New Computerized Traffic Signal System Design

EDMOND CHIN-PING CHANG

The city of Taipei is developing a new generation of computerized signal control and traffic management systems to combat growing urban congestion. An international team has successfully formulated a new system hardware and software design adequate for long-term expansion. Design considerations, control system design, functional components, and implementation strategies are described. The new system will provide centrally located, distributed-network, real-time traffic management for a metropolis of 3½ million people into the 21st century.

Maintaining adequate traffic control and improving urban mobility has become the top priority item on the political agenda for officials and traffic managers in many countries undergoing rapid economic growth. This is especially true in Taiwan, Republic of China (ROC), since the national economy relies heavily on the transportation infrastructure to support both international commerce and trade activities. Significant development has been made in the past decade in designing and implementing computer-based signal control systems in order to upgrade urban traffic operations. Furthermore, recent system development in the city of Taipei has allowed engineers to take advantage of advanced computer network control architecture, on-line timing plan generation capabilities, and dynamic traffic control strategies.

BACKGROUND

Located along the western highway corridor in Taiwan, the city of Taipei has been upgrading its signalized intersections under central computer control within the inner city. Several development efforts began in the 1970s. The first project was awarded in 1976 to Hitachi, Japan; two subsequent phases were completed, led by the Philips group of the Netherlands. This early development effort put 119 signalized intersections and 11 arterials under centralized time-based and hardware-interconnected control. However, the signal hardware and system software are not adequate to handle dynamic traffic needs because of out-of-date control technology and inflexible timing selection for the dynamic traffic demands.

Taipei has approximately 1,000 signalized intersections within the metropolitan area, as shown in Figure 1. Among them, 119 intersections are under computerized control and 147 are under hardware-interconnected coordination. There are also 51 intersections under time-base coordination, 96 under two-way progression, 116 under partial synchronization control, and 600 under isolated, pretimed control. Local equipment includes 96 loop detectors, 34 supersonic detectors, 2 changeable message signs, and 18 sets of closed-circuit television cameras. Located in a central control center, the present central computer equipment includes a PDP11 central computer, 27 units of Hitachi control-based subsystems, 42 units of Philips subsystems, 42 domestic-made subsystems, a communication conversion system, control console, video display, communication system, and other peripherals.

In the past several years, many domestic controller manufacturers, research communities, and governmental agencies in Taiwan have successfully developed several generations of microcomputer-based signal control systems that are equivalent in function to the closed-loop systems used in the United States. These software systems, such as COMDYCS and TRUSTS, can affectively assist signal timing plan development during daily operations. Many city and county officials have implemented these systems in traffic responsive mode with on-line optimization software based on the modified PASSER, TRANSYT, MAXBAND, and other packages. However, these systems were developed for signal networks with fewer than 90 intersections. There is a need to design a large-scale computerized traffic-responsive system that can respond to the metropolitan traffic control needs for the city of Taipei.

Since 1989, an international team consisting of the Taipei City Traffic Bureau; China Engineering Consultants, Inc. (CECI); DelCan International, Inc.; and overseas Chinese consultants has successfully formulated a long-term system hardware and software development plan. This new computerized traffic control and management system is being implemented in three development phases to update the signal control capabilities for the entire metropolitan area. The overall system development involves designing controller hardware, system control software, and traffic management strategies. This control operation, similar to the Urban Traffic Control System (UTCS) 1.5-GC system concept, has already been implemented; initial system integration tests were completed successfully during October 1991. This system design can comfortably coordinate more than 1,000 signalized intersections for the operational staffs in the traffic bureau to implement various traffic management techniques in the future.

OBJECTIVES

The overall system development was focused on developing a comprehensive system hardware and software design to improve traffic control capabilities by upgrading the existing

Texas Transportation Institute, Texas A&M University, College Station, Tex. 77843.

FIGURE 1 Taipei traffic signal control system.

traffic signal control systems used in the Taipei metropolitan area. Two studies—*Taipei City Signal Control System Upgrade Feasibility Study* and *Taipei City Signal Control System Manager Project*—were completed. The detailed study tasks included conceptual system design, functional specifications, staged development planning, and integration software. The studies also provided system manager supports during the system hardware contracting and implementation process.

