# SIMULATION OF A RAIL RAPID TRANSIT SYSTEM AT SEVERAL LEVELS OF DETAIL

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ABSTRACT

Rapid transit system simulations can be structured so as to be useful to a wide variety of users on a transit property. A structural outline for doing this is developed based on experience gained in the development of such simulations. A brief sketch of a simulation structure developed for BART (the Bay Area Rapid Transit District) is presented.

## I. INTRODUCTION

SRI has been assisting BART (The Bay Area Rapid Transit District) with a project that involves analyzing characteristics of its system by developing and exercising simulations of train movements. In the course of this project much has been learned about simulation needs of a transit district and the way in which simulation can be structured to meet those needs. This paper describes some of these needs and a structure developed by SRI to satisfy them.

From a historical viewpoint it appears that rail rapid transit systems should take a unified view towards their simulation needs. Properties often use entirely separate simulations in various stages of their development and in various departments. The theme of this paper, however, is that it is possible to use a family of related simulation modules with broad application to a variety of analysis tasks. Some modules can then be common to all users while others can be tailored to have the level of detail required for a particular user.

Section II contains observations on transit system users--their needs, their resources, and constraints under which they work. Some historical observations are also included. Section III presents some basic computational building block that have proved useful in developing general purpose rapid transit simulations. Section IV present's SRI's approach to fulfilling BART needs, which involved the building of a family of related simulation programs in a high level (SIMSCRIPT II.5) language.

## II. TRANSIT PROPERTY USERS--NEEDS AND CHARACTERISTICS

Table 1 illustrates typical classes of simulation users on a transit property.

TABLE 1

Rapid Transit Simulation Users

| User Class | Typical Problems |
|---|---|
| Planners | Estimate cost/benefits of capital improvements or special operational modes. |
| Schedulers | Verify schedules<br>Develop and test alternative schedules<br>Experiment with dwell and runtime variations (test schedule sensitivities)<br>Determine train load factors |
| Engineering | Develop local/system control strategies<br>Test and verify signalling<br>Validate global system characteristics such as capacity and transit times.<br>Test equipment and software<br>Estimate power requirements |
| Operations | Train operations training<br>Experiment with operating procedures<br>Perform systems tests |

Each user has different simulation requirements in terms of fidelity and output. Planners, for example, are often interested in comparing gross estimates of system performance for various configuration changes. Planners often work with system segments before they are well defined by engineers. Planners have at least two methods for modeling a system and generating simulation input. First, they can estimate high level descriptions of a system such as transit times over large pieces of the network (e.g., station to station runtimes) and gross estimates of how these are affected by congestion. Alternatively, planners can assume standardized building blocks such as fixed block lengths and fixed vehicle accelerations and simulate with these elements. For cost purposes planners generally need data on

- -how load factors and car miles are affected by network layout
- -how, qualitatively, passenger service will be affected by network layout
- -how fleet size requirements will be affected by system changes.

Schedulers try to choose dispatch times, dwells, etc. so as to optimize utilization of cars and operators while meeting passenger demand. They generally design schedules by using transit time estimates that assume trains are spaced at headways that do not involve interference with other trains via close following moves or interlock interference at merge points. Their use of a simulation is often to check results. Occasionally, however, they experiment with special schedules and/or the effects of unusual delays or routings.

Engineers on transit properties are generally attached to various specialty subgroups involved with propulsion, signalling, communications etc., so that their interests and areas of expertise vary considerably. They often need high fidelity simulations with detailed outputs of system state variables. Simulations run by engineers must be validated against measured data, particularly where issues related to safety are involved. For engineering use it is desirable to have inputs that correspond directly to system components (e.g., the length of a track circuit, the torque curves of motors).

Operations personnel need a polished simulation package for training, etc. They are interested in such outputs as when trains arrive at points where operators are notified and when trains are interfered with (and why). Operators like programs whose inputs correspond to the data which they provide to the system such as lists of dispatch or arrival times.

Table 2 summarizes some transit system operating constraints that must be considered when developing a simulation.

