Conceptual Master Plan for High-Tech Traffic Management for Twenty-First Century New York City

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New York City will face increased traffic congestion unless improvements in traffic management are made. Implementable, feasible, and cost-effective solutions must focus on managing congestion, whether triggered by normal demand-capacity imbalance, temporary network constrictions that result from traffic incidents, or road work. Advances in computer applications in traffic management and the availability of inexpensive, sophisticated components make the use of high-tech traffic management systems a realistic option. In Europe and Japan, research and development on intelligent vehicle-highway systems has been conducted and is enthusiastically supported by cooperative government-industry programs. New York City has not kept up with trends in alleviating congestion. The New York City Department of Transportation believes that high-tech traffic management systems can be used to optimally allocate the existing capacity to meet growing traffic needs. A conceptual master plan was developed to lay out possible applications of computer technologies to meet traffic management needs toward the end of this century and into the twenty-first century in New York City.

The 1985 Manhattan Annual Hub-Bound Travel Survey *(1)* indicated that on a typical fall business day, approximately 3.3 million persons entered the Manhattan central business district (CBD), which is defined as that portion of Manhattan lying south of 60th Street. Public transportation carried 65 percent of the arrivals, while automobiles, taxicabs, and trucks carried the remaining 35 percent of the arrivals. The number of motor vehicles that entered CBD totaled approximately 780,000. The number of persons entering CBD daily has grown continuously and this upward trend is expected to continue into the twenty-first century.

Measures taken to alleviate traffic congestion on surface streets taken by the New York City Department of Transportation (NYCDOT) in the late 1960s included automating traffic signals *(2,3)*. The computerization was initiated with selected traffic signals in Queens; the program was then extended to Brooklyn, the Bronx, and Staten Island. The computerization of traffic signals in Manhattan was delayed because of the high concentration of signalized intersections in a small area, which required an elaborate, well-distributed communications network. The program was begun in late 1983 to improve traffic flow inside the borough by coordinating these traffic signals locally and centrally, and is expected to be completed by 1992 *(4)*. It is evident that the city must face the dire consequences of traffic congestion unless improvements in traffic management are made continuously. Traffic growth in New York City is expected to continue to outpace the growth in basic roadway traffic capacity. Therefore, implementable, feasible, and cost-effective solutions must focus on managing the congestion, whether the congestion is triggered by normal demand-capacity imbalance, temporary network constrictions resulting from traffic incidents, or road work. Advances in computer applications for traffic management and the development of inexpensive, sophisticated components make the use of high-tech traffic management systems a realistic option.

In Europe and Japan, research and development on high-tech traffic management has been conducted and is enthusiastically supported by cooperative government-industry programs *(5–7)*. New York City, despite its economic prominence in the world, has not caught up to trends in alleviating traffic congestion that are taking place in other large cities. The department thinks that high-tech traffic management systems can be applied to optimally allocate the existing capacity to meet the growing traffic needs. A conceptual master plan was developed to lay out possible applications of computer technologies to meet the traffic management needs toward the end of this century and into the twenty-first century in New York City.

The objectives of this paper are to: *(a)* summarize current efforts by NYCDOT to manage traffic inside the city, *(b)* summarize the conceptual traffic management master plan for New York City, and *(c)* suggest a time frame and conceptual cost estimates for the master plan.

CURRENT TRAFFIC MANAGEMENT SYSTEMS

The Traffic Control Operations Center and Communications Center of NYCDOT are the two facilities that exemplify the level of sophistication of the city's current traffic management technologies. The following four topics will now be discussed: *(a)* traffic signal control, *(b)* traffic monitoring and surveillance, *(c)* incident detection and information dissemination, and *(d)* integrated traffic information data base.

Traffic Signal Control

As of May 1990, there were 9,848 signalized intersections spread in the five boroughs of New York City *(4)*. Thirty-

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nine percent of these signalized intersections had been computerized by December 1989 by means of the signal computerization program of the Bureau of Traffic. Table 1 shows the breakdown of the total number of signals placed on-line to the vehicular traffic control system (VTCS). The remaining traffic signals are controlled by conventional electromechanical controllers.