The study had three important design objectives. First, the strategy development objective was to devise the timing design to increase arterial circulation of all signalized intersections in the inner city and outlying areas. This systemwide control strategy will improve travel time along major arterials, thereby encouraging more systemwide arterial progression than the previous operations. The new system will enable engineers to obtain quickly real-time traffic measures, identify congestion hot-spots, and develop feasible signal coordination schemes. The system architecture was designed with hardware and software flexible enough to accommodate a wide range of urban control strategies. These include time-of-day operations, traffic responsive operation, and dynamic timing plan generation, they also provided a system communication and execution hardware and software infrastructure sufficient for experimenting with various adaptive signal control schemes. The study developed an open-end, large-scale control system architecture, a new-generation traffic signal controller, and assistance to the domestic electronic industry and signal controller manufacturers in implementing the upgraded design.

The system development process, control strategy, communication schemes, computer network architecture, and other advanced design features being implemented are summarized. This traffic control system will provide city traffic engineering staffs with a centrally located, distributed-network, real-time traffic management infrastructure that can be used to battle growing urban congestion problems within a metropolis of 3½ million people.

DESIGN CONSIDERATIONS

City officials and traffic managers have provided three guidelines during the new system development. These design considerations are addressed individually and well understood as the new system being developed for the potential implementation throughout the metropolitan area. First, this control system provides "open-architecture" system expansion capabilities for easy adaptation to future generations of control hardware and advanced control strategy. Second, the system will provide dynamic, on-line signal timing plan generation so that control operators can make up-to-date timing adjustments to accommodate traffic pattern changes during reconstruction, maintenance operations, recurring, congestion, highway incidents, and special events. Third, the new computerized system will provide a powerful traffic management tool that can take advantage of both foreign and domestic hardware, as well as software systems already being developed.

Operational Features

Most domestic system developments emphasize upgrading the control hardware and software for the smaller systems that provide basic pretimed, time-of-day operations. The system will integrate effective traffic control strategies into the system hardware and software design to improve traffic management capabilities that can apply existing technologies more efficiently. This computerized traffic signal control system has the following traffic control and operational features:

1. An effective traffic management system for responding to both short- and long-term changes in traffic demands and roadway conditions within the urban traffic network;
2. The capability to allow city control center operators and traffic engineers to develop traffic signal timing optimization plans quickly from updated traffic information;
3. The ability to evaluate real-time traffic control system performance as affected by the present and proposed signal timing control strategies in various traffic operating conditions; and
4. An open-architecture and user-friendly signal system control software based on advanced computerized hardware configuration to accommodate advanced and future on-line signal control operations.

Implementation

The overall control system upgrade is divided into three phases, and a number of signalized intersections and detectors were planned for installation in 1989. These system implementation efforts include replacing intersection controllers, installing the central control computer, renovating the communication network, developing control system software, and, after development is completed, providing system integration supports to assure maximum technology transfer to city traffic engineers for future system maintenance and operations.

Phase 1 of the system development was to install all the field equipment and central facilities to initially integrate the system hardware and software on 301 controllers and 200 detectors in the central business district. Phases 2 and 3 have also been awarded and are currently being implemented. The initial system integration tests on the field equipment, control center, and system control software for Phase 1 were scheduled to be completed at the end of 1991. The system integration carries a 2-year warranty period during which all the primary contractors are responsible for overall system hardware and software maintenance. After the completion of technology transfer activities the system will be operated and maintained by the traffic engineering staffs of the Taipei City Traffic Bureau.

For the system currently being upgraded, all the signalized intersections are equipped with pre-timed operations (PT), time-of-day (TOD), and dynamic computation (DC) operations. Some intersections also employ critical intersection control (CIC), and one or two intersections will be under experimental adaptive control (AC). However, all intersection controllers will be equipped with identical software and hardware capable of upgrading with all the control features for the full-scale implementation.

Besides the traffic signal control system upgrade project, Taipei is also undergoing several citywide infrastructure improvement projects and rapid mass transit construction. A number of urban freeway and expressway reconstruction proj-

ects are also underway, along with the relocation of at-grade railroad crossings underground within the urban area. Therefore, the control system design must be flexible enough to accommodate locations of both temporary and permanent control centers, meet traffic control needs during the roadway construction, and provide maximum system future expansion capabilities.

