

Human Factors in the Design of Displays for Traffic Operations Control Centers

by

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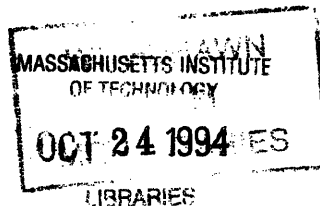
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THOMAS CHIH-HSING CHAO

Submitted to the Department of Mechanical Engineering on August 5, 1994 in partial fulfillment of the requirements for the Degree of Master of Science in Mechanical Engineering

ABSTRACT

Concept demonstrations were designed for the user interfaces of the traffic operations control center for the Central Artery/Tunnel (CA/T), a massive project to construct an extensive highway-tunnel system underneath the city of Boston scheduled to become operational by the year 2010. Reviews of the CA/T Integrated Project Control System (IPCS) system design documents were conducted from the human factors engineering perspective. The conceptual user interface utilizes multiple windows and graphical user interface concepts similar to the Microsoft Windows® operating systems as well as the X-windows for UNIX workstations. The review of the IPCS system design document revealed several human factors issues in the design of display panels to be discussed in this thesis. Experiments were conducted on navigation within the map display, multiple-dimensional coding for displaying traffic flow information, and symbols for control buttons. The result of the first experiment shows that the direct-pointing technique for map navigation results in a response time that is one-third of the response time using the scroll bar navigation method while the result of the second experiment shows that the multiple-dimensional coding technique for displaying traffic flow conditions results in a 50% reduction of response time compared with the response time of a more conventional bar-chart display. The experiment on the symbols for control buttons suggests a modified choice of symbols and icons for the user interface.

Thesis Supervisor : Professor Thomas B. Sheridan
Title : Professor of Engineering and Applied Psychology and
Professor of Aeronautics and Astronautics

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A journey. This acknowledgement is a record of the people that I met during my stay at MIT, a part of a journey that I am taking, a journey that starts on the day I was born and ends on the day I fade into oblivion. To romanticize the feelings about this journey, I would like to consider this part of the journey as a journey in the night. There are moments of jubilation, moments of despair, moments of celebrations and moments of loneliness in this journey in the night. Like stars in the night-time sky, these people not only have guided me through this part of the journey but have also alleviated the loneliness during the journey. And as I engrave these words onto this record underneath the twinkling eyes of a mid-July night, I began with these thoughts.

First of all, I would like to thank my family because without my family's support and sacrifice, it would not have been possible for me to come to MIT. And throughout my days at MIT, my family has provided continuous financial and emotional support to my endeavors and crazy ideas across the continental United States and the vastness of the Pacific Ocean. During my days of despair, they comforted me with their encouraging words and during my days of joy, they shared my pride and happiness. Especially, I would like to dedicate this thesis to my mother, Mrs. Chin-Hsiu Chou Chao, who has endured more than nine years of separation with my father to provide me with a comfortable and caring environment so that I can afford to concentrate on my studies instead of worrying about mundane trivialities.

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As Apollo drives his golden chariot from the eastern sky during his routine morning stroll, the veil of the night begin to fade. And as a new day, hence a new chapter in my life, begins, I am filled with cheerful memories of all the stars that has accompanied me throughout this journey in the night. Just like the stars are always present even in bright daylights, I know they will always be there for me and I thank them.

Thomas C. Chao

at Corporate Beach,
Cape Cod, Massachusetts

5:00 a.m., July 14, 1994

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Section 1. Introduction

1.A. Overview of the Central Artery/Tunnel Project

The Central Artery/Tunnel (CA/T) Project is a massive underground highway network being constructed to pass underneath the city of Boston (see Figure 1). In the north-south direction, the Central Artery (Interstate Highway I-93) itself extends from the southern end of Boston until Charlestown, while in the east-west direction, the tunnel starts at the junction of Mass. Pike (Interstate Highway I-90) and the Central Artery, and includes a Seaport Access Highway, the Third Harbor Tunnel and a new section of the Mass. Pike which ends at Boston's Logan International Airport.

In addition to being an impressive underground highway network, the Central Artery/Tunnel Project is also an example of an Intelligent Vehicle-Highway System (IVHS). For example, within the CA/T traffic system, there are more than 400 video cameras and approximately 200 loop detectors simultaneously monitoring the traffic flow conditions while an array of other sensor systems and environmental control equipment, including smoke detectors, hydrocarbon detectors, carbon monoxide detectors, fire control equipment, and ventilation systems monitoring and controlling the environment within the CA/T system to prevent the environment from posing health or safety hazards to the travelers inside the traffic system. Furthermore, various communication devices such as highway advisory radios (HAR), lane use signs (LUS), variable message signs (VMS), and variable speed limit signs (VSLS) are located throughout the tunnel to inform the motorists of the traffic conditions and to suggest alternate courses of action if necessary. To assist in the clearing of incidents, there are emergency response teams equipped with various emergency vehicles and devices located within or near the CA/T system.

At the heart of this massive system is the traffic control operators in the traffic Operations Control Center (OCC): each traffic control operator sits in front of a control console with two computer

monitors and six video camera monitors, in addition to the single large wall-mounted display screen visible to all operators.

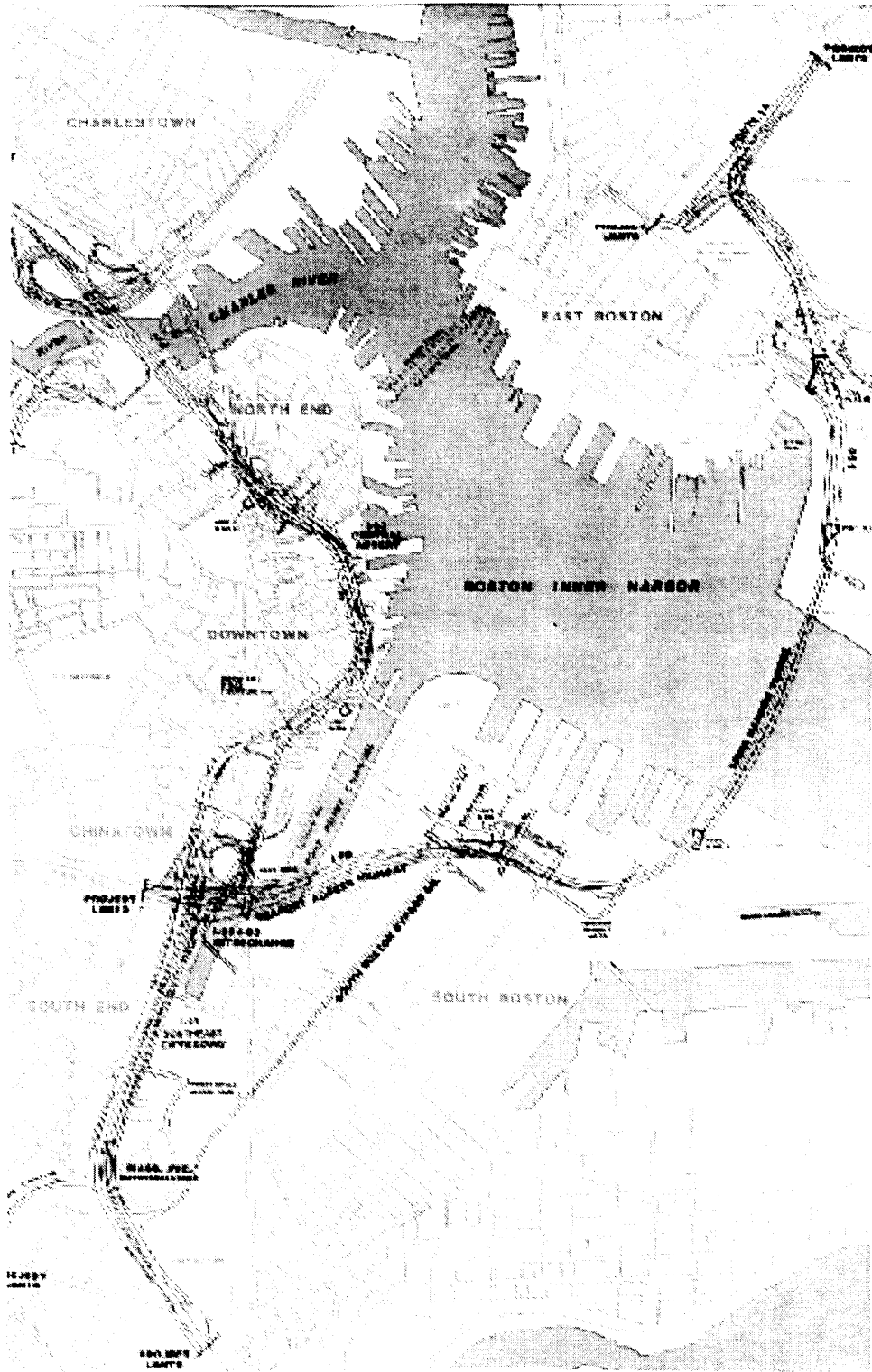


Figure 1. Project Overview of the Central Artery/Tunnel Traffic System

1.B. Display for Incident Management

Based on the current rate of traffic growth, which doubles the amount of traffic flow every twenty years, it is anticipated that the CA/T system may have to accommodate approximately 380,000 cars per day by the time the CA/T system becomes operational in 2010. Without a good incident management plan and procedures, an incident in the traffic system, whether expected or not, could potentially cause major delays in the traffic system. Major traffic jams and delays not only cause senseless waste of time and possible loss of revenue for the city and the businesses in the community, but most importantly, they pose unnecessary health and safety risks for the occupants of vehicles traveling in the traffic system because of inhalations of carbon monoxide and other harmful emissions. Therefore, it is imperative that appropriate procedures for incident management enable the operators of the CA/T traffic operations control center to detect the locations of incidents and to clear the incident sites in the most expeditious way.

Consequently, the importance of display design for incident management cannot be overstressed. With the massive amount of information collected and actions performed by all of the various types of sensors, devices and emergency response crews mentioned above, as well as the sheer number of these system components and the associated management tasks, any traffic control operator can be overloaded very quickly. In addition, where multiple incidents occur simultaneously, the operator can easily be confused unless an appropriate user interface is used. The goal of a well designed user interface for a traffic operations control center, thus, is to minimize the response time of the traffic control operator, to reduce the potential for errors, and to reduce the workload of the traffic controllers.

1.C. Some Previous Work in the Area of Display Design for Incident Management

A brief historical survey of some work in the area of display design for incident management includes applications in display design for nuclear power plants, the traffic control center of Long Island Expressway (LIE) in Long Island, New York, and the computerized display of Transport Québec in Canada.

Perhaps more than any other industrial applications, nuclear power plants are often cited as examples of incident management because of their inherent complexity and because of the disastrous consequences of even a minor incident. Since most nuclear power plants in the United States were constructed prior to the mid-1970s, their control panels and displays are dominated by conventional, single-purpose analog displays and digital readings such as dials, lights, switches, counters, tapes, etc (see Figure 2). Typically, the numbers of instruments in one of these control rooms could easily exceed 5,000. When the now notorious Three-mile Island reactor accident occurred in the late 1970s, with many lights and alarms activated simultaneously, the operators in the control room were attempting to determine the exact cause of the problem, to decide the best course of the action, and to monitor the situation throughout the entire incident. And the rest is history.

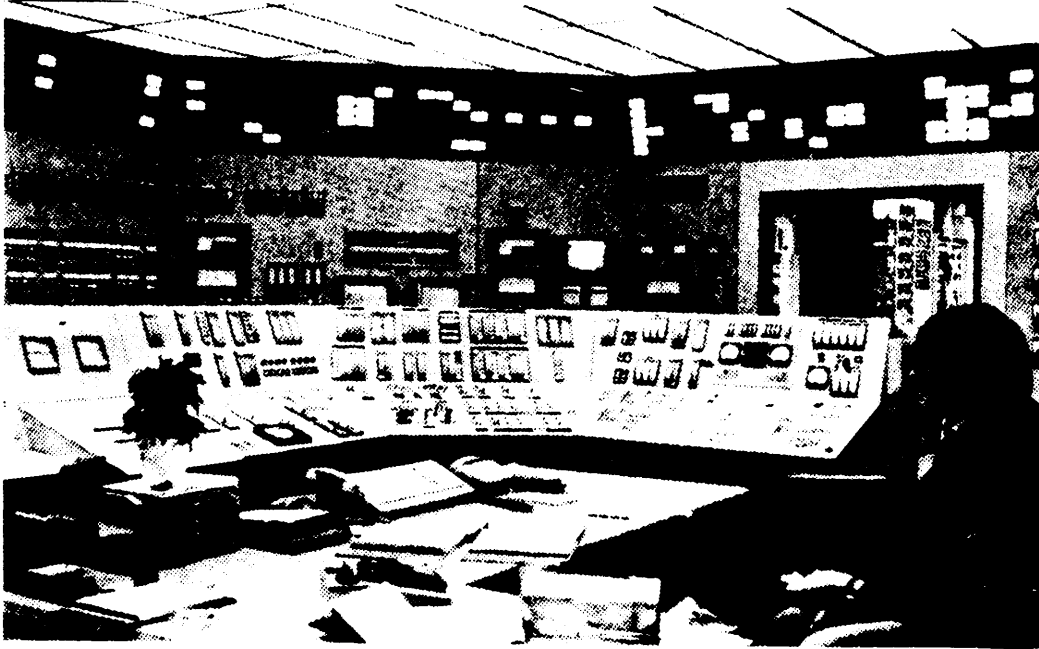


Figure 2. Interior of a Nuclear Power Plant Control Room [14]

Although much less complex than a nuclear power plant control room, many modern traffic operations control centers are still filled with analog instruments and digital indicators although most of these instruments have now assumed a new form as alphanumeric displays on a CRT display. For example, in the traffic control room of the Long Island Expressway (LIE, I-495) in Long Island, New York, which became operational in the early 1980s, there is a fixed map located on one wall with light emitting diodes (LEDs) fixed along various points on the map to indicate whether or not the traffic volume or speed has exceeded a preset threshold (Figure 3). Variable message signs, sensor detection thresholds, device status monitoring functions, camera control functions, etc. are displayed on computer terminals as text display menus (Figure 4) with the camera control functions coupled to a joystick input device. In order to access the information or to control the settings of a particular device, the operator has to go through a series of menus and to

type the associated identification numbers of the device. In the heat of multiple-traffic incidents, this input method is not only cumbersome but also probably error-prone.



Figure 3. Fixed Wall Mounted Map Display of LIE (I-495) Control Center

In the late 1980s, with the advances in computing power and availability of high-resolution visual display terminal (VDT) displays for workstations, graphical user interfaces for traffic operations control became a reality. One example of such an application is the Transport Québec project in Canada, which incorporates a graphical user interface for the control of surveillance cameras and messaging systems, and the analysis of sensor data in the Decarie interchange in Montreal. The Transport Québec project uses multiple-window display, similar in concept to the X-window, to display a variety of information on the same screen: for example, various sensor data such as a time plot of traffic data, an integrated camera control panel, and a window displaying the image from a selected camera, are displayed over the background of the display, which is a map of the

Decarie intersection. While the Transport Québec project represents a quantum leap over previous generations of display designs for traffic operations control center and is one of the forerunners in the international IVHS effort, the project is less complex than the Central Artery/Tunnel project because of the inherent environmental control problems associated with CA/T's underground tunnels and because of the fact that the sheer number of devices to be controlled in the CA/T project far exceeds those in the Transport Québec project. Nevertheless, the Canadian project can be considered as a good reference when designing future traffic operations control center.