Computerized traffic signals are connected to several main processors located at the Traffic Control Operations Center of the NYCDOT's Queens Plaza office, comprising the New York City VTCS. The advantage of this central control system is the two-way communication system that allows the traffic engineer to modify signal timing parameters from remote locations when the need arises. If any problem exists at a traffic signal, it is indicated by a light on the traffic signal display panel at the operations center, and a repair order will be sent immediately. Communication between the computerized traffic signal and the main processor is currently made through leased telephone lines. VTCS was first installed in Queens in 1968, and a total of 124 intersections were brought on-line in 1969. In 1977 VTCS was expanded to Brooklyn and the Bronx, and in 1988 to Staten Island *(3)*. By December 1989, a total of 3,073 traffic signals in these four boroughs were placed online *(4)*.

Computerization of traffic signals in Manhattan lagged behind the computerization of signals in the other four boroughs primarily because of the large number of signalized intersections in a small area (a total of 2,718 signals), which makes it difficult to add to the existing VTCS. (See Table 1.) A two-stage project was started in late 1983 as part of the Manhattan signal computerization program. The first stage was to lay down high-bandwidth coaxial cables between Manhattan's 2,710 selected traffic signals and the Central Traffic Control Center. The entire program is expected to be completed by 1992 *(3)*.

The ultimate goal of NYCDOT is to bring on-line some 8,000 selected traffic signals of the approximately 10,000 signals that exist and install 2,000 roadway sensors in the next few years *(3)*. In addition to the introduction of a new main processor for the Manhattan project, the main processors of the existing VTCS will be replaced with new ones. Every year, about 60 new traffic signals are added to the city's street system. A new system must, therefore, be flexible to accommodate continuous expansion.

Traffic Monitoring and Surveillance

Traffic monitoring and surveillance by NYCDOT are currently done by two means: traffic patrol cars and closed circuit televisions (CCTVs). Uniformed traffic patrol personnel have radio frequencies on which they can report traffic conditions and incidents, and their communication can be picked up by the Communications Center. They are also empowered to direct traffic at critical intersections when the need arises. CCTV cameras have been installed in selected places, but the number is still too few to perform citywide surveillance. CCTV cameras have also been placed at critical ramps of the Van Wyck Expressway, which leads to John F. Kennedy International Airport, the city's busiest airport.

Incident Detection and Information Dissemination

Incident detection and information dissemination are the primary tasks of the Communications Center, which is located in downtown Manhattan. The term "incident" means various events, ranging from an overturned tractor-trailer to a traffic signal malfunction. The Communications Center receives incident reports from several sources, including privately-owned Shadow Traffic Network and Metro Traffic Network. Other radio channels that the center monitors include frequencies used by personnel of the Bureau of Traffic, Bureau of Highways, and police radios. Incident information received by these sources is screened and decisions on incident mitigation are made by the center duty officers. Arterial traffic flow management is currently the main function of the center. Judgment, supported by years of experience of the center director and traffic personnel, is used to determine alternate routes when an incident necessitates areawide traffic rerouting. Incident information is provided to drivers through the media, primarily by the commercial radio and television broadcasting stations.

Other tasks performed by the center involve maintaining street and highway facilities, including the collection of information on defective traffic signals, roadway defects (pot holes, etc.), signs, and street lights. The center requests repairs directly from subcontractors and city agencies in charge. Two radio frequencies are reserved for communicating in-

TABLE 1 SUMMARY OF VTCS SYSTEM *(4)*

Borough	Signalized Intersections	Selected Intersections for Computerization	Completed for Computerization in the 1980s	Percent Completion 12/89
Brooklyn	3150	2205	1347	61%
Bronx	1450	947	461	49%
Queens	2200	1884	1041	55%
Staten Island	330	254	224	88%
Manhattan	2718	2710	50	2%
Total	9848	8000	3123	39%

formation about signal failures and loss or sign defects. Roadway defects are reported to the center first through Bureau of Highway radio frequencies. The center takes an inventory of repair requests and sends the repair orders back to the Bureau of Highways. The center is also in charge of the POTHOLE hot line after regular business hours. Similarly, sign repairs or replacement complaints are radioed to the center and work requests on these problems are sent to the Bureau of Highways.

As for the real-time traffic flow data collection and dissemination, the center's facility has not been developed to its full potential because of the lack of a citywide monitoring system to continuously monitor traffic flow at critical locations on highways. The installation of traffic sensors and closed circuit video systems needs to be made at critical points to resume this responsibility.