TABLE 2

Typical Rapid Transit System Simulation Constraints

- -Simulations tend to be applied intermittently rather than continuously
- -Data required to run simulations are copious and scattered throughout a system. It is seldom in convenient machine readable form.
- -The pieces of a rapid transit network are closely intertwined but a user is often interested in simulating only parts of a network.
- -It is often desirable to simulate situations that are conceptually simple but which imply many special initial conditions.
- -System owned computer resources are principally optimized for various MIS and/or bookkeeping functions rather than for engineering applications such as simulation.
- -Simulation users are generally scattered amongst departments that operate somewhat independently of one another.
- -Transit systems are characterized by a large number of state variables (e.g., the state of interlocking relays, train control system states, train dynamics for each train) so that selectivity of ouput for analysis and/or debugging is important.

## III. COMPUTATIONAL BLOCKS REQUIRED TO SUPPORT VARIOUS USER NEEDS

Most of the user needs mentioned above can be considered in terms of computational and I/O blocks. SRI has had success with four such blocks: a network monitor block, an interlocking block, a train motion block, and a centralized train control block.

NETWORK MONITOR BLOCK. Although engineers may occasionally be interested in the dynamics of one or more trains over a given section of track ignoring stations and the like, most simulation users are concerned with coordinated operation of the system as a whole. These simulation requirements involve generating a log of the sequence of trains arriving and departing various points in a network as they transit given routes. The network monitor block provides the control required to move trains throughout the network by orchestrating the work of other logical blocks to achieve this end.

INTERLOCKING BLOCK. Rapid transit systems contain relay and timing logic which can control routing, turnbacks and other special functions. In practice, a typical pair of switches can be protected by many relays with multiple contact points and complicated wiring. Figure 1 shows a small piece of interlocking logic for one station. SRI has developed a functional interlocking logic block which can be used to "build" interlockings from relatively primative descriptors of an interlocking.

CENTRAL CONTROL BLOCK. On many properties there exist such centralized control functions as the adjustment of train dwells and speeds, based on systemwide train performance. Such functions are lumped into a central control block.

TRAIN MOTION BLOCK. When trains travel over the network without seeing anything other than green lights, their motion between stations can be represented by front and rear wheel transit times. However, when trains are closely following other trains or when they see reduced speed signals transit time calculations must be estimated via models which can have varying levels of fidelity. The problem of handling the time histories of individual trains is handled in a train motion block.

## IV. AN EXAMPLE

The organization of simulation programs and subroutines into logical blocks is described above in relation to user needs. Here we provide further information on the functions performed by these blocks for a BART simulation.

The network monitor block coordinates the work of the other blocks by calling them at proper times, providing them with inputs and acting on their outputs. These actions include:

- -Calling for the central control block parameters such as dwell time and speed profile commands.
- -Providing information to the interlocking block to inform it of track zone occupancy and deoccupancy and to request train routes.
- -Calling the train movement block to advance a train through the system.