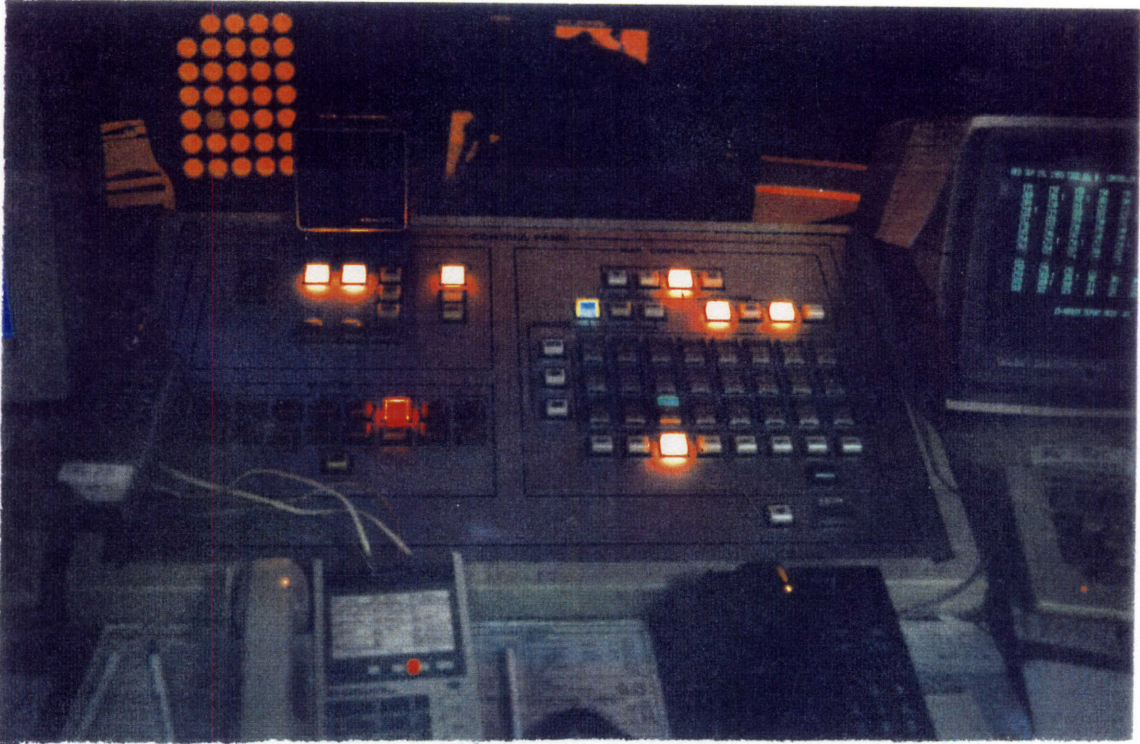


Figure 4. Control Panels and Alphanumeric Display (Right Side of the Photo) of LIE Control Room

1.D. The Organization of the Thesis

This thesis is divided into two major parts. The first part, which includes Sections 2, 3, and 4, is devoted mainly to the design aspect of the research effort. Section 2 describes an integrated map and device display and an experiment on the techniques to move around the map display. Section 3 presents two different approaches to display traffic density and speed on the map display and an experiment comparing these two methods. Section 4 discusses some other issues on display design such as a camera control panel, a predictor display added to a time-history plot of traffic or environment conditions, and the choices of icons. The second part, which includes only Section 5, focuses on issues raised following a comprehensive review of the Central Artery/Tunnel system design document.

Section 2. Map and Device Display and Map Navigation

Map displays are important to the design of graphical user interfaces for traffic control operation because the operator needs to be aware of the geographic relationships between system devices, sensors, the locations of incidents, and appropriate agencies responsible for the clearing of the incidents.

2.A. Integrated Map and Device Display

The integrated map and device display (IMDD) includes the following features: a main map display area, a reference map, navigation control scroll bars, a zoom control scroll bar, and a set of device and information display buttons (Figures 5, 6, and 7). Additionally, the operator has the ability to control some devices by direct selection of the devices on the map.

The main map display area is where the map of the project is displayed. This map contains the database for all major geographical features, highways, tunnels, relevant surface street accesses, ramps, buildings, locations of sensors, messaging devices, environment control equipment, and other system or subsystem components related to the project. At the lowest zoom level, the map is displayed in its entirety, while at higher zoom level only part of the map is displayed. At the upper left side of the main map display there is a reference map whose size does not change; associated with this is a rectangular outline whose proportions correspond to those of the main map display area. The relative size of the rectangular outline with respect to the overall size of the reference map provides the operator with a qualitative sense of the zooming factor while the location of the rectangular outline indicates the part of the map being displayed in the main map display area.

In order to navigate around the map, the operator has a choice of one of two methods. One of the map navigation methods employs the conventional technique of using scroll bars located at the

edges of the reference map display. By moving the scroll bar in either the horizontal or the vertical axis, the operator can move the rectangular outline within the reference map to change the part of the map to be displayed. The second technique of map navigation requires the operator to simply point the mouse cursor anywhere on the reference map area and click the mouse button. The rectangular outline, and hence the part of the map being viewed, will then be centered at that point. Alternatively, the operator can also click and drag the rectangular outline to the desired location.

The zooming control of the map is located at the left side of the reference map. To change the zooming factor, the operator moves the scroll button along the scroll bar. It should be noted here that both the zooming control and the navigation controls can be manipulated in a continuous manner. Following the convention of stimulus compatibility, when the operator pushes the scroll button to the top of the scroll bar, the maximum zoom factor is achieved; when the operator drags the scroll button to the bottom of the scroll bar, the minimum zoom factor is obtained.

Located underneath the navigation and zooming control panels is a set of device and information display buttons. By clicking on and off these buttons, information regarding traffic conditions or system device status can be displayed and/or controlled. For some devices which have simple controls, the operator can directly manipulate the settings of the devices on the main map display area. For example, the lane use sign (LUS) has three mutually exclusive settings: green arrow (meaning that it is all right to drive in a particular lane), yellow arrow (meaning that the driver should be prepared to change lane), and red X (meaning that the driver should not be driving in that lane). In order to display the settings of the LUSs, the operator can click on the LUS button in the control panel (see Figure 7) to enable the display of the locations and the settings of the LUSs on the map. Should the operator wish to change the settings of the LUSs, he/she only needs to click directly on the LUS of interest to cycle through the three states described above.

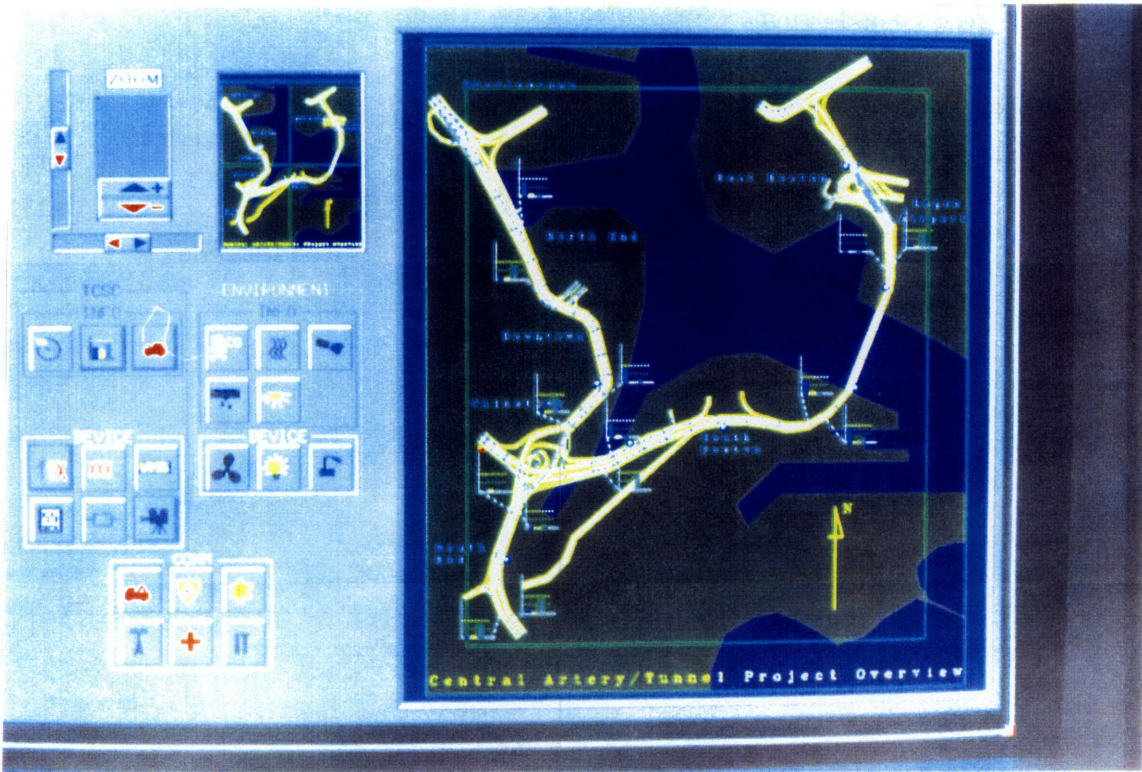


Figure 5. The Integrated Map/Device Display (Unzoomed)

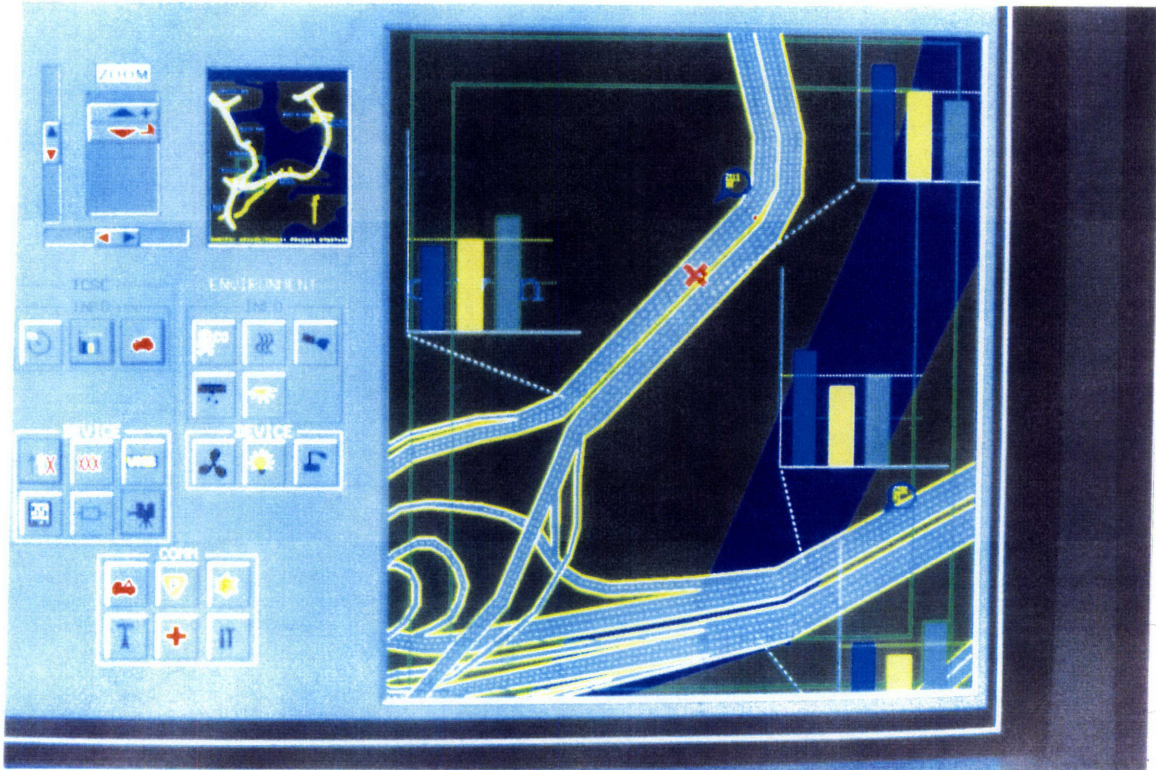


Figure 6. The Integrated Map/Device Display (Zoomed)

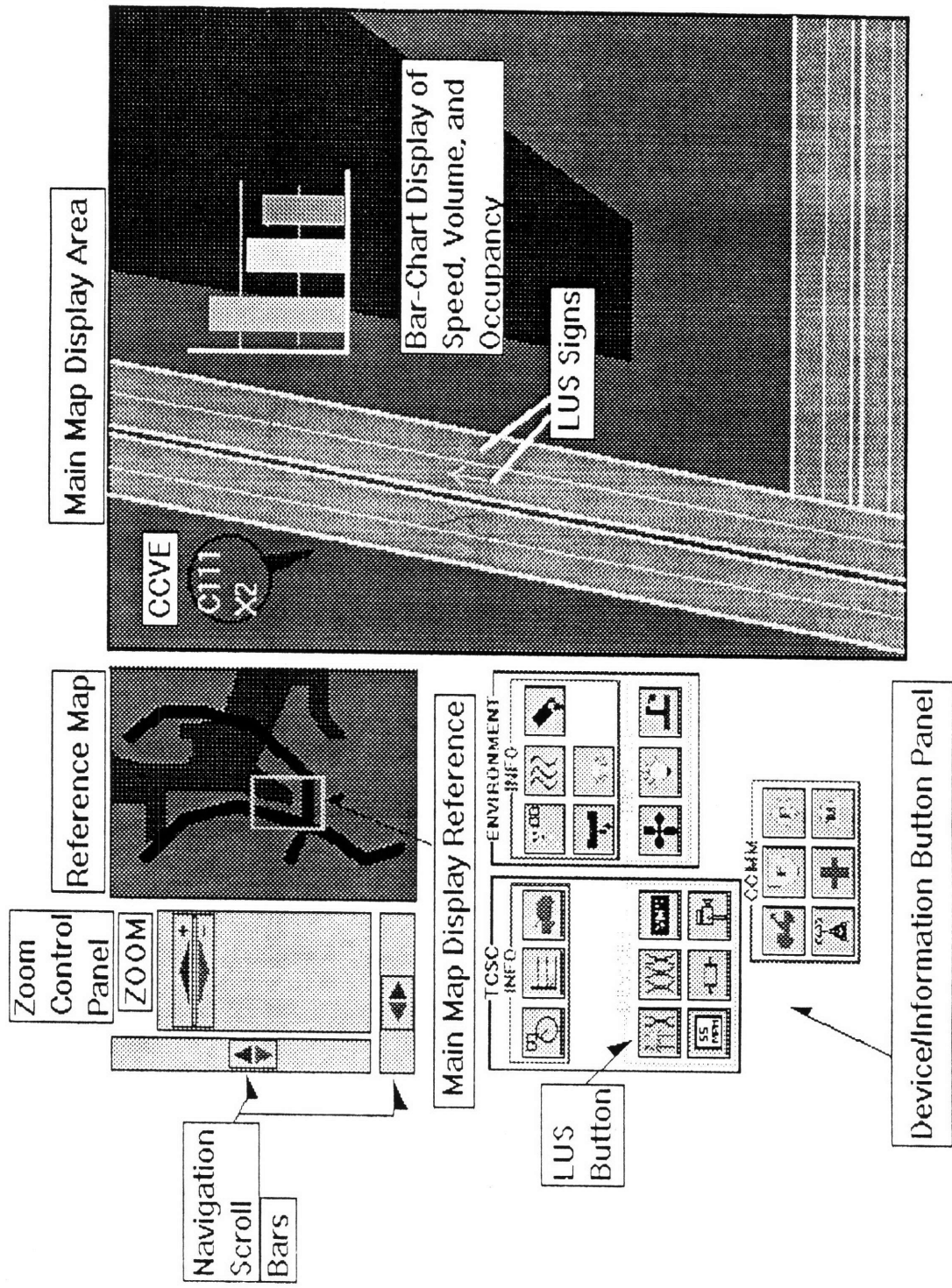


Figure 7. The Integrated Map/Device Display with Explanation and Legends

2.B. The Experiment Comparing of Response Times for Two Types of Map Navigation Methods

Problem Statement: One problem experienced by some video game players is that when they change their view point of a map from one zoomed section of the map to another zoomed section, the players sometimes cannot find the target area because they lose their perspective of the big picture. This problem could be waiting for future operators of the Central Artery/Tunnel Operations Control Center. Therefore, this study investigates the techniques that people employ to move from one zoomed section of a map to another. As mentioned in the previous section, there are primarily two types of map navigation methods: navigation by point-and-click in the reference map and navigation by scroll bars. The following experiment investigates the response times for these two schemes.

Experiment: In the first part of this experiment, the subjects were presented with a display panel (see Figure 8) which included nineteen buttons numbered from one to nineteen, a reference map with scroll bars, and a main map display area. At the beginning of each set of the experiment, the subjects were asked to reset the rectangular box to the upper left hand corner of the reference map. After the subjects pressed one of the nineteen buttons, an X would appear in the reference map at a random location. The goal was to move the rectangle in the reference map, which corresponds to the view point and the zoom factor displayed in the map display area, such that the X appears in the middle of the map display area. For the first ten buttons pressed, the subjects were to use the point-and-click navigation method and for the second nine buttons pressed, the subjects were to use the scroll-bar-dragging method. The response time was measured from the time that the X first appeared in the reference map to the time that the X was in the middle of the map display area. Three MIT mechanical engineering graduate students were used as subjects of this experiment. All of these subjects were fairly familiar with the operations of mouse and the standard Microsoft Windows® scroll bars. Each subject was given one sample test for each navigation technique for

the orientation. With each subject performing approximately ten trials for each map navigation technique, there are 28 data points for navigation using the scroll bars and 30 data points for navigation using the point-and-click method.

