tem, which will provide walking accessibility to more of the CBD. Had the guideway length been held constant, and the spacings and number of stations varied, the effect of station spacing on trip diversions would have appeared to be reversed.

The same problem of choosing which parameters to hold constant is the source of the intuitively unappealing trend of increasing diversions with increased station spacings shown in Figure 5. A reader could easily conclude from that figure that the best way to increase DPM ridership is to locate stations as far apart as possible, since the increasing ridership trend on that figure is the strongest of any presented in the paper. This, of course, disregards travelers' willingness to walk and walk-refusal distances. Would it not be less potentially misleading to present that figure with guideway length as the independent variable, or to replot the results for constant guideway length, with station spacings and number of stations varying?

There is a very real need for the development of planning tools that can be used to design DPM systems. The demand-related aspect of the work reported in the paper appears to be a worthy contribution toward filling this need, but the supply modeling seems to have suffered from some overly generalized geometric assumptions. Combination of the demand analysis reported here with a more geometrically specific supply analysis such as I suggested in another article (3) would produce a significantly more powerful DPM design tool. The results derived by use of such a DPM design tool need to be presented so that the significance of the respective independent and dependent variables is made unmistakably clear to avoid possible misinterpretations.

REFERENCE

3. S. E. Shladover. Activity Center Circulation: The Competition Between Automated Guideway Transit and Pedestrianization. Transportation Research, Vol. 11, No. 4, Aug. 1977, pp. 265-278.

Authors' Closure

The discussion is useful on two grounds: It ventilates some of the problems associated with the complexity of DPM system design and it provides the opportunity for us to clarify the possible misconceptions arising from the paper and omissions therein.

Let us handle the omissions and misconceptions first. Our analysis assumes that (a) the station coverage areas are diamond-shaped, not annular, which is indeed a necessary assumption for a grid street pattern; (b) stations are spaced equally, for to do otherwise would be unnecessarily complex and unmanageable; (c) guideways are aligned either as a loop or a shuttle; (d) stations are located to maximize coverage, which could, nevertheless, lead to overlap, particularly if there are a large number of stations, spaced close together; and (e) service is provided without skip stops, alternate routes, or other sophisticated arrangements, a reasonable assumption for the first wave of DPMs.

The explanation for the very different patterns of DPM diversions among walking trips and line-haul transit trips with respect to station spacing, number of stations, and coverage, lies in the fact that the walking trips diverted to the DPM involve two new walk links, access and egress, but the transit trips diverted involve only one. This occurs because the transit station and DPM station are located at the same point.

The discussant is quite right that the use of the system length as a variable in the graphics would add another valuable dimension to the paper. Indeed, longer system length would provide added DPM accessibility for walk trips, albeit with the danger of diminishing effectiveness. Unfortunately, in the interest of brevity, only a sampling of the derived relationships are shown.

The full report, which this paper summarizes, provides an estimate of DPM demand for 504 explicit combinations of DPM and CBD characteristics, including system length, for each of five categories of demand. From these, serious evaluation of alternative DPM configurations can take place. In addition, six DPM service alternatives, two line-haul transit arrangements, and a spectrum of highway configurations are treated in the analysis. We hope that a reading of the full report will remove any unintended misinterpretations that emanated from the necessarily telescoped version presented here.

Publication of this paper sponsored by Committee on Transportation Systems Design.

Development of Efficient Central Management Strategies for Advanced Group Rapid Transit Systems

Waheed Siddiqee and Peter J. Wong, Transportation and Industrial Systems Center, SRI International, Menlo Park, California
Norman R. Nielsen, Information Science Laboratory, SRI International, Menlo Park, California

This paper presents a summary of a computer-aided method for developing efficient central management system strategies for advanced group rapid transit systems by use of medium-sized, automatically controlled vehicles that travel on dedicated guideways. Some efficient central man-

agement system strategies developed for a test network that uses the method are presented and discussed in detail. The method consists of an iterative process in which experienced transit system operators make complex, judgmental decisions and a computer performs extensive and repetitive computations. This computer-aided method allows transit system operators to compare the consequences of various central management system strategies in terms of such measures as passenger wait times, number of passenger intermediate stops, vehicle fleet size, vehicle load factor, and vehicle flows in various guideway sections and at various passenger stations. After studying such measures, operators can develop a set of efficient and realistic central management system strategies. The computer-aided method and the associated computer simulation program are general in nature and can be used to develop central management system strategies for a variety of network configurations and trip demand data.

As part of a feasibility study of an advanced group rapid transit (AGRT) system in an urban environment, which was undertaken for the Urban Mass Transportation Administration (UMTA) (1, 2), we developed a powerful simulation program to test various central management system (CMS) strategies for the AGRT system proposed by Rohr Industries. The AGRT system uses medium-sized, automatically controlled vehicles that have a typical capacity of 12 passenger vehicles. Rohr's CMS is based on the nonsynchronous mode of vehicle control. Typical headways are 4-6 s; the minimum allowable headway is 3.1 s.

AGRT systems typically will be used in urban environments where the network to be served has a grid pattern. Furthermore, for AGRT systems that use relatively small vehicles to provide personalized service, demand-responsive service is more desirable than fixed-schedule service, particularly during off-peak periods. Even during peak periods, fixed-schedule strategies do not necessarily provide efficient service and a high vehicle-load factor. When a route network is even moderately complex and vehicle size is small, numerous routing and scheduling strategies between various origin-destination (O/D) pairs become possible. Therefore, a sufficiently detailed CMS simulation program was developed to test several strategies for a variety of networks and trip demand data.