Potential Benefits

Motorists in the metropolitan area will benefit substantially from the enhanced traffic control system features compared with the existing traffic control system. Through field observations and limited TRANSYT-7F network simulation, the feasibility study indicates that coordinated signal system operations, once completed and fully operational, can improve overall traffic operations with reduced travel time, delay, and a systemwide reduction in fuel consumption and air pollution.

Even with the conservative estimation, the potential reduction on the systemwide travel delay, improved travel time, and reduced fuel consumption can be converted to an approximate total dollar savings of nearly $1 billion (U.S.) a year. These system implementation benefits can be converted into an optimum rate of return on the overall investment of a 14:1 benefit-to-cost ratio during each year of system operation.

FEATURES

The following sections describe system operational features and unique control features available in the Taipei traffic signal control system design. These features include traffic control strategy, system control software, color graphics display, central communication unit, phone system, portable PCs, closed-circuit television system, and control center system interface to provide improved motorist information for eventual potential implementation throughout the entire city street network.

Control Strategy

Among the 1,000 intersections being upgraded, 301 traffic signals are inside the central business district and 349 are in the grid pattern. The remaining signals are in outlying areas. Phase 1 development focused on the city's central business district. Of the total 301 intersections, 5 will use queue control detectors, 4 will use actuated detectors, 6 will use critical intersection control, and 1 will use adaptive control. All installed controllers in the Taipei system will conform to the Ministry of Transportation and Communications Institute of Transportation (MOC/IOT) standard for solid-state, 16-bit–based microprocessors.

As shown in Figure 2, all intersections will be equipped with traffic system control features through either system automatic or operator selectable commands. The new system is designed with enhanced PT, TOD, dynamic table lookup (DTL), DC, and CIC modes with the capability of allowing AC in the future. Adaptive control software will initially be implemented at one or two selected intersections if successful, and may eventually be implemented throughout the entire metropolitan area.

Control System Architecture

The new control center will be upgraded in the existing location. A microcomputer-based interim control system was set up to monitor field equipment during the system hardware replacement. The permanent traffic control management center will be located in a building that also houses the central bus transit terminal in a city-owned joint development project. Along with the mass transit control center, the center will be used to coordinate the metropolitan transit system and traffic signal control center. In addition to accommodating all traffic signal system control hardware and software, this permanent control center will provide adequate office space for the traffic operations and signal maintenance staff. This arrangement provides better communication without requiring human operator intervention between those that optimize traffic operations and those that monitor the operating system around the clock. The target date for the completion of field implementation was the end of 1991.

As shown in Figure 3, the control system includes a communication network, dedicated 32-bit single-board computer (SBC), backup host computer, and a traffic control workstation (TCWS) with a Chinese-based operator interface. TCWS is a stand-alone, RISC-based system with graphics CPUs, keyboards, digitizing tablets, and high-resolution monitors (1,024 × 800 pixels, 19 in.). Besides providing traffic surveillance and real-time monitoring, TCWS can also display the control status of selected intersections, signal groups, arterial streets, and area operations. This real-time information includes error status display; red, yellow, and green indications; walks and don't walks; detector volumes and occupancies; vehicular types; intersection split-timing, signal phasing data; and many other advanced control features. TCWS will provide the operator command interfaces for initiating various control strategies. The TCP/IP- and NFS-based networked workstations can share real-time traffic and control information intelligently with any other units through VME Bus, Ethernet, SCSI, and RS-232C serial connections.

Based on the single-function, volume-distributed design concept, the control computer is configured with a series of Ethernet and VME NET connected 32-bit SBCs. Depending on the needed system surveillance, communication control, and display software functions, these SBCs will be divided further into regional traffic control computers (RTCCs), data gathering control computers (DGCCs), central communication units (CCUs), wall map control computers (WMCCs), and message display control computers (MDCCs). For the distributed data communication, two DGCCs will supervise six dedicated DGPs with 128 communication lines connected on each DGP. For the control function, RTCC can control 64 pieces of field equipment, such as intersections, detector units, and changeable message signs. In addition, one extra RTCC will serve as the on-line backup unit. It is important to recognize that all the targeted control functions are achieved mainly through these SBCs. These multi-CPU host computers are used mainly for system software development, operational monitoring, database server management, and system maintenance.

