Task Analysis and Operating Procedure Design for a Traffic Management System: Application to Boston's Central Artery/Tunnel

by

Rebecca C. Milam

Submitted to the Department of
Mechanical Engineering
in partial fulfillment of the requirements
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and

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Abstract

The Operations Control Center of Boston's Central Artery (I-93)/Third Harbor Tunnel (I-90) construction project, a complex traffic management system due for completion around the turn of the century, was researched and designed from the viewpoint of traffic and facility monitoring. In this thesis, the human factors engineering design methods that were applied to the Operations Control Center (OCC) consisted of three components--(1) task analysis, (2) critical operations identification, and (3) operating procedure development.

Task analysis was completed by identifying and evaluating all equipment, functions, and possible operations of the OCC. This step provided a structured diagram of the OCC operator action-decision process as well as a full description of all human and machine tasks necessary in the operation of the control center. Using the task analysis results, critical operations were identified as areas or tasks in which the system was placed under conditions posing a higher potential for error during operation. This stage also provided the sources of possible error which cause these operations to be critical. The development of procedures for OCC operation included evaluating the needs of the operator for a procedural aid. Design guidelines for the writing of these operating procedures were developed for both hard copy and computer-based use. The procedures use multiple levels of detail in order to accommodate all skill ranges of users. The procedures were also designed to account for the diversity in conceivable OCC incidents in which the operator encounters incomplete information.

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

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Finally, I would like to say thank you to the people who are most important to me--my family, Chad (Sweetie), Jud (Dad), Alice (Mom), Stephanie, Sarah, and Bubbles (The Cat). Not only do I appreciate your great sacrifice in actually paying for this education, but most of all, I appreciate your love and support that has been with me and guided me throughout my academic pursuits. I am truly blessed that your love will continue to be with me throughout the rest of my life as mine will with you.

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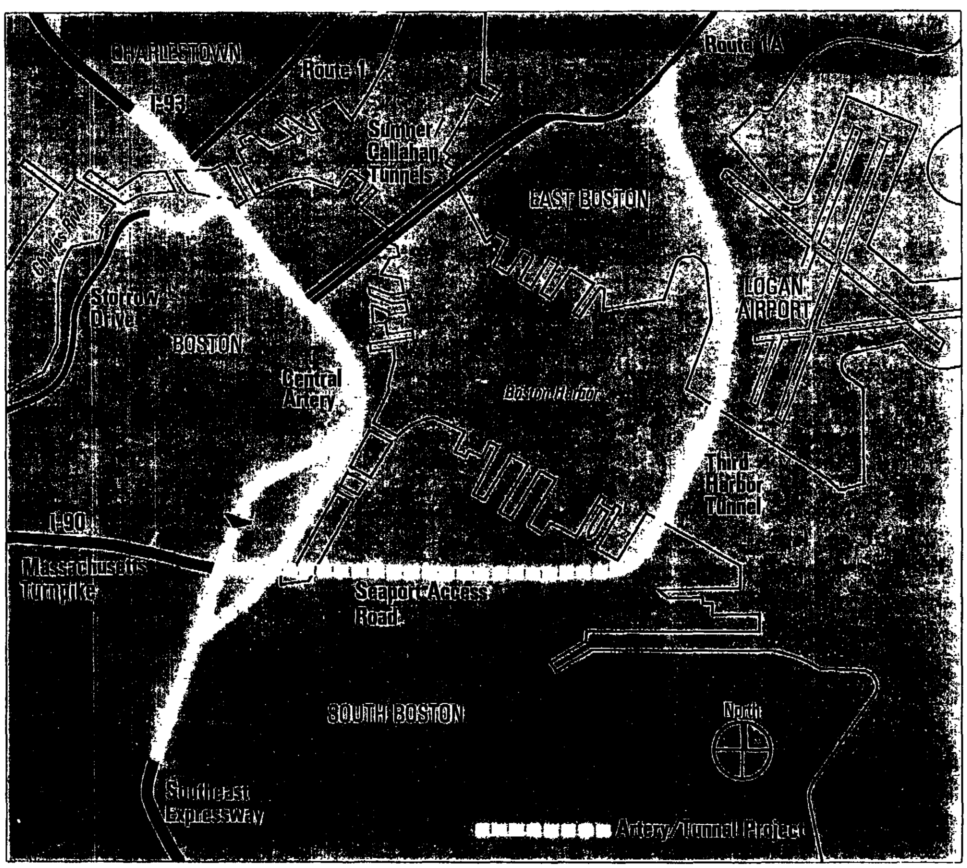
Chapter 1
Introduction

1.1 The Boston Central Artery/Tunnel Project

1.1.1 Project Description

The focus of this study involves the project in Boston, Massachusetts in which Interstates 90 and 93 are being reconstructed and expanded. The project is designed to create a new I-93, known as the Boston's Central Artery, that will possess greater traffic capacity and will pass through the city primarily underground. The new I-90 will be extended all the way to Boston's Logan Airport by way of a new tunnel through Boston Harbor. This tunnel is known as the Third Harbor Tunnel. Figure 1.1 portrays a general overview of the scope of the Central Artery (I-93)/Third Harbor Tunnel (I-90) construction project. The Central Artery/Tunnel (CA/T) project is a joint venture between the Federal Highway Administration and the Commonwealth of Massachusetts.



from "Now You See It. Now You Don't."

Figure 1.1: CA/T Project Overview Map

1.1.2 The Operations Control Center

A traffic system of such complexity as the CA/T requires a precise and detailed method of control. The Operations Control Center (OCC) (see location on Figure 1.1) is the center from which this control of the CA/T will take place. It is from this location that OCC operators will monitor and manage the activities of the CA/T system.

Although the general concept of a control center for the operations of a system is not new, it has not been applied to a great number of traffic systems in the past. Relatively speaking, the management of traffic is a new notion. The United States currently has only a handful of functional traffic management systems and most of them have not been in existence for very long. The Central Artery/Tunnel will be the most complex management system of all comprising numerous traffic functions as well as facility operations. Other fields have come before automotive ground traffic in the establishment of centers of operations control. Of these areas, some of the most common include the nuclear power station control and air traffic control.

The basic configuration of the OCC of the CA/T includes a large System-Wide Display screen to be viewed by all operators in the OCC. The screen will project the status of traffic and selected facilities on the roads composing the CA/T. The OCC will also consist of group of overhead monitors displaying the sections of the roadway via the CA/T video system. Finally, the Operations Control Center contains several operator consoles from which each operator may access all necessary displays and controls necessary to interact appropriately with the CA/T system. Each operator's console is made up of a computer processor with two Cathode Ray Tube (CRT) color displays and six video monitors for viewing the CA/T system. In the event of failure of the OCC, a Back-up OCC exists (shown in Figure 1.1).

1.2 Objectives and Scope of Research

As a system becomes more complex, it requires that more operations be performed, both by human and machine, in order to complete a task. A system with greater capabilities mandates a greater need for organized control of all of its individual components and operations. In the Central Artery/Tunnel, the Operations Control Center is that form of organized control. To ensure the proper level of accuracy in the performance of tasks by the human and machine elements, the OCC must be designed such that during its operation it facilitates the safe control of the CA/T subsystems.

Designing the Operations Control Center is a task consisting of many intricate steps. Some of the most important of those steps relate to designing the OCC to accommodate the human user. Because the operations that must be performed by human operators are of such importance to the successful operation of the OCC, the engineering of the OCC to suit the needs of the humans is a critical design stage. This study focuses on three major components of human factors engineering--(1) task analysis, (2) critical operations identification, and (3) operating procedure development. In the phase of task analysis, a model of the CA/T system and all of its human and machine task requirements is developed. Through the utilization of the information provided in the task analysis, critical tasks which present higher probability of error in OCC operation may be identified. The final phase of human factors research in this study is the development of guidelines by which operating procedures may be constructed. These procedures provide operators with instructions for the performance and completion of each task and may be utilized during the actual performance of a critical task. These three steps of human factors research will provide information which can be utilized in completing the design of the Operations Control Center.

From the brief descriptions of each of these phases of research, the primary purpose of this study can be summarized. Thus, the objective of this study is to research and complete the development of each of the following :

(1) A detailed analysis of the tasks performed in the operation of the OCC;
(2) An identification of the critical areas in OCC operation which present increased risk of operational error or breakdown;
(3) Guidelines for the construction of operational command and control procedures which govern the management of OCC tasks.

A more detailed look at each of the objectives is provided in the ensuing sections.

1.2.1 Task Analysis

Task analysis includes the examination and evaluation of all of the tasks to be performed in a system as well as all the equipment with which the tasks are performed. The results of this analysis are integrated into a diagrammed structure which defines the required tasks in the utilization of the Central Artery/Tunnel Operations Control Center. Task analysis utilizes both CA/T system and human functions to assist in identifying, classifying, and analyzing all system tasks. The design of this model includes the completion of the following objectives:

- specification of all system users;
- identification of all system output goals;
- analysis of all system functions and capabilities;
- development of functional action-decision diagrams for OCC users;
- identification of system equipment;
- identification and description of all tasks to be performed;
- analysis and grouping of tasks into general categories; and
- synthesis of information into a final task descriptive analysis diagram.

1.2.2 Critical Operations

Utilizing the information obtained from task analysis as a basis, the areas of criticality in operation may be both identified and defined. Such areas include tasks which present increased risk of error in operation. The identification of these critical operations includes the following steps:

- determination of sources and probability of operator error;
- evaluation of task analysis for presence of tasks possessing high potential for error; and
- classification of OCC tasks according to error sources;

1.2.3 Operating Procedure Guidelines

The development of human factors guidelines for creating operating procedures to be used as performance aids by the OCC operators is the final objective of this study. Through the utilization of the identified critical operation areas, these guidelines can be illustrated in forms representative of typical OCC tasks. The development of these guidelines will focus upon the following areas:

- determination of amount and type of information to be included in the content of the procedures;
- development of layout and presentation of the procedures, including format, textual and graphical structure and the form of medium; and
- determination of methods for the evaluation and revision for the operating procedures.