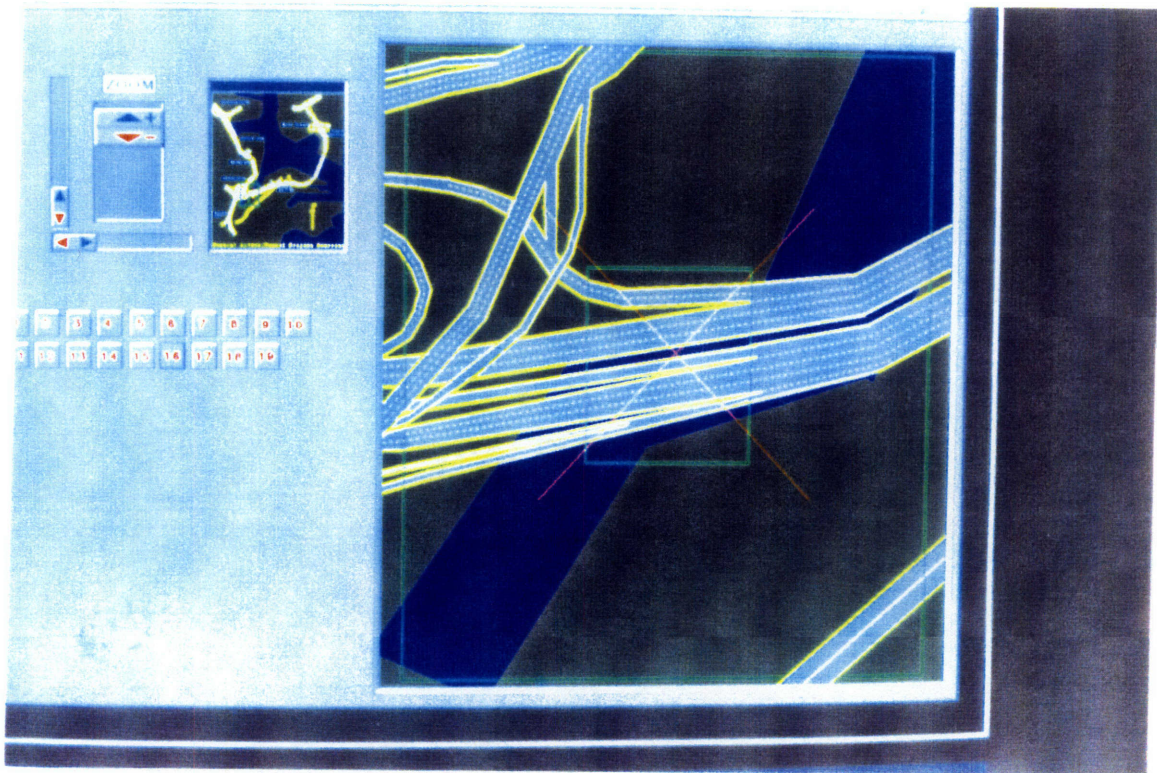


Figure 8. Experimental Setup for the Navigation Method Experiment (Zoomed)

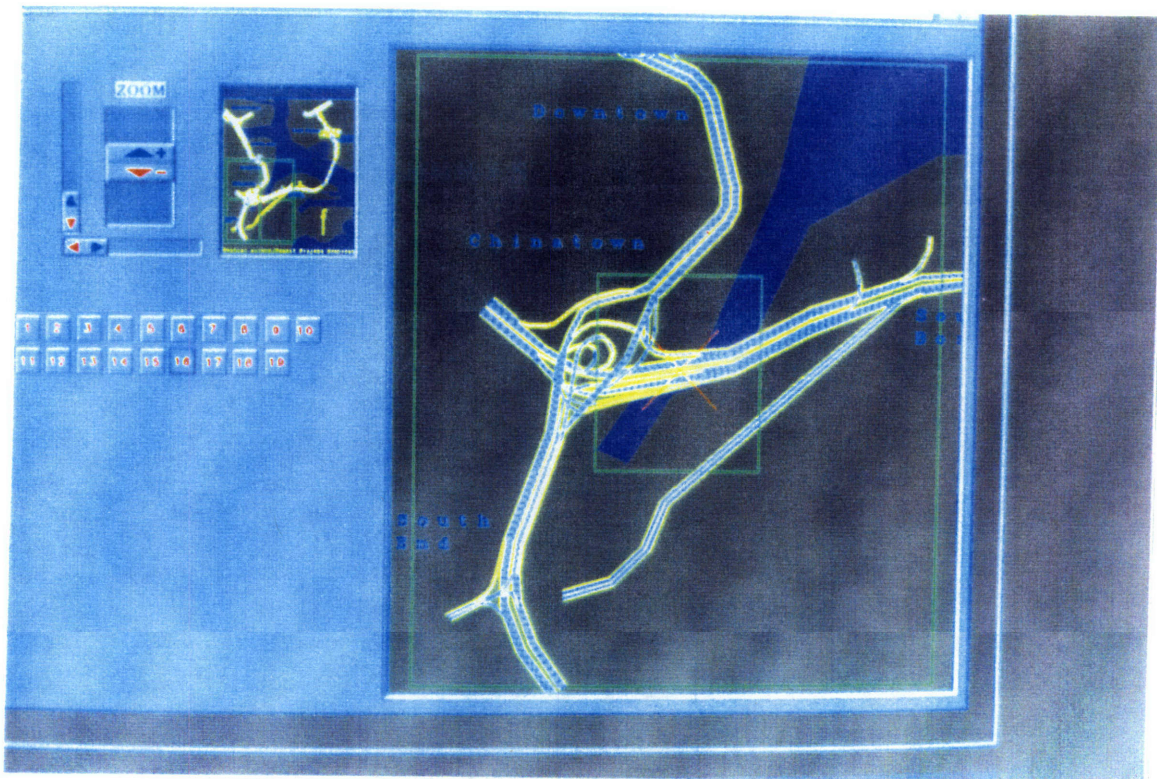


Figure 8A. Experimental Setup for the Navigation Method Experiment (Unzoomed)

Results and Discussion: The distribution of response times for this experiment is shown in Figure 9. The average response time (with 30 data points) of navigating using the point-and-click technique is 5.00 second with a standard deviation of 2.57 seconds while the average response time (with 28 data points) of navigating using the scroll-bar-dragging method is 12.52 seconds with a standard deviation of 3.77 seconds. Note that the area of motion in both cases is the same size of a 20-inch TV screen. Using a "t" test (simple difference of means test adjusted for small sample size), it can be concluded, with greater than 99.5 % confidence level, that the point-and-click technique represents a significant improvement of response time over the scroll-bar-dragging technique. One might hypothesize that the average response time of the scroll-bar-dragging technique is about two times that of the point-and-click technique because the two-axis motion of

scroll-bar-dragging is replaced by the one-axis motion of point-and-click. Any remaining difference can probably be explained by the movement from the x-direction scroll bar to the y-direction scroll bar.

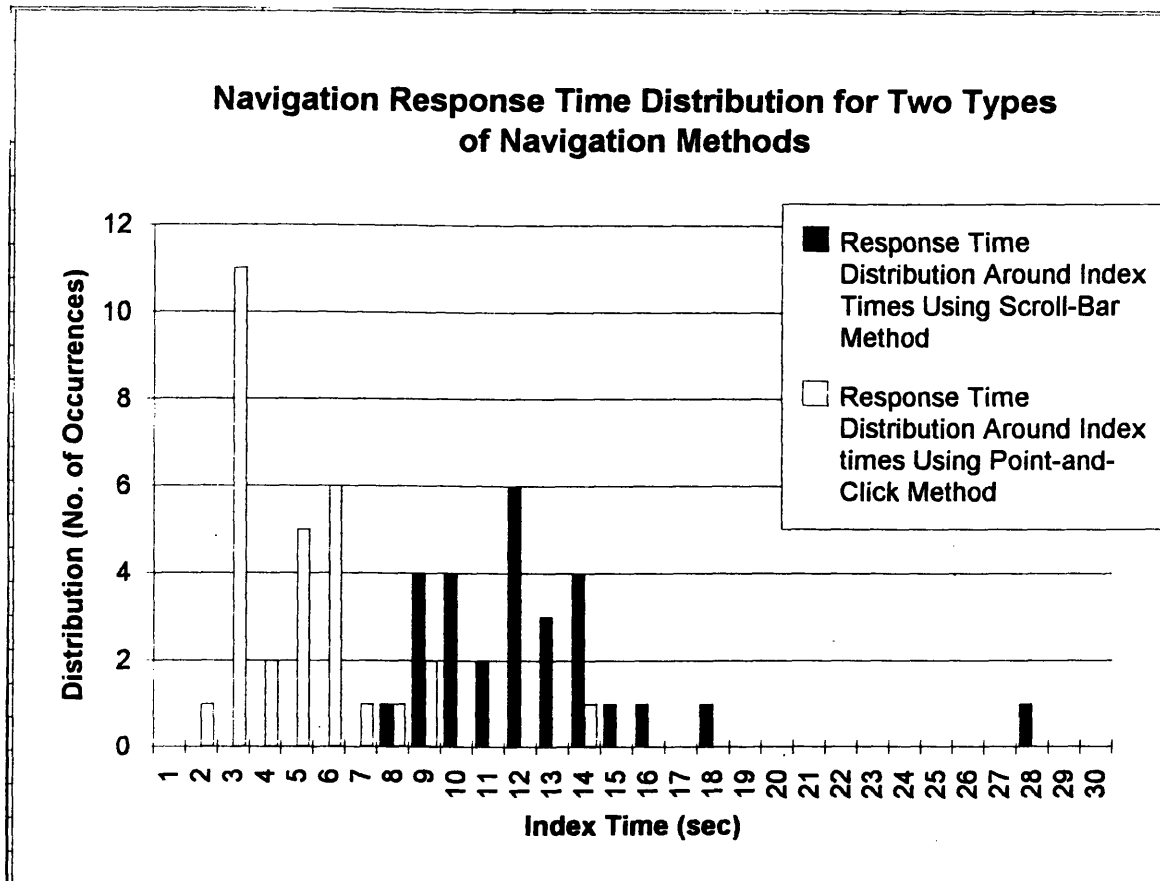


Figure 9. Navigation Response Time Distribution

Section 3. Occupancy and Speed Display

The original design specification requires a display capable of conveying the information of traffic occupancy and speed. Since occupancy is defined as the number of vehicles in a given length of the highway, occupancy is actually a measurement of traffic density. In addition, the traffic speed is defined as average speed of vehicles within a section of the highway.

3.A. Design of Occupancy and Speed Display

Two methods for displaying traffic flow information have been considered: the first scheme uses a bar-chart display to display the traffic speed and occupancy independently as bars of various length and colors, while the second method uses moving dots of various densities, colors, and speeds to indicate both the speed and the occupancy simultaneously.

The Bar-Chart Occupancy and Speed Display

The bar-chart display uses the threshold lines on the chart and the color of the bar to give quick qualitative references regarding the level of alert. Since both the occupancy and speed bars share the same threshold lines, both of the displayed information are normalized to provide qualitative information only (See Figure 10). For example, a green occupancy bar staying below the lower threshold line indicates that the occupancy is currently low; a yellow occupancy bar reaching between the lower and the higher threshold lines indicates that the occupancy is at medium level; and a red occupancy bar reaching above the higher threshold line means that the occupancy is high. Using similar techniques, a green speed bar reaching above the higher threshold line implies that the traffic speed is high; a yellow speed bar between the higher and the lower threshold line means that the traffic speed is at medium level; and a red speed bar staying below the lower threshold line indicates that the traffic speed is low. Astute readers should notice that the coloring schemes differ between the speed bar and occupancy bar. For example, while the color red implies that the condition is undesirable, this color is associated with the longest bar for occupancy display but the

shortest bar for speed display. This apparent contradictory use of the color is actually caused by the nature of information displayed: high occupancy and low speed are both undesirable. For a large number of these bar charts to be displayed simultaneously, such a technique is not only time-consuming but error-prone as well.

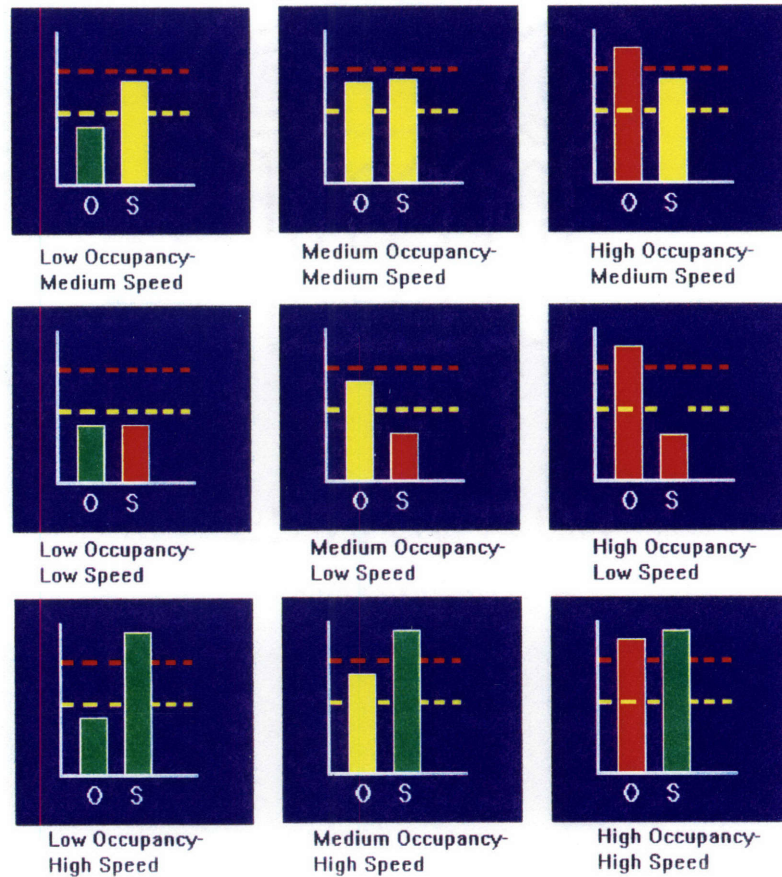


Figure 10. Various Combination of Traffic Speed and Occupancy Using Bar-Chart Display

The Moving-Dot Occupancy and Speed Display

The moving-dot occupancy and speed display uses the density and the speed of the moving dots to indicate both the occupancy and the speed of the traffic simultaneously (Figure 11). In practice, the entire highway system is divided into several display sections which contain moving dots of various densities and colors. The directions of the moving dots are the same as the directions of the traffic,

while the densities, speed and colors of the dots are determined from data collected by sensors located throughout sections of the highway system and are updated from time to time. The density of the dots indicates the occupancy of the traffic while the speed of the dots displays the speed of the traffic. In addition, to complement the speed of the moving dots, color is used as a secondary coding for speed display. For example, a section of the traffic system displayed by red, slow, medium-density moving dots signifies that the speed of the traffic is slow and the occupancy is at medium level while a section of the traffic system displayed by green, fast, high-density moving dots implies that the speed of the traffic is fast and the density is high.

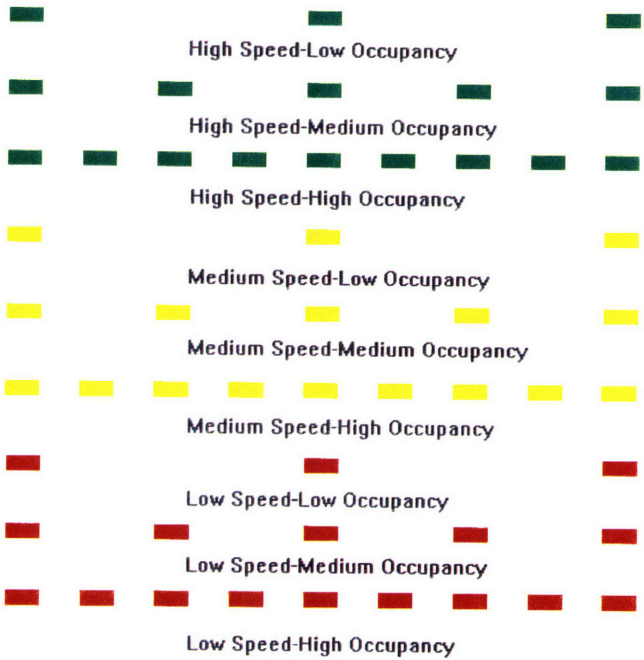


Figure 11. Various Combination of Traffic Speed and Occupancy Using Moving-Dot Display

Color coding can also be used to back up the occupancy display instead of the speed. In fact, during the development stage of the concept demonstration, demonstration displays of color coding for speed and for occupancy were designed and compared. However, after several preference

surveys, it has been concluded that color coding for density causes more confusion than color coding for speed; hence, it is recommended that color coding be used as a backup for the speed display.