This paper presents the basic functional details for the CMS simulation program and the results of the application of the program to a test network. The methodology and the simulation program developed are essentially independent of the design details of the AGRT system.

THE PROBLEM

Central management of an AGRT system requires the development of an efficient strategy of operations to serve a specified demand given (a) a guideway network in terms of the O/D nodes (passenger stations) and connecting links (guideway tracks), (b) the O/D demand data of passengers, and (c) the capacity of AGRT vehicles. Unfortunately, no single criterion of efficiency can be defined realistically. However, the following performance measures can be used to compare various alternatives:

1. Wait and trip times of passengers,
2. Number of intermediate stops between various O/D pairs,
3. Deviations from shortest distance routes between O/D pairs,
4. Vehicle fleet size required,
5. Vehicle flows on links and in stations,
6. Delays under failure conditions, and
7. Capital and operating costs.

The study of such measures will enable experienced transit system planners and operators to develop efficient CMS strategies after a few iterations.

METHOD OF APPROACH

The central management of an AGRT system has the following major functional requirements:

1. Vehicle assignment in response to a trip request,
2. Route designation of vehicles,
3. Empty vehicle management, and
4. Suitable contingency plans for failure conditions.

The alternatives available to the designer of a CMS essentially consist of two types of design variables:

1. Planning variables—variables that must be defined early in the design process (e.g., station sizes, turnarounds, bypasses, storage and maintenance areas, and fleet size), and
2. Operating variables—variables that can be adjusted dynamically once the AGRT system has been put in place (e.g., stopping policies, vehicle assignment policies, vehicle routing policies, and operating fleet size).

These design variables can be combined in a number of ways, and their combination requires considerable human judgment; however, the manual calculation of various performance measures for various combinations of design variables is a difficult and laborious process. In view of these considerations, the study team developed a method whereby complex judgmental decisions (such as the definition of alternative stopping policies) could be made by experienced transit system operators, and the extensive and repetitive computations needed to calculate various performance measures could be performed by a computer. A simulation program was developed to test various combinations of design variables, study their consequences in terms of relevant performance measures, and eventually develop a set of efficient CMS strategies. Figure 1 shows the overall human/machine iterative process by which suitable CMS strategies can be developed.

Figure 1. Man-machine iterative process associated with the development of CMS strategies.

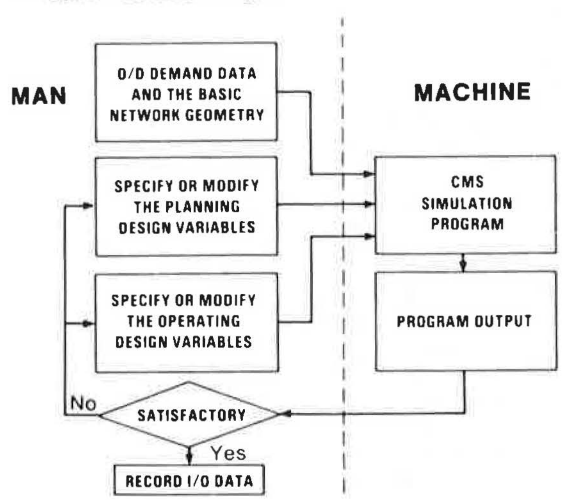


Table 1. Overview of the principal functional models of the CMS simulation program.

Functional Model	Purpose
Passenger-station interface	To generate random numbers of trip requests of varying party sizes and with varying O/D basis.
Gate operations	To calculate the dwell time a vehicle spends in a station on the basis of boarding and deboarding.
Vehicle-station interface	To calculate the time a vehicle spends in a station in addition to dwell time, as a function of station configuration.
Station capacity	To determine whether vehicles can enter a station based on a prespecified capacity.
Trip assignment	To locate a vehicle within a prespecified vicinity of trip requesting station, test its acceptability, and assign it to the request.
Routing	To route the vehicle on a switch-by-switch basis based on prespecified switching tables.
Empty vehicle distribution	To route empty vehicles based on prespecified algorithms. The algorithm will be developed offline.
Training vehicles	To study the possibilities and consequences of entraining the vehicles.
Scheduled vehicles	To model the operations of scheduled vehicles.
Zone management	To model the effects of zone congestion and the strategy for relieving this congestion.
Central scan	To model the central scan functions of the CMS.
Longitudinal/headway control	To ensure, in a simplified manner, that headway between vehicles is sufficient on the guideway based on average vehicle velocity and allowable number of vehicles.
Merge/demerge switch control	To calculate switch delay and sequence for a vehicle approaching a merge switch.
Vehicle position and velocity control	To describe the link position and link transit time of vehicles.
Network configuration	To describe and specify a network with links and switch points.
Link congestion	To model the effects of link congestion and the strategy for dealing with congestion.
Network status	To provide a report on link, zone, and station loading for purposes of vehicle management.
Alarm	To generate the time, type, and location of an emergency (i.e., failure conditions) based on a prespecified algorithm.
Failure management	To model failure management procedures for failures of a vehicle, link, station, and zone.
Performance measures and statistics generation	To generate the specified performance measures in the specified formats.