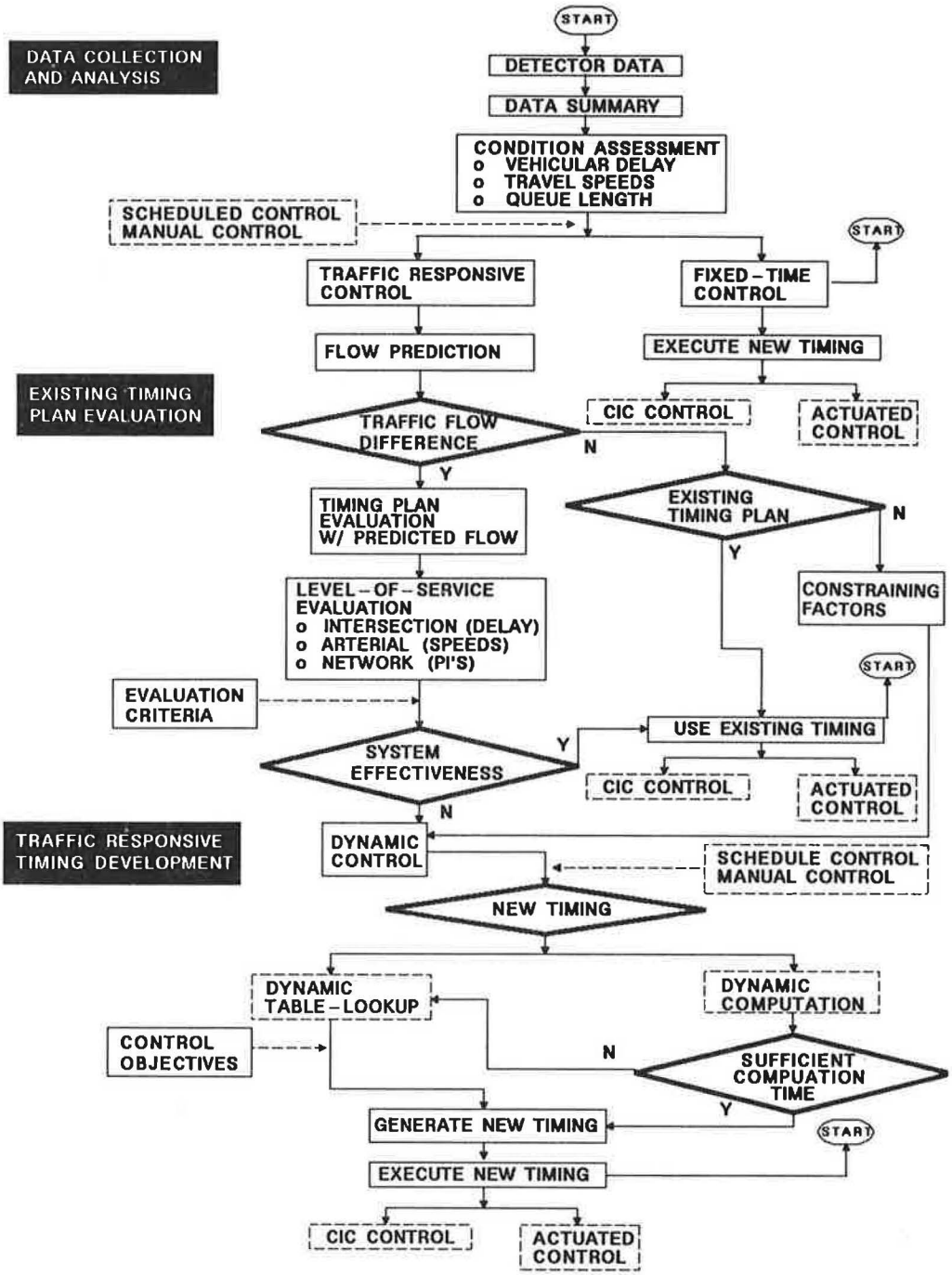

FIGURE 2 System traffic control strategy.

