	11.5	10.7	15.6	9.5	18.7

5. INSTRUMENTATION TO DETECT BUS MAINTENANCE PROBLEMS

The primary participant in this project was William B. Ribbens of the Department of Electrical Engineering and Computer Science. He is also the director of the Vehicular Electronics Laboratory.

The objective of this project is to develop instrumentation to detect incipient failures in certain critical components of busses. A system for detecting incipient bus system failures has been relatively expensive in the past compared with costs of providing ground-based transportation. However, the commercial availability of relatively low cost sensors and microprocessor-based electronics raises the possibility of applying this failure detection concept to bus fleets.

During the first year's efforts in this project, the efforts were directed toward developing the actual instrumentation and demonstrating that it can detect degredation in an engine's performance. The instrumentation was installed on a VW diesel-powered automobile and tested in laboratory and street conditions. The tests showed that simulated degredation of one cylinder's performance was easily detectable, even when operating the test car on rough, cobblestone streets. A technical report describing these tests in available.

The next stage in the project is to test the instrumentation on busses in revenue service. In addition to demonstrating the feasibility of installing the instrumentation and being able to detect performance degredation, the next stage will involve the collection of statistics relating performance degredation to system failures. These will be used to develop optimal maintenance strategies based on information collected through the instrumentation.

Description of the Instrumentation

The system under development in this project differs significantly from existing fleet maintenance aids or automatic diagnostic instrumentation. In the latter case, computer-aided testing is performed to identify the existing status of individual components in an attempt to detect existing failures. Such tests are normally performed at test stations and the monitoring results in a sample of the system's status at the time measurements are made.

In incipient failure detection, the vehicle's overall performance is continually monitored during normal operation. Performance degredation can be detected at an early stage. Whenever performance degredation is detected, an on-board diagnostic routine can be called upon to isolate the degraded components. Appropriate warning messages, calling for specific maintenance action, can be displayed or stored.

This project is currently directed toward monitoring engine output power. A simple, inexpensive, non-contacting sensor for torque measurement is now available. Engine output power can be obtained simply by multiplying the torque by crankshaft angular speed. This speed measurement can be obtained from the same sensor used to measure torque. Thus, a simple and inexpensive sensor exists for continuously monitoring engine performance. This sensor, in conjunction with a simple computer algorithm, can essentially instantaneously detect degredation in engine torque/power.

An important engine performance variable is torque non-uniformity. Although engine torque is inherently non-uniform, excessive non-uniformity is a direct indication of engine performance degredation. For example, a diesel engine having one partially malfunctioning fuel injector has a larger variation in cylinder-to-cylinder torque production than for a normal engine. The malfunction can be caused by wear, dirt in the injector nozzle assembly, incorrect pressures and many other non-catastrophic failures. Detecting these failures early can prevent major damage to an engine and save on maintenance costs.

This method of monitoring torque non-uniformity can isolate an individual malfunctioning cylinder and issue an alarm to identify it. This information is useful for preventive maintenance and can significantly shorten diagnostic time and repair time. Even when no major breakdown is averted, this system can improve maintenance efficiency.

Experimental Findings

Results during the first year are reported in more detail elsewhere, but a brief synopsis will be given here. Experimental measurements were made of the non-uniformity metric for a four cylinder 1.5 liter VW diesel engine. Separate sets of measurements were made with the engine in a test cell and in a vehicle driven on different kinds of streets.

Test cell measurements were made with the engine driving a water brake load through an elastic link coupling. The experiments were made running the engine at a variety of conditions consisting of various RPM and torque loads. In one set of measurements, the engine was operated with one fuel injector disconnected in order to achieve a condition of extreme torque non-uniformity. Comparing the non-uniformity metric for normal and three cylinder operation revealed very strong differences independent of RPM and load.

Additional tests were made using the same type of engine in a VW Passat, with a five-speed manual transmission and front wheel drive. The same sensor was used and data were recorded for analysis identical to that used in the test stand experiments. Street operation introduces random variations in the driveline angular speed. These random variations are added to the torque non-uniformity produced by the engine itself. These tests were conducted to see if engine degredation could be detected even in the presence of "noise" produced in actual driving situations.

Tests were conducted on a normal road, an expressway and an old cobblestone street. The latter test produced an extreme case of road-induced crankshaft speed non-uniformity. The street operation, especially on the cobblestone street, did produce a greater degree of non-uniformity than test cell measurements. However, with one cylinder disconnected, the additional non-uniformity is easily detectable, even for the most extreme street conditions.

Summary

First year results show that a relatively inexpensive sensor can be installed in production engines with minimal modification. Moreover, with relatively inexpensive electronic signal processing, the sensor produces information which can detect degredation in engine performance, even under extreme street conditions.

Experiments with a VW diesel engine are promising enough to plan to test the instrumentation in diesel busses in revenue service. The next stage in the project is to develop statistics that relate measurements of non-uniformity to engine failures and to use these statistics to improve maintenance scheduling. The final objective of the study will be to evaluate the improvements in maintenance efficiency that can be obtained through the use of this instrumentation.