1.3 Thesis Outline

This thesis is arranged such that each of the three primary human factors design categories are researched and discussed separately. Chapter 2 presents the results of the task analysis of the Operations Control Center of the Central Artery/Tunnel system. Additionally, it includes background and research steps in the completion of this portion of the study. The description of each of the tasks is provided in Appendix A as are some of the more complex diagrams. Chapter 3 contains the critical areas which were identified through the use of task analysis. This chapter also presents three sample incident scenarios constructed from the outcome of the critical operation identification. These sample incident scenarios are representative of the types of situations in which error may occur. They are further used to illustrate the capabilities of the operating procedures in the following chapter. The guidelines for the construction of operating procedures for OCC operators are included in Chapter 4. Also included are the criteria needed to be addressed by the procedural guidelines. Specific examples of operating procedures for several sample scenarios are provided in Appendix B. Finally, Chapter 5 discusses the research and results of the study.

Chapter 2
Task Analysis of the Central Artery/Tunnel Operations Control Center

2.1 Background and Purpose

The Central Artery/Tunnel (CA/T) is a complex system which consists of many sub-systems requiring a great degree of monitoring and control. Both the system equipment and the human operators who utilize these machines are required to perform certain functions to ensure the continuous, successful operation of the CA/T. The Operations Control Center (OCC) is the primary center from which these system functions are monitored and controlled.

In order to obtain information on which to base the design of an operation such as the OCC, a critical phase known as task analysis must be performed. To determine the process of task analysis, we must first define the concept of a "task." In the context of human factors engineering, a task may be defined the action or set of actions which lead, directly or indirectly, to the output of a system. Task analysis is described by Drury (1987) as a process consisting of two major components, the first of which being the identification and description of "units of work" or actions. The second portion consists of "analyzing the resources necessary for successful work performance" or system output. The resources described by Drury not only include environmental elements such as workstation controls and displays or procedural aids, but they also comprise human resources such as the skills and knowledge of a worker.

By examining the CA/T systems and their relation to the human operators and machine elements of the OCC, it is possible to develop an accurate model of the Operations Control Center of the CA/T system and all of its task requirements. Without this information as a basis, all further design of the OCC would be difficult to adequately complete. Through the use of task analysis, both OCC system and human functions as well as the tasks necessary to perform them can be identified, classified, and analyzed.

2.2 Approach and Methodology

Unfortunately, no one simple and straightforward technique exists by which task analysis can be performed for all jobs and systems. Instead, the process is composed of a variety of techniques comprising data collection and system definition and evaluation. Many experts have outlined various methods for the completion of task analysis, none of which are identical. This study utilizes portions of the generalized methodologies presented by Drury (1987) and by Sanders and McCormick (1987) as a foundation for the task analysis performed for the Operations Control Center of the Central Artery/Tunnel. This adapted approach is presented here and has been divided and classified into two primary steps--system analysis and task identification and description. The information utilized in performing the task analysis was obtained from two primary sources--the design specifications for the Integrated Project Control System by DeLeuw, Cather, and Company (1993) and a review of the control center for the Long Island Expressway in Islip, New York.

2.2.1 System Analysis

System analysis, the first of the two task analysis components, involves the description of the system, the definition of all its functions, and the evaluation of the use of each component in the functions of the system. To begin this phase requires the development of a basic model of the entire Central Artery/Tunnel system. This model is used to portray the role of the OCC in controlling the subsystems of the CA/T in order to achieve the system objectives. Additionally, the model assists in providing the direction in which system analysis should advance. The next necessary step in the process includes the definition of the elements of the basic model--system objectives and the performance requirements necessary to achieve these objectives. These performance requirements include the identification of the users of the system.

The definition of the functions which must be performed by the system in order to meet its objectives is the next stage of system analysis. To determine these functions, it was helpful in this instance to identify the modes in which the OCC operated. Operational modes define a sequence of actions which are related to a major phase of operation. By defining these modes, further identification of the functions required for the performance and completion of that mode may be finished. That is, the system functions may be broken down into categories and defined for a single mode rather than for the entire operation of the system.

Utilizing the design specifications for the Integrated Project Control System of the CA/T OCC (DeLeuw, Cather, and Company, 1993), the configuration of equipment necessary for the completion of each mode of operation was identified for each of the users of the OCC. This step assists in the determination of how the equipment is used to accomplish the various functions of the system.

The final stage of system analysis is the development of a functional flow diagram to depict the relationship between the system functions to be performed and the sequence in which they are to be performed. From this step, the actions performed by the operators and the equipment may be examined and analyzed to determine which actions may require more time, effort, or prior information. Additionally, actions which are performed more often than others may be identified.

2.2.2 Task Identification and Description

The second major phase of task analysis consists of identifying specific tasks, defining them, and describing them. Identifying the tasks to be performed by the system in order to achieve the system objectives is an important step. A portion of this stage includes the separation and classification of the tasks according to operator type and operational mode type. This concept will be demonstrated in section 2.3.2. For each task identified, a detailed description must be provided. This description includes all information necessary for the completion of that task. Some examples include the equipment needed, criteria to be met, method(s) for carrying out task, and source(s) of additional information. Finally, task analysis is completed with the incorporation of all information from system analysis and task description into a single flow chart listing all tasks, modes of operation, and system functions.

2.3 Presentation and Discussion of Task Analysis

2.3.1 CA/T Task Analysis Term Definitions

Incident:

Any event, traffic or facility, which falls under the domain of an Emergency Event. For example, a vehicle breakdown is a traffic incident. It falls under the jurisdiction of the traffic operator as an Emergency Traffic Operator Task. A CA/T system fire is a facility incident classified as an Emergency Facility Operator Task.

Warning Status:
Any abnormal or unusual activity, usage, signal, etc. conveyed to the operator by the CA/T OCC workstations, external and/or internal communications, or by operator notice/awareness. A warning status does not establish a system Emergency or Special Event. It does point to certain circumstances that are out of the ordinary and may be indicative of or lead to an Emergency or Special Event.

Internal CA/T Communications:
Communications which occur among CA/T personnel. Included in these communications is that among OCC operators and supervisors, maintenance, toll personnel, and emergency platform and station personnel.

External Agency Communications:
Communications which occur among CA/T OCC personnel and external sources. Included in these communications is that fire, police, EMS, weather, radio, government agencies, and citizens that may call in. All calls are directed to appropriate personnel.

2.3.2 CA/T System Analysis

The Central Artery/Tunnel is a system of roadways designed for the travel of traffic. It also consists of a number of facilities and traffic subsystems designed to assist in the flow of traffic through the system. The Operations Control Center of the CA/T was designed with the purpose of controlling these many subsystems of the entire CA/T system to achieve the goal of the passage of traffic. This system can be described by the control model of Figure 2.1 in which the Operations Control Center functions as the controller of the system. The OCC interprets the system objectives, makes decisions and actions to control the CA/T subsystems, observes and compares system outputs with objectives, and makes modifications to the control actions until, ultimately, the system objectives are achieved.

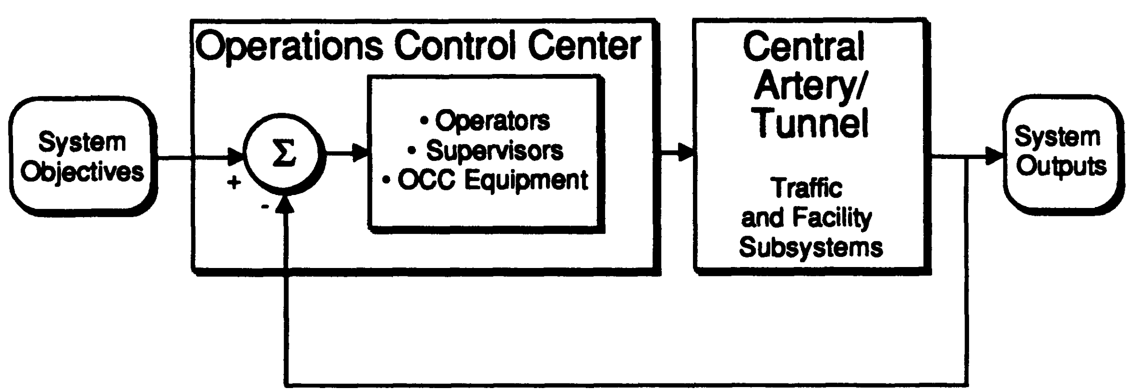


Figure 2.1: CA/T System Control Model

Based upon the system definition and model, the objectives of the CA/T OCC were determined to be the following:

(1) Maintain continuous, uninterrupted, and safe flow of traffic in both tunnel and open roadway sections.
(2) Maintain proper operation of all facility subsystems including
    - Electrical Load Distribution System
    - Tunnel Drainage System
    - Tunnel Lighting System
    - Communications System
    - Network System
    - Fiber Backbone System
    - Closed-Circuit Video Equipment System
    - Security System
    - Fire Detection and Protection Systems
    - Tunnel Ventilation System.

The system outputs consist of the actual state of the traffic or facility subsystems. Some examples would be retarded flow or no flow of traffic, malfunction of the Fiber Backbone subsystem, or high concentration of carbon monoxide levels. Examples of control actions which may be taken by the OCC in order to achieve the desired system objectives include the notification of the Boston Police Department, the dispatch of a maintenance crew, the use of a back-up subsystem, or the increase of a ventilation fan speed.