The control center is equipped with a large tile-assembled wall map to represent Taipei's street network currently under computerized signal control. In addition to display control area, the map will provide real-time operational and performance information to the control operator through assembled LED indicators, dot-matrix message boards, system measure of effectiveness (MOE) ranking scoreboards, and video screens. The high resolution RISC-based workstations, based on the Chinese graphics kernel system, can also display geographic-based traffic information. The operator can use multiwindow, zoom, and pan capabilities to modify the display screen to any selected scale down to one signalized intersection. The network communication speed of the TCWS color graphics computer will allow instant switch display from one TCWS to another.

System Software

This new computerized control system applies design concepts similar to the public-domain UTCS software, as supported by FHWA, U.S. Department of Transportation. The completely

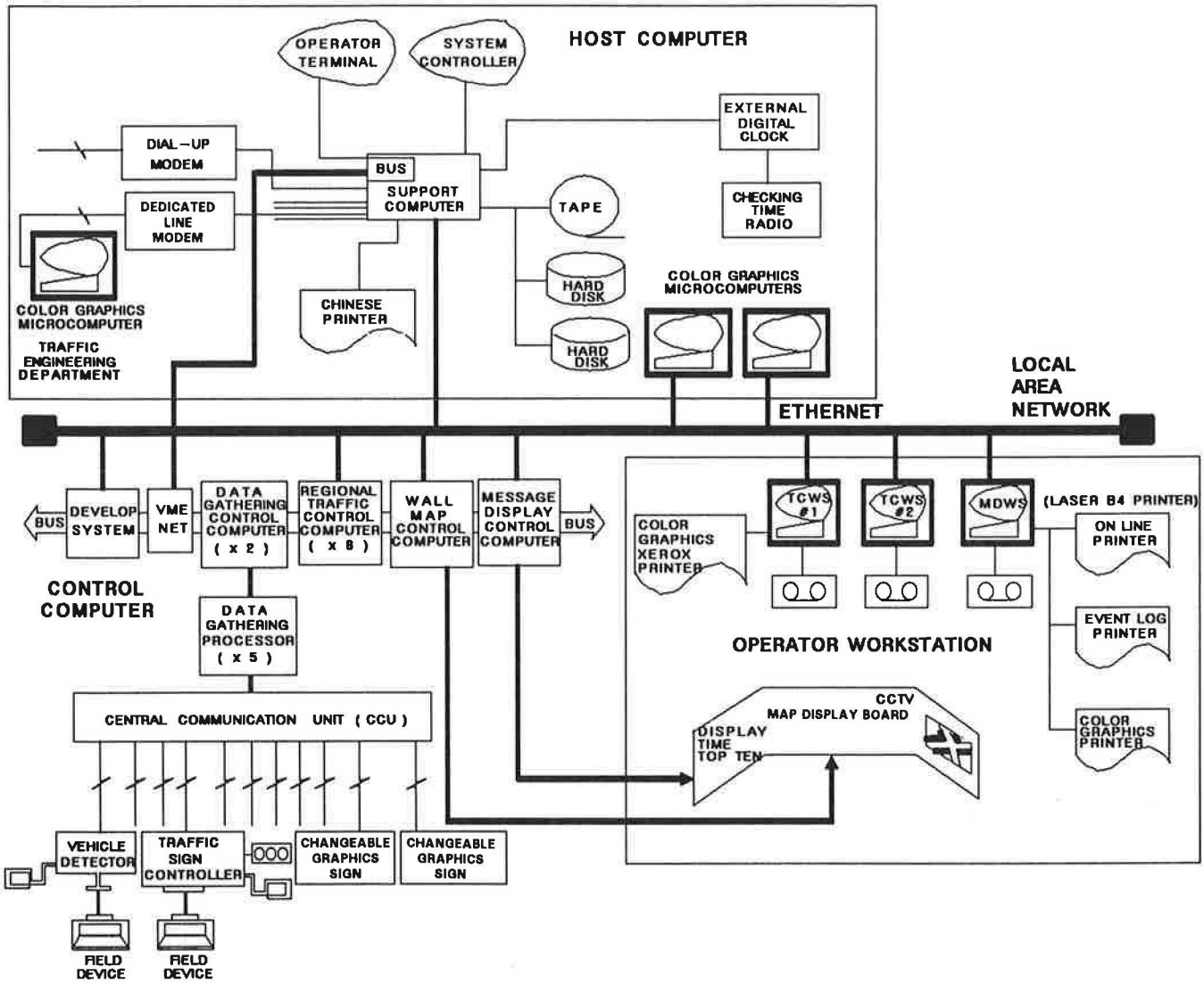

FIGURE 3 Control system network architecture.