SUMMARY OF THE CMS SIMULATION PROGRAM

A dominant consideration in the development of the CMS simulation program was to provide an efficient, cost-effective tool for testing CMS implementation concepts. Thus, a program was designed whose running time and costs per run were not excessive. This was accomplished by using sufficiently detailed models of the following basic CMS functions:

1. Trip assignment,
2. Empty vehicle management,
3. Failure management (e.g., vehicle, link, zone, and station), and
4. Performance measures and statistics.

Models associated with functions not directly related to central management (e.g., longitudinal-headway control) were relatively simple to model. Table 1 presents an overview of the functional models associated with the CMS simulation program.

SUMMARY OF PROGRAM INPUTS AND OUTPUTS

The input data for the CMS simulation program can be grouped according to

1. Network geometry,
2. Demand,
3. Parameters associated with certain models,
4. CMS strategies, and
5. Simulation run options.

Data related to network geometry typically consist of various link numbers, their lengths, connectivity, the location of stations and storages, and their relation to main-line links.

Data related to demand are generated by use of a random trip generation program based on the given or assumed average hourly O/D matrices for various hours of the day and certain specified parameters. The designer can select any period of a day (e.g., 6:00-9:00 a.m.) or an entire 24-h period to test various CMS strategies for that period.

The CMS simulation program contains certain models, such as vehicle movement in links and dwell time of vehicles at berths, that require specification of some parameters. For example, the velocity-headway curve is used to model vehicle movement in the links. The velocity-headway curve was modeled as a second-order equation of the form:

$$H = K_1/v + K_2 + K_3 v \quad (1)$$

where H = the headway in seconds and v = the velocity in miles per second. The program user has to specify the values of the coefficients K_1, K_2, and K_3.

Input data that specify the major elements of a CMS strategy under normal conditions consist of

1. Vehicle search regions associated with each station,
2. Vehicle type search priority,
3. Allowable en route stations between various O/D pairs,
4. Allowable number of stops between various O/D pairs, and
5. Route specification between various O/D pairs.

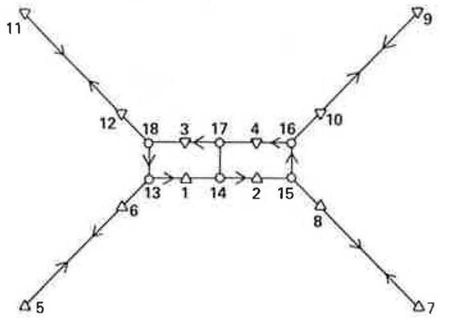
Vehicle search regions for various stations are specified in terms of links, other stations, and the storage and maintenance areas. The CMS simulation program is designed to search for vehicles sequentially in links, stations, and storages, in the order specified. Other elements of the strategy have to be specified in a similar way.

The program user can specify certain data associated with simulation run options. These data include the times at which the outputs are to be printed or the times at which network statistics are to be set to zero (e.g., at 8:00 a.m., 9:00 a.m., or 10:00 a.m.). A complete list of data related to simulation run options is included in the technical specifications for the AGRT-CMS simulation program (3, 4).

The CMS-simulation program was used to develop various efficient CMS strategies for a test network provided by UMTA. The basic geometric configuration of the test network is shown in Figure 2. Basic data about the network are given below (note 1 km = 0.6 mile).

Item	Information
Number of stations	12
Total length of one-way guideway	41.8 km
Number of passengers to be served during peak hours	~10 000/h
Total number of trips per day	~80 000
AGRT vehicle capacity	12 passengers

Figure 2. Test network provided by UTMA.



The CMS-simulation program provides a capsule report, for quick analysis, as well as detailed information associated with various performance measures, for detailed analysis. Typical output data from an actual run are presented in Figures 3-5. (The models were designed for U.S. customary units only; therefore, values in Figures 3-5 are not given in SI units.)

EXAMPLES OF CMS STRATEGIES FOR A TEST NETWORK

To demonstrate the effectiveness and performance of the CMS-simulation program, UMTA provided the study team with a test network and O/D demand data. The basic geometric configuration of the test network is shown in Figure 2. An initial detailed network layout was prepared by the study team based on the basic test network. The detailed network includes certain turnarounds to allow for one-sided stations and to provide an alternative path in case of failures of certain links. The network also includes six storage areas for vehicles that can be called on either a demand-responsive or fixed-schedule basis.