3.B. The Experiment Comparing the Response Times for Detection of Incidents Using Two Types of Occupancy and Speed Displays

Problem Statement: This problem arises from the requirement that the operators of the Central Artery/Tunnel Operations Control Center must routinely scan the overall system for occupancy and traffic flow speed at various sections of the system,. Displaying two types of information within the same geometric space is a challenge. The main goal of this experiment was, therefore, to study the two aforementioned types of displays that satisfy these requirements concurrently and to compare the performances of these two methods in terms of the required time to correctly identify the location of an incident.

Experiment: At the beginning of this experiment, the subject was asked to choose a set of traffic conditions for the Central Artery/Tunnel Project to be displayed from a menu located at the upper left hand corner of the screen. The traffic conditions were randomly generated so that there was only one incident site in any set of traffic conditions. A traffic incident was, in the context of this experiment, defined as the location where the average traffic speed is the lowest and the average occupancy is the highest. As soon as the subject had selected the set of traffic conditions to be displayed, the menu disappeared and the traffic conditions appeared. The goal of the subject was, therefore, to locate the incident site and to move the mouse to it. The response time was measured from the time that the traffic conditions were first presented to the time that the mouse cursor was at the incident site. The two types of displays mentioned in Section 3A were used to present the traffic conditions: the first type utilized the conventional bar charts located along sections of the highways (Figure 12) with marked threshold lines to indicate whether either the traffic flow speed

or the occupancy was above the preset threshold limits; the second type employed moving dots of various densities and speeds (see Figure 13) to display the same information (see Section 3A). Three MIT mechanical engineering graduate students participated in the experiment: only one subject was relatively familiar with the bar-chart display and some types of color-code display for traffic speed while the other two subjects had no prior exposures to either type of display. Despite the differences in their backgrounds, the results of these three subjects were similar. Each subject was given one sample of each type of display for orientation. With each subject performed approximately 19 trials with each display method, 59 data points were collected for the bar-chart display's response time while 57 data points were collected for the moving-dot display's response time.

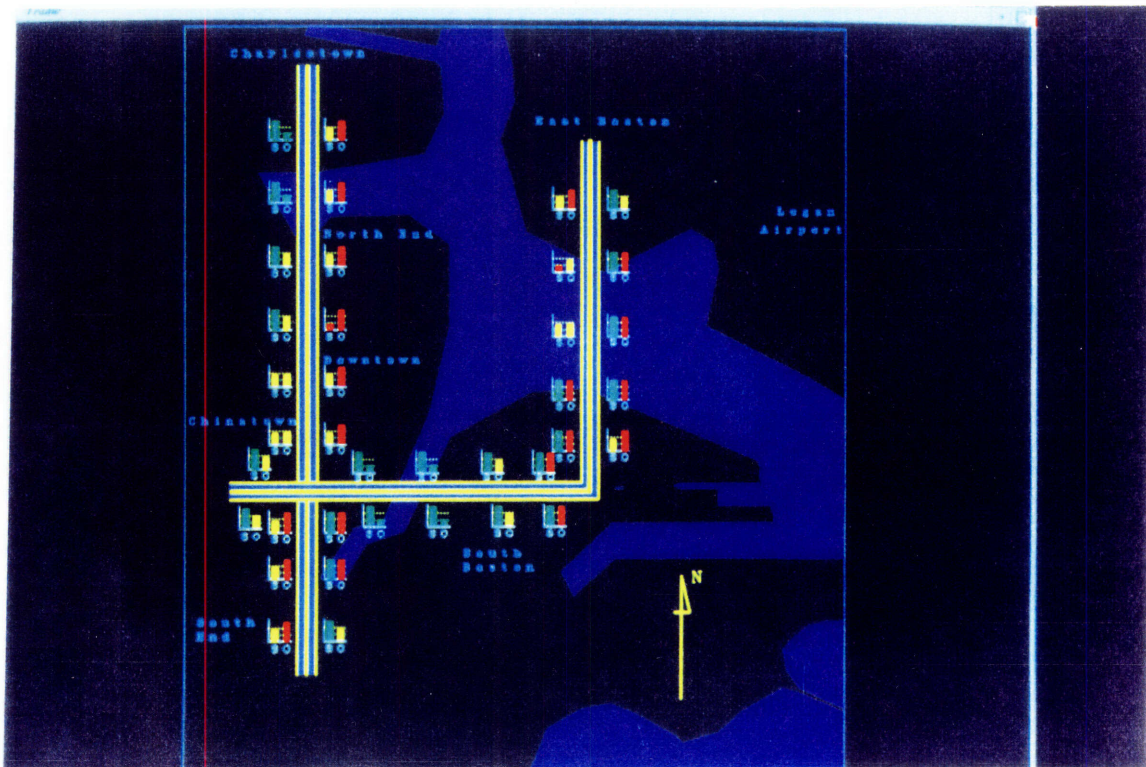


Figure 12. Experimental Setup of Bar-Chart Display for Traffic Conditions

Results and Discussion: The graph of the response time in Figure 14 shows the number of occurrences for each response time range versus the response time range. The average response time (with 57 data points) of the moving-dot display is 1.43 seconds with a standard deviation of 0.42 seconds while the response time (with 58 data points) of the bar-chart display is 2.89 seconds with a standard deviation of 1.69 seconds. Based on a simple statistical difference of means test, it can be concluded, with greater than 99.9 % confidence level, that the moving-dot display's average response time is significantly less than that of the bar-chart display. Since the range of movement is approximately the same for both display types, it is hypothesized that the difference between the response is mainly the time needed to recognize the patterns from the displays. Therefore, it can be assumed that the moving-dot display requires less time, in general, for locating incidents with the traffic system compared with the bar-chart display.

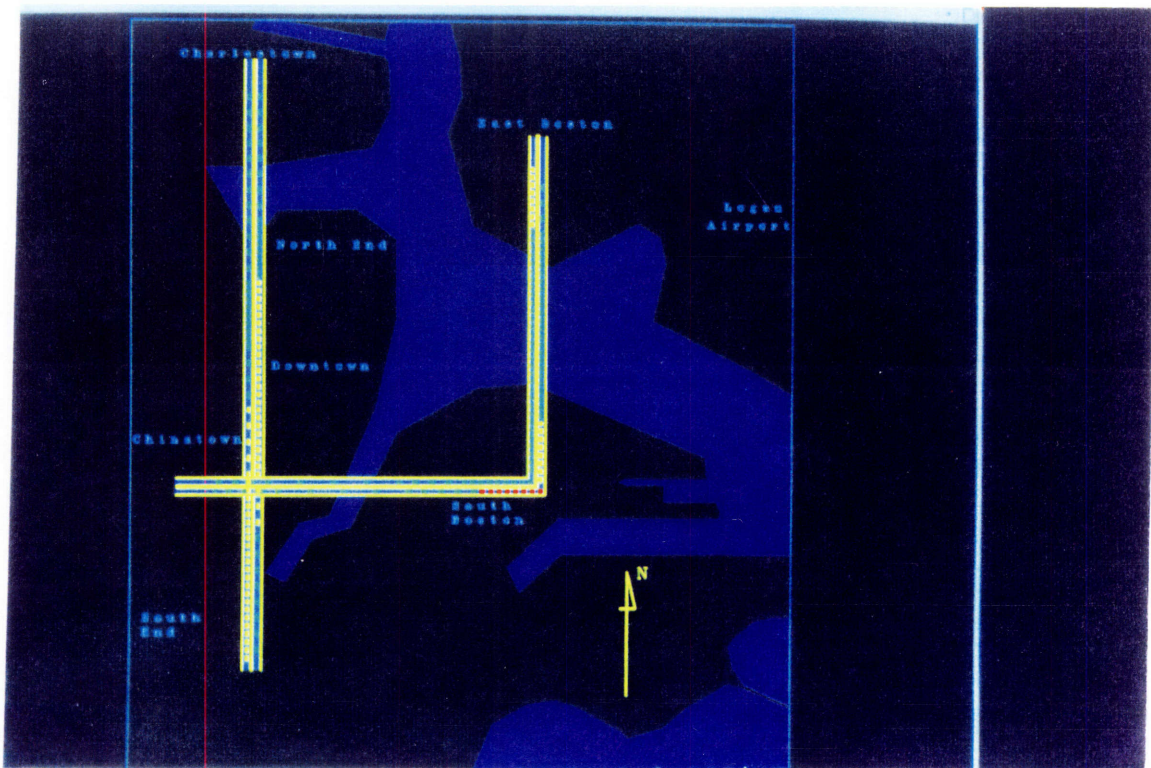


Figure 13. Experimental Setup of Moving-Dot Display for Traffic Conditions

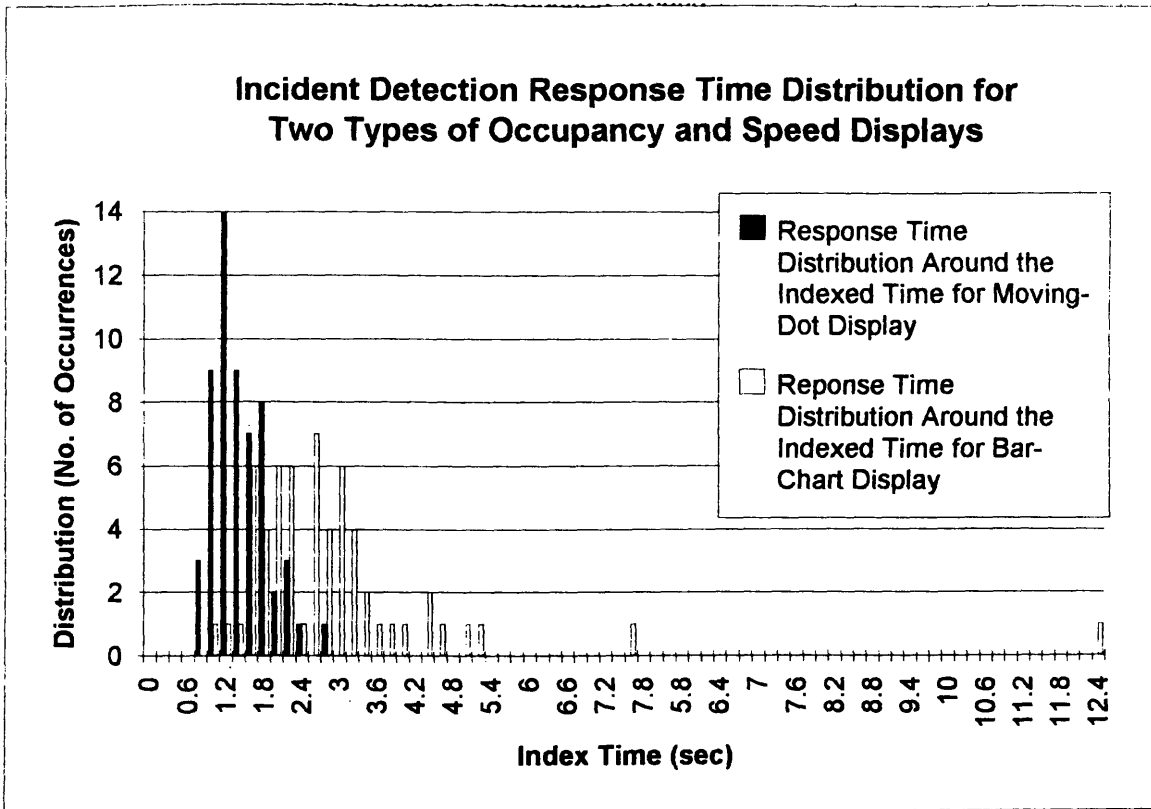


Figure 14. Incident Detection Response Time Distribution

Section 4. Miscellaneous Issues on Display Designs

Additional work in the area of display designs for the Central Artery/Tunnel Project includes a Camera Control Display panel, a predictor display for carbon monoxide concentration levels, and an experiment on the selection of icons and symbols to represent various subsystem and system equipment.

4.A. Camera Control Display

The camera control display (CCD) includes a reference map, a map display area and a set of zooming and map navigation scroll bars identical to those in the Integrated Map and Device Display (see Section 3A) with the exception that the map display area is now moved to the lower left-hand region of the camera control display (see Figure 15). In addition, there is a set of camera-to-monitor correspondence display (CMCD) and a image display window, located underneath the camera-to-monitor correspondence display along with a set of pan, tilt, and zoom (PTZ) control panel.

The main purpose of the map display area is to display the locations of the video cameras and their status. For example, a red circle with a pointing arrow indicates that the particular camera is malfunctioning while a blue circle with an arrow indicates that the camera is operating normally (the arrow indicates the direction at which the camera is aimed in the pan direction). Furthermore, within each circle, the first row of index displays the identification number of the camera (e.g., C111 means "Camera No. 111") and the second row of index displays the zooming factor (e.g., X4 means that the image is magnified at four times the default size). And once again, the reference map provides the operator with information regarding the relative size and location of the part of the map displayed in the map display area.

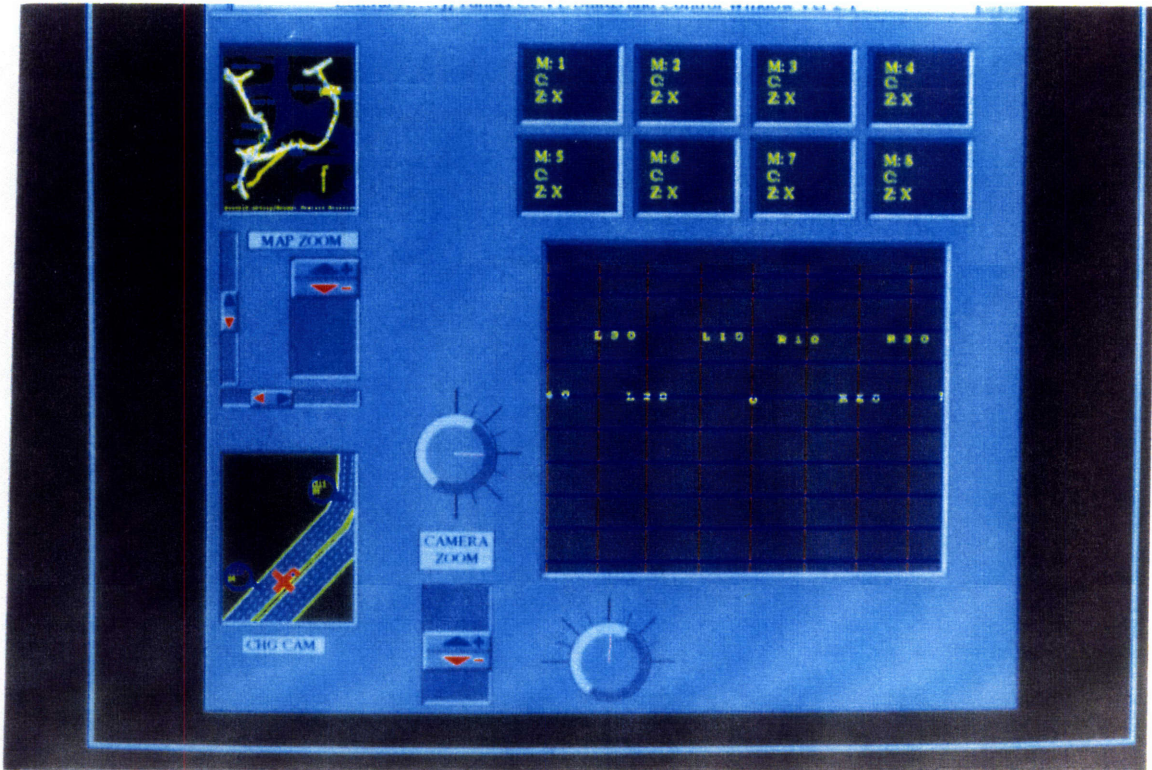


Figure 15. Camera Control Display

(Note: The image display window's grids are to test the inputs of pan, tilt, and zoom commands. The pan control is at the right of the CAMERA ZOOM scroll bar and the tilt control is above the CAMERA ZOOM scroll bar)

The second function of the map display area is to provide the operator with an interface to select and control the cameras whose images are to be displayed on the overhead monitors located in front of the operator's consoles. By double-clicking the camera on the map display area and then selecting the monitor on the camera-to-monitor correspondence display, the selected monitor is made to display the image from the selected camera. It is necessary, however, to note that the image of the camera is not actually displayed on the camera-to-monitor correspondence display,

only the information regarding the identification of the camera and the display monitor is displayed. For example, one of the monitors in the CMCD may display the following information:

M: 2

C: C123

Z: X4.

The displayed information can be interpreted as the following: Monitor Two is displaying the image from Camera C123 at a zooming factor of 4.