6. SECTION 15 REPORTING SYSTEM

The originally proposed concept for our Section 15 reporting system work included several long-term activities, each of considerable scope: acquisition of the existing Section 15 data with yearly updates thereafter; creation of a computerized database, together with appropriate user-oriented documentation, accessible to both remote and local users; formulation and conduct of training sessions for database users; conduct of special database analyses on request; and conduct of an on-going analysis and research program designed to assist transportation planning. The work was to concentrate on operational and equipment-related aspects of transit system performance.

Although the goals given above remain valid, a sharp curtailment of the intended program has been necessary because of the reduction in scope and effort of the overall program. Clearly the longer-term goals depend completely on acquiring the Section 15 data and putting them in a form suitable for subsequent analysis. Accordingly the efforts to date have been restricted to this activity.

The vehicle related information in the Section 15 reports has been organized on to data sets on MIDAS, the Michigan Interactive Data Analysis System. Thus, it is accessible for research on national level statistics dealing with vehicle-related problems. During the second year of Center operations, these data sets form the basis for a research effort to define peer transit agencies based on geographic data. The data sets are also being used by students for class research projects. This use will help to guide future organization of the data sets and, ultimately, make them useful to the research community at large. In this section, we report the progress made during the first year efforts.

Section 15 Data File-Building Activities

Four tapes containing the Section 15 data were obtained from the Transportation Systems Center of DOT's Research and Special Programs Administration. (Three of these contain the first three reporting years in the "standard" format, and the fourth contains the third-year data in an alternate format.) The third-year data are known to be more complete and less subject to reporting anomalies than those for the first two years, and it was decided to direct our initial efforts there. Subsets of the data--these are detailed in subsequent sections of this report--were created in MIDAS, the Michigan Interactive Data Analysis System. MIDAS datasets are readily converted to those suitable for use in OSIRIS, another of the popular data analysis programs both here and at other computing installations. If use of the Section 15 data by SAS or SPSS users is desired, then the MIDAS dataset can be written out in a format convenient for re-reading by either of those programs.

Two kinds of data manipulation and analyses are anticipated for these data. One kind is the generation of new variables from existing variables for each of the transit properties. An analyst might be interested in knowing, for example, the number of fatal accidents per total vehicle miles, a quantity readily calculated from data reported by the properties. The other kind involves comparison of various operating data across properties, either of directly-reported data or of derived variables.

For either of these applications, it is necessary to have all of the data for all of the transit properties in a single dataset. Accordingly, much of the effort to date has been directed to manipulating the data suppled by TSC into a MIDAS dataset suitable for subsequent analysis. As noted earlier, the focus here is on the operational aspects of transit system performance, so the data contained in the "400" series of Section 15 reporting forms have been combined into a single file. A rectangular file structure has been employed, wherein each MIDAS "case" contains all of the data for one reporting system. The result is that there are as many cases as there are reporting properties, 319 for the third reporting year used here.

The contents of the file are described in the next section. The MIDAS dataset variables are given together with their relationship to the Section 15 data forms and the documentation provided with the TSC data tapes.

Contents of MIDAS Dataset

The structure of the MIDAS dataset and its relationship to the Section 15 reporting forms are most easily understood by referring to Appendixes A and B. Appendix A presents the applicable reporting forms of the "400" series along with Form No. 001, TRANSIT SYSTEM IDENTIFICATION SCHEDULE. The MIDAS variable numbers are noted directly on the forms, and the variable numbers of derived variables closely related to the directly-reported data items are also given.

The table of Appendix B gives further information about the dataset. Data in the first three columns--the number, name, and number of levels of the MIDAS variables--are taken directly from the output of a MIDAS "DISPLAY INTERNAL FILE" command. Column 4 repeats the applicable form numbers, and Column 5 lists the Transportation Systems Center tape file number from which the numerical data were taken. This number, together with the "Table VIII - Detailed File Descriptions" documentation provided by TSC, will permit a complete reference to the original data if desired. The MIDAS variable names are generally a replication or variation of the TSC variable names as well.

Several derived variables appear throughout the file that are labeled as "ordinal" variables. These are commonly used here because a number of the original variables were received in alpha ("text," in the TSC documentation) form. These do not lend themselves to analysis in MIDAS, so their ordinal function was derived. This is simply a numeric ranking of the alpha variables in their normal collating sequence. Thus, for example, the four reporting levels (Variable 5) R, A, B, and C have ordinal values of 4, 1, 2, and 3, respectively. As noted, Variable 5 and its ordinal (Variable 6) identify the reporting level used by each transit property. Of the 319 properties in the file, a simple one-way tabulation shows that 182 (57.1%) report at the the "R" (required) level. The A level shows 23 (7.2%), the B level 40 (12.5%), and the C level 74 (23.2%). Twenty-five cases (7.9%) show a consolidation of two or more systems as indicated by Variables 7 and 8.

Many of the systems operate more than one mode of transit, of course. Table 9, obtained from derived Variable 12, presents the 17 different combinations observed among the 319 properties. All but 18 systems operate motor busses, and it can be seen that 188 of these 301 systems rely solely on busses. Another 96 systems operate in the demand response mode along with the bus mode. This fact provides additional impetus to our earlier decision to focus our efforts on bus-related issues of transit operations.

