Advanced Group Rapid Transit (AGRT) Operational Simulation

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ABSTRACT

This paper reviews an example of the use of simulation models to analytically implement command and control systems in fully automated surface transportation systems. An attempt is made to stress the importance of auxiliary simplified models as an aid in developing more complex simulations.

INTRODUCTION

The purpose of this paper is to provide a synoptic case history, describing the development and use of simulation models at the Boeing Company in support of the Advanced Group Rapid Transit, Phase 1A, program (contract DOT-UT-60074) during the period 1976-1978. Of particular interest to the author was the unanticipated high level interaction between the very simple analytic models (AGRT-AM) and the Detailed Network Simulation (DNS) model. Intelligent combinations of analytic modeling and simulation modeling significantly increased the scope and importance of all modeling results. The simulation ensemble described below actually includes two analytic models and only one simulation model in terms of the following definition for simulation models: Simulation model, as used in the remainder of this paper, refers to the artificial operational representation, in the form of a computer program, of some arbitrary system. The model labels are consistent with this definition. AGRT remains a competitive design program involving several contractors. For this reason specific numerical results have been omitted.

AGRT CONCEPT

Department of Transportation (DOT) Urban Mass Transit Authority (UMTA) AGRT program challenged several competing contractors to design people-moving surface transportation systems with the following properties:

- Fully automated vehicles
- Optimally sized vehicles
- High speed
- Dedicated guideway
- High reliability and safety
- Short operating headways
- Energy efficient
- Competitive levels of passenger service
- Economical system buildup and operation
- Deployability in complex, incrementally developing networks (i.e., modular composition)

AGRT objectives require creative and unique extensions of system concepts and engineering already developed in other surface transportation programs such as Morgantown PRT and International Oceanographic Exhibit Okinawa (IOEO) GRT.

The principal objective for this phase of the AGRT study program was to generate feasible system concepts and to establish concept creditability through analytical imple mentations backed up with "special case" hardware development.

In support of this effort, UMTA supplied basic network data which included the transportation networks shown in Figure 1 and origin/destination demand data based on a 24-hour demand profile like that shown in Figure 2.

A fully automated surface transportation system with the properties listed above requires an extensive command and control system (CMS). Design goals for the AGRT CMS included:

- Control up to 2500 vehicles
- Over 200 lane miles of guideway
- Up to 100 stations

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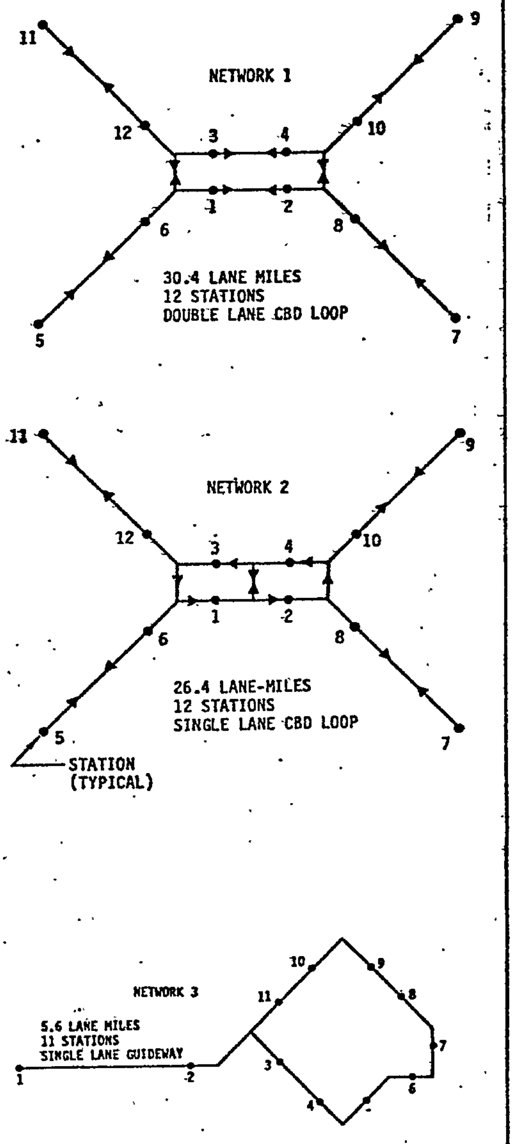
Figure 1 Basic Network Descriptions



- Link capacity of 14,000 seats per lane mile
- Modular design

An example of CMS functions and organization is shown in Figure 3. Here CMS functions have been organized in a four-level pyramid. The objective of CENTRAL, at the top of the pyramid, is to provide overall supervision for a number of REGIONS at the next level. CENTRAL functions include operator control system interface, operating policy selection, fleet management, status monitoring, and performance evaluation.