Figure 3. Sample of capsule report.

```
        CAPSULE REPORT

A. USER RELATED MEASURES

   1. STATION WAIT TIME
      MEAN WAIT TIME =       2.95 MINUTES
      MAXIMUM WAIT TIME =       7.52 MINUTES
      TRIPS WITH A WAIT .LE. 5 MINUTES =      82.19 PERCENT
      TRIPS WITH A WAIT .LE. 10 MINUTES =    100.00 PERCENT

   2. INTERMEDIATE STOPS
      PERCENTAGE OF TRIPS WITH NO STOPS =      88.83
      PERCENTAGE OF TRIPS WITH 1 STOP =     11.17
      PERCENTAGE OF TRIPS WITH 2 OR 3 STOPS =        0.00

   3. AVERAGE SYSTEM TRAVEL SPEED =    29.86 MPH

B. OPERATIONS RELATED MEASURES

   1.         2470 PASSENGERS BOARDED VEHICLES, AND         1853 PASSENGERS DISEMBARKED

   2. FLEET SIZE OF ACTIVE VEHICLES ON GUIDEWAY OR IN STATIONS
      TIME WEIGHTED AVERAGE FLEET =    123.55 VEHICLES
      MAXIMUM FLEET =      175 VEHICLES

   3. VEHICLE ARRIVAL RATE AT STATIONS
      SYSTEMWIDE TOTAL =      1019.00 VEHICLES/HOUR
      MAXIMUM ARRIVAL RATE =          98.00 VEHICLES/HOUR AT STATION       2

   4. PASSENGER QUEUE LENGTH IN STATIONS
      SYSTEM AVERAGE =          10.67 PASSENGERS
      MAXIMUM AVERAGE QUEUE =          20.74 PASSENGERS IN STATION    8

   5. MAXIMUM LINK FLOW =    314.00 VEHICLES/HOUR ON LINK  30

   6. VEHICLE REJECTIONS FROM FULL STATIONS
      TOTAL FOR ALL STATIONS =              0 VEHICLES
      REJECTIONS AS A PERCENT OF ALL ATTEMPTS TO ENTER STATIONS =         0.00

   7. SYSTEMWIDE VEHICLE LOAD FACTOR =      18.14
   8. MILES TRAVELLED
      TOTAL VEHICLE MILES =     3678.72 MILES
      TOTAL PASSENGER MILES =     8006.89 MILES
```

Figure 4. Sample of link loading data.

B. MEASURES RELATED TO NETWORK MANAGEMENT.

1. VEHICLE LOADING BY LINK.

LINK NUMBER	HIGHEST VEHICLE DENSITY/MILE	TIME-WEIGHTED AVERAGE DENSITY/MILE	PERCENT TIME LINK ABOVE MINIMUM HEADWAY DENSITY	VEHICLE FLOW PER HOUR
1	9.89	3.14	0.00	124.00
2	14.23	4.55	0.00	179.00
3	17.86	6.21	.26	145.00
4	20.92	7.86	14.28	297.00
5	24.24	5.60	6.60	204.00
6	24.39	7.81	8.22	292.00
7	21.23	5.15	1.41	186.00
8	24.39	7.58	2.73	290.00
9	24.24	5.14	4.12	190.00

Figure 5. Sample of O/D data.

FINAL REPORT

ORIGIN-DESTINATION DATA FOR DEMAND TRIPS

FOR PASSENGERS TRAVELING FROM ORIGIN STATION 1

DESTINATION STATION	NUMBER OF PASSENGERS	AVG. NET TRAVEL SPEED (MPH)	WAITING TIME (MINUTES) MAXIMUM	MEAN	STD DEV	TRIP TIME (MINUTES) MEAN	ST DEV	MEAN WAIT TIME AS PERCENT OF MEAN TRIP TIME
2	3	29.43	4.73	3.48	1.22	5.51	1.29	63.11
3	5	24.63	5.65	3.36	1.63	6.62	1.61	50.70
4	6	28.18	5.03	4.22	1.49	8.79	1.65	48.03
5	3	28.82	4.42	4.36	.04	14.70	.06	29.68
7	11	30.63	5.72	3.65	1.84	12.22	1.82	29.89
8	5	28.82	5.44	4.04	1.29	8.33	1.16	48.53
10	2	28.15	4.59	4.45	.14	9.37	.42	47.48
12	7	25.28	5.65	3.71	1.58	9.44	1.44	39.29
TOTALS FOR ORIGIN 1	42	28.13	5.72	3.83	1.53	9.70	2.90	39.49

Table 2. O/D demand data for the morning peak period.

Origin Station Number	Destination Station Number 1	2	3	4	5	6	7	8	9	10	11	12	RSUM
1	0	3	10	12	7	0	3	3	0	5	0	12	55
2	2	0	7	2	6	11	10	11	0	3	8	13	73
3	11	11	0	1	13	14	10	15	4	14	3	38	134
4	1	7	12	0	9	3	2	7	0	9	0	12	62
5	133	118	121	117	0	51	7	51	42	5	47	20	712
6	48	35	51	46	85	0	20	22	22	39	18	36	422
7	100	120	82	112	52	39	0	25	14	13	9	0	566
8	153	186	56	142	59	62	47	0	56	51	9	61	882
9	103	98	41	80	0	3	0	43	0	21	0	31	420
10	39	33	20	31	12	17	0	13	0	0	0	38	203
11	124	110	156	88	51	61	0	0	0	2	0	41	633
12	38	52	27	34	0	13	0	14	0	9	8	0	195
CSUM	752	773	583	665	294	274	99	204	138	171	102	302	4357

Note: The numbers given are baseline numbers of trips. To calculate the passenger demand during morning peak hour (8:00-9:00 a.m.) numbers should be multiplied first by a factor of 2 to reflect the peak effect and then by a factor of 1.175 to reflect average party size. These factors were specified by UMTA.

Basic O/D demand data for the morning peak demand period are shown in Table 2. Similar tables were provided for off-peak and evening-peak periods. By use of these basic hourly demand data and certain specifications, we generated a random trip demand file for the entire 24-h period, during which approximately 80 000 trips were requested.