Table 9

Reporting Mode Combination and Frequencies

Freq.	Motor Bus	Rapid Rail	Street Car	Trolley Bus	Demand Response	Ferry boat	Other
188	X	-	-	-	-	-	-
4	X	X	-	-	-	-	-
1	X	X	X	X	-	-	-
1	X	X	X	X	X	-	-
1	X	X	X	-	X	-	-
2	X	-	X	-	-	-	-
1	X	-	X	X	X	-	X
1	X	-	X	-	X	-	X
1	X	-	-	X	-	-	-
1	X	-	-	X	X	-	-
96	X	-	-	-	X	-	-
2	X	-	-	-	X	-	X
1	X	-	-	-	-	X	X
1	X	-	-	-	-	-	X
2	-	X	-	-	-	-	-
15	-	-	-	-	X	-	-
1	-	-	-	-	-	X	-

Data from Form 401 appear in the "100" series of variables, Form 402 data in the "200" series, and so on. Two exceptions will be noted. The first is that Form 406 (TRANSIT SYSTEM SERVICE SUPPLIED, etc.) generated over 100 variables, numbered from 600 to 718. This will not create confusion in that Form 407 deals only with rail modes of transit, and thus is not included in our current file-building efforts. The second exception is that data from Form 408 (REVENUE VEHICLE INVENTORY SCHEDULE) have not yet been added to the file. This will be completed during the second year when certain issues relating to high missing-data rates on certain of the variables are resolved.

Potential users of these data, whether desiring direct access through MTS or copies of the data in hard-copy or tape form, should contact James O'Day (313-764-6504) or Lyle Filkins (313-763-3230) for further information.

7. THE ESSENTIALS OF TRAFFIC ENGINEERING FOR TRANSIT MANAGERS

The Center conducted a training course for mid-level transit managers during the week of September 20-24, 1984. The course was concerned with presenting traffic engineering principles of particular interest to transit property operators as well as a detailed introduction to the use of personal computers in such applications. The course was presented at UMTRI's building in Ann Arbor, Michigan.

Faculty and Supporting Personel

Faculty involved in the course included Mr. James O'Day, Acting Director of UMTRI, Dr. Donald E. Cleveland, Professor of Civil Engineering and course manager, Dr. Lidia P. Kostyniuk, Associate Professor of Civil Engineering at Michigan State University, Dr. Cyrus Ulberg, Center program coordinator, Dr. Aaron Adiv, Assistant Professor of Urban Planning, Mr. Michael Sayers of the UMTRI scientific staff, Mr. Gary Waissi, Doctoral Applicant in Civil Engineering and Professor Herbert S. Levinson of the University of Connecticut.

Administrative and logistic assistance was provided by Ms. Michelle Barnes who prepared the course attendance certificates on the Macintosh personal computer and Mr. Bruce Bertram of the UMTRI professional staff. Demonstrations were also made by Mr. Charles Green of UMTRI. Graphic and photographic services were provided by Ms. Kathleen Richards. Field trips were made with the cooperation of Mr. Edward Stokel of General Motors Coach (a visit to the manufacturing facility for GM buses in Pontiac and a discussion of bus maintenance issues), Mr. Richard Simonetta (a visit to the almost completed new maintenance facility of the Ann Arbor Transportation Authority) and Mr. David MacDonald of the Southeastern Michigan Transportation Authority (a post-course tour of the downtown people-mover currently under construction in Detroit).

Participants

Seven students participated in the course. There were six UMTA Section 10 grantees from four larger and one smaller transit property representing the following cities and properties:

Duluth, Minnesota (Ms. Katherine Turnbull, Director of Transportation Development, Arrowhead Regional Development Commission)

San Antonio, Texas (Ms. Janet Nordstrom, Planner and Mr. Calvin Joe Rogers, Scheduling Supervisor, VIA Metropolitan Transit)

Portland, Oregon (Mr. William Coffel, Senior Planner, Tri-Metropolitan County Transit District)

Atlanta, Georgia (Mr. P.D. Johnson, Chief of Scheduling, Metropolitan Atlanta Rapid Transit Authority)

Seattle, Washington (Mr. Charles Kirchner, Capital Projects Coordinator, Municipality of Metropolitan Seattle)

Lecturer Wenzhi Wang of Jilin Technical University of the Peoples Republic of China and visiting transit scholar at UMTRI also attended the course.

Course description and logistics

The course began on Monday, September 24, 1984. It had been anticipated that some of the attendees might arrive at Detroit that morning but all had come in on the previous evening, and accordingly, it became possible to start the technical program early with an overview of the week and an introduction to microcomputers and estimates of their future usage in transit properties.

The group ate together and were all housed in a nearby motel. Transportation was provided by the University between the course headquarters, the motel, eating establishments, and field trip locations. With the exception of one evening, the group ate two meals each day with at least one member of the senior faculty. This was found to be an excellent way to obtain feedback on the progress of the course and interests of the students and to adapt later sessions to some of these needs.

On Monday afternoon there was a demonstration of a recently introduced spread sheet program by a local computer outlet representative as well as an introduction to some special uses of the Apple 2 and Macintosh computers. The use of the TRS-80 as a data collection and compiling aid was also demonstrated within a street transit operation framework. The students were then given an assignment to go through these various procedures themselves in a hands on mode and with one instructor for each student or group of students when they preferred to work together. The assigned problem took them through a simulated data set acquisition, compilation, reduction and presentation sequence of steps. Monday evening there was a social reception at Dr. Cleveland's home.