The users of the Central Artery/Tunnel system are the motorists who will be traveling on it. The users of the Operations Control Center workstations include three types of operators--traffic operators, facility operators, and supervisors. The traffic system is to be controlled by one of two traffic operators, each governing a specific interstate (I-90 or I-93). The facility subsystems are to be controlled by a single facility operator. The traffic and facility operators will be required to perform their assigned CA/T tasks (traffic tasks or facility tasks respectively). The supervisor will be required to monitor these operators in the performance of their tasks. In addition, the supervisor will also be responsible for performing some CA/T tasks assigned to traffic and facility operators as well.

The performance requirements necessary to achieve the first of the system objectives, the maintenance of continuous, uninterrupted flow of traffic, includes the control and coordination of the traffic functions of the system in order to achieve the following goals:

- Expeditious removal of traffic obstacles (vehicles, spillage, ice, snow, water, etc.) from the CA/T,
- Deterrence of overheight vehicles from tunnel entry, and
- Informational assistance for motorists.

In order to accomplish the second system objective, the maintenance of proper operation of all facility subsystems, the performance requirement necessary involves the control and coordination of the facility functions of the system to achieve the following:

- Expeditious return to normal of abnormal environmental alterations (fire, high carbon monoxide (CO) or hydrocarbon (HC) levels, ice, snow, water, etc.),
- Expeditious apprehension of unauthorized personnel,
- Expeditious repair of inoperative subsystem components, and
- Utilization of provided back up components if necessary.

The CA/T design specification documents (DeLeuw, Cather, and Company, 1993) outline five operational modes in which an OCC operator may work. These modes are listed below in chronological order. The supervisor also performs in these modes of operation in a supervisory role.

(1) Monitoring of the CA/T system for Warning Status (Warning Status is the occurrence of an abnormality which may signal an emergency).
(2) Detection of Warning Status in CA/T system.
(3) Confirmation of emergency or special event occurrence upon receipt of Warning Status signal.
(4) Response to emergency or special event.
(5) Termination of an emergency or special event.

System Functions are the functions which must be performed by the system (either human or machine) in order to accomplish the designated objectives and requirements. For the Operations Control Center of the Central Artery/Tunnel, these system functions have been identified and are presented here according to respective modes of operation.

Because three types of operators will be utilizing the OCC workstations of the CA/T system, the system functions as well as the equipment configuration were classified according to three categories. One category was designated for each respective operator type, traffic operator, facility operator, or supervisor. In the identification of system functions, the functions of the traffic and facility operators were very similar with the exception of the fact that each was governing a different set of subsystems. For this reason, the traffic and facility operator functions have been lumped together.

Traffic/Facility System Functions

(1) Monitoring of CA/T traffic/facility systems
- Surveillance of traffic/facility systems via OCC workstations

(2) Detection of Warning Status
- Detection of abnormal CA/T occurrence possibly indicative of emergency or special situation

(3) Confirmation of Emergency or Special Event
- Receiving of Information
- Verification of Emergency or Special Event
- Classification of Emergency or Special Event
- Determination of occurrence of false alarm

(4) Response to Emergency or Special Event
- Selection of System-Generated Response Plan
- Receiving of system-generated response plan
- Modification of system-generated response plan
- Acceptance of system-generated response plan
- Management of Emergency or Special Event Response Plan
- Carrying out of response plan
- Modification of response plan
- Determination of completion of response plan

(5) Termination of Emergency or Special Event
- Termination of response plan once Emergency or Special Event is inactive
- Return to normal of traffic/facility systems

Supervisory System Functions

(I) All Traffic and Facility System Functions (as previously described)

(II) Coordination of Traffic and Facility System Functions

(1) Monitoring of CA/T traffic/facility systems
- Surveillance of traffic/facility systems via OCC supervisor workstation

(2) Detection of Warning Status
- Detection of abnormal CA/T occurrence possibly indicative of emergency or special situation

(3) Confirmation and Assignment of Emergency or Special Event
- Receiving of Information
- Determination of Available Personnel
- Assignment of Task to Traffic/Facility Operator
- Placement of Task in Alarm/Incident Queue
- Performance of Traffic or Facility System Functions (section I.)
- Determination of Occurrence of False Alarm

(4) Response to Emergency or Special Event
- Monitoring of Operator Response
- Determination of Incident Active Status
- Determination of Operator Handling Ability
- Rerouting of Tasks to Other Operators
- Removal and Placement of Task in Alarm Queue
- Performance of Traffic or Facility System Functions (section I.)

(5) Termination of Emergency or Special Event
- Supervising the Termination of response plan once Emergency or Special Event is inactive
- Supervising the return to normal of traffic/facility systems

The equipment needed to accomplish each defined system function of the Central Artery/Tunnel has been identified. Here, the equipment is organized according to the operator type as well as the mode of operation.

Traffic Systems Equipment

(1) Equipment for the Monitoring of CA/T traffic systems
- Vehicle Detectors
- Video Vehicle Detectors
- Incident Detection Algorithm
- Overheight Vehicle Detectors
- Horizontal Attenuators
- Closed-Circuit Video Equipment (CCVE)
- Communications Systems (external agency, weather, maintenance, emergency stations, etc.)
- Operator Workstation Console
- Network System

(2) Equipment for the Detection of Warning Status
- Operator Workstation Console

(3) Equipment for the Confirmation of Emergency or Special Event
- Operator Workstation Console
- Closed-Circuit Video Equipment
- Network System
- Communications System

(4) Equipment for the Response to Emergency or Special Event
- Field Devices (Variable Message Signs (VMS), Lane Use Signals (LUS), Blank Out Signs (BOS), Control Signals (CS), Variable Speed Limit Signs (VSLS), etc.)
- Network System
- Operator Workstation Console
- Communications System (external agencies, emergency stations, Highway Advisory Radio (HAR), maintenance, etc.)

(5) Equipment for the Termination of Emergency or Special Event
- Operator Workstation Console
- Communications System

Facility Systems Equipment

(1) Equipment for the Monitoring of CA/T facility systems
- Network System (Remote Terminal Unit (RTU): HC & CO sensors, Programmable Logic Controllers (PLC), Local Field Controllers (LFC), etc.)
- Intrusion Detection System
- Fire Detection System
- Communications System
- Operator Workstation Console

(2) Equipment for the Detection of Warning Status
- Operator Workstation Console

(3) Equipment for the Confirmation of Emergency or Special Event
- Operator Workstation Console
- Network System
- Communication System
- Closed-Circuit Video Equipment

(4) Equipment for the Response to Emergency or Special Event
- Network System
- Operator Workstation Console
- Communications System (external agencies, emergency stations, HAR, maintenance, etc.)
- Fire Protection System

(5) Equipment for the Termination of Emergency or Special Event
- Operator Workstation Console

Supervisory Systems Equipment

(1) Equipment for All Traffic and Facility System Functions (as previously described)

(2) Additional Equipment for the Coordination of all Traffic and Facility System Functions
- Network System
- Supervisor Workstation Console
- Communications Systems

The functional action-decision or flow diagram was used to assist in the depiction of the relationship between the system functions to be performed and the sequence in which they are to be performed. Because the role of each operator varied slightly, functional flow diagrams were specifically designed for each operator role.

Because the modes of operation as well as system functions of the traffic and facility operators are similar, the creation of only one functional flow diagram governing both operator roles was possible. Figure 2.2 displays the functional action-decision diagram for the traffic and facility operator. Each of the modes of operation is clearly labeled on the diagram as is each of the system functions and decision conditions.

The supervisory role was slightly different from the traffic and facility operator roles in that the supervisor interacts in each of the modes as a coordinator of the traffic and facility operations. The supervisor functional flow chart is provided in Figure 2.3. The supervisor may also perform functions from the traffic or facility operator flow chart if deemed necessary.