Experiments for Morning Peak Period

The following five strategies were tested for the morning peak period:

1. All en route stations eligible for stops, and no limit on number of intermediate stops;
2. All O/D pairs served nonstop;
3. Same as for strategy 1, but only one intermediate stop allowed;
4. Nonstop service for high-demand O/D pairs, one intermediate stop allowed for medium-demand O/D pairs, and no limit on stops for low-demand O/D pairs; and
5. Same as for strategy 3, but 20 special service routes used for highest demand O/D pairs (e.g., station 5 to station 1, special service vehicles every 2 min; station 5 to station 2, special service vehicles every 2.5 min).

Comparative summaries of several performance measures for these five strategies are given in Table 3. Strategies 1 and 2 generate some unacceptable situations. For strategy 1, the average effective travel speed becomes very low, 40 km/h (25 mph); only 55 percent of the trips are served within a mean wait time of 5 min; the vehicle arrival rate at station 4 is excessive, and total station rejections are very high. For strategy 2, the needed vehicle fleet and link flows are quite high compared to other strategies. The philosophies of strategies 3, 4, and 5 appeared promising and were improved by use of later versions of the program, by modifications of the capture regions, and by improvements in selection of allowable stops.

Experiments for Midday Period

The following strategies were tested for the midday period (12:00 n.-1:00 p.m.):

1. All en route stations eligible for stops, and no limit on number of intermediate stops;
2. All O/D pairs served nonstop; and
3. Same as in strategy 1, but only one intermediate stop allowed at most.

None of the three strategies creates any unacceptable situations, and each one is a reasonably good candidate strategy. Strategy 1 requires the fewest number of vehicles, but only 32 percent of the trips are served nonstop; the other trips served have one or more intermediate stops. Strategy 2 is the best from the passengers' point of view, but it requires a larger fleet

Table 3. Comparison of five CMS strategies for the morning peak period.

Performance Measure	Strategy 1	2	3	4	5[a]
Number of passengers					
Boarded	10 213	10 276	10 383	10 319	10 369
Disembarked	9 954	10 174	10 214	10 180	10 279
Station wait time					
Mean wait time (min)	4.08	3.59	4.44	3.25	2.62
Maximum wait time (min)	22.92	15.17	13.87	10.95	16.25
Trips, ≤5-min wait (%)	~55	~73	~57	~80	~90
Trips, ≤10-min wait (%)	~89	~100	~99	~100	~100
Stops (%)					
Trips, nonstop	~34	100	~56	~91	~90
Trips, one stop	~36	-	~44	~9	~10
Trips, two or three stops	~30	-	-	0	-
Average system travel speed (km/h)	~40	~54	~52	~56	~56
Time-weighted fleet	262	308	244	267	311
Vehicle arrival/departure (vehicle/h)					
Systemwide	3 245	2 432	2 760	2 507	2 771
Maximum	405	264	343	271	323
Station number	4	2	1	8	8
Passenger queue					
System average	62	51	63	46	37
Highest average	155	133	178	116	88
Station number	11	5	5	5	5
Maximum link flow (vehicle/h)	734	865	709	788	837
Link number	32	4	34	6	8
Rejections					
Total	362	12	55	9	15
Percent	11.5	0.5	2	0.4	0.55
Systemwide vehicle load factor	0.55	0.36	0.46	0.39	0.35

Note: 1 km/h = 0.6 mph.
[a]20 special routes.

size and generates higher link flows than either strategy 1 or 3. Strategy 3 offers a good combination of attractive user-related performance measures (54 percent of the trips are nonstop; 46 percent have only one intermediate stop) and a medium-sized fleet. Only a minor fraction of passengers waits the maximum of 10 min. This could be rectified easily by improvements to the search sequence of links in the vehicle search region.

During periods of low or medium demand it is possible to implement several policy variations with acceptable operations and user-related performance measures. Thus, one could use a large number of vehicles and provide nonstop service or use relatively fewer vehicles and provide service with at most one stop.

Experiments for Evening Peak Period

Results of the morning peak period simulation runs indicated that the two extreme strategies of allowing all stops (strategy 1) or serving all O/D pairs nonstop (strategy 2) create certain unacceptable situations. Since the traffic volumes in the evening peak period are the same as those in the morning peak period (reverse direction), we did not test the two extreme policies for the evening peak period. Strategy 4, tested for the morning peak period, appeared to be a good candidate for the first test experiment for the evening peak period. Thus strategy 4 was tested after appropriate adjustments in the directionality of high-demand O/D pairs and stations to be stopped at and some modifications in capture regions to account for the reverse flows. The results of this experiment are comparable to the results of the strategy 4 experiment for the morning peak. This strategy was refined later by use of the final version of the program.