On Tuesday morning, Professor Levinson gave his lectures on traffic engineering actions which could be made to improve street transit operations. Following lunch Professor Levinson led a discussion of relevant transit issues involving traffic engineering matters. Professors Cleveland and Kostyniuk then described the TAPM (Transit Action Performance Model) microcomputer programs developed at the University of Michigan in the Civil Engineering department under an UMTA grant. These programs calculate optimal signal timing considering bus passengers as of equal importance to passenger car occupants, explore the effects of bus preemption systems and consider the effects of different bus stop spacings on transit service and operation. Although the evening was free the students were encouraged to return to the class area where more than one personal computer was available for each student. The computers which were available included the Apple Macintosh, Apple 2-plus and e and IBM PC and IBM PC XT. These had been made available to the course on a loan basis by UMTRI and other University units. It was found necessary to rent computers one day when there was another need for some of the machines.

Wednesday morning was devoted to hands-on experience with the TAPM models by the course participants. On Wednesday afternoon, there was a description and hands-on laboratory experience with several transit programs developed elsewhere and made available through UMTA. This included some maintenance management and transit demand programs developed by Dr. Ulberg. Mr. Waissi demonstrated the McTrans program package from the University of Florida. Wednesday evening there was a visit to the Ann Arbor Transportation Authority's bus maintenance facility in the final stages of construction. An informal evening was spent with representatives of the Authority.

On Thurdsay there was a visit to the GMC bus assembly plant in Pontiac, a discussion of bus maintenance data and a group luncheon with GMC representatives at the Pontiac Silverdome restaurant. In the late afternoon Mr. Sayers presented a description and demonstration of the UMTRI program developed for the FHWA which determines the amount of off-tracking of a large vehicle turning at an intersection. An example using an articulated bus currently being marketed in the U.S. was demonstrated. An informal banquet was held Thursday evening.

On Friday morning, there was a presentation of the neighborhood transportation system management game developed by Dr. Adiv for METRO in Washington, D.C. under an UMTA grant. Following an evaluative discussion of the need for the type of material presented,the course ended. Some participants made a sponsored visit to the SEMTA people mover facilities under construction in Detroit. The students were asked to evaluate the course and to participate in a continuing cooperative effort to use software provided to them by the Center and to provide feedback on their use of this software.

Course materials

Each student was provided with a notebook with handouts which supported each lecture and demonstration and minimized the need for taking notes. In addition, the various public domain programs were made available to the students in the form of diskettes and other software was loaned to them for an indeterminate time period on condition that they would provide an evaluation of their usefulness to the Center.

Extensive use was made of draft materials prepared by Professors Levinson, Cleveland and Kostyniuk for UMTA as a part of a publication to be entitled TRAFFIC ENGINEERING FOR PUBLIC TRANSPORTATION. Comments were solicited from the students and several useful suggestions were received. As a result of their comments, some of the user-communication aspects of the TAPM models were revised for the IBM PC programs.

Evaluation

Formal evaluation forms of the type regularly used at the University of Michigan were made available to each student with the request that they be returned to the Center after arriving at their home station and reflection on and discussion of the value of the program with their manangement. Early responses initiated a particular interest in the traffic engineering aspects of the course and a desire that the training in the general use of microcomputers be lessened. It was apparent that the institutional structure at some of these larger properties had already foreclosed the extensive individual use of personal computers by analysts. It is the belief of the Center staff that smaller properties may be more flexible and find personal computer training of more value. We found no indication that these employees, with their wide variance in background, were unprepared for the material presented to them in this course.

Marketing

This course was originally planned to be offered in early May of 1984. Publicity, in the form of a leaflet had been prepared with the intention of a promotional mailing shortly after January 1. It was then learned that an additional approval at the state level would be required and that there was particular urgency in processing applications for Section 10 grants. Accordingly, the APTA membership list was culled for properties in the midwest and those large enough to receive benefit from traffic engineering improvements in their service areas. The training officer in each of these properties was contacted by telephone and the program described and questions answered. It is believed that this personal contact was of particular value. Contact with possible course participants was maintained throughout the Spring and it is believed that the participation was greater than it would otherwise have been as a result of this effort.

Conclusions

Center staff believes that the course was successful. The continuing interest of the participants throughout the week attested to that. The feedback received in the lively and often continuing informal interaction during the presentations was of particular value to Center personnel.