Figure 2 Expected Passenger Demand

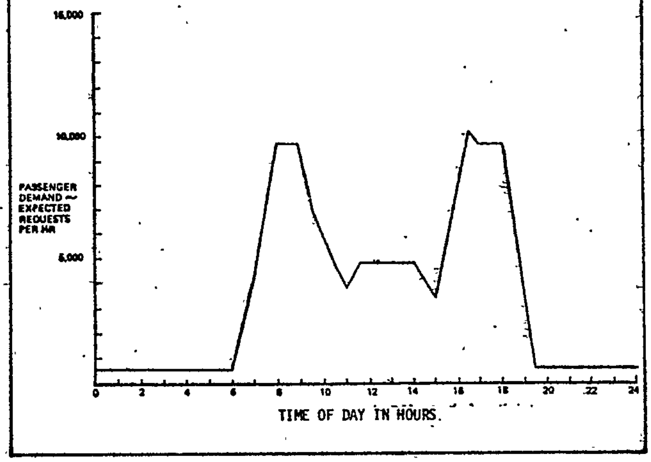
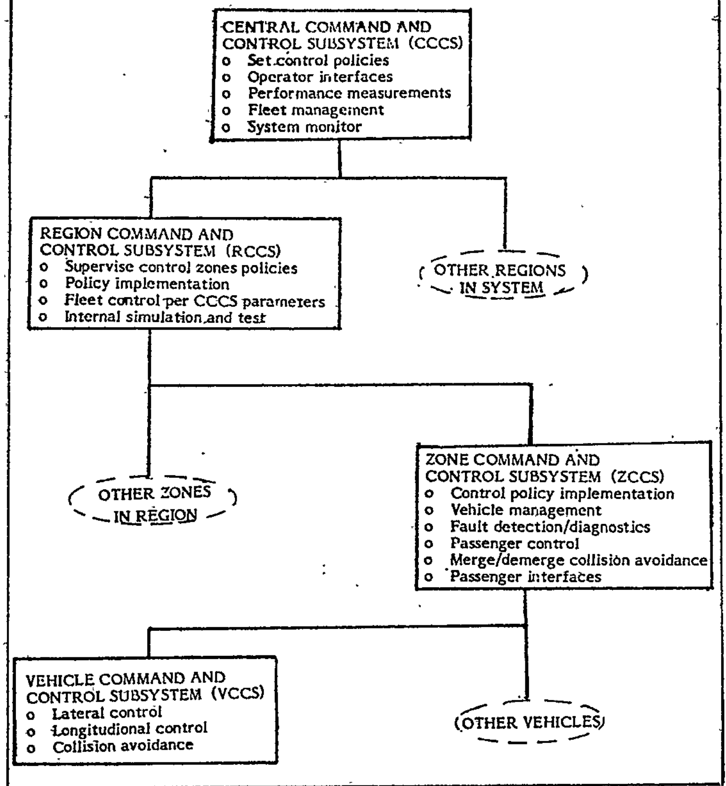


Figure 3 Command and Control System Structure



In turn each REGION is responsible for the supervision of an arbitrary number of ZONES. REGIONS are responsible for implementation of the operating policies selected by CENTRAL.

ZONES establish and control all communication with vehicles located within the zone. Functions at the ZONE level include implementation of control policies, fault detection and diagnostics, merge/demerge control, and station stop control.

