Abridgment

Caltrans–Cal Poly Traffic Operations Center Simulator

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The California Department of Transportation (Caltrans) is developing traffic operations centers (TOCs) in many urbanized areas throughout the state. To help in planning and operating these centers, Caltrans has contracted with the California Polytechnic State University, San Luis Obispo (Cal Poly), to build and operate a TOC simulator. The project is organized in three phases. In Phase I a prototype simulator was built to clarify the type of facility required. The permanent facility was constructed in Phase II. Testing and training using the permanent simulator is currently underway in Phase III. The design, functions, and principal considerations that guided its development are described.

Urban congestion is one of the critical issues of the 1990s. Transportation professionals recognize that meeting the growing travel demand cannot be achieved by adding capacity to the system. By the year 2000, population in California is predicted to grow by nearly 26 percent, vehicle registration by 55 percent, and miles traveled by 105 percent. This is in a state that during the last decade increased new roadways by only 2 percent (*1*, p. 6).

Emphasis is being placed on improving the operating efficiency of existing highway systems. One strategy is the use of centralized control to monitor highway conditions and respond appropriately to problems as they occur. The California Department of Transportation (Caltrans) has been implementing centralized control by developing traffic operations centers (TOCs).

To effectively develop TOCs, Caltrans decided that it needed a facility for testing alternative TOC configurations, methods for presenting and processing information, and training. Simulation was the method selected to meet these needs.

TOC SIMULATOR PROJECT

The California Polytechnic State University, San Luis Obispo (Cal Poly), has created a TOC simulator as a three-phase project funded by Caltrans. Phase I developed a facility plan, equipment specifications, and computing requirements and constructed a prototype simulator facility. On the basis of experience gained with the prototype facility, Phase II constructed and calibrated the permanent simulator. In Phase III, the research team is using the simulator to represent a wide range of traffic control situations in training and strategy testing.

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During each simulation session, workstation and communication equipment locations in the simulator facility can be configured to resemble the layout of particular TOCs. This can provide a training or test environment unique to each urban area in an off-line setting.

TOC CONCEPTS

Most transportation systems operate with a combination of centralized and distributed control. Centralized control systems have three necessary elements:

1. A means of detection to determine the status of the system,
2. A means of responding to system conditions and modifying the system configuration and operation, and
3. A centralized control facility.

Estimates of the potential benefits of centralized control in the highway environment are limited. New and improved methods of acquiring traffic data are becoming available rapidly. Advances in sensors, communications, and information-processing technologies offer an increased capability in centralized highway traffic control. Advances in computer support for human decision making and automated control offer additional possibilities for significant improvements.

Centralized control requires rapid analysis of system status. Often it is not clear which control strategies are most effective in responding to specific conditions. The TOC simulator provides an environment in which system control alternatives can be tested and evaluated under various scenarios.

TOCs have a wide range of beneficial control measures for urban congestion. Examples include dispatching incident response teams, diverting traffic, providing motorist information through changeable message signs (CMSs), radio, and television; and eventually directing transmission of information to on-board navigation-display units.

FUNCTIONS OF TOC SIMULATOR

The TOC simulator provides an off-line facility on which the environment and operations of an actual TOC can be modeled without affecting real traffic. The activities within the Simulator can be characterized as input, output, and processing. Each of these activity sections has specific functions associated with it.

Flow Monitoring

The flow monitoring function is part of the input activity section and allows the TOC to detect, verify, and monitor incidents. Input sources for the simulator represent a variety of methods including loops, closed-circuit television (CCTV), calls from the California Highway Patrol (CHP) and Caltrans field units, and calls from the general public. Loop input is provided by a traffic simulation program developed at Cal Poly. Outputs from this simulation are fed to a graphical display program that presents the freeway system as a network of colored sections. As different display parameters are selected, levels of speed, flow, or density are shown through changes in color.

The simulator has a computer console that replicates a direct two-way communications link to the CHP incident data base. CCTV cameras deployed in the field are represented by video tape recorders that show footage selected from a library of scenes of actual traffic conditions and incidents. Telephone and radio communications simulate exchanges with Caltrans field personnel, tow service patrols, enforcement personnel, transit operators, and so forth.

Traffic Management

Traffic management is part of the output activity section. In the simulator, TOC personnel respond to current conditions on a real-time basis. In the event of major incidents, the TOC can communicate directly with simulated response teams, media representatives, and others.

Motorist Information Services

Motorist information is another function of the TOC output activity section. TOC personnel can send information to drivers using CMSs, highway advisory radio, highway advisory telephone, computer dial-up services, and other media. As technology advances, the TOC can also simulate data transfer to on-board traveler information and navigation systems.