Form No. 001

TRANSIT SYSTEM IDENTIFICATION SCHEDULE

TRANSIT SYSTEM ID [| | |] V1 V11 = ORDINAL(V1)

FISCAL YEAR [|] Month V3 [|] Day V4 [|] Year V2

1. Transit system name: ______________________

2. Transit system address:
   Street Address ______________________
   City ______________________
   State [|] Zip Code [| | | |]

3. Person to be contacted regarding the report:
   ______________________, ______________________
   Last Name First Name and Initial(s)
   Title ______________________
   Telephone [| |] Area Code [| |] [| | |] Number [| | | |] Extension

4. Please check the instruction manual under which you are reporting V5 V6 = ORDINAL(V5)
   (see the Preface to the instruction manual)
   - [ ] R Required Manual
   - [ ] A Level A Voluntary Manual
   - [ ] B Level B Voluntary Manual
   - [ ] C Level C Voluntary Manual

5. Please indicate the mode(s) which you are reporting V9 = SINGLE OR MULTI MODE V10 = ORDINAL(V9)

   V12 = REPMODES V13 = ORDINAL(V12) V14 = REPMODID

   - [ ] 1 Motor Bus
   - [ ] 2 Rail Rapid Transit
   - [ ] 3 Street Car
   - [ ] 4 Trolleybus
   - [ ] 5 Demand Response
   - [ ] 6 Ferryboat
   - [ ] 9 Other Identify ______________________

6. Please indicate the number of revenue vehicles in your fleet(s) as of the end of the fiscal year being reported.

   [| | |] A Rail rapid transit cars
   [| | |] B Street cars
   [| | |] C Trolleybuses
   [| | |] D Motor Buses, Class A V15
   [| | |] E Motor Buses, Class B V16
   [| | |] F Motor Buses, Class C V17
   [| | |] G Demand Response Vehicles V18
   [| | |] H School Buses
   [| | |] I Ferry Boats
   [| | |] Y Other Revenue Vehicles

7. Is this report a consolidation of two or more systems? (Please review instructions)

   Yes [ ] V7 No [ ] V8 = ORDINAL(V7)

Form UMTA F2710.100 (7-78)

Form 401

TRANSIT SYSTEM SERVICE PERIOD SCHEDULE

Transit System ID V1 [| | |]

Level [ ]

Fiscal Year Ended [|] Month V3 [|] Day V4 [|] Year V2

Mode V101 Code [ ]

LINE NO.	ITEM	WEEKDAYS (b)	SATURDAY (c)	SUNDAY (d)
	LIMITS OF SERVICE PERIOD:			
01	Time AM service begins	V 102	V 113	V 116
02	Time AM *PEAK* service begins	103		
03	Time Midday service begins	104		
04	Time PM *PEAK* service begins	105		
05	Time Night service begins	106		
06	Time Night service ends	107	114	117
	TOTAL HOURS			
07	AM Peak period	108		
08	Midday period	109		
09	PM Peak period	110		
10	Night period	111		
11	ENTIRE DAY—TOTAL HOURS	112	115	118

Form UMTA F2710.63 (7-78)

Form No. 402

REVENUE VEHICLE MAINTENANCE PERFORMANCE AND ENERGY CONSUMPTION SCHEDULE

Transit System ID V1 [| | |]

Level [ ]

Fiscal Year Ended c — V3 Month, V4 Day, V2 Year

Mode b ______ V201 Code [ ]

LINE NO.	ITEM	AMOUNTS
	NUMBER OF ROADCALLS	
01	For mechanical failure	V202
02	For other reasons	203
03	TOTAL ROADCALLS	204
04	TOTAL LABOR HOURS FOR INSPECTION & MAINTENANCE	205
	NUMBER OF LIGHT MAINTENANCE FACILITIES	
05	Serving under 200 vehicles	206
06	Serving 200-300 vehicles	207
07	Serving more than 300 vehicles	208
08	TOTAL LIGHT MAINTENANCE FACILITIES	209
	ENERGY CONSUMPTION	
09	Kilowatt hours of propulsion power (000)	
10	Gallons of diesel fuel	210
11	Gallons of gasoline	211
12	Gallons of LPG or LNG	212
13	Gallons of bunker fuel	

Form UMTA F2710.64 7-78

Form No. 403

TRANSIT WAY MILEAGE SCHEDULE

Transit System ID V1 [| | | |]

Fiscal Year Ended [|] [|] [|]
Month V3 Day V4 Year V2

MODE CODE: V301 Level [R]

LINE NO	RAILWAY CLASSIFICATIONS	b MILES OF DIRECTIONAL ROADWAY	c MILES OF ELECTRIC TRACK	d NUMBER OF CROSSINGS	e NUMBER OF STATIONS
	RAIL RAPID				
01	At grade, exclusive row*				
02	At grade, with cross traffic				
03	Elevated on structure				
04	Elevated on fill				
05	Open cut				
06	Subway				
07	TOTAL				
	STREETCAR				
08	At grade, exclusive row*				
09	At grade, with cross traffic				
10	At grade, mixed and cross traffic				
11	Elevated on structure				
12	Elevated on fill				
13	Open cut				
14	Subway				
15	TOTAL				
16	FERRY BOAT MILES OF WATERWAY				

	BUS ROADWAY CLASSIFICATIONS	DIRECTIONAL MILES ON EXCLUSIVE ROW*	DIRECTIONAL MILES ON CONTROLLED ACCESS ROW*	DIRECTIONAL MILES ON MIXED TRAFFIC ROW*
17	MOTORBUS	V302	V303	V304
18	TROLLEY BUS			
19	TOTAL MILES			

*ROW = right of way

A-4

Form No. 404

TRANSIT SYSTEM EMPLOYEE COUNT SCHEDULE

Transit System ID V1 [| | |] Level [ ]