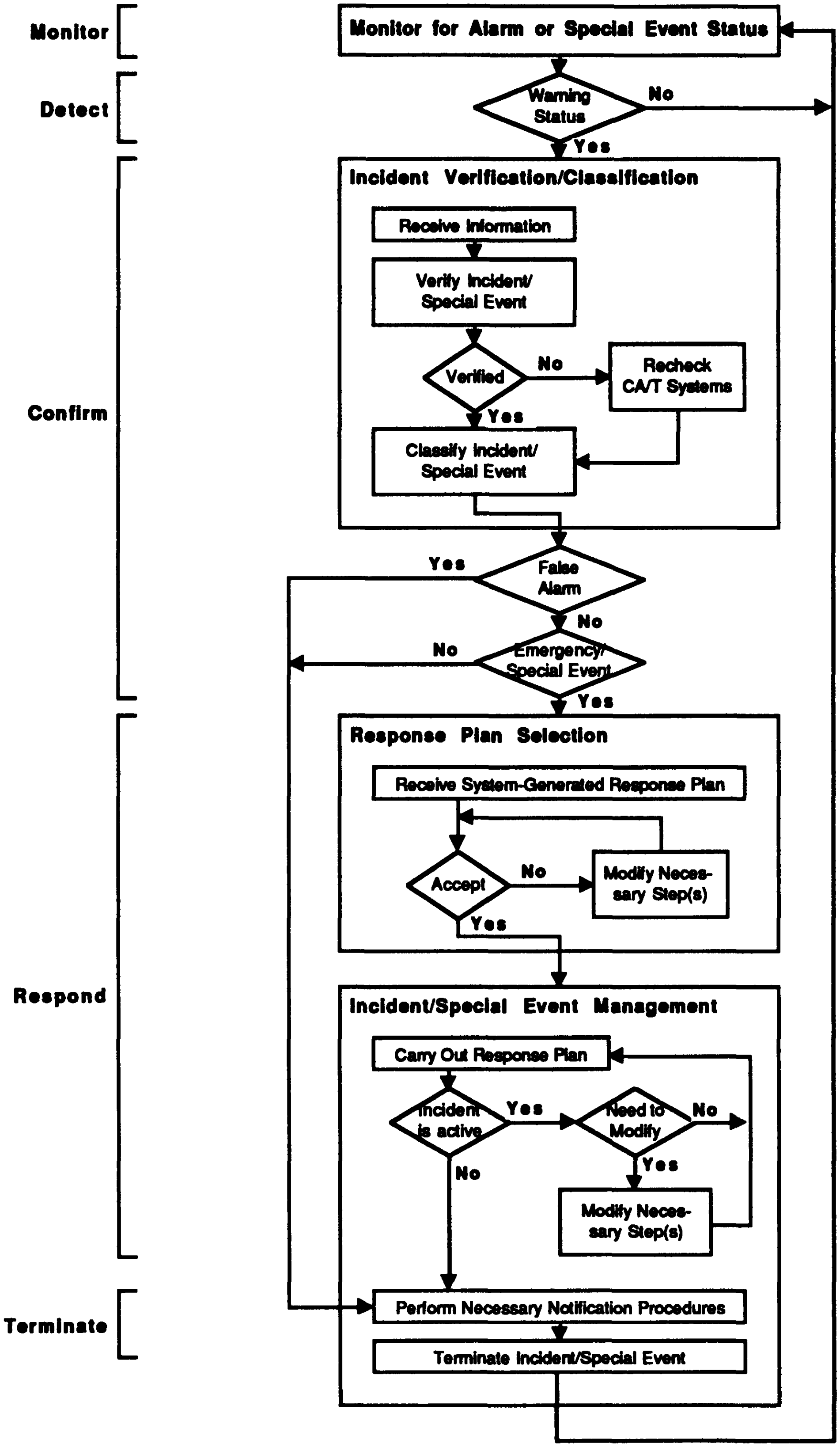


Figure 2.2: Traffic and Facility Operator Functional Action-Decision Diagram

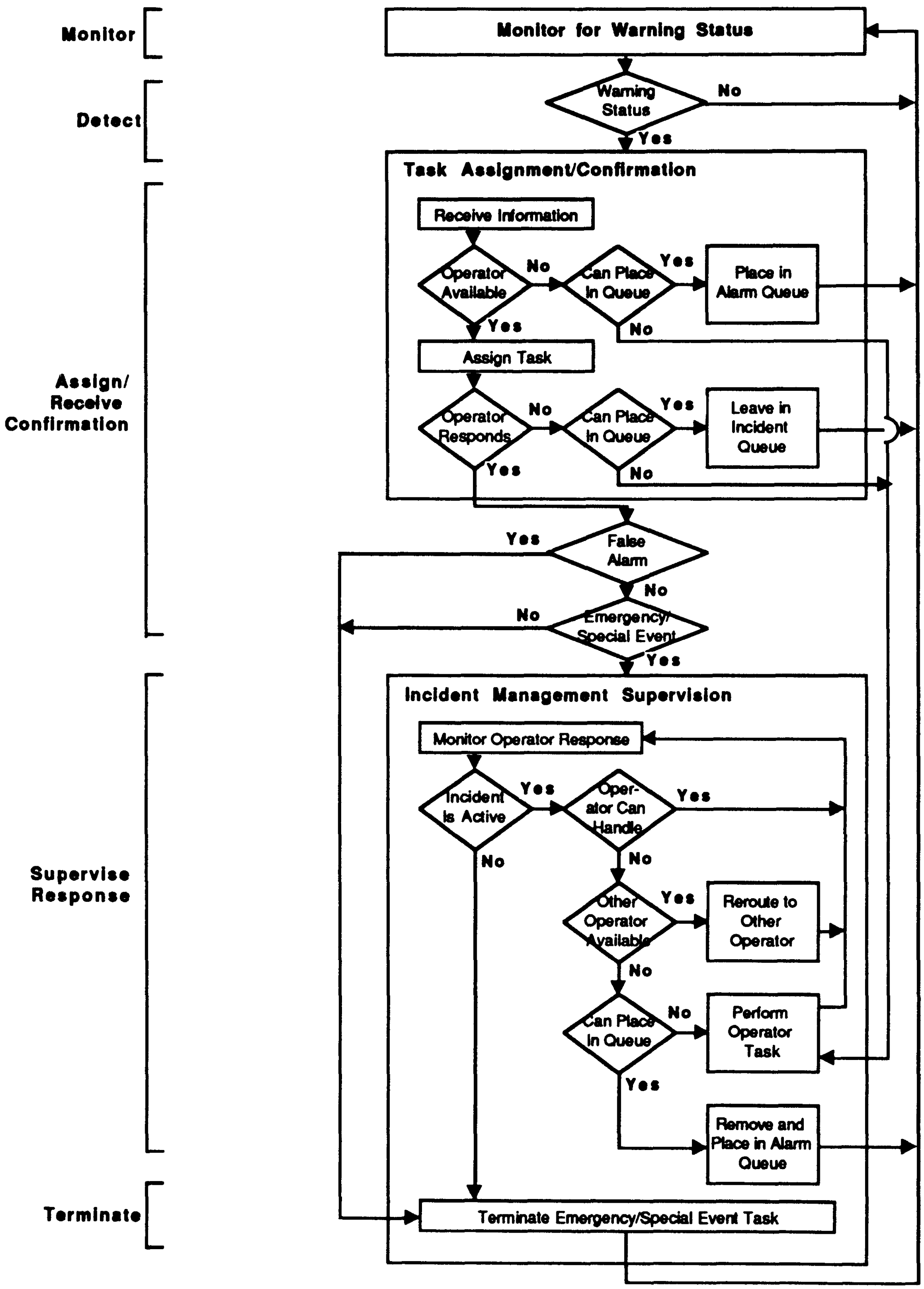


Figure 2.3: Supervisor Functional Action-Decision Diagram

Upon examination of the functional flow charts, it becomes obvious that the majority of the operators' time will be spent in the first three of the modes of operation--monitoring, detection, and confirmation. The modes of response and termination are limited to the times in which emergency or special, non-emergency events occur. For this reason, the tasks which fall under the jurisdiction of the first three modes of operation are classified as Routine Tasks. These are the "normal" or expected tasks to be performed by the operators under normal circumstances. The tasks in the remaining two operational modes are "abnormal" or "off-normal" (Drury, 1987) tasks and thus classified as either Emergency Tasks or Special Event Tasks respectively. An abnormal or emergency task is one which is dangerous to the operation of the CA/T system and will impede the achievement of the system objectives. Off-normal tasks are ones which are not dangerous but pose a threat to the CA/T system if not handled specially. They are thus termed special event tasks. Because the tasks of the operators may be divided in this manner, the functional flow diagrams may likewise be separated into smaller functional flow diagrams governing routine tasks and emergency or special event tasks.

2.3.3 CA/T Task Identification and Description

The identification of all of the tasks to be performed by the system was completed by breaking the tasks down according to task category (routine, emergency, or special event) and then according to operator type (traffic, facility, or supervisor). Each of the Routine Tasks for all operators consists of the modes of operation of Monitoring, Detection, and Confirmation.

Routine Tasks

(1) Routine Traffic Operator Tasks
- Routine Traffic Incident Detection Task
- Routine Overheight Vehicle Detection Task
- Routine Roadway Equipment Malfunction Task
  - Routine CCVE System Malfunction Task
  - Routine Field Device Malfunction Task
  - Routine Tunnel Lighting System Malfunction Task
- Routine Congestion Detection Task
- Routine External Agency Communications Task
- Routine Weather Advisory Forecast Task
- Routine Planned Special Events Task
- Routine Traffic-Affected Facilities Tasks
  - Routine CA/T System Power Failure Task
  - Routine Tunnel Water Level Task
  - Routine Hydrocarbon Levels Task
  - Routine Security Intrusion Task
  - Routine Fire Detection Task
  - Routine Carbon Monoxide Levels Task
  - Routine Structural Damage Task

(2) Routine Facility Operator Tasks
- Routine Electrical Load Distribution System Task
- Routine Tunnel Drainage System Task
  - Routine Water/Refuse Tank Level Task
  - Routine Pump Operation Malfunction Task
- Routine Communication System Malfunction Task
- Routine Fiber Optic Backbone System Malfunction Task
- Routine Network System Malfunction Task
- Routine Planned Facility Events Notification Task
- Routine Security System Malfunction Task
- Routine Fire Systems Malfunction Task
- Routine Tunnel Fan and Ventilation Zone Malfunction Task

(3) Routine Supervisor Tasks
- Routine Traffic and Facility System Task
- Routine Alarm and Operator Incident Queue Task
- Routine Device Configuration Change Notification Task

Each Emergency Task is a possible emergency event which could occur in the CA/T system. Each of these tasks for all operators consists of the operational modes of Response and Termination for the emergency incident or event. The Emergency Supervisor Task includes the supervision and control of the handling of an emergency event by either a traffic or facility operator. Tasks with an asterisk (*) indicate traffic or facility incidents which may affect each other and may require coordination between traffic and facility operators.