Traffic Analysis

The last function of the TOC is traffic analysis, part of the processing activity section. The TOC provides an environment conducive to evaluating the effectiveness of control measures and other system changes. The traffic analysis function also provides the means for archive storage and retrieval of data used in trend analysis.

DESCRIPTION OF TOC SIMULATOR FACILITY

The Cal Poly TOC simulator facility is the result of an in-depth investigation into TOC research and training needs and a review of actual TOC designs across the nation. Several layouts were evaluated, leading to the permanent facility plan shown in Figure 1. Construction of the facility began in March and was completed in November 1990.

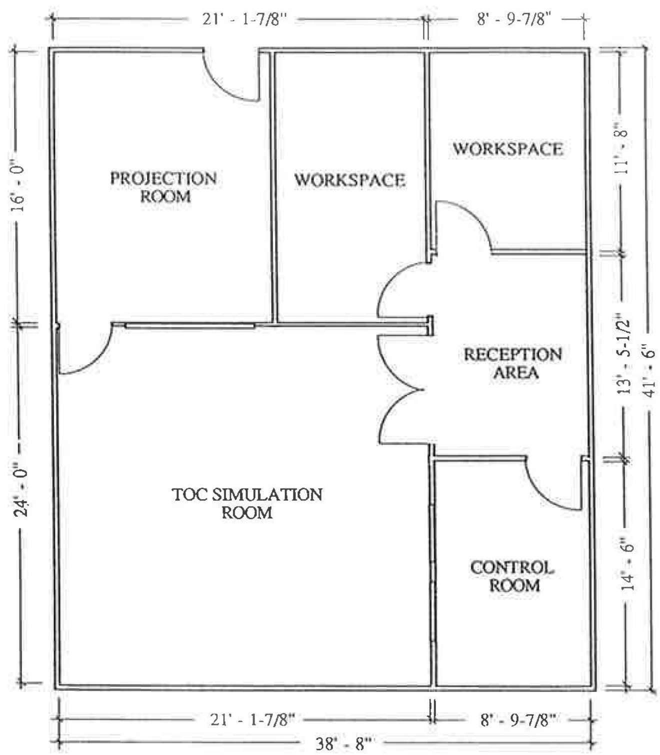

FIGURE 1 TOC facility dimensions and layout.

Two main rooms are the heart of the simulator: the simulation room and the control room. Several support rooms complete the facility.

In the simulation room, operators simulate activities that take place in a real TOC. This 24 × 21-ft room has a suspended acoustic ceiling and raised modular floor to facilitate rapid reconfiguration and placement of cables and conductors. The consoles provide equipment for flow monitoring, radio and telephone communications, computer data entry and retrieval, and CCTV network monitoring; there is also a writing surface and storage space.

Other important features of the simulator room are a CHP communications workstation that represents a link to the CHP data base for incoming information from field officers, call boxes, citizens band radios, cellular telephones, and calls by citizens. A Caltrans dispatch workstation represents a direct line to the Caltrans field dispatch center, and a rear projection display is linked to several video input sources, including the traffic conditions display, log programs from the communications console, and simulated CCTV images.

The control room, adjacent to the simulation room, contains communications, computer, and display equipment used to manage simulation activities. Audio input from recorded tape or live voice input can be transmitted to the operators in the simulation room using the public address system.

A Sun SPARC Station I workstation in the control room runs the simulation program that provides traffic input to the simulation room. The simulation supervisors can manipulate the traffic simulation program in real time to influence highway network conditions observed by operators in the simulation room. Four VCRs in the control room feed video images to the monitors in the simulation room. Finally, a "masterslave" configuration of three IBM-compatible microcomputers handles the transmission of all other information used during simulation.

COMPUTER SIMULATION OF TRAFFIC CONDITIONS

The traffic simulation is performed on a computer network that handles three overlapping tasks: (a) modeling traffic flows on the transportation network, (b) displaying traffic conditions to the TOC controllers, and (c) allowing for the interactive exchange of information between the model and the TOC. Three UNIX (Sun SPARC I) workstations with high-resolution color displays, linked via Ethernet, perform the traffic simulation and graphics processing. The UNIX environment provides substantial processing power, the opportunity for increased processing power when needed, and a high degree of portability.

The simulation and graphics software runs best on workstations with at least 10 M of memory, RISC processor performance (1 to 2 MFLOPS, 5 to 10 MIPS), a megapixel 8-bitplane color display, and 500 M of hard disk space. A black and white display can be used, but it results in a considerably degraded user interface.