Fiscal Year Ended V3 [ ] Month V4 [ ] Day V2 [ ] Year

Mode V401 Code [ ]

a b c

LINE NO.	EMPLOYEE CLASSIFICATION	EMPLOYEE EQUIVALENTS: OPERATING LABOR	EMPLOYEE EQUIVALENTS: CAPITAL LABOR
01	11. Transportation Executive, Professional and Supervisory Personnel	V402	V413
02	12. Transportation Support Personnel	403	414
03	13. Revenue Vehicle Operators	404	415
04	21. Maintenance Executive, Professional and Supervisory Personnel	405	416
05	22. Maintenance Support Personnel	406	417
06	23. Revenue Vehicle Maintenance Mechanics	407	418
07	24. Other Maintenance Mechanics	408	419
08	25. Vehicle Servicing Personnel	409	420
09	31. General Administration Executive, Professional and Supervisory Personnel	410	421
10	32. General Administration Support Personnel	411	422
11	TOTAL TRANSIT SYSTEM EMPLOYEES	412	423

Form No. 405

TRANSIT SYSTEM ACCIDENTS SCHEDULE

Transit System ID V1 [| | |] Level [ ]

Fiscal Year Ended a: V3 (Month) V4 (Day) V2 (Year) Mode V501 Code [ ]

LINE NO.	ITEM	b COLLISION	c NON-COLLISION	d STATION
	NUMBER OF ACCIDENTS CLASSIFIED AS:			
01	Fatality, Personal Injury & Property Damage	V502	V509	V516
02	Fatality & Personal Injury	503	510	517
03	Fatality & Property Damage	504	511	518
04	Fatality Only	505	512	519
05	Personal Injury & Property Damage	506	513	520
06	Personal Injury Only	507	514	521
07	Property Damage Only	508	515	522
08	TOTAL ACCIDENTS	569	570	571
	NUMBER OF FATALITIES CLASSIFIED AS:			
	Revenue Vehicle Occupants			
09	On-Duty Occupants	V523	V529	V535
10	Others	524	530	536
	Other Vehicle Occupants			
11	On-Duty Employees	525	531	537
12	Others	526	532	538
	Pedestrians			
13	On-Duty Employees	527	533	539
14	Others	528	534	540
	NUMBER OF PERSONS INJURED CLASSIFIED AS:			
	Revenue Vehicle Occupants			
15	On-Duty Employees	541	547	553
16	Others	542	548	554
	Other Vehicle Occupants			
17	On-Duty Employees	543	549	555
18	Others	544	550	556
	Pedestrians			
19	On-Duty Employees	545	551	557
20	Others	546	552	558

Form UMTA F2710.57 (7-78)

Form No. 406

Non Rail Modes

TRANSIT SYSTEM SERVICE SUPPLIED, SERVICE CONSUMED AND SERVICE PERSONNEL SCHEDULE

Mode ______ Code [ ]

Transit System ID [ ][ ][ ][ ]

Fiscal Year Ended [ ][ ] Month [ ][ ] Day [ ][ ] Year

Level [R]

a		b	c	d	e	f	g	h
LINE NO.	ITEM	AM PEAK*	MIDDAY*	PM PEAK*	NIGHT*	AVERAGE WEEKDAY	SATURDAY**	SUNDAY**
	SERVICE SUPPLIED							
01	Number of vehicles in operation	V601	V617	V633	V649	V665	V683	V701
02	Total vehicle miles	02	18	34	50	66	84	02
03	Total vehicle hours	03	19	35	51	67	85	03
04	Total vehicle revenue miles	04	20	36	52	68	86	04
05	Total vehicle revenue hours	05	21	37	53	69	87	05
06	Revenue capacity miles	06	22	38	54	70	88	06
07	Charter Service Hours					71	89	07
08	Charter Service Miles					72	90	08
09	School Bus Hours					N.A.		
10	School Bus Miles					N.A.		
	SERVICE CONSUMED							
11	Unlinked passenger trips	V607	V623	V639	V655	V673	V691	V709
12	Unlinked passenger miles	08	24	40	56	74	92	10
13	Average time per unlinked trip (min)	09	25	41	57	75	93	11
	SERVICE PERSONNEL (No.)							
	Scheduled vehicle operators							
14	Full time	V610	V626	V642	V658	V676	V694	V712
15	Part time	11	27	43	59	77	95	13
16	Revenue vehicle movement control personnel	12	28	44	60	78	96	14
17	Ticket/Token sales agent, fare collectors, gate keepers	13	29	45	61	79	97	15
18	Route/schedule information operators	14	30	46	62	80	98	16
19	Security agents	15	31	47	63	81	99	17
20	TOTAL SERVICE PERSONNEL	16	32	48	64	82	700	718

*For average weekday **Average Saturday or Sunday

Form UMTA F 2710.60 (7-78)