Integrated Traffic Information Data Base

NYCDOT has been developing a computerized traffic information system, which collects information from several sources and disseminates it to agencies that participate in the program. Traffic flow data from the traffic sensors is the primary source of information *(8)*. This system is called the Computerized Area Tracking System (CATS). CATS is not a traffic control system and it does not directly control traffic signals as VTCS does. Rather, it is a sophisticated communication system that will expedite the flow of information among the concerned agencies.

The primary purpose of CATS is to establish a centralized traffic information dissemination system for dynamic traffic management. It will have an interface with the city's VTCS. Information will be presented by text or by graphic display for dynamic, real-time information evaluation. The goal of the system is to assist in providing smoother traffic flow in the five boroughs of the city. On-line information on traffic conditions can also be presented to the media.

CATS' central computers are connected to color graphic terminals at participating agencies. Traffic information on streets and highways in the area is fed by inductive loop sensors and on-line traffic signals. In addition to these on-line facilities in the city, information is transmitted on-line from the sensors in the Queens portion of the INFORM system of the New York State Department of Transportation and from the Van Wyck Expressway surveillance system. Other information can be input by terminal operators (e.g., construction schedules, police enforcement and patrols, permit issuance, etc.). Data collected by closed circuit cameras can also be incorporated into the system.

Figure 1 shows the major functions of CATS. CATS consolidates information on construction and maintenance that take place on the streets and highways of the city. Permit consideration and issuance will be facilitated by CATS's on-

I. Construction Co-ordination and Maintenance

* Active Permit Management
* Special Permits - Parades
* Emergency Permits - Street Openings
* Status of Construction Sites
* Major Sites/Troubled Areas

II. Roadway Traffic Impediments Notification

* Lane Closures
* Route Selection/Diversion
* Detours - Planned and Unplanned
* Bus Lanes

III. Incident Management

* Display Troubled Areas
* Display Alternate Routes
* Clear Incident Site
* Manage Incident Team

IV. Traffic Flow Monitoring and Forecasting

* Sensor Data Vehicle Counts
* Planning Tool
* Day to Day Traffic Flow Changes
* Forecasting Traffic Problems

V. Public Information/Advisement

* Graphics/Text/Video Data
* Charts Showing Best Routes
* Traffic Incidents
* Street Closings

FIGURE 1 Major functions of CATS *(8)*.

line search capability. The status of construction sites and troublesome areas will be identified speedily. Information on traffic impediments in the street and highway system, such as lane closures and the existence of bus lanes will be located readily. Also, the task of detour route selection will become part of CATS. Troublesome areas will be shown on the display terminal and alternate routes will also be suggested. Information regarding the trouble spots will be transmitted to enforcement agencies to quicken the formation of incident management teams and to expedite the clearance of incident sites.

HIGH-TECH TRAFFIC MANAGEMENT MASTER PLAN

Basic technologies necessary for dynamic traffic management systems are already available in the market except for in-vehicle route guidance systems. Figure 2 summarizes the recommended high-tech system elements to meet the needs of increasing traffic in the twenty-first century in New York City. This table shows only the options that can be applied in New York City. It is not an exhaustive list of available and emerging technologies. Detailed discussions on the use of these high-tech options can be found in the final report of the conceptual master plan *(9)* or other references *(10–12)*.

This section covers the following primary areas of improvements particular to NYCDOT:

- Organization and responsibilities of the Traffic Control Operations Center and the Communications Center;
- Intra- and interagency communications;
- Traffic control of limited-access highways;
- Traffic control of surface streets;

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I.    Data Collection
      * Inductive loop traffic sensors
      * Closed circuit TV cameras (CCTV)
      * Highway traffic patrol and police
      * Emergency phones and cellular phones
      * Helicopters
      * Commercial traffic broadcasting networks
           (Shadow Traffic and METRONET)
      * NYCDOT radio frequencies
      * On-line traffic data exchange with other systems
           (INFORM, Port Authority, Triborough Bridge and
            Tunnel Authority, TRANSCOM)
      * CATS
      * VTCS
      * On-site mobile TV units

II.   On-line/Off-line Data Processing
      * Main-frame computer
      * Mini-computer
      * Workstations and Microcomputers