The needs of the TOC simulator facility placed heavy demands with respect to software requirements. Good programs are available for both graphics and traffic simulation modeling, but none met the performance criteria and none was available for modification. Consequently, new graphics and simulation software were developed.

The graphics program displays traffic data in a maplike format and allows an operator to obtain detailed information about traffic activity. The server program generates simulated traffic data and coordinates activities between different operators. Communication between the server and graphics programs is done via UNIX Internet stream sockets, so the communication code will work properly on any network of computers running Berkeley-style UNIX.

The graphics program provides a maplike display of conditions on the freeway system. The program uses the X Windows system (X), one of the most portable of window systems available. The graphics program permits the screen to be divided into rectangular windows each showing a different portion of the freeway system. The graphics program also supports operator communication using shared bulletin-board windows. A special supervisor mode adds features so that the simulation supervisor can alter network characteristics and introduce incidents.

The server program provides simulated freeway traffic statistics on flows, speeds, and densities. It employs a standard link-node highway network representation and a macroscopic fluid-flow traffic model. Link traffic variables are recalculated at fixed time intervals of less than 1 sec.

The current first-generation traffic simulation includes only freeways with links corresponding to sections of ramps, connectors, and basic freeway sections. This program, iterating each ½ sec, can simulate more than 5,000 links in real time on an otherwise idle Sun SPARC I workstation. The model is now being reformulated to include major arterials, signalized intersections and special facilities such as high-occupancy vehicle lanes.

The freeway-only version represents link performance by rudimentary functions interrelating speed, flow, and density. Although the initial simulation for training purposes uses the Greenshield's formulation (linear speed–density relationship), any speed-density-flow relationships may be used, including tabulated functions. The simulation logic uses a simple conservation-of-flow rule and carefully accounts for how queues grow and shrink within subnetworks of congested links.

Conservation-of-flow equations such as the following simplest case are used to calculate the changes in link densities for each time interval:

$$dk_i = (q_{i-1} - q_i) * \frac{T}{L_i}$$

where

- q_i = flow from a link i to the next downstream link $i + 1$ during the time interval (veh/sec),
- T = length of simulation time interval (sec), and
- L_i = length of link i (mi).

The average link density k_i after each time interval is obtained by adding dk_i to the k_i value from the previous interval. Unless constrained by link capacity or the presence of a queue, the flow exiting link i during the next time interval is calculated from k_i based on the link's characteristic $q-k$ function. Link speed is calculated directly from density and flow.

The calculations for actual links may be complicated by the presence of junctions where route choice is determined from turning ratios. Turning ratios are exogenous data in the first-generation simulation and will be based on a trip matrix and route-choice algorithm in later versions.

Link calculations may also be complicated by the link capacity constraint and the presence of forced flow (queuing) within the current link or within links immediately downstream. This logic, too intricate to describe here, is fully documented in the Phase II technical report (*2*).

Besides running the traffic simulation model, the server program coordinates the activities of different operators, answers requests for information from operator workstations, and ensures that bulletin-board messages are transmitted to all operators.

The TOC software was designed to be portable, modular, and easily modifiable with the anticipation of changing any portion as experience and needs dictate. The current version (Graphics 2.2 and Server 2.2) consists of 11,000 to 12,000 lines of traditional C code, in 40 to 45 files. The software utilizes X11 Release 4, the Sun equivalent of Berkeley 4.3 UNIX, and makes heavy use of the Xlib interface to X. Some portions of the code use the Athena widget set.

NEW DIRECTIONS

The trend in California toward developing primitive traffic operations centers (PTOCs) has influenced the direction of the TOC simulator project. A PTOC uses existing resources and technology to begin center operations quickly at minimum cost. PTOCs are now operational in several urban areas and will continue to be implemented throughout California.

One of the primary benefits of the TOC simulation project is to provide an off-line test bed for evaluating the components of a functioning TOC. Another related role is the development and testing of new traffic management technology.

SUMMARY

New methods to improve highway traffic operations are needed. This paper examines one specific tactic, the traffic operations center, and one specific tool, simulation. The Cal Poly TOC simulator project has achieved its stated goal of providing design information, software, and a permanent facility to develop control methods and train TOC personnel.

ACKNOWLEDGMENTS

The authors acknowledge the support of the California Department of Transportation. Although the work described in this paper was funded by the California Department of Transportation, the statements and conclusions expressed are those of the authors and not necessarily those of the State of California or Caltrans. This paper does not constitute a standard, regulation, or specification. The mention of commercial products, their sources, or their uses in connection with materials reported herein is not to be construed as an actual or implied endorsement of such products.

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Publication of this paper sponsored by Committee on Freeway Operations.