In order to control the camera, the operator first double-clicks the camera and then use the PTZ control panel to adjust the panning (right and left), tilting (up and down), and zooming motions of the camera. To pan the camera in the horizontal direction, the operator uses the Pan Adjust knob; to tilt the camera in the vertical plane, the operator uses the Tilt Adjust knob; and to change the zoom factor, the operator slides the Zooming Scroll Bar. These controls are designed to preserve directional compatibility. The Pan Adjust and the Tilt Adjust knobs are made to rotate in the same ranges as the motion range limit of the video camera. Maximum magnification is achieved by pushing the Zooming Scroll Button to the top of the scroll bar, and minimum magnification is achieved by dragging the Zoom Scroll Button to the bottom of the scroll bar. Once the camera has been selected, the image from the camera is immediately displayed in the image display window to provide the operator with feedback. Finally, the operator double-clicks the camera again to deselect the camera. The operator may then select another camera and send a motion command input to the newly selected camera. Alternatively, the operator may change the image currently displayed on the monitors by selecting the monitor on the CMCD. For example, to adjust the image from Camera C123 displayed on Monitor Three, the operator only needs to select Monitor Three from the CMCD and then uses the PTZ controls to adjust the image and then select Monitor Three again to

terminate the control inputs. The motion of Camera C123 is automatically controlled by the command sent.

4.B. Local Carbon Monoxide Concentration Display

The local carbon monoxide concentration display (LCOD) (see Figure 16) presents the carbon monoxide concentration level at one section of the highway system at a time. The LCOD displays both a time history of the carbon monoxide and a predictor display of the projected carbon monoxide concentration at various times in the future.

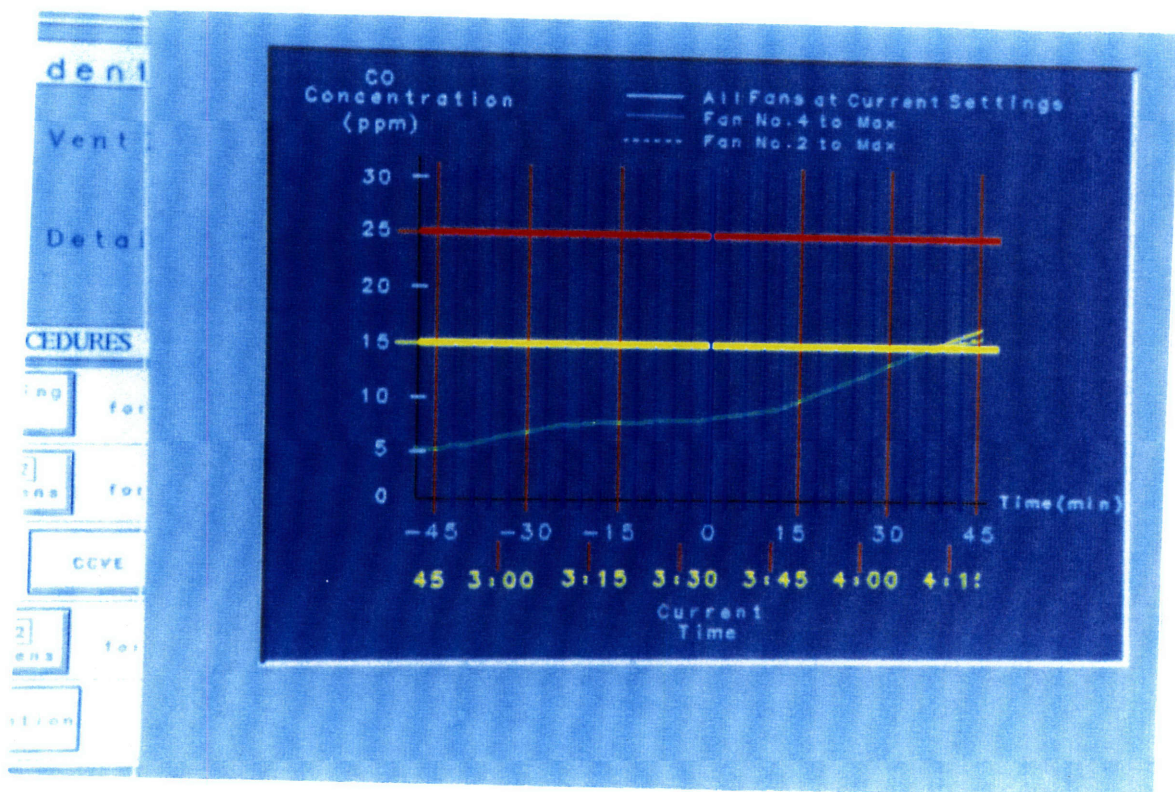


Figure 16. Local Carbon Monoxide Display

The LCOD is activated by clicking at various sections of the highway system while the LCOD (see the "Skull" in Figure 6) button on the IMDD is "pressed down." Upon activation, a window

appears in the middle of the display showing a curve plot of the carbon monoxide concentration level. Located at the bottom of the CO plot are two time displays. The first time display is stationary and indicates the relative time with respect to present: the center line of the plot is marked by time equal to zero; any time to the left of the center line is marked by a negative number indicating past times; any time to the right of the center line is marked by a positive number indicating future times. The second time display is a real time clock and moves to the left at the same speed as the curve plot. The plot itself is divided into two parts in the middle of the window: the left-hand side shows the past history of carbon monoxide concentration levels, while the right-hand side displays the predicted level of the CO concentration levels based on an internal model of the CO concentration levels and the current CO concentration as well as past histories of the Central Artery/Tunnel's operations. The development of the internal model and its combination with past operating history of the CA/T project are really subjects involving mass transfer, thermodynamics, artificial intelligence and a wide variety of areas and are therefore beyond the scope of this thesis. Furthermore, as a decision-aid device, the display can be made to display the predicted CO levels for various settings of control devices. For example, the display can present, in addition to the time history plot and the predicted CO concentration level if the operator does not intervene, the predicted CO concentration levels resulted from various possible actions of the operator. With the ability to at least predict the outcomes with some certainty, the operator is in a better position to make time and safety critical decisions.

4.C. The Experiment Comparing of Two Sets of Symbols to Represent Device and Status Buttons

Problem Statement: In order to reduce the training period and minimize the number of errors committed during the operation of the Central Artery/Tunnel's Operations Control Center, a set of appropriately designed icons and symbols is required. Since some of the symbols described in the CA/T IPCS system design document are confusing while others are not exactly designed according

to the guidelines for effectively designed symbols¹, a set of icons was designed and compared with the symbols shown in the CA/T system design document to evaluate their effectiveness. The CA/T system design document includes the symbols for the following system displays: Closed-Circuit Video Equipment (CCVE's), Ventilation, Fire Control and Alarms, Illumination, Drainage, Traffic Conditions, Computer and Communication Networks, and Security/Intruder Alerts. Additional symbols were developed for each of these system displays and the two sets of symbols were evaluated based on the ability of subjects to correctly identify the symbol meanings and the subject preferences. Furthermore, two sets of symbols for both Maintenance, and Carbon Monoxide Concentration displays, although not described in the CA/T system design document, were also developed to evaluate their effectiveness. All of these symbols are shown in Figure 17.

¹According to Mark S. Sanders and Ernest J. McCormick's *Human Factors in Engineering and Design*, pp.122-123[1], a well designed symbol should, at least, conform to some of the following guidelines:

- In general, a solid shape is preferred over line figures.
- Whenever possible, a figure with closed boundary is preferred over a figure with discontinuous boundaries.
- A symbol should be only as complex as it has to be.
- All components of the symbols should be contained within a single well-defined boundary.





















| | | |
|---|--|--|
| Fire Alarm and Control: | Extinguisher  | Flame  |
| Maintenance: | Hardhat  | Hammer  |
| Ventilation: | Fan  | Fan Blade  |
| Closed-Circuit Video Equipment: | Video Camera  | Movie Camera  |
| Traffic Conditions: | Signal  | Car  |
| Illumination: | Down Light  | Up Light  |
| Drainage: | Ripple  | Dripping  |
| Computer and Communication Network: CPU Net |  | Node Net  |
| CO Concentration: | Skull CO  | Smoke CO  |
| Security/Intruder Alert: | Lock  | Intruder  |

Figure 17. Symbols, Their Names and Their Corresponding Meanings

Experiments: There were two tests to be taken by each subject: the first test was the Identification Test and the second test was a preference survey of the subject's opinions on the symbols. For the Identification Test, the images of each one of the symbols in Figure 17 was displayed to the subjects for 0.5 seconds. The subjects were then asked to determine the meaning of each symbol from a list of the names mentioned above. There were two symbols for each meaning. The responses of the subjects were recorded and tabulated in Table 1. Immediately following the Identification Test, the subjects were asked to choose a symbol to represent the systems based on their personal preferences. The results of this preference test is shown in Table 2. Note that the subjects are under no time pressure in taking both tests. The objective of the Identification Test was to determine if the subject could correctly match the symbol with the system to be represented by the symbol. The recognition rate was therefore defined as the number of subjects who had correctly identified the system divided by the total number of subjects. For a given system, the symbol which had the higher recognition rate was determined to be the better symbol of the two. The objective of the preference test was to determine, subjectively, which symbol was the preferred. The preference rate was thus defined as the number of subjects who preferred to use the symbol to represent the system divided by the total number of subjects. The higher the preference rate, the better the symbol. Eight MIT mechanical engineering graduate students participated in both the Identification Test and the Symbol Preference Survey. All but two of these subjects had limited exposure to the area of display design and none of these subjects had prior exposures to any of the symbols. Two additional MIT mechanical engineering graduate students, who had seen these symbols during the development stage, participated in the Symbol Preference Survey.

| Icon ID# | Icon Name | Icon Meaning | # of Correct ID | # of Wrong ID | % Right | % Wrong |
|----------|--------------|-------------------|-----------------|---------------|---------|---------|
| 0 | Extinguisher | Fire Control | 7 | 1 | 87.5 | 12.5 |
| 1 | Flame | Fire Control | 8 | 0 | 100 | 0 |
| 2 | Hardhat | Maintenance | 6 | 2 | 75 | 25 |
| 3 | Hammer | Maintenance | 8 | 0 | 100 | 0 |
| 4 | Fan Blade | Ventilation | 8 | 0 | 100 | 0 |
| 5 | Fan | Ventilation | 8 | 0 | 100 | 0 |
| 6 | Movie Camera | CCVE | 8 | 0 | 100 | 0 |
| 7 | Video Camera | CCVE | 7 | 1 | 87.5 | 12.5 |
| 8 | Car | Traffic Condition | 8 | 0 | 100 | 0 |
| 9 | Signal | Traffic Condition | 4 | 4 | 50 | 50 |
| 10 | Down Light | Illumination | 5 | 3 | 62.5 | 37.5 |
| 11 | Up Light | Illumination | 5 | 3 | 62.5 | 37.5 |
| 12 | Ripple | Drainage | 8 | 0 | 100 | 0 |
| 13 | Dripping | Drainage | 8 | 0 | 100 | 0 |
| 14 | CPU Net | Network | 6 | 2 | 75 | 25 |
| 15 | Node Net | Network | 6 | 2 | 75 | 25 |
| 16 | Smoke CO | CO Level | 3 | 5 | 37.5 | 62.5 |
| 17 | Skull CO | CO Level | 6 | 2 | 75 | 25 |
| 18 | Lock | Security | 8 | 0 | 100 | 0 |
| 19 | Intruder | Security | 7 | 1 | 87.5 | 12.5 |

Table 1. Icon Identification Test Results

| | No. of Subjects who Prefer the Left Set | No. of Subjects who Prefer the Right Set | Percent Preference - Left Set | Percent Preference - Right Set |
|-------------|---|--|-------------------------------|--------------------------------|
| CCVE | 5 | 5 | 50.00 | 50.00 |
| Ventilation | 3 | 7 | 30.00 | 70.00 |
| Maintenance | 9 | 1 | 90.00 | 10.00 |
| Fire | 4 | 6 | 40.00 | 60.00 |
| Light | 2 | 8 | 20.00 | 80.00 |
| Drainage | 3 | 7 | 30.00 | 70.00 |
| Traffic | 4 | 6 | 40.00 | 60.00 |
| Network | 10 | 0 | 100.00 | 0.00 |
| Security | 3 | 7 | 30.00 | 70.00 |
| CO | 10 | 0 | 100.00 | 0.00 |

Table 2. Symbol Preference Survey Results

The left set is the symbols in the left side of Figure 17; the right set is the symbols in the right side of Figure 17.

Results and Discussion: Based on the results shown in Tables 1 and 2, the set of recommended symbols is shown in Table 3. The symbols were selected based on the following criteria:

- If both the Identification Test and the Preference Test indicated that Symbol A was better than Symbol B for a particular meaning, then Symbol A was selected.
- If one of the test indicated a draw while the other test determined that Symbol A was a winner, then Symbol A was selected.
- If the two tests yielded conflicting results, then the recommended symbol was determined by the winner of the Preference Test.
- If both tests indicated a draw, then no recommendation was made.

Note that in the third criterion, the results Preference Test overruled the results of the Identification Test because, while the Identification Test represented the initial effectiveness of the symbols, the Preference Test revealed the acceptability of the symbols.

| Meaning of System or Devices | Recommended Symbol |
|------------------------------------|--------------------|
| Fire Alarm and Control | Flame |
| Maintenance | Hardhat |
| Ventilation | Fan Blade |
| Closed Circuit Video Equipment | Movie Camera |
| Traffic Condition | Car |
| Illumination | Up Light |
| Drainage | Dripping |
| Computer and Communication Network | CPU Net |
| Carbon Monoxide Concentration | Skull CO |
| Security/Intruder Alert | Intruder |

Table 3. Recommended Icons and the Corresponding System or Devices

Section 5. Review of System Design Documents of the Central Artery/Tunnel Project

The review of the system design documents of the Central Artery/Tunnel Project reveals several human factor issues which are addressed in this section. Furthermore, based on this review some guidelines regarding the design of graphical user interface for the traffic control operators display console of the Central Artery/Tunnel project are proposed.

5.A. Review of Control Logic and Graphical Issues of the Interface Design

During the review of the Integrated Project Control Systems (IPCS) system design documents of the Central Artery/Tunnel Project, the following issues were raised:

1. Map navigation and zooming,
2. Orientation of system map,
3. Coloring of map displays,
4. Graphical representation of analog displays,
5. Accelerator keys and hot key functions,
6. Grouping of control buttons,
7. Monitor display real estate allocation,
8. Combination of individual display windows and/or panels into an integrated display window.

The first four issues are related to map and graphical object displays; the next two issues are related to logical grouping and arrangement of locations of control buttons; and the last two points are concerned with the space allocation problem of graphical displays. In the following sections, the original designs are presented and are followed by some discussion of the designs and techniques to improve the design. (Unless otherwise mentioned, all display designs or features are understood to be images on the display terminal's monitors.)

Map Navigation and Zooming:

According to the original design, the complete CA/T system map is to be stored as several individual maps with each map covering a section of the total map. Furthermore, because of the nature of this design, zooming and navigation of the map will be in discrete steps. Therefore, for example, for a five-zoom-level map with each successive higher zoom level having a zoom factor of two, there is one map for the first level, four (two by two) maps for the second level, sixteen (two by two by two by two) maps for the third level, 64 maps for the fourth level and 256 maps for the fifth level. The total design concept of the map can be summarized in Figure 18.

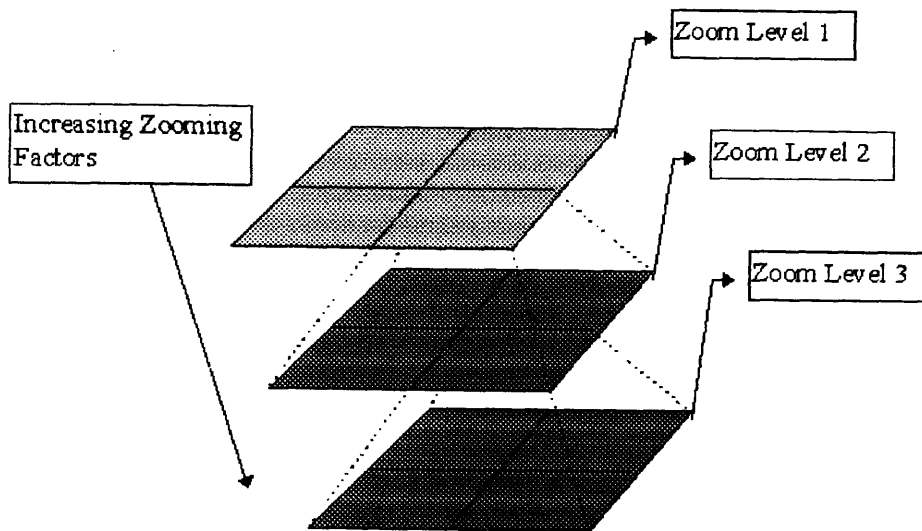


Figure 18. CA/T IPCS System Design Documents' Design Concept for Zooming.