III.  Information Presentation and Traffic Control
      * Variable message sign (VMS)
      * Wide range radio broadcast
      * Emergency signal and short range broadcast
      * Ramp metering
      * Traffic signal coordination by the VTCS system
      * Actuated traffic signals
      * In-vehicle route guidance with traffic updating

IV.   Communication among Agencies and for Enforcement
      * Conventional telephones with hotlines
      * Teleconference
      * Video-conference
      *  In-vehicle navigator and/or vehicle locator for
           enforcement personel
      * In-vehicle data transmission to central database for
           vehicle information, scofflaws, etc.
      * Electronic mail

V.    Motorist Information Service
      * Publications (pamphlets, magazine and news articles)
      * Periodic news bulletins by radio and television
      * Traffic information by telephone and cellular phones
      * Facsimile traffic information subscription
      * Teletext
      *  Videotex (traffic and parking information, route
           guidance)
      * In-vehicle route guidance with broadcast updating
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FIGURE 2 Elements of NYCDOT high-tech traffic management.

- Tunnel and bridge traffic management;
- In-vehicle route guidance; and
- Incident management.

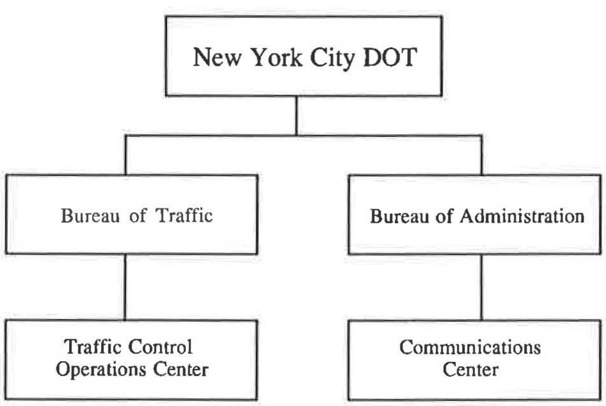
ORGANIZATION AND RESPONSIBILITIES

To meet the challenge of dynamic traffic management systems and to increase the capability of information dissemination to the motoring public in the twenty-first century, it is necessary to reorganize the roles of the existing Traffic Control Operations Center and Communications Center. Figure 3 shows the responsibilities of these organizations. The following defines their responsibilities.

Traffic Control Operations Center

The Traffic Control Operations Center will have direct control over traffic on surface streets and on limited-access highways in the city, from day-to-day operation to incident management. The center will have two control groups: one to control surface streets and the other to control limited-access highways. The term "limited-access highway" includes interstates, parkways, and expressways in this conceptual master plan.

Each group will have its own traffic control room because the characteristics of traffic and control procedures for these two groups are different. The focus of traffic control over a surface street signal network is the coordination of signals to achieve maximum flow through arterial roads in the network. Traffic control on limited-access highways, on the other hand, is concentrated on ramp metering, which regulates the entrance of vehicles to the main flow on the highways. During morning and afternoon peak periods and incidents, close coordination between the two control rooms will be needed. The control center will dispatch appropriate enforcement personnel.



* Traffic Control of limited access highways
* Traffic control of surface street networks
* Incident management
* Tunnel and bridge traffic management
* In - vehicle route guidance

* Publications
* Traffic news by telephone and cellular phone
* Facsimile traffic news subscription
* Teletext
* Videotext
* Short range emergency radio broadcast
* Parking management and availability guidance

FIGURE 3 Organization and responsibilities.

Communications Center

The Communications Center will concentrate on collection and dissemination of information to meet the needs of motorists. Incident management, which is currently included in the mission of the center, will be phased out and a new set of responsibilities will be added. The center will promptly disseminate information crucial to the motoring public through various means. Primary sources of traffic information for the Communications Center will come from the Traffic Control Operations Center. The Port Authority and the Triborough Bridge and Tunnel Authority will also be significant information sources.

The Communications Center will continue to serve as a clearing house for repair information and staff will coordinate repairs for the street and highway networks in the city. However, the traffic information and the repair coordination must be handled separately because information handling procedures for these two groups will be significantly different.

By these changes, the Communications Center will truly become a central information center, where drivers can get access to traffic information or report any infrastructure-related defects for immediate attention.

Traffic information, especially on incidents, is currently disseminated only through commercial radio. However, as the need for traffic information increases, the Communications Center should provide information through additional media. In line with the European and Japanese methods *(12,13)*, the following media will be planned for New York City: its own traffic related publications, newspapers and magazines, commercial radio and television stations, telephone, teletext, facsimile, videotex, short-range emergency radio broadcast, and parking availability guidance system.