new control software, developed jointly by CECI and the consulting team, is fully equipped with many advanced signal control features to suit Taipei's unique operational characteristics and traffic patterns. To support the most critical processing requirement adequate for future real-time adaptive control, the system uses advanced microcomputer electronics, network client-server communication schemes, fault-tolerant control hardware architecture, and simultaneous real-time system data base mirror-backup design. The new control system design has basic system functions similar to 1.5-GC UTCS system software and is equipped with on-line data base management in a distributed computer networking environment. The system can obtain all historical information stored in the controllers and local detector units. The control system will use either smoothed real-time or default historical volume and occupancy data for timing plan regeneration.

Detector System Design

The city of Taipei has more operational problems with heavily mixed traffic flows in the signal network than many other metropolitan areas in the world. These mixed-traffic problems result from a high percentage of bus transits, motorcycles, pedestrian crossings, and on-street parking. Since the geometric conditions and available roadway capacity are very limited at most signalized intersections, one major design objective is to identify the traffic volume and percentage of motorcycles presented through the intersection area at the beginning of the green light. The identification then would allow adjustment for the operational impacts and would provide a better assessment of available saturation flows for improving intersection signal timing design. Similar to the treatment of bus traffic, all motorcycle units will be converted to adjustable equivalent passenger car units (PCUs) in the signal timing optimization.

As shown in Figure 4, a double-loop detector was designed to collect detailed information, such as volume, occupancy, travel speeds, and vehicle classification. With this detector design at divided traffic lanes, the detector system can accurately detect the presence of a passenger car (95 percent), bus (80 percent), and motorcycle (90 percent). Because of the limits of roadway reconstruction, real-time data processing efficiency, and historical data storage requirements,

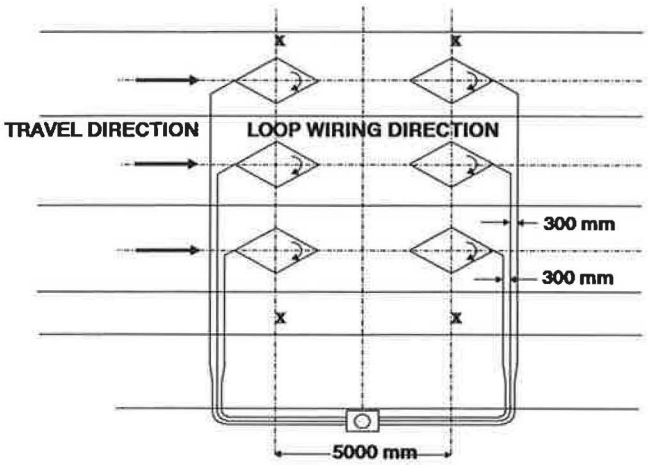

FIGURE 4 Double-loop detector system design.

a separate detector cabinet was designed. The detector unit will house the detector processing unit, provide a data consistency check, apply historical smoothing during detector failure, and use field-to-central communication schemes similar to those used in the traffic signal controller.

Central Communication Unit

Two communication systems were developed to collect and process traffic information, video images, and control commands between the CCU and field equipment. The first communication system uses the MOC telephone network through 1,200-baud dial-up modems and links data wires to the separate signal controller and detector units. The system will later be upgraded with twisted-pair cable and fiber optics during video surveillance upgrade. The system will continuously monitor all field devices through second-by-second or operator-selected, fixed-interval communication to each piece of field equipment. In turn, the control system will receive and confirm response messages. The majority of the response messages are based on the Communication Protocol Agreement developed by MOC/IOT for providing the needed communication interface between controllers from different signal manufacturers within the same traffic control system.

Basic communication message contents include current signal phases, pedestrian call locations, detector volumes, occupancy values, and so on. These transmitted commands and response messages will be updated for every signalized intersection and detector unit. In operation, the central computer will coordinate all signalized intersections by issuing needed communication commands. The local controller recognizes these commands as a prompt to either force out or leave the current signal timing interval and go to the next interval or to needed plan switching activities. These command sets will ensure that network coordination is adequately maintained in order to maintain signal coordination settings throughout the city.