(With each successive higher zooming factor, the number of required maps is multiplied by four, assuming a zooming factor of two).

Although the original CA/T IPCS system design document does not specify the actual mode of navigation, it is easier, from the operator's perspective, to include a set of scroll bars located next to the main display area to permit navigation in incremental steps. These scroll bars should function as the standard Microsoft Windows[®] scroll bars: a click on the arrows at the ends of the

scroll bar allows incremental movement; a click on the bar itself permits larger incremental movement; a click-and-drag on the scroll button permits continuous incremental movements. In addition, it is highly recommended to have a reference map similar to that discussed previously in Section 2A to allow rapid accessing of other locations of the map while using the scroll bar features for more precise manipulations of the view window.

Since the navigation scheme is designed so that both zooming and navigation of the map will be in discrete steps, in operation, when the operator moves the view point from one map to another, the map currently viewed is removed from the display and replaced by the new map (see Figure 19). Such a sudden change of image may be confusing to the operator of the traffic control center because a sense of image (or visual) continuity is lost. In order to avoid such a complication, the following two techniques are proposed; each technique requires a slight modification to either the original map design or the map navigation algorithm.

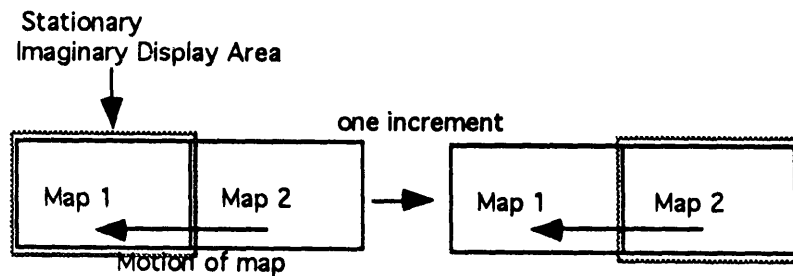


Figure 19. Navigating from One Zoomed Map to Another: One Map at a Time with Non-Overlapping Maps

Adjacent Maps Do Not Over Lap. This technique uses the original map design and a modified version of the controlling algorithm of map navigation: when the operator moves his viewing window from one map to another, the current map displayed in the viewing windows disappears one section at a time while the new map moves into the viewing windows one section at a time.

Consider the move from Map A to Map B in Figure 20. The first incremental motion makes Section A.1 of Map A disappear and Section B.1 of Map B appear; the second incremental motion makes Section A.2 of Map A disappear and Section B.2 appear; eventually, after the last incremental motion, Section A.3 of Map A (thus, the entire Map A) disappears and Section B.3, and thus the entire Map B, appears in the viewing window.

Adjacent Maps Overlap Each Other. In contrast with the first technique, the second method requires a slight modification to the original map design while employing the original map's navigation algorithm: the adjacent maps overlap each other so that the operator can relate the connection point between the new map and the originally displayed map. For example, consider the move from Map A to Map B in Figure 21. Since Section A.3 and Section B.1 are identical, the operator has an image of where one road located at the edge of Section A.3 will lead to in Map B.

Although the second method may appear easier to implement than the first technique, in practice, the second method causes one serious problem compared to the first one. The problem with the second technique is a direct consequence of the adjacent maps overlapping redundancy. Because adjacent maps are required to overlap each other, the second method requires more individual maps than the first technique to cover the same total area. As a result, the second method requires a larger total memory storage requirement than the first method. For example, to cover the same length of the road which would require only three maps using the first method, the second method would require four maps (assuming 33 percent overlap). If the analysis is extended to a two-dimensional map, then the ratio of the numbers of required map would be 9:16. In fact, the ratio can be computed by the following formula:

$$\text{Ratio of Maps} = (1 + \text{Percentage of Overlapping with Previous Map})^2 .$$

For a set of 32 maps using the first method, the number of required maps using the second method with ten percent overlapping would be 39 maps; and for a more realistic number of 100 maps with the first technique, the second method would require 121 maps instead. As the resolution of maps increases, the amount of memory storage space needed rapidly outgrows the amount of extra coding required to modify the navigation techniques needed in the first technique.

Furthermore, with the first technique, it is actually easier to include zooming functions because some of the extra coding needed to zoom maps is already included in the modification coding for navigation using the first technique. It can be envisioned that (see Figure 22) at a higher zoom factor only one of the maps or sections of several adjacent maps are displayed in the viewing window, while with a lower zooming factor, many of these maps can be displayed completely at the same time. If the second method to preserve map's visual continuity were used, it would require a whole new set of extra coding for the zooming functions in addition to the already large memory storage requirement.

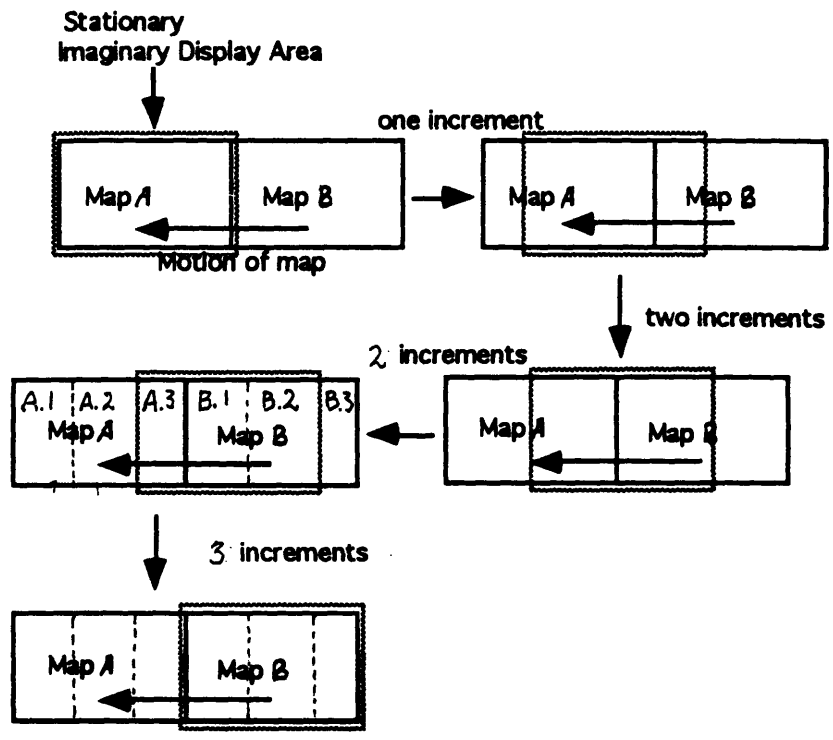


Figure 20. Navigating from One Zoomed Map to Another: One Section of the Map at Time

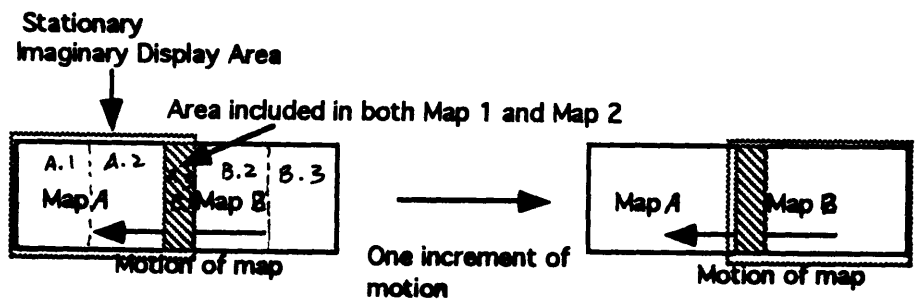
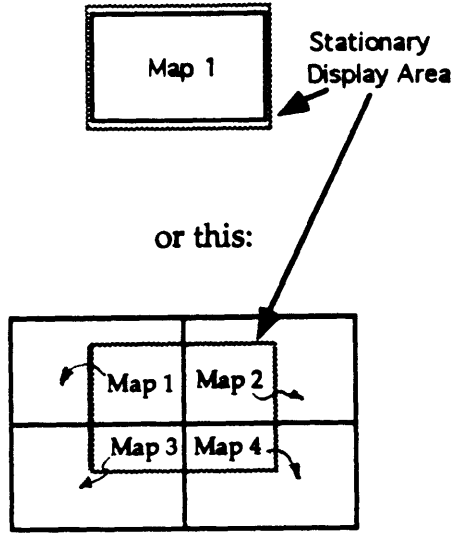


Figure 21. Navigating from One Zoomed Map to Another: One Map at a Time with Overlapping Maps

At the lowest zoom factor, you can see only either this



while at a higher zoom factor, you can see this:

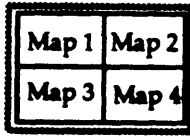


Figure 22. Maps to Be Shown at Various Zoom Factors

Orientation of System Map:

According to the system design document's figures, the system map is oriented such that the northern edge of the project is located at the right-hand side of the map instead of the top edge of the map. Such a display can be dis-orienting because the operator's mental model of geographic features may not be identical to what is displayed on the monitor.

It was argued that because of the relationship between the aspect ratios of the system map and the display monitor (the north-south direction of the map is longer than the east-west direction of the map while the display terminal's monitor is longer in the up-down direction), it is preferred to orient the map so that the longer edge of the map points in the same direction as the longer side of the display monitor to maximize the map display area and to display the maximum possible details. However, such a concern can be dismissed given the facts that the zooming ability and device display selection ability (to avoid cluttering the display area) are built-in features of the system and that the display monitor provides sufficiently large display area (a 20-in display monitor is currently proposed). In addition, although the operator's stereotype of map orientation can be altered after prolonged training and exposure to operations, and control-display and visual-motor compatibilities² may be preserved, when operators talk to each other or to the supervisor during emergencies, confusion may rise because of the stereotype that the north is usually positioned at the top of the map. Therefore, from a human-factors engineering point of view, it is recommended to orient the map display such that the north edge of the map corresponds to the top of the display area.

²Control-display compatibility is achieved when that motion in a certain direction produces display feedback in the same absolute direction while visual-motor compatibility is achieved when motion of operator's limb produces motion that "appears" identical to the limb's motion (pp.312-313, Sanders and McCormick [1]).

Coloring of Map Displays

The CA/T IPCS system design document does not specify the general rules on the uses of colors except for citing some examples on uses of colors to demonstrate the features of some panel or window design. However, the issue on general rules for the uses of colors deserves special attentions here because an improper use of colors not only causes dizziness and severe eye-strain felt by operators but is also a major source for operator disorientation and confusion. The result is reduced efficiency and work performance and increased possibility of error. The following is a list of proposed guidelines when considering the use of colors on the traffic control operator's console displays.

- No more than eight colors should be used simultaneously within a region of the size three inches by three inches. For example, some of the appropriate colors include red, yellow, dark blue, light blue, cyan, green, magenta, white and gray.
- In general, whenever it is required to change the color of a zone (a zone is section of the system covering a certain portions of highways, roads, ventilation systems, electrical systems, etc, see Figure 23), it is recommended to implement the color change to the entire zone instead of applying the change of colors to only the border of the zone. This is because changing the color of the entire zone would catch the operator's attention more effectively than changing the color of the border only. However, if the change of color to the entire map zone is not possible due to software development or other problems, it is suggested that by ensuring the width of the zone's colored border to be at least 1.5 mm to 2.0 mm (no thicker that 3.0 mm), the same goal of catching the operator's attention can be achieved.

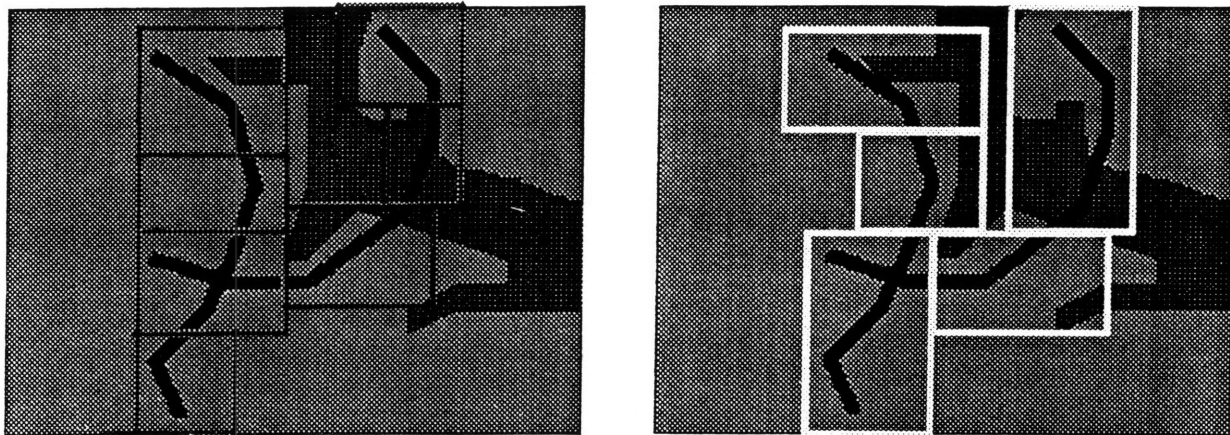


Figure 23. Examples of Different Zones May Be Used for Different Subsystems or Devices

- It is recommended that background geographical features, such as land and water, should be colored in a darker tone in order to avoid competition for attention with important features of the system such as roads, tunnels, highways, etc. For example, on a scale from 0 to 255 for RGB colors with 0 being the darkest tone (black) and 255 being the brightest tone of the respective colors, the land should be colored by green with a brightness of 24, the water should be colored by blue with a brightness of 24, and the borders of zones should be colored by green with a brightness factor of 127, with yellow, or red being of brightness 255 depending on the status of the system.
- The CA/T IPCS system design document specifies that a section of the highway or a system or a system component is to be colored in gray if the status of the device or the system is indeterminate. Such a color scheme may be interpreted as if the system or the device is currently inoperative. To avoid confusion, it is suggested that flashing yellow should be used to indicate the indeterminate nature of the system or system components (apparently, the operator should be alerted if the status of a system or device is unknown) while gray is reserved to express inoperative systems.

Graphical Representation of Analog Displays:

According to the CA/T IPCS system design document, some of the device status displays are to be in forms of a "conventional dial" display (similar in format to a potentiometer, see Figure 24). This design features a "backplate" area with a moving "needle pointer" that rotates according to the device status. Although widely adapted in various applications, this type of display (and its physical analog counterpart as well) may cause the pointer to appear to be vanishing when the color of the pointer is similar to that of the backplate, or when the tone of the color (brightness) of the pointer approaches the same level as the backplate. For example, when a red pointer moves into a red section of the backplate indicating emergency status, the pointer may "appear" to be merged into the background and disappear. In times of crisis or emergency, such a visual illusion may cause time delays because the operator may need extra time to find the pointer. Some of the proposed solutions are listed below.

Use Only Bright Colors for the Backplate Coloring: By using bright colors (red, yellow or green of brightness factor 255) for the backplate and dark colors (black, blue of brightness factor 24) for the pointer, good contrast between the backplate and the pointer can be obtained. Furthermore, the width of the pointer should be at least 2 mm wide to avoid the "blinking" effect caused by the bright background.

Use Rotating Sections Instead of a Needle Pointer: A circular display similar to the original display except that the pointer is replaced by a rotating section of a colored disk (see Figure 25). For example, on a semi-circular dial, the semicircle can be partitioned into three zones: green, yellow, and red. Each zone will cover a 60-degree section of the semi-circle. Therefore, for the example in Figure 25, when the displayed value is below the threshold for alert status, the section is green; if the displayed value is between the threshold for alert status and the threshold for alarm status, the section changes to yellow; and when the value to be displayed exceeds the threshold for alarm

status, the section changes to red. Similar display technique can also be applied to a linear tape display (see Figure 26).

Use a Tick Moving Along the Outer Edge of the Dial: Another remedy to correct the "disappearing" problem for potentiometer-type display is to have a tick marker moving along the outer edge of the display dial (see Figure 21). It is important to note that in order to avoid repeating the same problem as with the original dial, the brightness or color contrast between the tick and the outer background should be sufficiently strong. Furthermore, the size of the tick should be sufficiently large compared to the backplate (at least as large as the proportion shown in Figure 27).