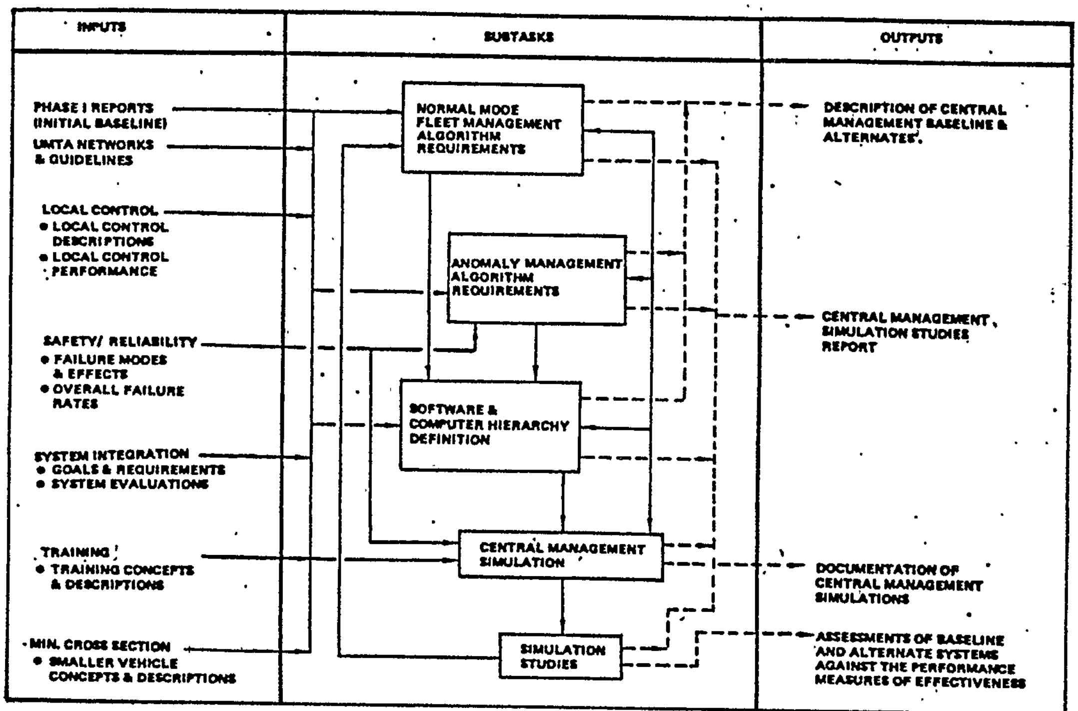
Finally, at the base of the pyramid, Vehicle Command and Control (VCCS) implements ZONE commands by controlling the vehicle motor, brakes, steering, and all on-board safety systems.

Broadly stated the primary objectives of the CMS study were to:

1. Develop detailed operational descriptions and scenarios for CMS.
2. Develop CMS simulations that:
    a. Provide individual passenger and vehicle representation.
    b. Provide for and show the effects of dynamic passenger demand.
    c. Reflect vehicle acceleration and deceleration characteristics.
3. Utilize the CMS simulations to verify operational efficiency and levels of service.

In order to achieve these objectives the CMS study was organized into five interrelated task groups as shown in Figure 4.

Figure 4 Central Management System Development Logic Diagram



As indicated above, following the development of a provisional set of algorithms for all required CMS functions, it becomes the collective responsibility of the simulation ensemble, discussed in the next section, to evaluate the resulting operational performance. In order to facilitate this task and to achieve some level of standardization, UMTA and the participating contractors jointly developed the performance measures shown in Table 1.

CMS MODELS AND SIMULATION

The objective of CMS analytic implementation was accomplished using four computer models designed to support the verification of CMS design alternatives and to measure corresponding system performance. The four computer models were the Passenger Demand Model (PDM), the AGRT Analytic Model (AGRT-AM), the People Mover Analysis Program (PMAP), and the Detailed Network Simulation (DNS). Characteristics of these models are summarized in Table 2. In order to assure credibility of the CMS simulations, actual software and hierarchy were developed in sufficient detail to establish the feasibility of the chosen algorithms. These algorithms were then used directly in the DNS simulation (and in less detail in AGRT-AM and PMAP).

The two simulations (PMAP and DNS) were verified using AGRT-AM results. AGRT-AM provides expected values for such basic parameters as fleet size, link loads, passenger wait-time, and vehicle load factors; and is simple enough to assure correct answers within limitations of the model. All variations from AGRT-AM results were carefully examined in order to determine the reasons for the variations. Variations were expected due to the stochastic nature of the simulated passenger demand and the results of algorithms which dynamically control individual vehicles. Sufficient diagnostics have been included in simulation outputs to determine whether the variations were due to the reasons above or were the result of an error in the simulation program.