Agency Communication Systems

The existing telephone system is not meeting the needs of agencies involved in incident management. It is essential to develop a communication system that allows the responsible agencies to communicate directly because incident management requires the cooperation of several city agencies and other outside agencies such as INFORM and TRANSCOM. The latter agency is a regional transportation consortium and an incident information clearing house in the New York-New Jersey metropolitan region. Directors of the incident management team should be able to talk simultaneously, despite the physical separation of their offices, to expedite their decision making toward the mitigation of incidents. To provide simultaneous participation of responsible personnel, agencies will be equipped with facilities for teleconference, video-conference, or both.

Traffic Control on Limited-Access Highways

Technologies for dynamic traffic control on limited-access highways are available and are widely used. A traffic control system for these highways consists of three parts: data collection, data processing, and information presentation. Added to these three components are the actual traffic control actions taken by the Traffic Control Operations Center and the advanced identification of alternate routes. Data collection will be made by inductive loops, CCTV, highway patrol, and when available, traffic observers from helicopters. Presentation of information will be made by variable message signs and short-range radios. Ramp metering will be used to control traffic entering limited-access highways.

Traffic Control on Surface Streets

VTCS will be the basis for a high-tech solution to traffic control on surface streets in the city. About 8,000 traffic signals in the city will be placed on-line with a set of new computers and new VTCS software. About 2,000 electronic sensors will be laid out for collecting information on traffic flow on surface streets *(3)*. CATS will be completed in the near future, and participants in the CATS information network can receive on-line traffic information that can be graphically displayed.

Tunnel and Bridge Traffic Management

The Port Authority and the Triborough Bridge and Tunnel Authority have their own traffic management systems. The information they collect should be made available to the Traffic Control Operations Center to smooth the transition from city streets to the tunnels and bridges for the drivers. Also, automatic toll collection systems are suggested as a method to reduce delays at bridge and tunnel toll gates.

In-Vehicle Route Guidance

The application of the in-vehicle route guidance system will be the last system element recommended in this conceptual master plan. This system can be applied in the early part of the twenty-first century. It is necessary for the in-vehicle guidance technologies to mature and gain popularity before they are implemented in New York City. It will be necessary to coordinate efforts among the traffic agencies in the metropolitan area to make this system attractive to motorists and cost-effective.

Incident Management

Incident management will be significantly improved once a fast communication system is installed, which allows NYCDOT to identify the extent and duration of an incident, make estimates of effects on the surrounding network, and disseminate accurate incident information to drivers. This fast communication system will be backed by data acquisition, data analysis, centralized traffic control, and reliable information dissemination systems. It will consist of five components: *(a)* detection of incidents, *(b)* dispatch of enforcement, *(c)* emergency radio broadcast, *(d)* on-site TV communication, and *(e)* diversion of traffic.

IMPLEMENTATION STRATEGY AND TIMING

Figure 4 presents a suggested time frame for introducing high-tech traffic management systems to the twenty-first century New York City. This figure shows the suggested target years (darkened square dots) and the periods of preparation (lines preceding the square dots). This entire program can be split into three five-year stages. All the systems except the in-vehicle route guidance system could be completed by 2000. Despite anticipated difficulties in applying in-vehicle route guidance, this system is expected to be the state-of-the-art of traffic control in the next century *(14)*.

The first task of NYCDOT to implement the high-tech traffic management systems will be the reorganization of the Traffic Control Operations Center and the Communications Center, which needs to be completed by 1992 or 1993 before the direct communication facilities are installed. The direct communication facilities will be completed within the first five years of system implementation. Facilities to house the two traffic control rooms of the Traffic Control Operations Center and the new Communications Center will be completed by 1995.

The modernization of VTCS is expected to be completed and operational by the end of 1992. By the end of 1995, the traffic management systems for surface street networks will be completed.