Some Conclusions Related to Peak and Off-Peak Period Strategies

After we conducted experiments for the morning peak, midday, and evening peak periods and established that the two extreme strategies of allowing all en route stops (strategy 1) and no en route stops for all O/D pairs (strategy 2) produced certain unacceptable phenomena (e.g., high link flows and excessive station rejections), we concentrated on refining strategies that use a combination of nonstop, fixed route (both one-way and closed loop), and one intermediate stop strategies for various O/D pairs. Several combinations were tested. Based on the results of these tests we concluded that

1. For both the morning and evening peak periods, a demand-responsive strategy that provides nonstop service for high-demand O/D pairs and (at most) one intermediate stop service for medium- and low-demand O/D pairs gives the best overall combination of passenger- and operation-related performance measures. Other strategies result either in high link flows, excessive wait times, or excessive station arrival and departure rates.
2. For medium-demand periods (i.e., 11:00 a.m.-3:00 p.m.) a variety of strategies is possible. Even the two extreme strategies of serving all O/D pairs nonstop or allowing all en route stops between each O/D pair result in service that is acceptable and do not cause any excessive link flows or station arrival and departure rates.
3. For very low-demand periods, no significant operational advantage results, even if en route stops are allowed, unless very long wait times (greater than 10 min) are tolerated. Most passengers dislike long wait times or intermediate stops, particularly at night. Thus it was concluded that nonstop, demand-responsive service is most appropriate for very low-demand periods during nighttime (e.g., from 10:00 p.m. to 6:00 a.m.).

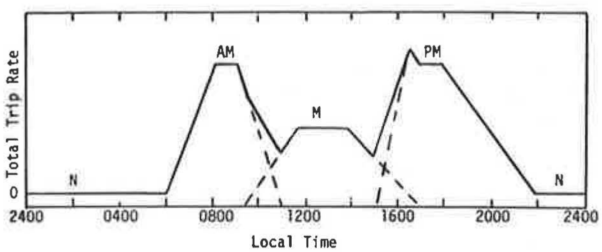
Experiments to Develop CMS Strategies for the 24-h Period

A final set of experiments was conducted to develop composite CMS strategies for various periods of the day. The overall pattern of the demand level at various periods of the day as specified by UMTA is shown in Figure 6. Between 10:00 p.m. and 6:00 a.m. the demand level is very low—approximately 300 passengers/h. On the other hand, the demand during the 8:00-9:00 a.m. and 4:00-8:00 p.m. periods is substantially high—approximately 10 000 passengers/h. During the midday period, the demand is medium—about 5000 passengers/h.

The general strategies used for various periods of the day are shown below.

Period	Strategy
12:00 m.n.-6:00 a.m.	All O/D pairs served nonstop
6:00-11:00 a.m.	High-demand O/D pairs served nonstop; medium- and low-demand O/D pairs served with one intermediate stop allowed
11:00 a.m.-3:00 p.m.	All O/D pairs served nonstop
3:00-10:00 p.m.	High-demand O/D pairs served nonstop; medium- and low-demand O/D pairs served with one intermediate stop allowed
10:00 p.m.-12:00 m.n.	All O/D pairs served nonstop

Figure 6. Diurnal variations of demand for UMTA's test network.



Vehicle search regions were also adjusted to suit the demand and empty vehicle availability patterns. A summary of hourly performance during various periods of the day is shown in Table 4. Variations of some important performance measures at various hours of the day are shown graphically in Figures 7 and 8.

SUMMARY OF RESULTS

During morning and evening peak periods, a demand-responsive strategy that serves high-demand O/D pairs nonstop and makes at most one intermediate stop between medium- and low-demand O/D pairs proved to be very effective. During off-peak periods, all O/D pairs can be served nonstop within a mean wait time of about 3 min if a demand-responsive strategy is used.

Demand-responsive strategies adapt easily to fluctuations in demand. An overall increase of up to 140 percent in the demand levels throughout the network can be handled without creating a serious problem in vehicle flow rates. The system appears to degrade gracefully under increasing demand levels.

The results of the failure experiments (wherein a vehicle, a link, and a station were failed separately for 15 min each), as measured by the extra wait times and the number of passengers that had to be diverted, appeared to be within tolerable limits and were as expected.

A maximum fleet of about 265 vehicles is needed to provide satisfactory service during morning and evening peak periods within a systemwide mean wait time of slightly more than 3 min. Under normal operating conditions, 80-90 percent of the passengers can be served within a 5-min mean wait time during morning and evening peak periods; 97 percent can be served within a 7-min mean wait time. Almost nobody has to wait more than 10 min.

Average systemwide speed is 45-48 km/h (28-30 mph). This takes into account the civil speed limits of 32 and 40 km/h (20 and 25 mph) imposed by right-of-

Table 4. Summary of hourly system performance during different periods of the day.

Performance Measure	Time Period 1:00-2:00 a.m.	8:00-9:00 a.m.	1:00-2:00 p.m.	5:00-6:00 p.m.	9:00-10:00 p.m
Number of passengers					
Boarded	300	10 291	4918	10 323	1699
Disembarked	305	10 271	4909	10 425	2032
Station wait time					
Mean wait time (min)	4.10	3.07	3.12	3.55	3.24
Maximum wait time (min)	7.01	8.64	9.78	11.33	7.60
Trips, 5-min wait (%)	~64	~88	~85	~80	~85
Trips, 10-min wait (%)	100.00	100.00	100.00	99.79	100.00
Stops (%)					
Trips, nonstop	100	~90	100	~91	~97
Trips, one stop	0	~11	0	~8	~3
Trips, two or three stops	0	0	0	~1	0
Average system travel speed (km/h)	49.30	45.90	52.77	44.75	48.00
Fleet size					
Time weighted	34	226	181	252	129
Maximum	40	234	190	265	137
Vehicle arrival/departure (vehicle/h)					
Systemwide	272	2 008	1415	2 105	1000
Maximum	39	213	178	240	100
Station number	2	8	3	8	8
Passenger queue					
System average	2	44	21	51	7
Highest average	3	92	24	128	16
Station number	2	8	3	2	2
Maximum link flow (vehicle/h)	92	575	543	619	371
Link number	34	20	46	20	36
Rejections					
Total	0	0	0	0	0
Percent	0	0	0	0	0
Systemwide vehicle load factor	8.78	51.34	27.83	48.01	15.57

Note: 1 km/h = 0.6 mph.

way constraints in certain portions of downtown areas and in turnaround links.