Appendix B - Contents of MIDAS Section 15 Data Set

Table B1
Contents of MIDAS Dataset

MIDAS VARIABLE			FORM	TSC
#	Name	Levels	#	FILE #
1	TR SY ID	9055	All	All
2	FY YEAR	1981	All	All
3	FY MONTH	12	All	All
4	FY DAY	31	All	All
5	RLEVL	4	001	62
6	ORDRLEVL	4	-	-
7	CONSL	2	001	62
8	ORDCONSL	2	-	-
9	SOMMD	2	-	62
10	ORDSOMMD	2	-	-
11	ORDTRSY	10871	-	-
12	REPMODES	1234500	-	-
13	ORRMODES	17	-	-
14	REPMODID	188	-	-
15	MTRBSA#	4568	001	2
16	MTRBSB#	262	001	2
17	MTRBSC#	85	001	2
18	DR VEH#	243	001	2
101	MODE	9	401	39
102	AMSRB	900	401	39
103	AMPSB	900	401	39
104	MYSRB	1330	401	39
105	PMPSB	1800	401	39
106	NTSRB	2200	401	39
107	NTSRE	2445	401	39
108	AMPRD		401	39
109	MDYPD		401	39
110	PMPRD		401	39
111	NGTPD		401	39
112	TOTHR		401	39
113	AMSRBSAT	1050	401	40
114	NTSRESAT	2442	401	40
115	TOTHRSAT		401	40
116	AMSRBSUN	1600	401	40
117	NTSRESUN	2430	401	40
118	TOTHRSUN		401	40
201	MODE	9	All	All
202	RCMFL	203118	402	28
203	RCOTH	32777	402	28
204	RCTOT	232249	402	28
205	INMNL	8718913	402	28
206	MFAC1	21	402	28
207	MFAC2	12	402	28
208	MFAC3	15	402	28
209	MFTOT	32	402	28

Table G1 (continued)
Contents of MIDAS Dataset

MIDAS VARIABLE #	Name	Levels	FORM #	TSC FILE #
210	DFUEL	30219724	402	28
211	GSOL	962721	402	28
212	LPGLN	2984039	402	28
301	MODE	4	All	All
302	DMEXR	11	403	23
303	DMCAR	64	403	23
304	DMMXR	5340	403	23
401	MODE	9	All	All
402	OPTR EPS		404	24
403	OPTRSPRT		404	24
404	OPRV OPS		404	24
405	OPMN EPS		404	24
406	OPMNSPRT		404	24
407	OPRVMNMK		404	24
408	OPOTHMNM		404	24
409	OPVHSRVC		404	24
410	OPGNAEPS		404	24
411	OPGNASPR		404	24
412	OPTOTEMP		404	24
413	CATR EPS		404	24
414	CATRSPRT		404	24
415	CARV OPS		404	24
416	CAMN EPS		404	24
417	CAMNSPRT		404	24
418	CARVMNMK		404	24
419	CAOTHMNM		404	24
420	CAVHSRVC		404	24
421	CAGNAEPS		404	24
422	CAGNASPR		404	24
423	CATOTEMP		404	24
501	MODE	9	All	All
502	COLFPIPD	4	405	22
503	COLFTPI	2	405	22
504	COLFTPD	3	405	22
505	COLFTOLY	3	405	22
506	COLPIPD	1063	405	22
507	COLPIOLY	2656	405	22
508	COLPDOLY	5915	405	22
509	NCOFPIPD	1	405	22
510	NCOFTPI	1	405	22
511	NCOFTPD	1	405	22
512	NCOFTOLY	8	405	22
513	NCOPIPD	1053	405	22
514	NCOPIOLY	2849	405	22
515	NCOPDOLY	2425	405	22

Table B1 (continued)
Contents of MIDAS Dataset

MIDAS VARIABLE #	Name	Levels	FORM #	TSC FILE #
516	STAFPIPD	1	405	22
517	STAFTPI	1	405	22
518	STAFTPD	1	405	22
519	STAFTOLY	1	405	22
520	STAPIPD	175	405	22
521	STAPIOLY	376	405	22
522	STAPDOLY	94	405	22
523	FCLODYRV	1	405	25
524	FCLOTHRV	1	405	25
525	FCLODYOV	1	405	25
526	FCLOTHOV	6	405	25
527	FCLODPED	1	405	25
528	FCLOTPED	3	405	25
529	FNCODYRV	1	405	25
530	FNCOTHRV	8	405	25
531	FNCODYOV	1	405	25
532	FNCOTHOV	1	405	25
533	FNCODPED	1	405	25
534	FNCOTPED	2	405	25
535	FSTODYRV	1	405	25
536	FSTOTHRV	1	405	25
537	FSTODYOV	1	405	25
538	FSTOTHOV	1	405	25
539	FSTODPED	1	405	25
540	FSTOTPED	1	405	25
541	ICLODYRV	462	405	27
542	ICLOTHRV	3726	405	27
543	ICLODYOV	39	405	27
544	ICLOTHOV	1417	405	27
545	ICLODPED	14	405	27
546	ICLOTPED	194	405	27
547	INCODYRV	674	405	27
548	INCOTHRV	2849	405	27
549	INCODYOV	27	405	27
550	INCOTHOV	44	405	27
551	INCODPED	122	405	27
552	INCOTPED	61	405	27
553	ISTODYRV	160	405	27
554	ISTOTHRV	48	405	27
555	ISTODYOV	1	405	27
556	ISTOTHOV	11	405	27
557	ISTODPED	371	405	27
558	ISTOTPED	45	405	27
569	COLTOTAL	9089	- -	- -
570	NCOTOTAL	5282	- -	- -