Emergency Tasks

(1) Emergency Traffic Operator Tasks
- External Agency Emergency Task
  - Vehicle in Tunnel to be Apprehended by Police Emergency Task
  - Emergency Vehicle Passing Through Tunnel Emergency Task
- Approaching Overheight Vehicle Emergency Task
- Traffic-Affected Facilities Emergency Task*
  - CA/T System Fire Emergency Task
  - Abnormal Carbon Monoxide Levels Emergency Task
  - Abnormal Hydrocarbon Levels Emergency Task
  - Unauthorized Personnel Emergency Task
  - CA/T System Power Failure Emergency Task
  - CA/T System Structural Damage Emergency Task
  - Abnormal Tunnel Water Levels Emergency Task
- CA/T Roadway Traffic Incident Emergency Task
  - Blocked Lane or Vehicle Breakdown Emergency Task
  - Vehicle Accident Emergency Task
- Roadway Equipment Emergency Task
  - Field Device Malfunction Emergency Task
  - CCVE System Malfunction Emergency Task
  - Tunnel Lighting System Emergency Task
- CA/T Roadway Debris or Spill Emergency Task
  - Non-Hazardous Debris or Spill Emergency Task
  - Hazardous Debris or Spill Emergency Task*

(2) Emergency Facility Operator Tasks
- Abnormal Water/Refuse Tank Levels Emergency Task
- CA/T Roadway Hazardous Debris or Spill Decontamination Emergency Task
- Facility Equipment Malfunction Emergency Task*
  - Electrical Load Distribution System Malfunction Emergency Task*
  - Security System Malfunction Emergency Task*
  - Network System Malfunction Emergency Task*
  - Fiber Optic Backbone System Malfunction Emergency Task*
  - Communications System Malfunction Emergency Task*
  - Drainage System Malfunction Emergency Task*
  - Fire Protection/Detection Systems Malfunction Emergency Task*
  - Ventilation System Malfunction Emergency Task*

(3) Emergency Supervisor Tasks
- Emergency Event Handling Supervision Task

Each Special Event Task is a possible special event which could occur in the CA/T system. Each of these tasks for all operators consist of the operational modes of Response and Termination for the special event. The Special Event Supervisor Tasks include the supervision and control of the handling of a special event by either a traffic or facility operator. In addition, they include the supervisor authorized configuration of special system devices.

Special Events Tasks
(1) Special Event Traffic Operator Tasks
- Peak Traffic Flow Periods Special Event Task*
- Special (Non-emergency) Vehicle(s) in or Passing Through Tunnel Task
- Facility Maintenance or Cleaning Affecting Traffic Flow Task*
- External Event Affecting Traffic Flow Task
- Hazardous Weather Conditions Task
  - Heavy Rain or Flooding Special Event Task
  - Snow, Blizzard, or Ice Special Event Task
  - High Speed Winds, Tornadoes, Hurricanes Task

(2) Special Event Facility Operator Tasks
- Facility Systems and Equipment Testing Special Event Task*
- Facility Maintenance or Cleaning Special Event Task*

(3) Special Event Supervisor Tasks
- Special Event Handling Supervision Task
- Special System Device Configuration Task
  - Highway Advisory Radio Configuration Task
  - Variable Message Sign Configuration Task
  - System Wide Display Configuration Task
  - Overhead Monitor Configuration Task
  - User Profile Configuration Task

These tasks have been arranged into charts so as to provide a method of easily distinguishing tasks according to operator type and task category. Additionally, they have been classified with numbers for easy referencing. Figure 2.4 depicts all the routine tasks of the CA/T OCC. Figure 2.5 shows all the emergency tasks, and Figure 2.6 shows all the special event tasks.

Once the tasks of the OCC have been identified, they must be fully described. The description of each of these tasks in detail is provided in Appendix A, section A1. Each task identification number corresponds with the task listed on the charts of Figures 2.4, 2.5, and 2.6.