Taipei's DGP unit uses one-to-one data communication modems to receive and transmit data between the CCU and field equipment. The DGP unit will also synchronize time-based control during an interconnect or central computer failure. Each unit will control up to a maximum of 64 separate units, whether local signal controllers, local detector units, or changeable message signs. Through a telephone service agreement, MOC is providing the traffic bureau with channels for the local controller and detector units. The city will pay only the actual cost to extend telephone lines, to drop connections to signal cabinets, and for special electronics transmission. This decision can significantly reduce the initial capital investment as opposed to developing the system's dedicated communication network. MOC maintains a very extensive telephone network. Using the telephone interconnect is relatively the most inexpensive solution, compared with other alternative communication schemes, before establishment of the city-owned fiber communication/fiber trunk network during the closed-circuit television (CCTV) video transmission upgrade.

Phone System and Portable PCs

Because the majority of the communication systems will be based on the local telephone network, two serial RS-232C modular communication ports are included in all traffic signal controller and detector cabinets to establish data communication with the control center. In this way, field technicians can log on the central host control computer and provide data upload and download conveniently to improve system operations in the field. This local system can also interface with portable laptop microcomputers and hand-held microcomputer units for field equipment interface. While at the controller cabin, the technician can plug these units into one of the two RS-232C serial communication ports as well as dial up the central computer for control status reports on the system. These portable units will also conduct systemwide signal-timing, implement immediate field changes, and update modifications.

Closed-Circuit Television System

The existing CCTV system will continue to provide basic traffic surveillance, monitor selected arterials, and offer visual confirmation of field operating conditions. With the CCTV, engineering staffs in the control center or other locations can quickly monitor traffic operations status, assess the operational impacts of special events, and detect and confirm unusual incidents, including emergency situations. The current CCTV system consists of 11 video cameras strategically located on buildings or poles for wide coverage of both major downtown streets and key access points to and from the freeway and expressway system.

Currently under design, a combined coaxial cable and fiber trunk communication network will initially improve video signals and eventually upgrade all the field devices to the control center at the high-speed, high-quality transmission. At the control center, four 19-in. color monitors will be mounted on a map display board to allow operator-selected display of the video cameras for condition assessment. One 13-in. monitor will be mounted on the control desk. Using a dedicated CCTV control panel, system operators can select which camera to view on which monitor and make adjustments on the remote video cameras. A video tape recorder will record special events or gather specific traffic information for traffic operations studies.

Motorist Information Service

Several prototype experiments are being developed worldwide to demonstrate the potential benefits of providing improved traffic information service to the general public and motorists before and en route to their final destination. In particular, several route guidance systems are being integrated to provide real-time traffic information using the dead-reckoning wheelbase, in-vehicle equipment, massive on-board digitized map storage, global position system, or automatic vehicle control systems. However, these complicated route guidance systems, traffic network optimization schemes, and the intelligent vehicle highway system (IVHS) will not be able to function properly without reliable and updated traffic data base information collected from the traffic control systems.

Besides the various traffic signal control functions currently being developed, the up-to-date traffic operating condition and system status data base will also provide the basic infrastructure for improving travel assistance information using techniques similar to the computerized weather network service currently available in the United States. The selected motorist travel assistance information network may include network travel time information, traffic loading conditions, network congested hot-spots, scheduled roadway maintenance locations, and current incident locations. The potential users may include control centers, other city departments, television and radio stations, traffic service agencies, major office complexes, individual motorists, and research agencies.

Based on the electronic bulletin board system (EBBS) concept, a graphics-based software system design can allow any potential user of the highway network, using a remote PC terminal emulation program to be supplied by the city or third-party software vendors, to log on the computer system, retrieve partitioned data bases, and examine remotely the system situation map and current network performance. Since only restricted and summarized data base information will be made public, users can access the small, extracted data base through the EBBS using the telephone modem dial-up, direct communication lines, or videotext method. With the availability of various communication media, such as telephone, cable news network, and cellular telephone, the user can examine the network traffic status and adjust route selection in advance or enroute to their final destination.