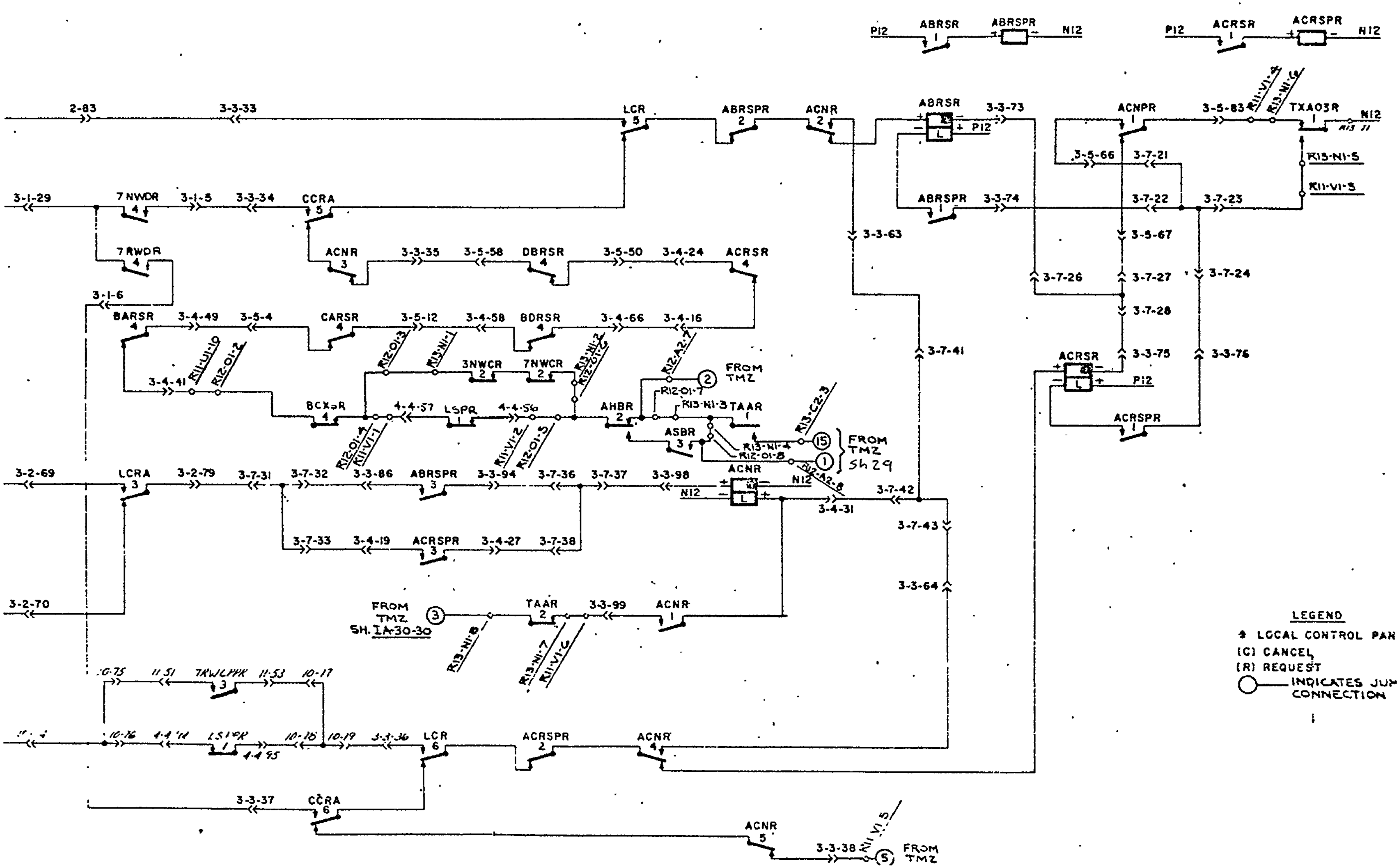
The network monitor block also performs various functions such as maintaining lists of trains in track sequence,determining where the next event occurs for each train and updating train status during platform dwell.

This block uses much of the SIMSCRIPT II.5 event scheduling machinery. Like the other blocks, this block has approximately 20 user generated source subroutines of 40 to 50 lines each. Extensive use is made of SIMSCRIPT's list management features.

The interlocking block accepts routing requests that are generated when the trains reach certain points in the network and, based on the request, modifies network linkages to simulate the operation of switches. Other outputs of this block include the signals that control train speed in and about switch areas and in turnback zones. Delays in passage through switch areas are accurately represented by delays in changing the aspects of these signals. Other features represented include time locking delays that can occur during congested operations, proper sequencing of trains at merges during