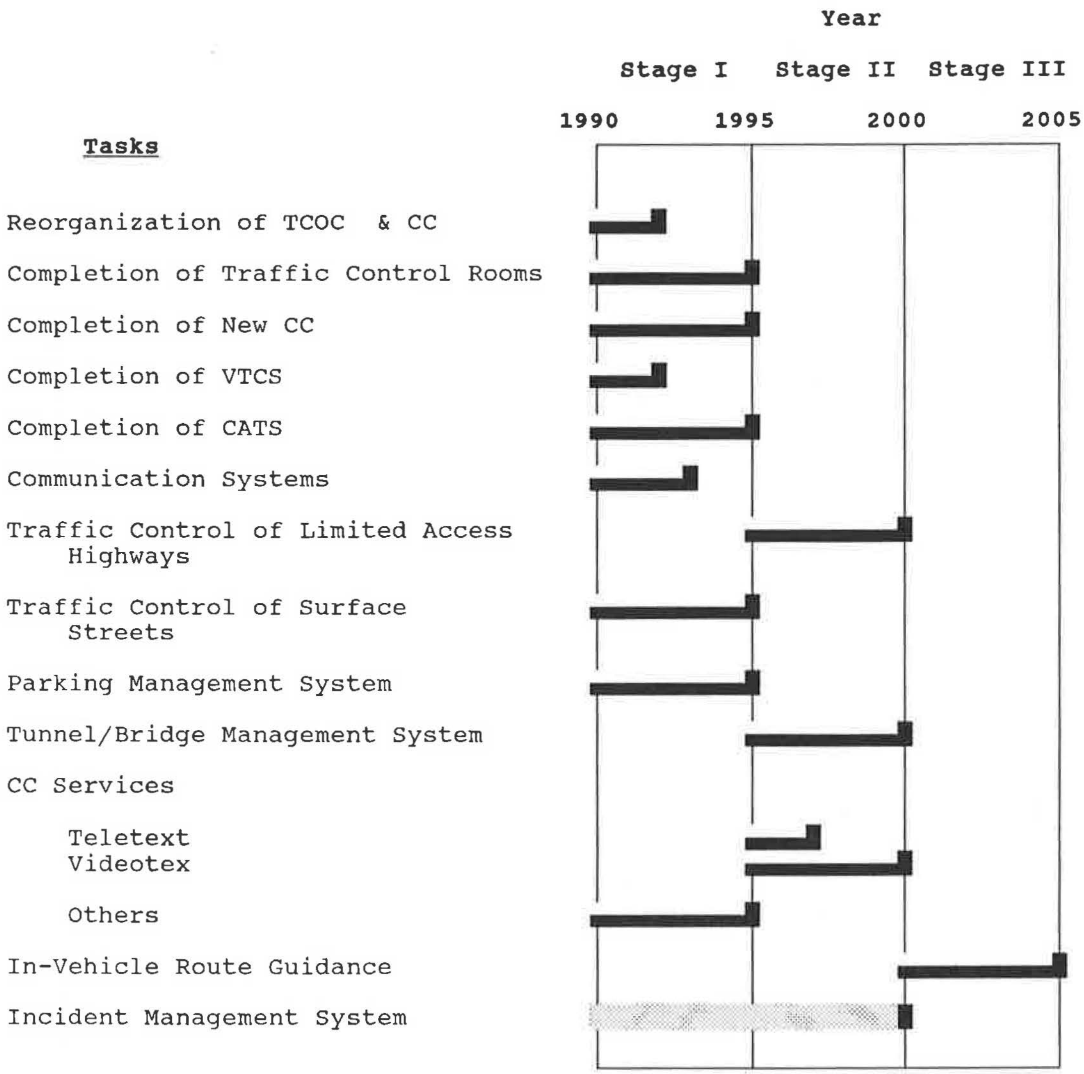
CATS is expected to be fully operational by 1995. This system will become the source of traffic information and the basis for many real-time services provided by the Communications Center. The parking management system can be added to CATS and made operational in the same period.

Upon completion of the facilities and systems, implementation of the traffic control system of limited-access highways will commence. During the same period, coordination of traffic management systems with the Port Authority and the Triborough Bridge and Tunnel Authority will begin. The system for high-tech oriented toll facilities at bridges and tunnels will also be completed.

Upgrading motorist services provided by the Communications Center can begin immediately. Such motorist services as publications, traffic news bulletins on radio and television, traffic inquiry by telephone and by facsimile subscription will be started in the first five years. Teletext and videotex services require a complete and operational data base to provide real-time information on traffic. These services will be made available in the second five years.