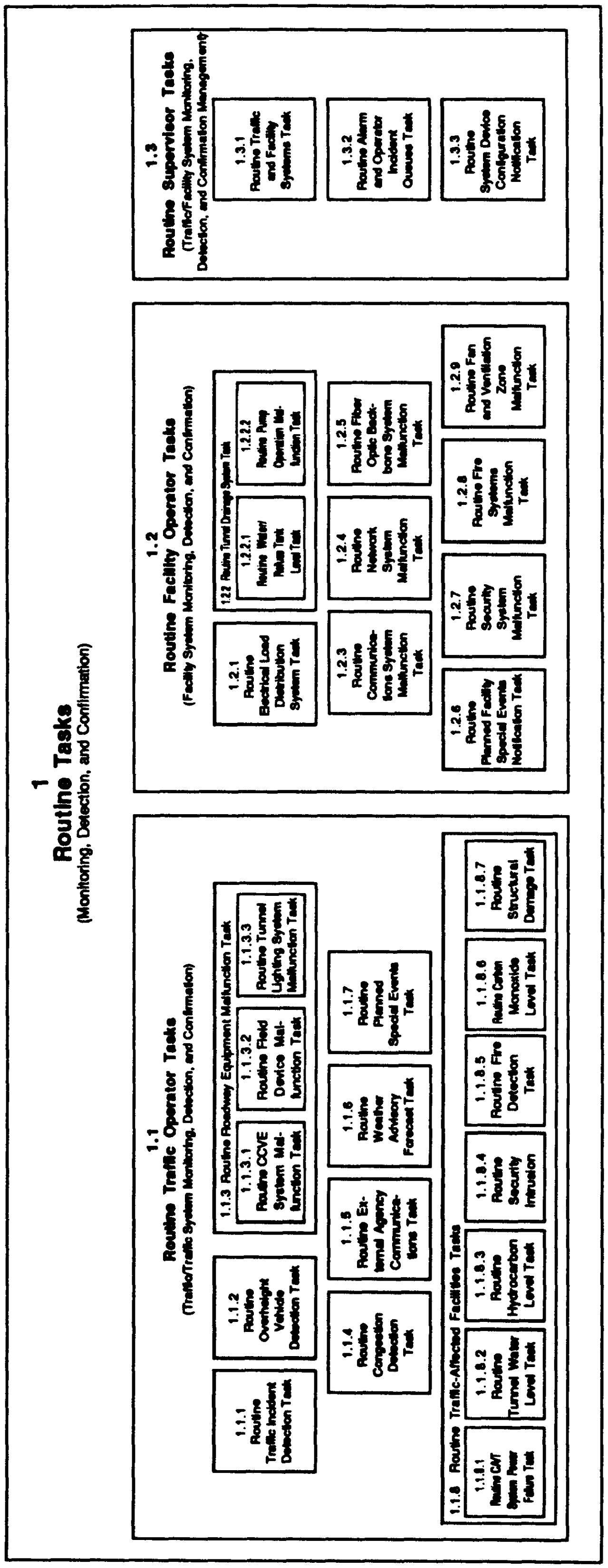


Figure 2.4: Routine Tasks

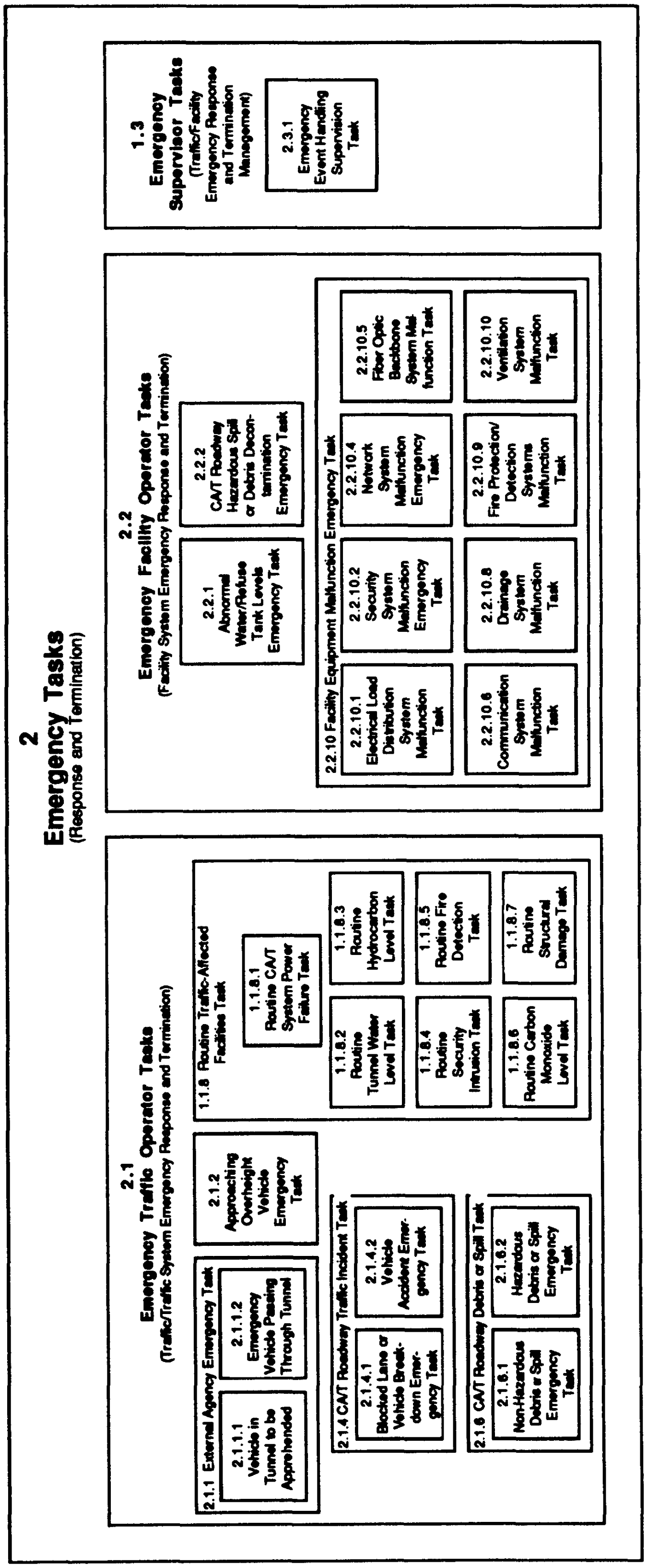


Figure 2.5: Emergency Tasks

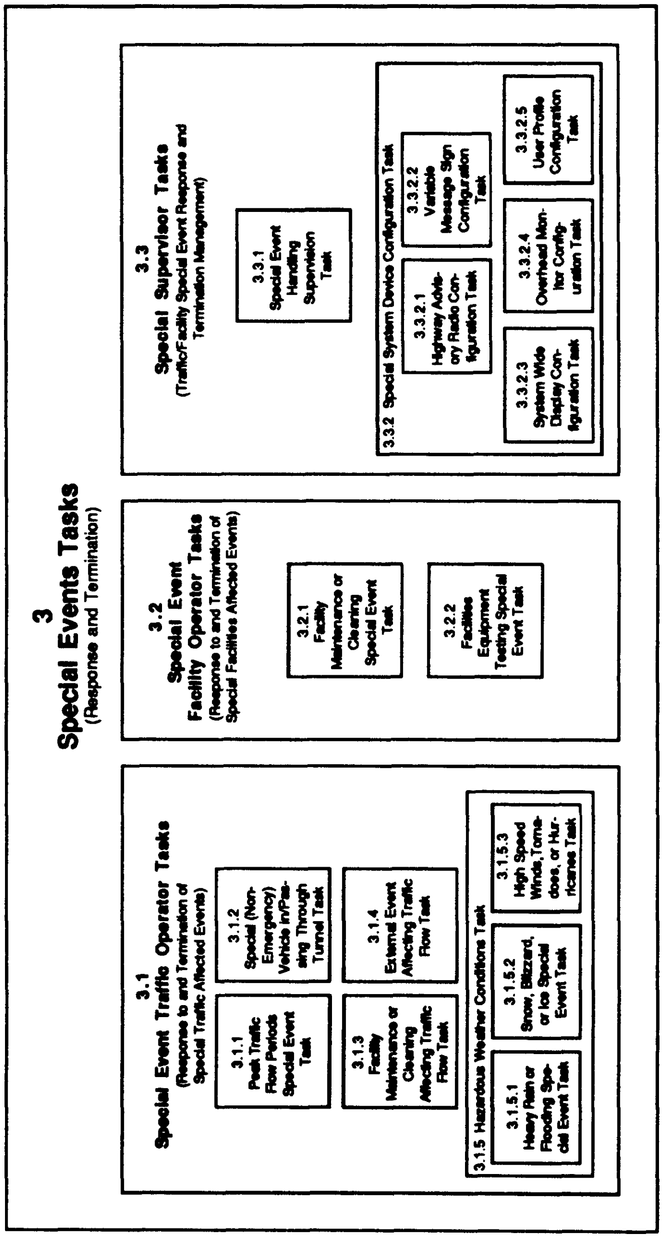


Figure 2.6: Special Event Tasks

Task analysis is the process by which the functional components of the system are combined with the informational components of the tasks to be performed. This process analyzes the steps taken in order to ensure the successful operation of the Central Artery/Tunnel system. Thus, at this point, the functional components obtained from system analysis are incorporated with the tasks identified and described.

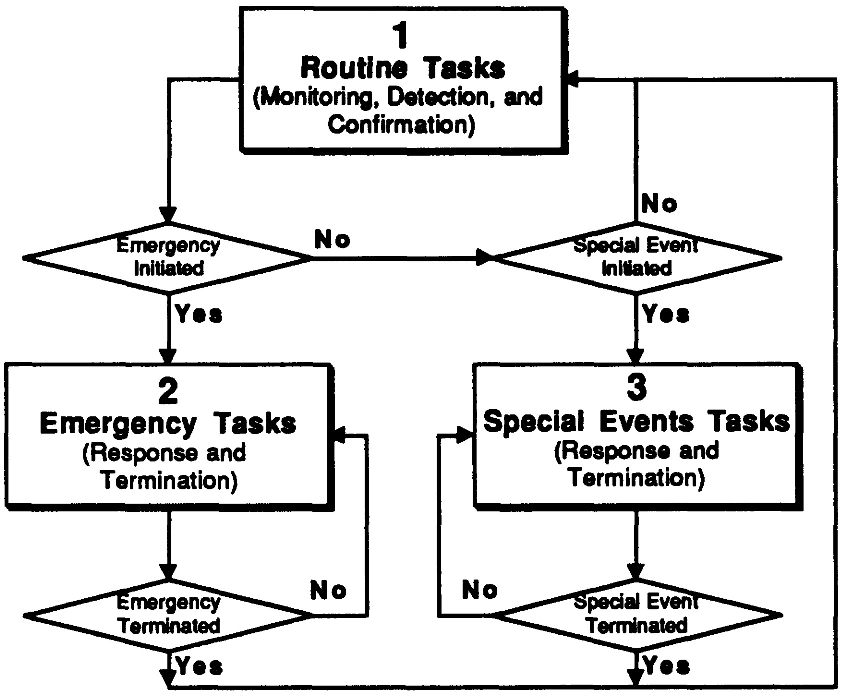


Figure 2.7: CA/T OCC Task Analysis Overview

Figure 2.7 portrays the general movement of an operator through each of the task categories--routine, emergency, and special event. Under normal operating conditions, an operator would perform routine tasks. In the event an operator detected and confirmed an incident, s/he would proceed to perform either emergency or special event tasks depending upon the type of incident confirmed. At the termination of the incident, the operator would return to the routine tasks. An expanded, second level version of the general task analysis outline shows the individual operator roles--traffic, facility, and supervisor. This level is illustrated in Figure 2.8. An expansion the task analysis to a third level of detail includes the specific tasks determined during task identification. This expanded model (see section A2 of Appendix A) now includes all tasks to be performed during the operation of the CA/T OCC.

At this point, we are able to discern the use of the functional elements in the scheme of the task analysis. Under each task appearing in the second level task analysis (section A2 of Appendix A), is the functional flow diagram portraying the actions and decisions of the operator and equipment for that particular task. These functional flow diagrams, which have been broken

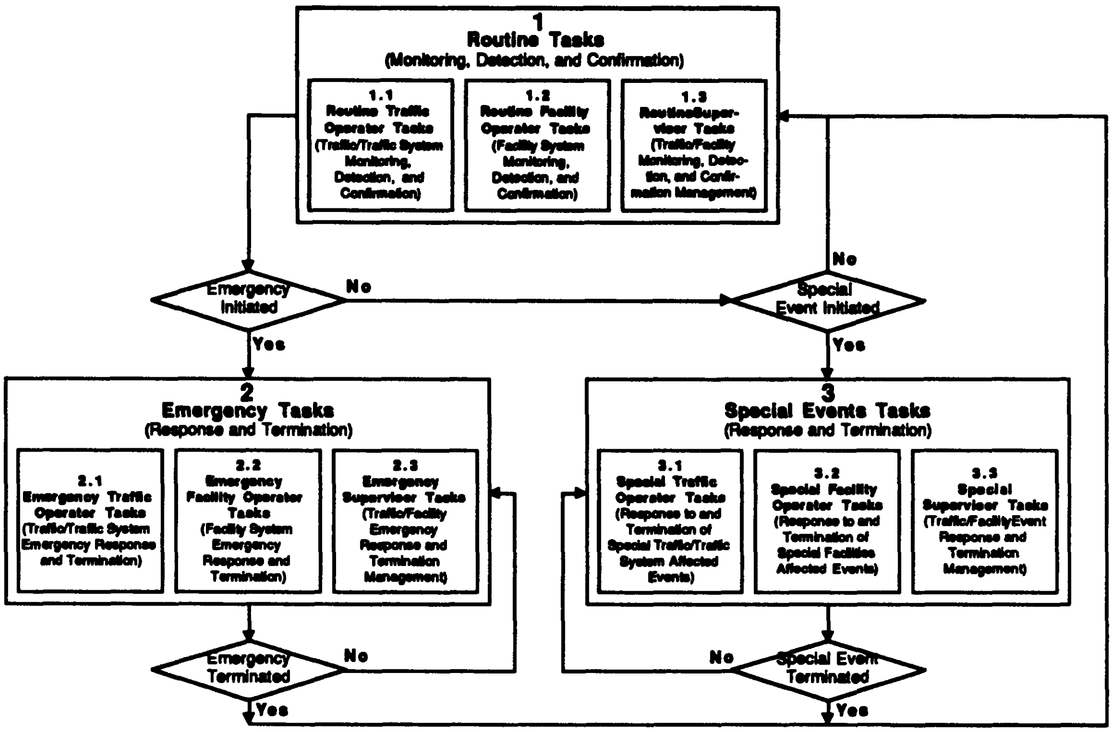


Figure 2.8: CA/T OCC Task Analysis Second Level-Operator Roles

down from their original forms in Figures 2.2 and 2.3 into forms relating to task categories (i.e.- Routine, Emergency, and Special Event), are provided in Figures A3.1, A3.2, A3.3, and A3.4 of section A3 of Appendix A. The insertion of these functional flow diagrams into the task analysis outline would consist of the next level of expansion.

Finally, into the functional flow diagrams can be inserted the information contained in the task description table. The flow diagrams display actions and decisions of the operator as well as the information required to perform these functions. This information has been provided using task description.

Due to the overwhelming amount of information included in the three levels of task analysis, an attempt at including the entire pieced together, expanded version would be too immense and convoluted for the physical bounds of this paper. Instead, the second level of expansion has been provided, as well as the unassembled lower level elements.

Chapter 3
Identification of Critical Operations

3.1 Background and Purpose

The study of operations which are prone to error is a very important step in the design and evaluation of a system. This stage is particularly important in a situation such as the Central Artery/Tunnel Operations Control Center in which errors made during operation have the potential to result in severe consequences. By identifying tasks or operations which are critical in nature, system designers are given the opportunity to reduce the possibility of error though optimization of the system.