Systemwide load factors during morning and evening peak periods are about 51 and 49 percent, respectively. These values are in close agreement with those calculated theoretically. The load factor at night is about 9 percent. The demand at night is very low and passengers should not have to wait too long. The load factor during midday is about 28 percent if a nonstop strategy is used. This seems quite acceptable when the nonstop service and short wait times are considered. However, the load factor can be improved if stops and longer wait times are allowed. It is possible to trade off mean wait time with fleet size, particularly during off-peak periods.

Figure 7. Mean wait time and system average speed during various periods of the day.

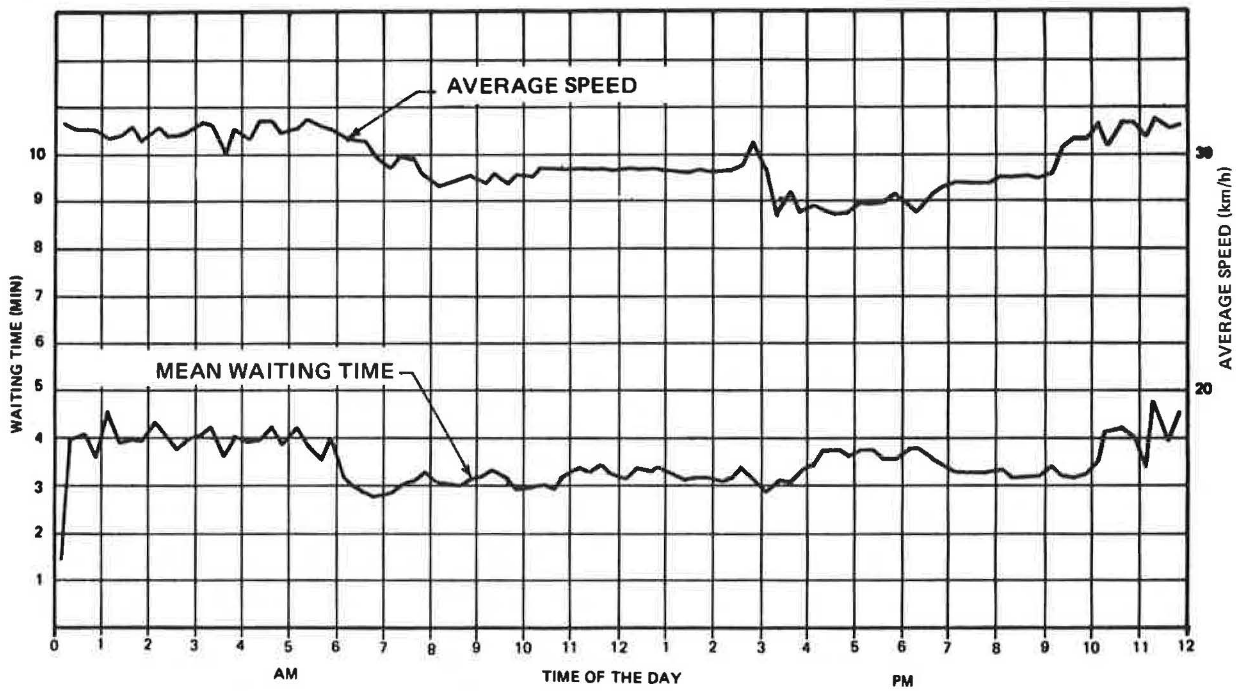
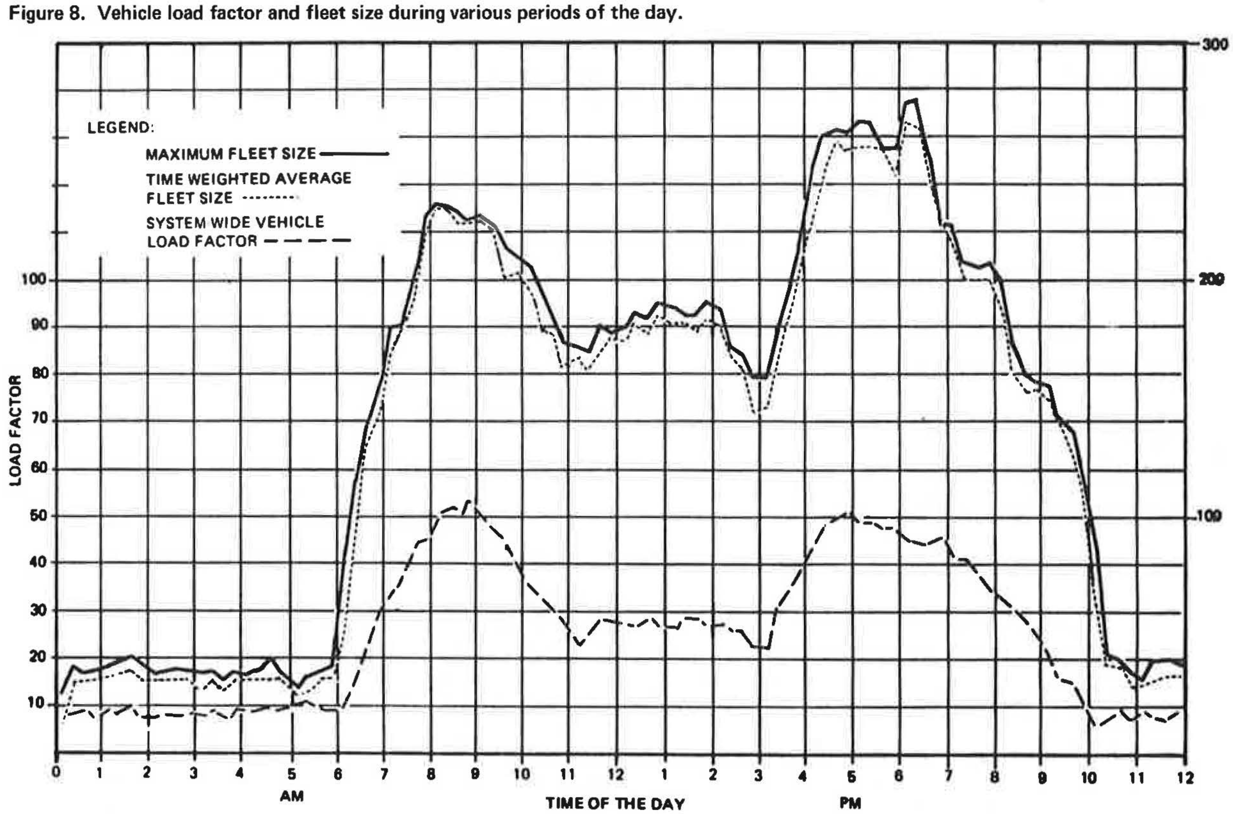