The incident management system will be developed gradually during the ten years before 2000, upon completion of other individual elements. The completion of on-line data acquisition, processing, and presentation systems and the installation of new communication systems will be essential to begin a fully developed incident management system. Nevertheless, searching for detour routes during emergencies by expert systems can be started during the first five years.

Motorist information systems will be improved during the second five years. By the time the application of in-vehicle guidance systems is scheduled to begin (in the beginning of the next century), hardware for these systems is expected to be substantially improved and their popularity to increase. Also, by that time, it is expected that other agencies in the New York City metropolitan area will show interest in co-



Notes: 1. TCOC = Traffic Control Operations Center
2. CC = Communications Center
3. VTCS = Vehicle Traffic Control Systems
4. CATS = Computerized Area Tracking System

FIGURE 4 Time frame to implement high-tech traffic management systems.

ordinating the application of such systems in the area. All communication systems will be completed by year 2000, making the addition of in-vehicle route guidance more feasible for the city than at present.

CONCEPTUAL COST ESTIMATES

The conceptual cost estimates of the high-tech master plan were developed by examining the costs of the INFORM system in Long Island (Contegni, unpublished data), the Smart Corridor Demonstration Program of Los Angeles *(15)*, and records of the existing freeway management systems as summarized by Sumner, et al. *(16)*. Costs were adjusted to 1990 dollars using the Means' building construction cost indices *(17)*. Detailed discussion of the procedure to estimate conceptual costs can be found in the final report of this conceptual master plan *(9)*. Note that the following conceptual cost estimate was made assuming that most of the limited-access highways in the city would be covered by the high-tech corridor management system discussed in this paper. If a smaller-scale program is adopted, the funding requirements for this component of the conceptual cost will become less than the amount shown in Table 2.

The conceptual costs shown in Table 2 consist of three components:

- Capital costs,
- Implementation costs, and
- Annual operations and maintenance costs.

TABLE 2 CONCEPTUAL COST ESTIMATES OF THE HIGH-TECH MASTER PLAN (IN MILLIONS OF DOLLARS)

Cost Component		Conceptual Cost Estimates (1990 Price)
Capital Costs		
Traffic Operations Control Center (Two control rooms)		$6.0
Communications Center		$3.0
Surface Street Signal Systems, including VTCS and CATS		$85.2*
All others including: Control of limited-access highways, Parking management, bridge/tunnel management, incident management, and facility for in-vehicle guidance		$307.0
Subtotal of capital costs		$402.1
Adjustments for errors	40% extra	$562.0
	10% less	$361.0
Subtotal of capital costs with inflation (10%)		**$397.0 to $618.0**
Implementation Costs		
Approx. 45 percent of capital costs		$163.0 to $253.0
Implementation costs with inflation (10%)		$179.0 to $278.0
Total Capital and Implementation Cost		$524.0 to $815.0
With 10 % Inflation		**$576.0 to $896.0**
Annual Operations and Maintenance Costs		
Approx. 10 percent of capital costs		$36.0 to $56.0
With 10 % inflation		**$40.0 to $62.0**

Note: * - $85.2 million had been requested under the VTCS expansion project (Reference 8).

Because the presented in Table 2 were made using a small sample, adjustments were made to account for possible errors. An error range of +40 percent and −10 percent were chosen arbitrarily. Considering the uncertainty in inflation and cost overruns associated with new ventures, such a wide margin of error may be acceptable. This is a range that can be used for a level 1 accuracy in construction management to estimate conceptual costs *(18)*.

Estimates for the two traffic control rooms and the communications center were developed on the basis of the costs for the operations centers and the communications centers of the INFORM system and the Smart Corridor project. Both the INFORM and Smart Corridor systems required about $2.5 million for purchasing equipment. An additional expenditure is necessary to prepare for a control room. In total, an estimate of $3.0 million to prepare each control room would be a fair estimate. Upgrading the Communications Center would require a similar amount of money; thus $3.0 million was used as an estimate.