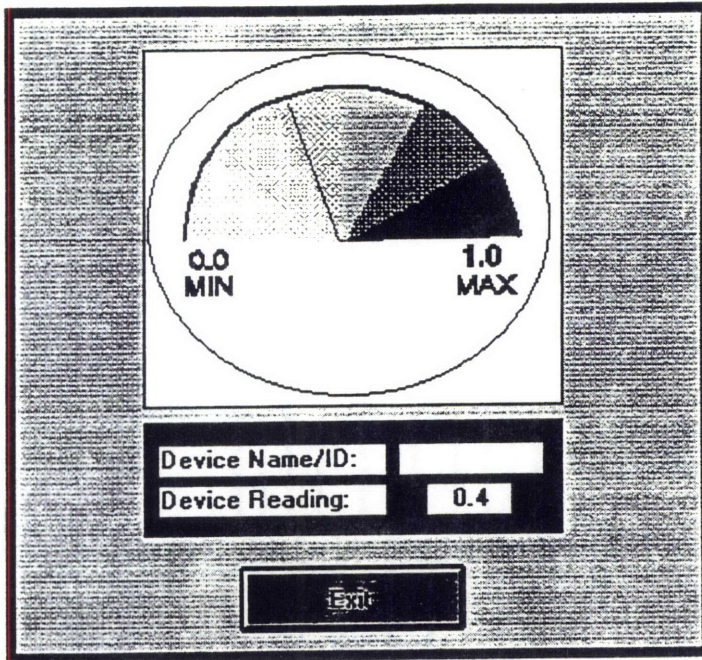


Figure 24. Original Analog Display shown in the CA/T IPCS System Design Documents

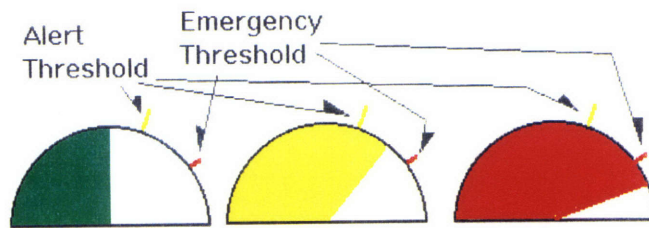


Figure 25. Three States of the Rotating Section Displays (Below Alert Threshold, Between Alert and Emergency Thresholds, and Above Emergency Threshold)

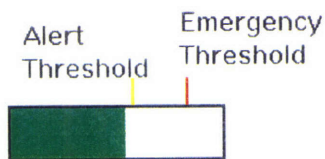


Figure 26. Linear Analog of the Rotating Section Display

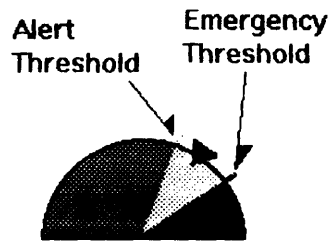


Figure 27. Moving Outer Tick Display

Accelerator Keys and Hot Key Functions:

The CA/T IPCS system design document proposes the use of accelerator keys for common or critical functions without an on-screen display backup. Alternatively, the document proposes to have a "resident window" for these functions which appears following a mouse selection of the main menu bar and stays on the display until closed by operators. Therefore, these common or critical functions can be activated by either the function keys on the keyboard or by mouse selections.

The use of accelerator keys without an on-screen display backup will, in general, cause an operator to delay the selection of a button or to press the wrong accelerator key because the operator may sometimes forget the actions that the function keys are to represent. Furthermore, although the "resident window" concept does seem to provide the operator with some sort of on-line help display, it is very likely that the resident window can be hidden underneath other windows or be lost among several windows as the number of displayed windows increases.

To solve both of these problems, it is proposed to use a fixed on-screen display bar for critical function keys located at the bottom of the display area. This function key bar displays both the critical or common functions and their corresponding accelerator keys (see Figure 28). As a result,

whenever the operator forgets the corresponding accelerator key to a particular critical task, he/she can always scan the bottom of the display area for a quick reference. By limiting the range of window displays so that the top edge of the function key bar is the bottom limit of window movements, the function key bar is never lost or hidden among several windows. Consequently, the operator always knows where the help is located because the consistency in location, an important human factor principle, is preserved.

Furthermore, to prevent accidental activation of a critical function while using the mouse or pressing the wrong accelerator key, an operator is required to respond to a dialogue window prompting the operator to confirm the initiation of critical functions. Therefore, it is expected that, by installing a fixed on-screen display bar, error rate and response times relating to the use of accelerator keys can be reduced.

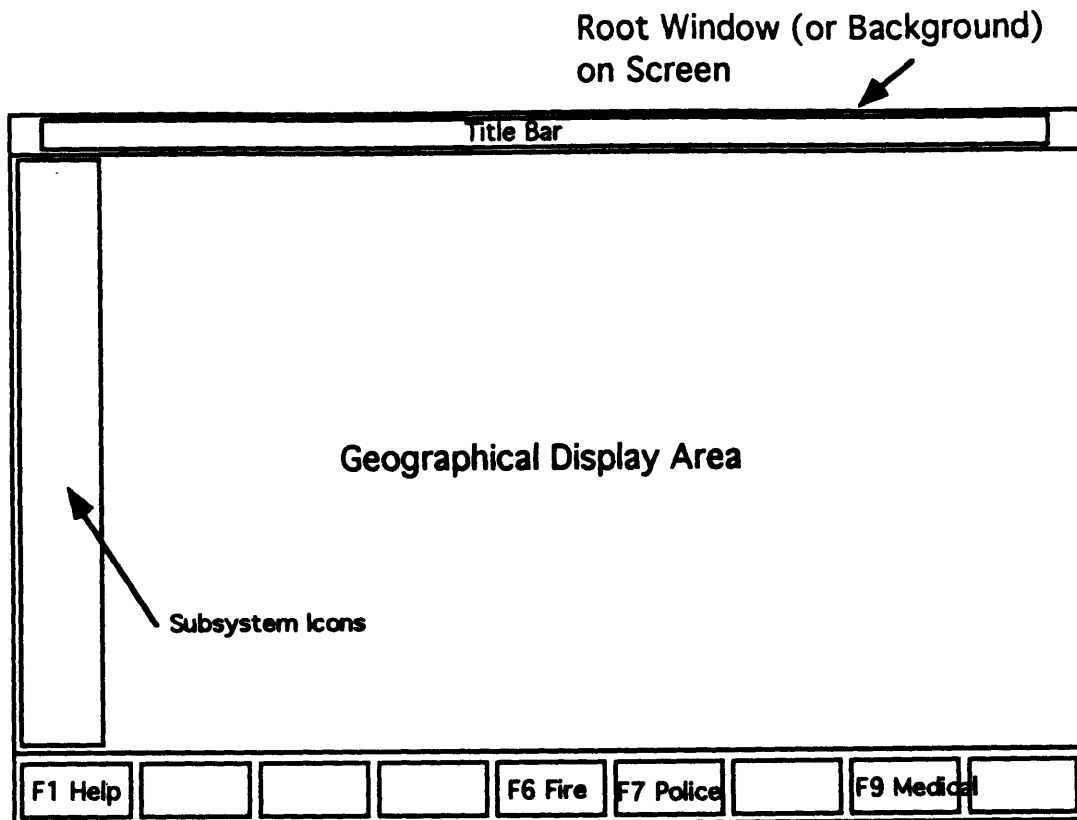


Figure 28. Function/Accelerator Key Display at the Bottom of Display Area

Grouping of Device/System Display-Control Buttons:

The arrangement of icons (or buttons) for device/system display and control shown in the CA/T IPCS system design documents (see Figure 29) does not represent a logical manner in which the placement of these icons should be organized because relatively non-related systems or device control buttons are grouped together. For the example in Figure 29, the CCVE (closed-circuit video equipment) and TRAFF (traffic condition) icons are traffic-control related symbols while LIGHT and DRAIN (drainage) icons are environment-control related symbols; yet, the CCVE and TRAFF icons are separated by environment-control symbols, likewise for LIGHT and DRAIN icons.

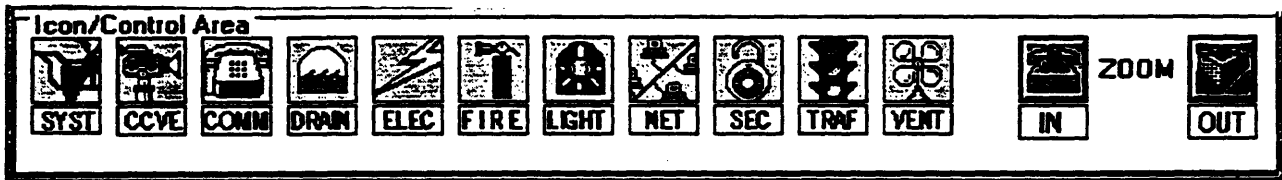


Figure 29. Grouping of Buttons in the CA/T IPCS System Design Documents

Such a placement of control buttons may cause time delays to the operator's responses because this violation to one of the rules for a well-designed user interface means that the operator may need to spend extra time to find the correct symbol. The length of the required extra amount of time may be relatively insignificant for the number of icons shown in the Figure 29; however, as the number of icons (or symbols) increases, the length of this of extra time may become a significant factor in the operator's response time and may correlate with increased error. Therefore, the importance of properly arranged device/system display-control icons and symbols (or in short, control panel layout) cannot be overemphasized.

Some approaches to properly designed control panel layout include grouping by function or task (to handle traffic-control tasks or environmental-control tasks), and grouping by types of actions (to display information or to enable control of devices). In general, when the number of symbols is relatively small, simple grouping by tasks should be satisfactory while grouping by tasks and grouping by actions should be used together when the number of symbols (or control buttons) becomes large. For example, the grouping by task technique in Figure 30 represents an improvement over the original design in Figure 29 by separating traffic-control symbols and environment-control symbols into two groups. Consequently, the operator can focus the search in the section containing traffic-control-related symbols instead of having to search over the entire set of symbols.

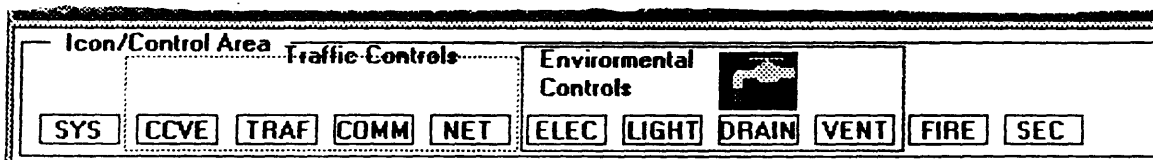


Figure 30. Grouping of Control Buttons by Associated Tasks

Two further examples showing the combined use of grouping by both tasks and actions are included here to demonstrate the advantage of these grouping techniques. The first example features a rectangular array arrangement of the buttons (see Figure 31) while the second example sports a hexagonal concentric-ring design (see Figure 32). In the first example, the symbols are grouped by functions from left to right and by action types from top to bottom: the traffic-control functions are placed at the left, the environment-control functions are placed at the right side of the panel while the communication devices, needed for both functions, are placed in the middle between the traffic-control buttons and the environment-control buttons. The buttons which display system information are located at the top section, the icons which display locations and status of devices and permit control or manipulation of these devices are placed in the middle section, and

the communication devices which initiate auto-dial sequences to corresponding agencies are located at the bottom of the control panel. In the second example, with the exception of communication devices and video camera control button, the left side of the control panel is occupied by traffic-control icons while the right side of the control panel is filled with environment-control related symbols (the video camera symbol is placed in the middle because it is an "extra" item from the traffic-control side of the control panel and because it may be used in both traffic and environment control operations). Furthermore, the inner-most ring is occupied by communication devices, the middle ring is occupied by symbols which display system information while the outer-most ring is occupied by symbols which display the location and status of controllable devices, and permit the manipulations of these devices. Both of these designs represent logical grouping of symbols; however, it seems that the rectangular array design is a more conservative design.

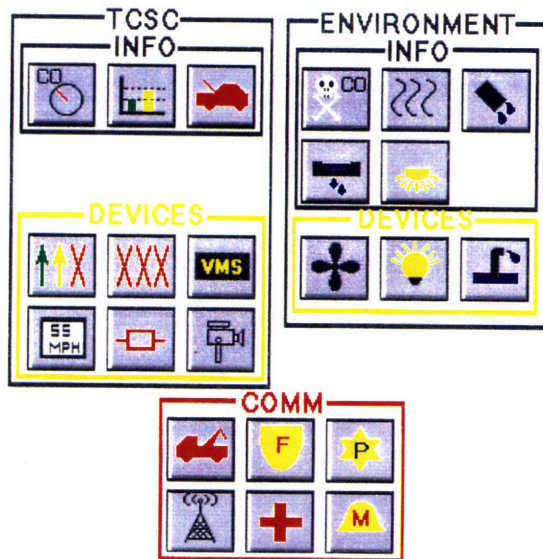


Figure 31. Rectangular Button Panel Layout

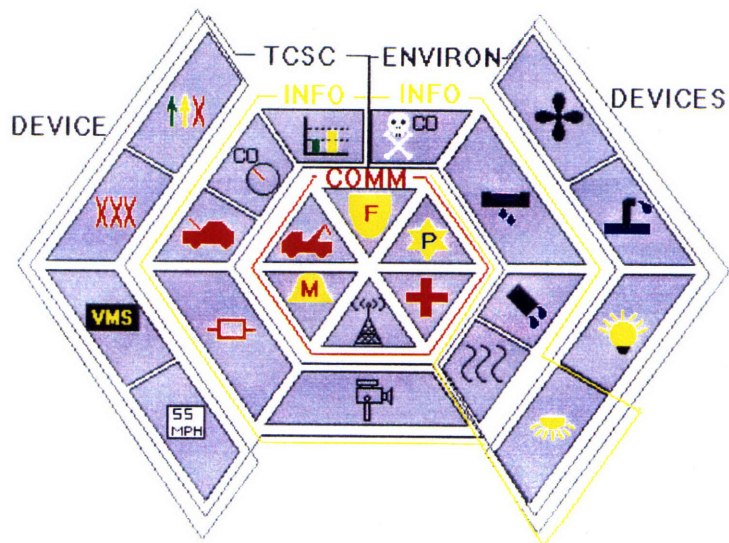


Figure 32. Hexagonal-Ring Button Panel Layout

Monitor Display Real Estate Allocation:

The issue of monitor display space distribution and allocation is never addressed in the CA/T IPCS system design document. Nevertheless, this issue deserves a great deal of attention because the

designs of the graphical user interface components, such as device control panels, incident management windows, system information and status displays, maps, etc, are hinged upon the appropriate and logical distribution of display real estate. As mentioned in the beginning of this thesis, each operator shall have two computer monitor displays at his/her console. These monitors are placed side-by-side such that the operator essentially has one display screen that is two monitors wide and one monitor high. Based on this physical hardware layout, the two display monitors can be allocated in the following manners (the left monitor is called Monitor A and the right monitor is called Monitor B):

- Monitor A can be used to display textual data only while Monitor B can be used to display graphical information.
- Monitor A can be dedicated to process one incident while Monitor B can be used to process another incident.
- Monitor A can be assigned to display all information or device control panels related to traffic incident management while Monitor B can be utilized to display all information or device control panels related to facility and environment controls.
- Monitor A can be used to display device control panels and Monitor B can be devoted to display system and equipment status and information and maps.

Among the four alternatives considered, the first approach represents the least attractive option because as presently conceived, Monitor A is essentially an old-fashioned alphanumeric display which, in itself, defeats the whole purpose of integrated graphical user interface. In addition, the operator's attention may be drawn to Monitor B for the graphical information display and the operator may ignore the text display altogether. The second arrangement is probably a better design than the first option because the second arrangement is more focused design. With the second approach, the operator can concentrate on one incident at a time and therefore can reduce the likelihood for committing errors. The fourth alternative is similar in design philosophy to the

grouping-by-action-type method mentioned in the previous section while the third scheme is similar to the grouping-by-task concept. It appears that, at this moment, the third alternative is the most attractive design because the operator can focus attention on one display monitor for each type of incident, traffic or environment, rather than switching between the two monitors for two different incidents of the same kind (although experiments may be needed to verify this hypothesis).

In addition to allocating the display tasks for the monitors, it is also proposed to make available display windows of various height-to-width (or aspect) ratios, because irrelevant or extra information can be excluded and because the unused space can be used to display other information. The aspect ratios can be changed by click and drag at the corners or the edges of the display windows. It is also important to note that while the aspect ratios of the display windows may be changeable, it is imperative that the aspect ratio of the map objects or the maps themselves remains constant.