Figure 8. Vehicle load factor and fleet size during various periods of the day.



CONCLUDING REMARKS

The computer-aided method and the CMS simulation program discussed in this paper can be used to develop

1. Efficient CMS strategies for urban transportation networks, including vehicle assignment (demand responsive, fixed schedule, and mixed), stopping and routing, empty vehicle management, and failure management for vehicle, station, and guideway link failures;
2. Network geometry details, such as station capacities, location of bypasses and turnarounds, and storage and maintenance areas; and
3. Optimum vehicle fleet size consistent with the desired level and quality of service.

Although the simulation program was developed with reference to an AGRT system that uses 12-passenger automated vehicles, it is highly modular. Those few modules that are unique to a particular system can be easily modified and used to evaluate alternative CMS strategies for other types of transportation systems, such as bus systems or other forms of automated guideway transit systems.

The simulation program was used to develop several CMS strategies for a test network and O/D data provided by UMTA. The test results indicate that CMS strategies are readily adjustable so that 80-90 percent of trips can be accomplished within a mean wait time of 5 min. The generally held notion that fixed-schedule service is superior to demand-responsive service during high-demand periods was found to be incorrect. Some demand-responsive strategies developed and tested for the test network for peak demand periods also gave extremely good results—that is, high vehicle load factors and very short mean wait times. In addition, the demand-responsive strategies were found to be more adaptive to failures and dynamic variations in demand than fixed-schedule strategies.

CMS strategies, particularly for transportation systems that use small vehicles on complex routes, require further research and experimentation so that basic guidelines can be established for the development and refinement of algorithm parameters for planners of future systems. The simulation program developed is a powerful tool with which to test various CMS strategies. It can be improved further, however, to expand its capabilities.

ACKNOWLEDGMENT

The research work on which this paper is based was carried out by SRI International as part of a research project for UMTA under subcontract to Rohr Industries. The support of UMTA and Rohr and their permission to present and publish the paper are gratefully acknowledged. The contents of this paper reflect our views, and we are responsible for the facts and accuracy of the information presented. The contents do not necessarily reflect the official views or policies of either Rohr or UMTA.

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Publication of this paper sponsored by Committee on New Transportation Systems and Technology.

Electric Cars for Urban Transportation

William Hamilton, General Research Corporation, Santa Barbara, California

Within 10 years rapid technological advances will make the production of electric cars by a major manufacturer a likely possibility. Widespread use of electric cars would drastically reduce the amount of petroleum consumed for urban transportation and also cut automotive air pollution and noise significantly. Under current conditions and trends, however, sales of electric cars are likely to be relatively modest, unless a larger role is deliberately planned for them in order to reap their potential benefits for conservation and environmental quality. This paper is a summary of an investigation of the effects of large-scale use of electric cars on energy, the environment, and the economy.

Electric cars offer major potential advantages for urban transportation: the convenience and mobility of the internal-combustion automobile without its dependence on petroleum or its major environmental problems. Recent electric cars have had very limited appeal, primarily due to the short range between recharges and high overall costs. New batteries that will substantially relieve both range and cost disadvantages are expected soon. With these batteries and more ef-