Methods of identifying critical task areas are neither determinate nor comprehensive. Sanders and McCormick (1987) acknowledge that "many accidents result from complex chains of events that cannot be adequately described by existing classification systems." Thus, it is the mission of these identification techniques to best determine critical tasks based on operations presenting possible sources of error.

3.2 Approach and Methodology

Determining the areas of criticality in operation of the OCC was approached through a hybrid methodology consisting a number of techniques and previous studies in the area of critical operation identification. Baber and Stanton (1993) describe a technique of error identification utilizing task analysis. The first component of task analysis for error identification (TAFEI) begins with the performance of task analysis to determine the actions that need to be performed by humans or machines in order to complete the task. This step would correspond to task identification and description completed and presented in the previous chapter of this thesis. Baber and Stanton describe the second portion of their technique as the development of state transition diagrams tracing the history of the system throughout its various states. This diagram is very similar to the use of the functional action-decision diagram described and constructed in Chapter 2. Finally, Baber and Stanton map the actions from their task analysis onto their state transition diagrams in order to determine those places in which "problem spaces" may occur. Their study was specifically designed for use in the evaluation of VCRs.

When the tasks of the operators are mapped onto the action-decision diagrams, the results are then compared against several measures to help determine the presence of a critical operation. A critical task can be and is defined by a number of means. Based on past research and studies into the area of sources of error, the results of TAFEI were identified and classified according to these error sources. For instance, an operation could promote possible error simply because the operator is responsible for too many tasks at once. In this case, TAFEI would be examined for areas in which the operator is responsible for an unusually large number of task actions. Another example involves a study by Redding (1992) in which he finds that the primary cause of errors in air traffic control is the operator's failure to maintain situational awareness. Based on this fact, TAFEI would be used to determine tasks which provide a number of opportunities for the operator to lose his/her awareness of the situation. All other sources of error and their resulting critical tasks, which were determined in this study, are presented and discussed in the ensuing section.

3.3 Results and Discussion of Critical Task Areas

This section will present criteria used in the determination of potential sources of error and, thus, critical tasks. Additionally, it will present the tasks identified as critical in nature as determined through the use of task analysis for error identification.

3.3.1 Errors Due to Excessive Operator Workload

The workload of the operator is a primary indicator of potential for error in the operation of a system. The greater the workload, the greater the chance of the operator to err. Errors which may occur as a result of a heavy workload include (1) the inability to perform all of the actions in the allotted time frame, (2) confusion from numerous tasks, and (3) action mistakes. Point one simply states that if an operator is required to perform more tasks than are physically possible in a given time period, an error may occur because the appropriate actions have not been taken. Point two indicates that the greater the number of actions to be performed, the more confusing the performance of this sequence of tasks will be. Finally, the third point attributes excessive actions error to the mistakes of the operator. Redding determined that a frequent source of controller error was a result of "action slips" (i.e.-incorrect key punched on the keyboard) of the operator. These mistakes are more likely to occur under conditions of excessive actions in which the operator has more operations to perform, at a greater speed, and thus, with more potential for mistakes in the form of "action slips." Using TAFEI, the OCC tasks and occurrences which could potentially cause such forms of error were determined and are included here.

- Several emergency incidents occur at the same time, all of which require immediate action. In its proposed form, the OCC has only two traffic operators, a facility operator, and a supervisor. Assuming that all operators are equally trained to handle both facility and traffic tasks, a fact that may or may not be the case, any instance in which several incidents requiring immediate response occur have the potential to place excessive duties on the operators. The occurrence of more than one major emergency incident may not be so uncommon, particularly in the event of a cascading vehicular "pile up."
- The supervisor must perform the task of a traffic or facility operator while simultaneously maintaining appropriate control over his/her specific supervisor functions.

3.3.2 Errors Due to Operator's Loss of Situational Awareness

The research undertaken by Redding involved the examination and evaluation of all Federal Aviation Administration reports of operational errors for Fiscal Year 1989. His conclusions indicate that the majority of operational errors for air traffic controllers occurred under conditions in which the incident was not considered "critical." Instead, incidents which were classified as normal operating conditions promoted the highest percentage of mistakes. From the results of the study, most of these mistakes were attributed to the operators' loss of situational awareness. The entire realm of situational awareness can be broken down into several specific regions necessary for the operator to maintain situational awareness. The errors which occur for each of these regions help in promoting the general loss of cognition of the operational state. These errors were found in the study to arise from the following: (1) lack of proper communication and coordination; (2) incorrect identification (or lack of identification) and use of data presented to the operator by the system; (3) lack of information; and (4) "mismatch" of the expectations of the controller regarding a future event and the actual event.

Communication, the first of the regions contributing to operator situational awareness, is a very important factor in facilitating the operators understanding of the incident. A lack of communication between the controller and other controllers, field personnel, and external agencies can result in potential error. Additionally, the coordination of the operations of each of these parties is necessary for the successful completion of a task. Using TAFEI, the tasks found to be most prone to error due to communication and coordination difficulties in the CA/T OCC were the following:

- All emergency traffic operator tasks which require the dispatch of an Emergency Response Team/Platform.
  The OCC operator is responsible for maintaining constant communication with the Emergency Response Team/Platform while s/he continues to manage the remainder of the emergency task. Any difficulties in communication can cause delay or errors in the response.
- All emergency and special event tasks which require the assistance of an external agency.
  The coordination of the activities of external agencies with internal CA/T personnel is very important due to its vulnerability to error. The presence of several different parties all with different agendas at the scene of an incident has the potential for creating confusion, particularly if each of the individual parties is not aware of the actions of each other.
- All OCC tasks which require the cooperation and coordination of the traffic and facility operators.
  The coordination of incidents or events which affect both facility and traffic operation is necessary for the successful operation of the OCC. The operators must have a definite plan for communication with each other in order know the actions and responsibilities of each other and to coordinate an appropriate response.
- The delegation of alarms to the Incident or Alarm Queue.
  As an alarm waits in a queue, it has the potential to become obtain higher and higher priority levels with the passage of time. The operator must not be allowed to forget that incidents are waiting in a queue and becoming more severe.
- Traffic incidents which occur outside of CA/T jurisdiction.
  Although vehicular accidents which occur outside the bounds of the CA/T do not specifically fall under the authority of the OCC, the incident still possesses the potential to back up into CA/T area and cause difficulties in traffic flow. Communication and coordination of some form are necessary to acknowledge problems and assure that difficulties will not occur on CA/T roadways due to external incidents.

The second contribution to operator comprehension is the identification of data incorrectly or not at all. When the controller identifies data presented to him/her in the wrong manner, s/he then consequently, utilizes it in the wrong manner. Additionally, if the operator does not identify that data is being presented, no appropriate actions will be taken at all. Tasks determined to provide a good chance of this misidentification or lack of identification are provided here.

- All tasks which utilize monitoring devices and/or screens (i.e.-Routine Tasks, Emergency Tasks requiring monitoring of traffic, facilities, etc.)
- All tasks which require the operator to interpret data.
- Periods of operator boredom.
- Periods of operator drowsiness.
- Periods of general operator inattention.

Lack of information is the third listed factor in the absence of the operator's awareness of incident status. This problem can be caused by various circumstances. One such instance simply involves the inability of the system to detect or provide information regarding an incident that is taking place or beginning to do so. Another instance stems from a general lack of attention. The need for the operator to pay attention to the operations being performed is crucial in the use of the OCC. Unfortunately, the ability of the operator maintain this attention is not always present. The inattention of the operator can lead to lack of recognition of potential problems which may be occurring. It can also lead to carelessness in the collection of data which could potentially point to abnormal situations. Listed here are tasks identified as promoting a general lack of information to the operator regarding the tasks being performed.

- The return of an operator from a break.
  In this circumstance, the operator may be unaware that an emergency situation is developing because s/he has not been there long enough to witness all system states and changes from the beginning.
- The changing of a shift .
- Previously unencountered incidents for which the system has no previous data and can provide no information regarding the situation.
- Incidents which occur during the malfunction of CA/T system equipment designed to sense the situation and provide information to the operator.
- Incidents occur in which the CA/T system does not possess the proper equipment for detection and/or analysis.

The fourth and final source of situational awareness loss--the mismatch of expectations and actuality--is claimed by Redding to be primarily due to the failure of the operator and the system to update situational awareness as changes in the status of the incident occur. Additionally, he asserts this problem can be fostered by a lack of appropriate alternative control center plans designed to a variety in the evolution of incidents. Klein also addresses this issue in his 1993 study. He refers to this phenomena as "incomplete or inadequate mental simulation." Mental simulation is a common method of human reasoning. In this process, the human will hypothesize a chain of events that will take place to guide the system in transforming through several states. This method of reasoning helps the operator determine his/her succeeding course of action. Difficulties arise, however, when the user has incorrectly simulated the chain of events and enacts the wrong actions particular to the actual situation. Potential areas of operator "mismatch" include the following as determined by TAFEI:

- All OCC tasks in which the operator is required to make a determination based on past experience.
- All tasks which resemble other tasks used frequently by OCC operators.
  One illustration of this point is found in the case in which the experienced operator has memorized the operating procedures of the response plan for a particular type of incident because of its frequent occurrence. The operator begins work on another response plan extremely close in nature to this memorized incident, but different enough for the computer to generate a different default response plan. The operator immediately accepts it and goes to work on it without examining closely, assuming that s/he fully knows its contents. The actions of this experienced operator result in error in the resolution of this incident.