Combination of Individual Display Windows and/or Panels into an Integrated Display Window:

Due to the system complexity of the Central Artery/Tunnel Project, there are numerous device control and monitor panels, traffic incident response plans covering several contingencies, incident management user interfaces, etc. If these display components are presented to the operator in an unorganized manner, it is very possible that the traffic control operator may be confused and that human errors may occur frequently. For example, according to the original CA/T IPCS system design document, in order to handle a normal traffic incident, the operator has to go through at least four to six different windows or panels such as the Incident Confirmation Window (to verify the alarm), the Incident Management Window (to actually control the clearing process of the incident), the Response Selection, the Response Plan Element, and various sensor readings. Even if these display components are presented separately in a logical and organized manner, the operator may still be overwhelmed by the number of windows and panels appearing on the screen.

Therefore, it is desirable, whenever possible, to combine several individual display windows and panels into an integrated display. The integrated display window not only reduces the number of windows appearing on the screen, hence, reducing the clutter of the screen, but also presents the individual components in a more coherent manner. Since the possibilities of integration are infinite, the following sections provides only two examples for integration.

The first example is the integration of the Variable Message Sign Status (Figure 33) and the Variable Message Sign Control windows (Figure 34). By using the integrated display (Figure 35), the operator can directly check the VMS device status and modify the VMS message contents in the same window instead of having to view the contents of the message in one window and then type a new message in another window. In cases where only some modifications of the original message are needed, the integrated display permits the operator to modify the original message directly rather than having to type the entire message again.

| | |
|----------------------|----------------------|
| VMS ID: | <input type="text"/> |
| VMS Type: | <input type="text"/> |
| Name of Message: | <input type="text"/> |
| Priority: | <input type="text"/> |
| MESSAGE TEXT: | |
| Line 01 | <input type="text"/> |
| Line 02 | <input type="text"/> |
| Line 03 | <input type="text"/> |
| Line 04 | <input type="text"/> |
| Line 05 | <input type="text"/> |
| Line 06 | <input type="text"/> |
| Line 07 | <input type="text"/> |
| Line 08 | <input type="text"/> |
| Line 09 | <input type="text"/> |

Figure 33. Variable Message Sign Status Window

Current Message:

| Number | Name of Message | Phases |
|--------|-----------------|--------|
| | | |

Message Text:

| | |
|----------------|----------------------|
| Line #1 | <input type="text"/> |
| Line #2 | <input type="text"/> |
| Line #3 | <input type="text"/> |
| Line #4 | <input type="text"/> |
| Line #5 | <input type="text"/> |

Figure 34. Variable Message Sign Control Window

Current Message: Priority:

VMS ID:

Type:

| Number | Name of Message | Phrases | Priority |
|--------|-----------------|---------|----------|
| | | | |

Message Text:

Line #1

Line #2

Line #3

Line #4

Line #5

Figure 35. Integrated Variable Message Sign Status and Control Window

The second example is the integration of the Incident Verification/Classification Window (Figure 36), the Incident Management Window (Figure 37), the Response Selection Window (Figure 38), and the Response Plan Element Edit Window (Figure 39). The resulting Incident Verification/Management Window (Figure 40) incorporates elements from the Incident Verification/Classification Window at the upper half of the window while including elements of the Incident Management Window and the Response Selection Window at the lower half of the display and functions of the Response Element Edit Window at the lower right region of the display. The integrated display eliminates some of the redundancies in the individual panels and reduces the number of windows to be displayed from four to one. Furthermore, by having elements of the Incident Verification/Classification Window and the Response Plan Selection Window in the same window, it takes the operator less time to determine whether the computer-suggested solution is appropriate than had these components been displayed in separate windows.

Vehicles Involved:

Estimated Time to Clear: **minutes**

Potential Injuries Yes No

Fire Yes No

Dangerous Spill Yes No

Send Message Yes No

Figure 36. The Incident Verification/Classification Window

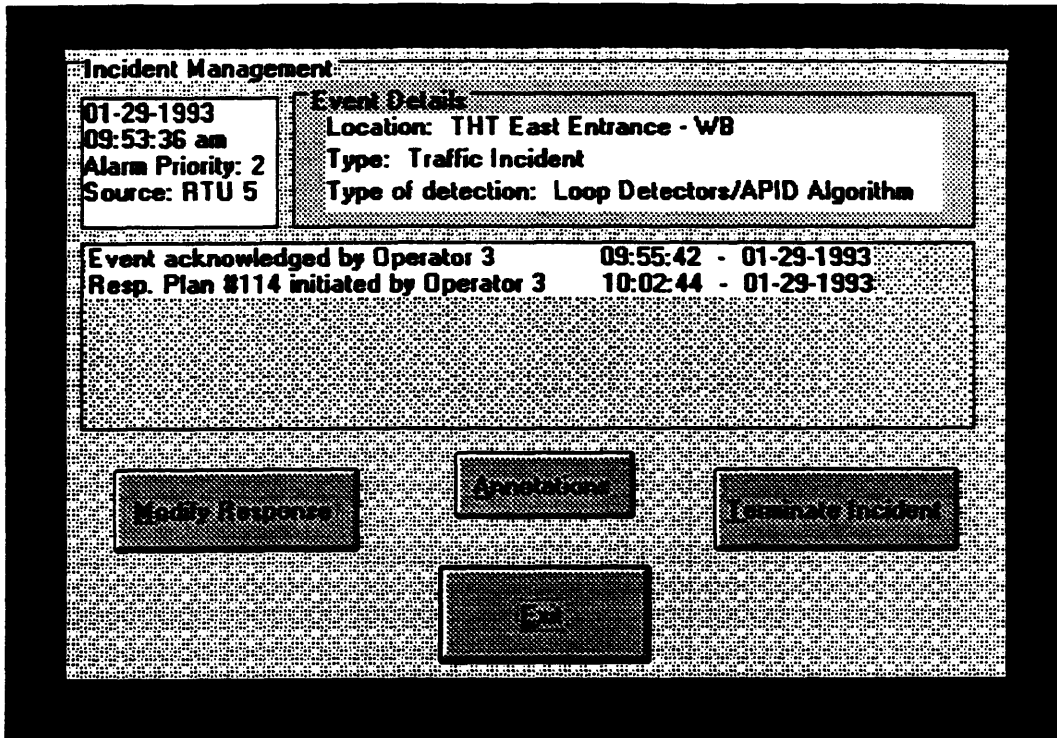


Figure 37. The Incident Management Window

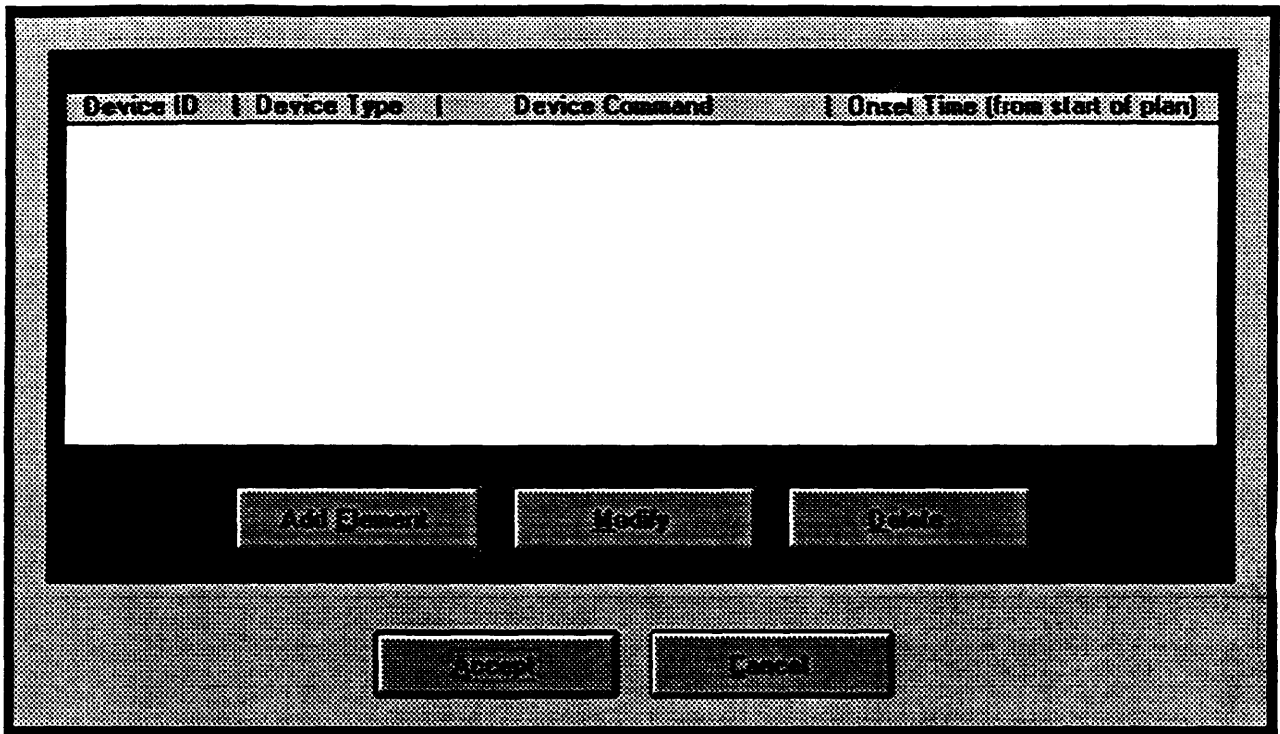


Figure 38. The Response Plan Element Window

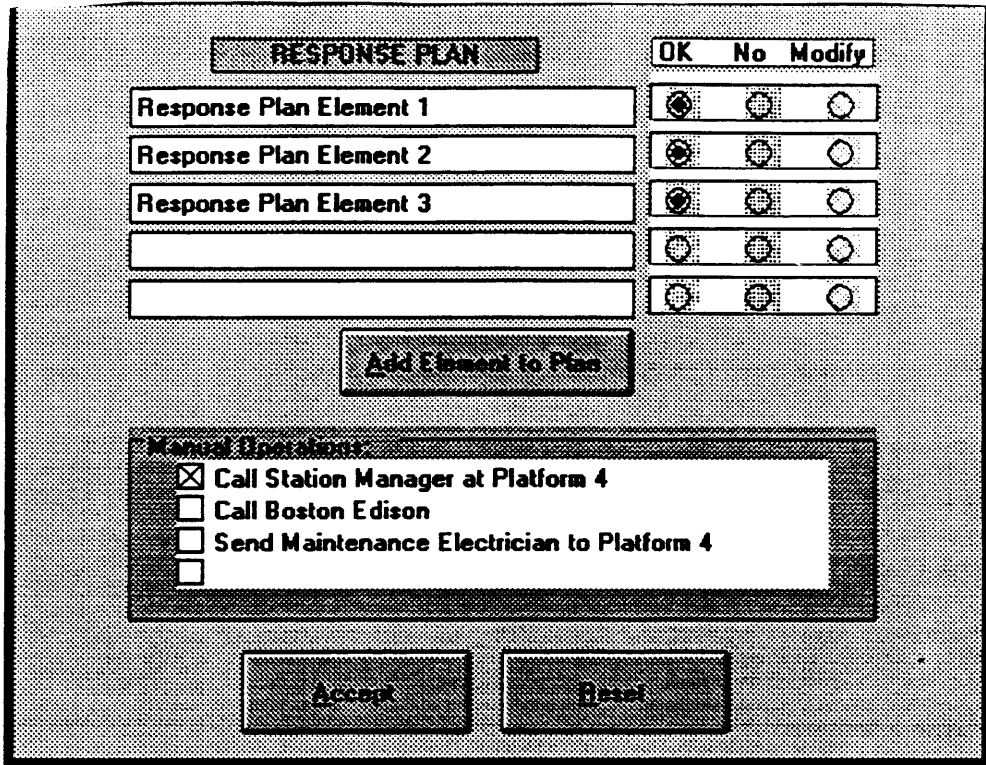


Figure 39. The Response Plan Selection Window

Incident Verification/Management

04-20-1994
09:45:15 a.m.
Alarm Priority: 2
Source: RTU 5

Incident Status

Location: Lanes Affected: 1 2 3 4

of Vehicles: Detailed Information:

Detected by:

Estimated Time to Clear: Hr. Min.

Response Plan

Response Log:

| | | |
|------------------------------------|----------|---|
| Event acknowledged by Operator 3 | 09:40:45 | + |
| Plan # 114 initiated by Operator 3 | 09:42:13 | - |

Response Plan Selection:

Response Plan 114

Response Procedures:

1 MONITOR UNTIL Incident is Terminated

3 DISPATCH Emergency Response Team DISPATCH

4 CHANGE Traffic System Components to direct traffic flow

5 WHEN All Termination Criteria is met

TERMINATE Emergency Task

Modify

Add

Delete

Terminate

Confirm Modification

Exit

Figure 40. The Integrated Incident Verification/Management Window

5.B. Interface Design Guidelines

From the review of the Central Artery/Tunnel Integrated Project Control System design documents the following interface design guidelines emerge:

Consistency with Operational and Incident Management Procedures:

In order to perform the assigned duties most effectively, the traffic control operator needs an interface that conforms to the flow of the system's control logic or operation procedures. Using the example of the re-designed Incident Verification/Management Window described above, the new integrated window was designed following the standard operation procedures of traffic incident management, which include, in chronological order, detection, verification and classification of incidents, the selection and modification (if necessary) of the response plans, and the execution of the response plan. To process an incident, the operator starts at the top of the window by verifying and classifying the occurrence of the incident using the Incident Status Panel (along with video images displayed on video monitors), and proceeds downward to first select a response plan and then execute it in the Response Plan Panel while simultaneously monitoring the progress and modifying procedures using the modification functions at the right side as necessary.

Simplicity:

The fundamental advantage of graphical user interfaces over conventional alphanumeric interfaces is their simplicity and intuitiveness. In a complex system such as the Central Artery/Tunnel project, it may take ten or more screens to completely display the status (not images) of all the video cameras (there are over 400 cameras in the system), while it may take only one or two screens of map and icons to display the same amount of information. Therefore simplicity is not an option but a requirement, as the operator can easily be overburdened with the amount of information or the large number of windows and device control panels. Using the Incident Verification/Management Window for an example, again, the new design reduces the

number of windows to be displayed from four to one. This reduction of the number of windows not only gives a more orderly appearance of the display area, but it also means that the operator does not need to search all over the display area to locate all four windows. As a result, response time is reduced.

Consistency of Formats:

Because the Central Artery/Tunnel Project includes many different type of system and subsystem operations, it is very likely that an operator cannot memorize all the command functions and inputs all the times. Therefore, format consistency of commands and displays from one window or panel to another becomes important. Commonality and familiarity across various windows panels reduces the operator's mental workload and chances for confusion and error. The consistency requirement is not only limited to the system windows and panels; consistency with popular software is to be considered as well. With the recent popularity of the Microsoft Windows[®] operating environment, it is anticipated that traffic control operators of the Central Artery/Tunnel Project will be somewhat familiar with the Windows[®]. Therefore, a user interface compatible with Windows (at least in the input command level) not only reduces the training period but also reduces the likelihood of confusion during operation.

Section 6. Conclusions and Future Works

Several proof-of-concept computer-graphic display designs for the Boston Central Artery/Tunnel Operations Control Center, including the Integrated Map/Device Display, the Camera Control Display, the Occupancy and the Speed Display, and the Local Carbon Monoxide Concentration Display, have been demonstrated. Some experiments to validate the designs, including comparisons of point-and-click versus scroll-bar-dragging techniques for navigation, and moving-dot versus bar-chart displays for presenting both the traffic speed and density at the same display space, were conducted. The result of the navigation experiment indicates that the direct point-and-click technique for map navigation reduces the response time by over 60 percent compared with the response time using the scroll-bar-dragging method. And the result of the traffic speed and density display experiment demonstrates the effectiveness of the multiple-dimension coding of moving-dot display over the conventional bar-chart display: the required time for detecting a simulated traffic incident was reduced by 50 percent. An experiment comparing display icons was done, and a set of symbols to be used in the actual user interface of the CA/T project is proposed.

In addition, a comprehensive review was made of the CA/T IPCS system design document, including a discussion on map navigation and zooming, proper orientation of the system map, coloring of the map displays, graphical representation of analog displays, accelerator keys and function keys, grouping of control buttons, monitor display space allocations, and the integration of individual display windows and/or panels.

Future efforts in this project may include the integration of the already demonstrated displays with a traffic simulation and an operator-in-the-loop incident response simulator (both currently under development). The resulting simulators may be used to evaluate and validate design concepts or to act as prototypes for traffic controller training. As a spin-off of the study on symbols, it would be interesting to study the use of text backup for the symbols. In most cases, text backup of symbols

may reduce the number of errors. However, the presence of text backup necessarily increases the complexity level of the symbols; therefore, it is desirable to study the tradeoff between the added clarity of the symbols' messages and the cost of increased complexity.

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