Table 1 AGRT Performance Measures

PASSENGER-SERVICE RELATED

Wait Times
- Platform Wait Time (Sec)
- Transfer Wait Time (Sec)
- Total Trip Time (Sec)
- Instantaneous Wait Time (Sec)

Speed
- Travel Speed (MI/H)
- Net Travel Speed (MI/H)
- Trip Speed (MI/H)

Stops/Transfers
- Intermediate Stops (%)
- Transfer Trips (%)

SYSTEM LEVEL-SYSTEM OPERATION RELATED

Fleet Management
- Vehicle Load Factor (Pass MI/Seat MI)
- Vehicle Trip Productivity (Pass/Veh Hr)
- Vehicle Energy Usage (kWh/Seat MI)
- Vehicle Usage (Veh Oper Hr/Day)
- Routing Efficiency (%)
- Average Vehicle Miles Per Day
- Vehicle Occupancy (%)
- Dead Heading (%) (Empty Veh MI/Total Veh MI)
- Fleet Size

Traffic Management
- Station Rejection Rate (%)
- Merge Junction Delay (Sec)
- Link Utilization (%)

Stations
- Station Vehicle Throughput (Vehicles/Hr)
- Station Maximum Vehicle Throughput (Vehicles/Hr)
- Vehicle Entrance Queue Time (Sec)
- Station Passenger Throughput (Pass/Hr)
- Station Maximum Passenger Throughput (Pass/Hr)

Failure Management
- Total Passenger Delay Time (Hr)
- Failure Clearance Time (Min)
- Maintainability Index

COST PRODUCTIVITY

Capital Cost
- Guideway Cost/Mile
- Vehicle Cost
- Station Cost
- Capital Cost/Lane Mile
- Capital Cost/Daily Passenger Load

Operating Cost
- Per Passenger Mile
- Per Passenger
- Per Vehicle Mile

Life Cycle Cost
- Per Passenger
- Per Vehicle Mile
- Per Lane Mile

Productivity
- Employee Productivity Index (Pass/Empl)
- Employee Vehicle Productivity (Veh MI/Employee)
- System Man-Hour Ratio (Man-Hr/Veh Hr)
- Maintenance Cost
- Operating Staff

Table 2 Simulation Ensemble Summary

AGRT Analytical Model
- Expected value
- Perfect merges
- Ideal trip times
- Evenly spaced vehicles
- Parametric output
- Easily modified/inexpensive

Coarse Network Simulation
- Individual passengers and vehicles
- Station throughput--dwell only or simplified moveup
- Follows quantized time-varying passenger demand
- Functionally reflects deceleration/acceleration of vehicles
- Functional merge/demerge models
- Outputs service-related performance measures

Detailed Network Simulation
- Individual passengers and vehicles
- Follows time-varying passenger demand
- Detailed vehicle kinematics
- Reflects deceleration/acceleration of vehicles
- Performs action at same time as actual system
- Performs same procedure as actual system; e.g., precise station, merge, dispatch, headway management algorithms
- Outputs all service-related performance measures

Demand Generator
- Based on UMTA-supplied demand model
- Includes individual and batch (bus, train,...) arrival models
- Generates individual party, time-varying demands

COMMENTARY

Up to this point CMS analytic implementation has appeared orderly and well planned; however, as is probably true for most projects of this scope, that is only partially true. PMAP and DNS were planned from the outset of the program and work on them was initiated at the beginning of the study. Soon thereafter the requirement for PDM was recognized and PDM became the first model to be completed. The fourth model (AGRT-AM) came about somewhat by chance!

Initially the CMS modeling objectives were to produce two simulations. One would be a coarse network simulation supporting broad parametric studies. The other was to be a detailed network simulation possessing the capability to respond to the complete list of system performance measures. During startup of the AGRT study unforeseen events brought about a reassignment of modeling responsibilities. This did not affect the development of DNS, which ultimately came to life and performed as planned. In the case of the coarse simulations a decision was made to modify an existing Boeing computer program. The existing program was PMAP.