Figure 1

A Small Portion of a Typical Transit Interlocking



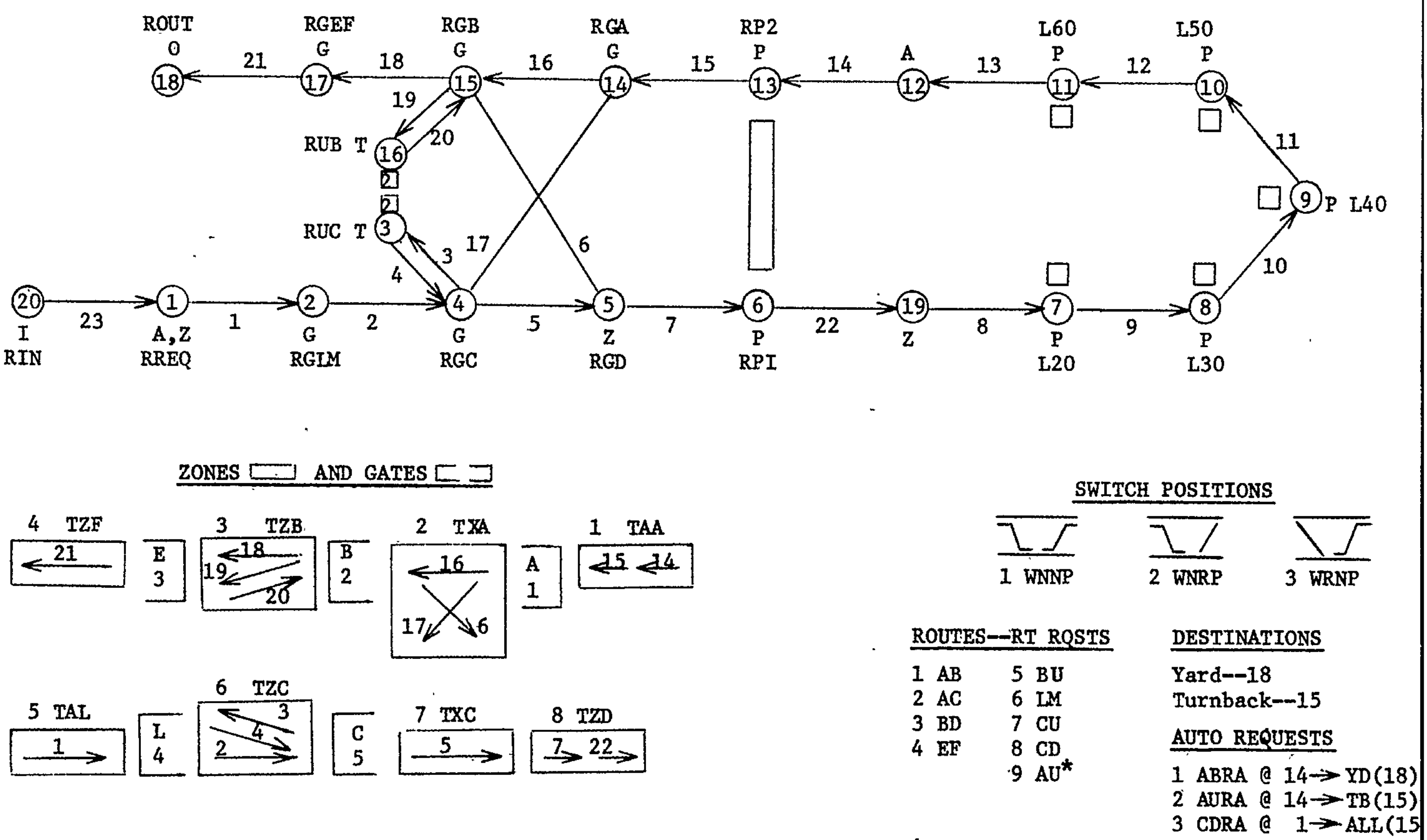
congestion and automatic use of secondary routes.

Special input programs have been built which support the network and interlocking logic. These programs accept descriptive data such as that shown in figure 2 in transit property nomenclature

FIGURE 2

Interlock and Network Input Schematic

Maximum Node Number = 20
Maximum Tube Number = 23




*Indefinite turnback request

and, via SIMSCRIPT constructs, generate appropriate variables and data for simulation. For example, figure 2 contains nodes identified as