Control Center Interface

Since the 1980s, the Taiwan Area National Freeway Bureau and MOC have jointly developed a comprehensive, computerized freeway traffic surveillance, communication, and control (SC&C) system to manage the freeway system in the northern section between the Keelung and Yangme section of No. 1 Freeway. The initial system concentrated on traffic surveillance in the northern freeway corridors. An emergency phone network is being extended to the southern portion of the freeway system for continuous traffic monitoring along the entire freeway corridor. The control system will also be expanded to the second freeway and other interconnected expressway systems on the island of Formosa.

Traffic information systems are an integral element of the freeway corridor management system that includes driver information system, traffic surveillance, vehicle detectors, and incident management. The driver information system applies freeway guide signing, changeable message signs, and AM/FM radio. Through vehicle detectors, CCTV surveillance, and emergency telephone network, traffic surveillance provides needed traffic control for the northern portion of the western freeway corridor. Through reserved voice communication channels, traffic data communication display, and related changeable message displays, control center coordination will enable city traffic control systems and the freeway traffic surveillance center to share essential real-time traffic information, status display, and coordinate control strategies. The computerized traffic control system will also provide the needed media interface to relay vital traffic information and recommended actions to motorists during freeway incidents or urban congestion within the metropolitan area.

The city traffic control system and freeway bureau's traffic surveillance center will work together through the improved system communication and operational status display to improve the traffic information service within the Taipei metropolitan area. The freeway bureau is primarily responsible for the freeway system, and the traffic bureau handles the urban street system. The two systems will be coordinated to form a complete highway information system through reserved voice communication channels, traffic data communication displays, and related changeable message displays. Successful implementation will depend on close agency cooperation between the traffic control centers of these two operating agencies.

In addition to the freeway systems, several municipalities are also developing computerized traffic SC&C systems to support freeway corridor communication and control activities. Often, the freeway agencies will handle the freeway system and the city traffic engineering department will handle urban street system with separate control objectives. The initial system development primarily concentrates on upgrading the traffic surveillance capability in the urban arterial segment, but work is still under way to integrate available information and operational management related to the entire corridor. The success of this integrated computerized traffic information system depends heavily on improved communication and cooperation among various operating agencies through control center interface capability.

CONCLUSIONS AND RECOMMENDATIONS

Increasing mobility and traffic service are vital to the economic growth and well-being of any nation. Urban transportation systems contribute significantly to overall economic growth through improved work-force productivity, business investment patterns, international competitiveness, and economic growth. The rapid expansion of urban areas, along with increasing population concentration, automobile ownership, freeway network development, and infrastructure reconstruction, has resulted in urban congestion in many developing countries. To sustain long-term economic growth and international commercial development, the transportation infrastructure must be able to move people and goods efficiently from origin to destination with minimum traffic delays and vehicular stops. Successful operations depend on the coop-

eration of reliable field operational equipment, control hardware platform, system control software, operating strategies, and the rapid identification of any equipment malfunction to assist operators in making system improvements. For the city of Taipei, this means expanding the existing traffic control system.

The new design begins with a system control strategy developed to improve the arterial circulation capability of signals on the city's major arterials, then the minor arterials and collector streets, and finally the signal intersections in outlying suburban areas. Now being implemented, an open-architecture system design will enable new subsystems to be added to the existing computer system at a relatively low cost. With this modular design concept, all traffic signals in the city may be connected eventually to the centrally located, distributed-network, real-time control system. Unlike previous development efforts, extensive, on-the-job training and technology transfer were achieved by the development team approach throughout the system design and management process. Thus, once the central system framework is established, city forces and domestic manufacturers can be responsible for traffic operations and system maintenance and expand the system according to self-contained system specifications.

Computerized traffic responsive strategies are in the experimentation stage as the system is being integrated. Staff training, operational capability, and response philosophy will continuously be enhanced as more operational experience is obtained. Nevertheless, the overall traffic control environment, including the advanced hardware platform, integrated system software, and control strategy design, has already given the city the necessary basic building blocks adequate for long-range expansion. The implementation of this system integration approach will result in positive traffic management for the city of Taipei and for other similar developing countries to meet growing urban mobility needs and sustain economical growth well into the 21st century.

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