PMAP, in its own right, is a very powerful and useful tool. However, the PMAP computer program proved to be very difficult to modify in AGRT terms and ultimately could only be used to test a limited set of design points. PMAP could not satisfy the original objectives set for the coarse simulation. However, PMAP was much more detailed than AGRT-AM, was on-line for some time prior to DNS, and it was inexpensive. PMAP was a good insurance package for awhile.

As indicated above the Passenger Demand Model was built very quickly. Shortly thereafter, sensing an unresolved requirement for basic performance data, the author elected to develop a very simple network flow model using interactive PDP-11 BASIC. The initial objective was to take expected origin-to-destination passenger requests and convert this information to yield aggregate link flow rates for passengers. It was soon obvious that it was a simple step, using proposed passenger service strategies, to convert passenger departure requests to vehicle departures, thereby obtaining estimates of vehicle link flow rates. An optimization capability was added to schedule enough empty trips to balance station input and output. The combined results provided a picture of ideal steady-state flow for the network. With this capability many of the top-level system parameters (i.e., fleet size, passenger wait time, and vehicle load factors) could be computed. At this stage in the project the Analytical Model was the only model producing answers and it was used to perform many of the tasks originally assigned to the coarse simulation. And it was very cheap and quick to run. However, one important question could not be answered until PMAP and DNS produced their own answers. That question, of course, was how good were the answers coming out of AGRT-AM.

As it turned out, considering the simplicity of the Analytical Model, the answers were pretty good. Table 3 shows, for one arbitrary case, the percent variation between values developed by AGRT-AM and corresponding data generated by DNS. If values of percent variation less than 10% are judged acceptable for design purposes, then only average trip time is unacceptable. A large variation in the trip time parameter results from the use of ideal trip times in the analytical model (i.e., no delays) whereas the DNS results are based on the actual simulated performance trip times. When an average delay time is added to the analytical model trip times the large difference disappears, and, in fact, the variation in the other two parameters is reduced also.

Table 3 Results Comparison: AGRT-AM versus DNS

PERFORMANCE MEASURE	PER CENT VARIATION
FLEET SIZE	2.8
AVERAGE TRIP TIME	29.5
AVERAGE VEHICLE OCCUPANCY	7.5

Once the Analytical Model had been developed its primary objective was to generate a wide range of parametric data for the whole list of system operating strategies. However, because the Analytical Model was developed so early in the program, it also functioned in a supporting role for DNS by satisfying a number of DNS input data requirements. This included an expanded description of the baseline study network (network 2), origin/destination shortest path descriptions, and scheduling data.

Viable schedules for vehicle departures had to be generated before DNS could evaluate scheduled mode operating strategies. At peak operating periods on network 2 it was necessary to schedule more than 2000 departures per hour. After several false starts the solution to the scheduling problem emerged as a fairly simple algorithm. Basic algorithm steps are listed below:

1. Use Analytical Model to generate O/D trip data.
2. For each destination determine arrival sequence by trip origin.
3. For each destination, using all origins, determine overall average arrival interval.
4. Combine results of 2 and 3 with trip time data to determine corresponding departure times for each trip.
5. Sort result into single list of trips by departure time.
6. Manually inspect resulting list for scheduled departure conflicts and make necessary adjustments.
7. Deliver schedule data to DNS.

For an example of the adjustment process in step 6 consider a station with an overall arrival rate of 224 vehicles per hour. The average arrival rate is 16+ seconds. If the minimum allowable time between successive arrivals was set at 6 seconds, any scheduled departure to this station could be advanced or retarded up to 10 seconds and still not cause an arrival conflict. A critical assumption underlying the scheduling algorithm was that queuing of vehicle departures was preferred over queuing of vehicle arrivals. A schedule was improved by using DNS results to modify Analytical Model inputs and repeating the whole procedure.

CONCLUSIONS

The author has used an example taken from the AGRT CMS study in an attempt to illustrate the value of simple model development in conjunction with the development of more complex simulations. Frequently results from a simple model can aid in the checkout of more complex models. In some cases a simple model can be used to generate input data for the complex model. And results from the complex models can often be explained more easily in terms of a simple model.

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