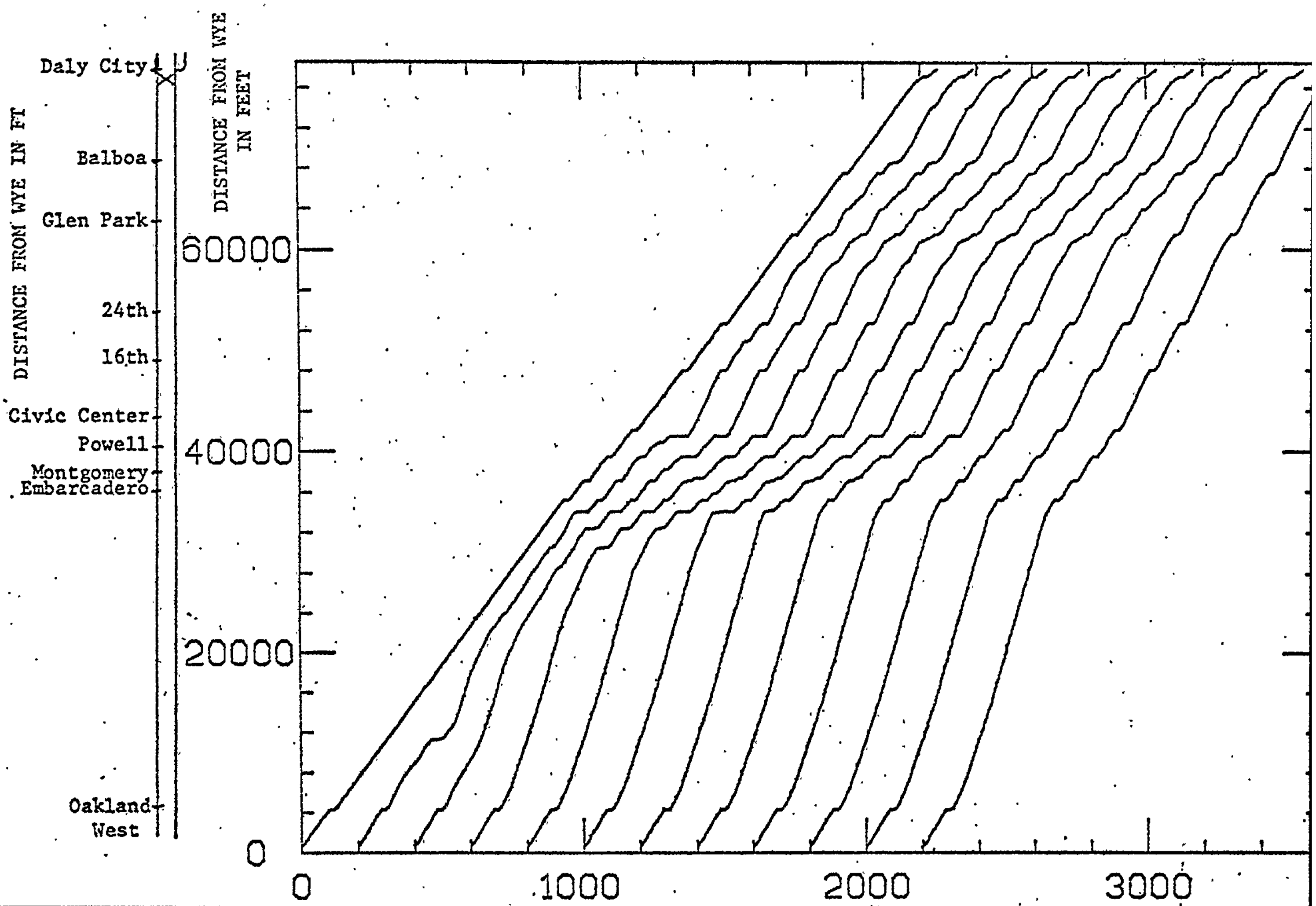
'G' nodes. This G stands for gates that are points which protect switches or other feaures guarded by an interlocking. The BART input programs contain a G card for each one of these gates with a string of data discribing the zones it protects, what tubes enter the gate, where a train must start to slow down if the gate is closed etc.. The input programs create variables such as approach sticks and switch locks that accurately depict interlockings. No transit times or train dynamics data is part of this input.

The central control block dispatches trains and attempts to keep them on schedule by making the kinds of changes to dwells and speeds that central controllers issue. Input to this block operates the simulation in terms of creating trains, giving them routes, and specifying how the trains are to be controlled.

Finally the train movement block determines the progress of trains over the network and provides information to following trains to permit them to approach at appropriate speeds (simulating block signals.) Two versions of the train movement block are in use. One simulates the detailed dynamics of train motion and can be run by engineers for detailed analysis without the other blocks. Another uses transit times of train front and rear wheel movements to get system behavior. This latter model uses simplified approximations to determine how trains will move near switches with restrictive signals and how trains will approach trains ahead. Both models are compatible with the other blocks discussed above. Figure 3 presents an output of detailed

FIGURE 3

A Failed Train Followed by 11 Trains at 200 second Headways




movement along one segment of BART trackage in the case where a failed (restricted speed) train is moving along a line. Train motion is numerically integrated using propulsion data, signal blocks, grades, etc..

## V. CONCLUDING COMMENTS

A unified approach to developing simulation capability has proven to be effective for BART. That capability is being used to analyze a wide variety of planning and engineering problems. These problems require various levels of detail but use one basic simulation package. It is anticipated that the programs now in use will be extended to interactive and real time use in the near future.