The cost estimate of the surface street signal system was developed on the basis of a previous report on the expansion of VTCS and the development of CATS *(8)*. No effort was made to update the total $85.2 million since it had been already requested as an VTCS expansion program. This cost was kept in the table to estimate implementation, operations, and maintenance costs. All other capital costs were grouped into one cost group. This cost group includes equipment needed for dynamic traffic control of limited-access highways, parking management, tunnel and bridge management, incident management, and in-vehicle route guidance systems. At best, only a rough estimate can be made because of the limited number of sample cases that currently have a dynamic traffic corridor management system coupled with a route guidance system. A unit cost for this group was computed in millions of dollars per center line mile of the corridor to be affected, using the information obtained from INFORM, Smart Corridor, and the other freeway management systems mentioned previously *(9)*. A unit cost for this portion of the capital was estimated to be about $1.874 million per center line mile of the corridor. About 164 centerline miles of limited-access highways in New York City were assumed to be covered by this high-tech traffic management system. Therefore, the conceptual cost estimate of this portion totals $307.0 million.

The implementation costs were estimated using the cost estimates developed for the Smart Corridor system. The ratio of the total implementation costs to the total capital costs was about 45 percent for the Smart Corridor system. Implementation costs consisted of design, construction, contingency, installation, and so forth.

The annual operations and maintenance costs were estimated by rule of thumb to be between 10 percent and 12 percent of the capital costs.

The capital costs of the system elements in this conceptual master plan totaled approximately $402.1 million in January 1990 prices. Applying the error adjustments, total capital costs would be between $361 million and $562 million. When implementation costs are added to the capital costs, total system costs range from $524 million to $815 million. The estimated annual operations and maintenance costs range from $36 million to $56 million.

A 10 percent inflation adjustment was made because the master plan recommends a fifteen-year program. The capital and implementation costs total about $576 million to $896 million. Surface street signal system costs of $85.2 million are subtracted. About $40 million to $62 million will be needed for the annual operations and maintenance costs.

COST-EFFECTIVENESS

To fully develop the high-tech options included in this report, capital investments will be substantial. However, benefits derived from the successful application of the system's advanced features can be quantified in many areas. First, the effective management of chronic congestion through coordinated traffic signals on surface street networks and metering ramps on limited-access highways can substantially reduce excessive stops and delays, thus reducing air pollution and increasing fuel savings. Second, the loss of work hours can be reduced and stress felt by commuters can be lessened, thus effecting higher productivity at the work place.

Motorists will be better informed because of the high-tech options in the master plan, and it is believed that such information on the causes and solutions to traffic problems will help commuters feel assured. Also, the speed of incident removal will be accelerated, thus reducing the time to restore normal traffic flow after an incident. Drivers will be given more timely and accurate information, options to cope with incidents, and erroneous information can be avoided.

Applications of some high-tech traffic control equipment have already proved beneficial to the city. For instance, it was reported that benefits of computerizing traffic signals using the VTCS in New York City have been substantial. The annual savings per intersection based on the 1,900 computerized traffic signals was determined to be about $20,000, and the initial investment was recovered within 12 months after VTCS installation *(3)*. When the scheduled 8,000 traffic signals are computerized, an annual savings of about $160 million can be realized by VTCS alone. The coordination of traffic signals also contributed substantially to the reduction of vehicle emissions *(2)*. Besides the savings from VTCS, savings will be gained by managing traffic flow on limited-access highways. The money will be well spent to provide better traffic conditions and improve environmental quality.

SUMMARY

Traffic management systems are probably the only way left to deal with ever-growing vehicular traffic in New York City. Motorists may accept the fact that streets and highways in New York City are chronically congested; however, at the same time, they desire to have congestion lightened by any means available. As the supplier of traffic systems in the city, NYCDOT is obliged to prepare for the traffic of the coming century. This is a formidable challenge. However, there will always be ways to use the existing network more efficiently. The key to success are fast communication systems and using computer technologies in parts of the traffic management system.

Some work has already been initiated, such as the Manhattan traffic signal computerization program and the CATS information system. It is urgent that these programs be completed as they were planned so that the city will be able to apply high-tech solutions to growing traffic congestion problems on the city's street and highway systems.

The conceptual master plan presented here includes options that can be applied in the city by the turn of this century. In the final 10 years of this century, United States and foreign automobile manufacturers will exert unprecedented effort toward developing intelligent vehicles. To meet the demand of drivers who possess intelligent vehicles, it is essential for New York City to be prepared. The elements of high-tech options discussed in this conceptual master plan are intended to build the information network and the powerful information analysis systems to facilitate the transition to a full application of intelligent vehicles-intelligent highway systems by the turn of this century.

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