Table G1 (continued)
Contents of MIDAS Dataset

MIDAS VARIABLE #	Name	Levels	FORM #	TSC FILE #
571	STATOTAL	376	- -	- -
601	SNVOP IAM	3396	406	30
602	STVMI IAM	142642	406	30
603	STVHR IAM	19019	406	30
604	STVRM IAM	131150	406	30
605	STVRH IAM	17487	406	30
606	SRCMI IAM	9495037	406	30
607	CUPTR IAM	1870845	406	30
608	CUPMI IAM	3920877	406	30
609	CATPT IAM		406	30
610	PSVOF IAM		406	30
611	PSVOP IAM		406	30
612	PRVMP IAM		406	30
613	PTSAG IAM		406	30
614	PRIOP IAM		406	30
615	PSAGT IAM		406	30
616	PTSPR IAM		406	30
617	SNVOP IMI	3396	406	30
618	STVMI IMI	142642	406	30
619	STVHR IMI	19019	406	30
620	STVRM IMI	131150	406	30
621	STVRH IMI	17487	406	30
622	SRCMI IMI	9495037	406	30
623	CUPTR IMI	1870845	406	30
624	CUPMI IMI	3920877	406	30
625	CATPT IMI		406	30
626	PSVOF IMI		406	30
627	PSVOP IMI		406	30
628	PRVMP IMI		406	30
629	PTMIG IMI		406	30
630	PRIOP IMI		406	30
631	PMIGT IMI		406	30
632	PTSPR IMI		406	30
633	SNVOP IPM	3396	406	30
634	STVMI IPM	142642	406	30
635	STVHR IPM	19019	406	30
636	STVRM IPM	131150	406	30
637	STVRH IPM	17487	406	30
638	SRCMI IPM	9495037	406	30
639	CUPTR IPM	1870845	406	30
640	CUPMI IPM	3920877	406	30
641	CATPT IPM		406	30
642	PSVOF IPM		406	30
643	PSVOP IPM		406	30
644	PRVMP IPM		406	30

Table G1 (continued)
Contents of MIDAS Dataset

MIDAS VARIABLE			FORM #	TSC FILE #
#	Name	Levels		
645	PTPMG|PM		406	30
646	PRIOP|PM		406	30
647	PPMGT|PM		406	30
648	PTSPR|PM		406	30
649	SNVOP|NI	3396	406	30
650	STVMI|NI	142642	406	30
651	STVHR|NI	19019	406	30
652	STVRM|NI	131150	406	30
653	STVRH|NI	17487	406	30
654	SRCMI|NI	9495037	406	30
655	CUPTR|NI	1870845	406	30
656	CUNII|NI	3920877	406	30
657	CATPT|NI		406	30
658	PSVOF|NI		406	30
659	PSVOP|NI		406	30
660	PRVMP|NI		406	30
661	PTNIG|NI		406	30
662	PRIOP|NI		406	30
663	PNIGT|NI		406	30
664	PTSPR|NI		406	30
665	SNVOP|AW	3396	406	29
666	STVMI|AW	344683	406	29
667	STVHR|AW	43792	406	29
668	STVRM|AW	301981	406	29
669	STVRH|AW	40264	406	29
670	SRCMI|AW	24400000	406	29
671	SCSHR|AW	1425	406	29
672	SCSMI|AW	24522	406	29
673	CUPTR|AW	3965775	406	29
674	CUPMI|AW	9701685	406	29
675	CATPT|AW		406	29
676	PSVOF|AW		406	29
677	PSVOP|AW		406	29
678	PRVMP|AW		406	29
679	PTSAG|AW		406	29
680	PRIOP|AW		406	29
681	PSAGT|AW		406	29
682	PTSPR|AW		406	29
683	SNVOP|SA	3396	406	29
684	STVMI|SA	344683	406	29
685	STVHR|SA	43792	406	29
686	STVRM|SA	301981	406	29
687	STVRH|SA	40264	406	29
688	SRCMI|SA	24400000	406	29
689	SCSHR|SA	1425	406	29

Table G1 (continued)
Contents of MIDAS Dataset

MIDAS VARIABLE #	Name	Levels	FORM #	TSC FILE #
690	SCSMI|SA	24522	406	29
691	CUPTR|SA	3965775	406	29
692	CUPMI|SA	9701685	406	29
693	CATPT|SA		406	29
694	PSVOF|SA		406	29
695	PSVOP|SA		406	29
696	PRVMP|SA		406	29
697	PTSAG|SA		406	29
698	PRIOP|SA		406	29
699	PSAGT|SA		406	29
700	PTSPR|SA		406	29
701	SNVOP|SU	3396	406	29
702	STVMI|SU	344683	406	29
703	STVHR|SU	43792	406	29
704	STVRM|SU	301981	406	29
705	STVRH|SU	40264	406	29
706	SRCMI|SU	24400000	406	29
707	SCSHR|SU	1425	406	29
708	SCSMI|SU	24522	406	29
709	CUPTR|SU	3965775	406	29
710	CUPMI|SU	9701685	406	29
711	CATPT|SU		406	29
712	PSVOF|SU		406	29
713	PSVOP|SU		406	29
714	PRVMP|SU		406	29
715	PTSUG|SU		406	29
716	PRIOP|SU		406	29
717	PSUGT|SU		406	29
718	PTSPR|SU		406	29