3.3.3 Errors Due to Lack of Experience

Klein (1993) conducted an evaluation of the decision studies of several different domains including forestry service, commercial airlines, and the military. From the analysis, Klein identified several decision error categories, and of these categories, the largest one was that of errors due to a lack of experience. A lack of experience on the part of the operator can lead to such difficulties as the operator's failure to anticipate problems associated with such a task, inability to perform the task quickly enough for proper response outcomes, or improper judgment in carrying out an action. These difficulties stem not only from an operator's "newness" to the job, but they can also occur when an experienced operator must perform an event never before encountered. Rather than provide a list of OCC tasks which fall into this category, this section simply anticipates that all tasks have the potential of facing lack of experience errors. In particular, responses of the OCC to incidents for which the system had not previously accounted has a greater chance of encountering these errors even by "experienced" operators. These incidents have a greater chance of going undetected or alerting the operator only to partial information regarding the status of the occurrence. Some particular incidents posing a threat due to infrequent performance include the following:

- The switch of operations to the Back-up Operations Control Center in the event of disaster or malfunction in the OCC.
  A situation such as this one is unlikely to occur very often and will, thus, promote difficulties due to lack of operator experience in performing this task.
- Any task which is new and/or does not have complete information to the OCC.
  Incidents not before encountered will bring with them a certain amount of uncertainty because they have never been performed before.
- All OCC tasks not frequently performed.

3.4 Presentation of Critical Operation Scenarios

The following scenarios have been constructed in order to demonstrate situations in which the operator may be placed under conditions which may lead to error. These scenarios are meant to emulate occurrences in which the operator is prone to error of some of the forms described in the previous sections. These scenarios will also be utilized as examples in the development of the operating procedure guidelines in Chapter 4. Each incident scenario was based upon information provided in the DeLeuw, Cather, & Company *System Design Document*, and each incorporates various aspects of CA/T OCC operations. The use of these incidents as examples, thus, provides a demonstration of the capabilities of the operating procedures under a range of CA/T traffic and facility system operations.

3.4.1 Incident Scenario 1: High Carbon Monoxide Levels, Unknown Cause

> Fan 7EF-1 in Exhaust Duct Zone WB-E2 becomes inoperable. A malfunction in the Programmable Logic Controller (PLC) has prevented notification to the OCC. It has also prevented Event Handling from compensating for the down fan by altering ventilation control to increase the settings on the remaining fans.
>
> Because the fan is no longer operating, the carbon monoxide levels begin to rise in the tunnel controlled by that ventilation zone of Vent Building 7. The traffic operator for I-90 then receives an alarm that the carbon monoxide levels for a specific section of tunnel roadway have increased. The cause of the increase cannot be immediately determined by the computer system; thus, the symptom-oriented response plan is started.

This scenario is one which is "symptom-oriented." That is, the operator is alerted to a specific abnormality but is unaware of the cause of the abnormality. This particular operation requires the operator to investigate all possible disturbance causes while enacting preventative measures (see Figures B1.1 and B1.2 for full operating procedures). For instance, the computer will instruct the operator to increase ventilation in the affected area in order to decrease the level of carbon monoxide. While dangerous air levels begin to fall due to the ventilation increase, the computer will be providing the operator with instructions for determining the cause of the problem. As the operator investigates each possibility and inputs his/her findings to the computer system, the response plan will direct the operator to the investigation of the next possible cause. Simultaneously, the system would require that the operator maintain awareness of the carbon monoxide readings and the ventilation step level. Once the source of abnormality has been found, the system would recommend the appropriate task-oriented response plan that should be initiated to resolve the existing problem. If the cause cannot be determined, the computer would instruct the operator to notify the supervisor that a determination cannot be made.

A primary reason for the importance of this scenario is that the operator must work under conditions which are uncertain and undetermined. Unlike task-oriented procedures in which the operator has knowledge of the situational problem and a plan of how to correct it, in this instance s/he has no set response plan. This previously unencountered situation has the potential to be prone to errors due to lack of experience and excessive workload.

3.4.2 Incident Scenario 2: Vehicle Collision on Tunnel Roadway

> A two vehicle collision occurs on a section of tunnel roadway. The traffic operator for I-93 witnesses the traffic accident while routinely monitoring the roadway using CCVE. The operator immediately initiates the emergency task for "Vehicle Collision on Roadway."

The second scenario is designed to be a typical, often encountered "fender-bender" to which the traffic operator would initiate a "task-oriented" response plan. A task-oriented procedure is one for which the operator has already been alerted to and has confirmed the incident. Because the incident in known, the operating procedures will provide the operator with all of the steps necessary to complete the response and resolve the incident (see Figures B2.1 and B2.2 for full operating procedures).

Critical operations accompanying this scenario are those associated with the operator's loss of situational awareness. Frequently occurring tasks such as these were discussed in previous sections to be primary targets for operator error due to this loss of situational awareness. This particular incident will require that the operator coordinate the operations of and maintain communications with the Emergency Response Team and CA/T internal personnel. In addition, Incident Scenario 2 requires that the operator conduct ongoing or continuing procedural steps (such as the monitoring of a specific section of roadway) while also performing other steps.

3.4.3 Incident Scenario 3: Vehicle Collision with Fire on Tunnel Roadway

> A two vehicle collision occurs on a section of tunnel roadway. The traffic operator for I-93 witnesses the traffic accident while routinely monitoring the roadway using CCVE. The operator notices that a fire has begun to consume one of the involved automobiles. The operator immediately initiates the emergency task for "Vehicle Collision on Roadway" and specifies that a fire is present in this incident.

Like the second incident, this scenario is also task-oriented. In this example, however, an additional abnormality has occurred which requires special attention of the operator--a fire in the vehicle collision. This example is, again, demonstrative of the error that can arise from the loss of operator situational awareness. The critical tasks of this scenario include the coordination of the activities of internal CA/T personnel as well as the activities of external agencies. The occurrence of a fire in a vehicle collision will warrant the need for the Boston Fire Department and, in turn, the need for the successful integration of their activities into those of the CA/T system response.

Although the potential for critical operations is present in their current forms, Incident Scenarios 2 and 3 were primarily developed that they may demonstrate the occurrence of changing incident status and the response of the operator to that change. In this instance, the operator has detected, verified, and initiated a response to a vehicle collision on a tunnel roadway (i.e.-Incident Scenario 2). While the operator is in the middle of his/her response to the incident, a fire erupts at the collision site. Had the fire been present when the incident was first detected, the response plan of Incident Scenario 3 would have been initiated by the operator and computer. The difficulty lies in that the operator must now incorporate the steps of the response to Incident Scenario 3 with those of Scenario 2. The need for the operator to be able to easily receive and comprehend all information regarding the situation, the changes in the situation, and the updates made to the response plan as a result is crucial. Specifications for the operating procedures to fulfill these needs are provided in Chapter 4.

A situation of this form can be classified as a critical operation for several reasons. This situation, more so than the previous scenarios, mandates that the operator maintain awareness of the situation and all of the changes occurring therein. Not only has the status of the incident changed to include a fire, but as a result, the operating procedures will have to be modified such that they include appropriate measures for a response to the fire. The duties of the Emergency Response Team, the OCC, and other internal CA/T personnel will change. The traffic operator will be responsible for coordinating and communicating these changes. Thus, errors due to excessive operator workload are not unlikely in this situation. Finally, any variety of changes in addition to a fire can take place during the operator response to an incident. Many of these changes will be previously unencountered or even unaccounted for. For this reason, errors due to lack of experience may be common in this critical operation.

Chapter 4
Operating Procedures for the Operations Control Center

4.1 Background and Purpose

Operating procedures for the Central Artery/Tunnel (CA/T) Operation Control Center (OCC) are instructions utilized by the operator to assist in performing a task or sequence of tasks. Whether they be utilized often or not at all, these procedures must be available to the operator and provide guidance which ensures the successful completion of the task(s). The operating procedures may be used as a training or learning tool, or they may be used as an on the job performance aid capable of guiding assisting the operator in completing a task. In this application to the CA/T OCC, operating procedures will most likely play a major role in the management of incidents which occur in the CA/T system. Because the CA/T is a system of such complexity, the response of the OCC to incidents will contain a large number of steps and will rely heavily upon the actions of the operator. The ability of the system user to utilize operating procedures to guide him or her through an incident response plan will greatly affect the resolution of the incident.

To maximize the effectiveness of the operating procedures, proper measures must be taken to design the procedures with human factors issues in mind. A set of instructions which facilitates easy, effective use of the human operator will ensure greater levels of success and accuracy in the performance of tasks. In order to provide this usefulness, the operating procedures must encompass all aspects of the operation of the CA/T system. Accounting for all such elements is necessary in the development of a set of effective operating procedures.

This chapter provides a discussion of the criteria necessary in designing the operating procedures. Additionally, it outlines the methods by which the operating procedures were developed for use in the Operations Control Center. Finally, the chapter presents a set of guidelines to aid in the future development of operating procedures specific to the traffic control system of the CA/T OCC.

4.2 Criteria in the Design of Operating Procedures

In the design of procedures oriented towards effectively guiding a human operator through the efficient and accurate completion of a task, several factors must be determined–the information to be included in the operating procedures, the manner in which the procedures are to be presented to the operator, and the methods by which the procedures will be evaluated and revised. Although many sources provide various information regarding these three design factors, Wright (1988) describes three "...broad classes of decision-making factors for the document designer: What information to give; How to give it; How to asses its adequacy."

The design process began with the completion of the task analysis of the CA/T OCC. From the information provided in this document, each task involved in the operation of the CA/T system was analyzed. Based on the specific human and technological needs of each task, the operating procedures were developed such that they incorporated the requirements necessary for the completion of each task.

4.2.1 Layout and Presentation Criteria

Certain human factors must be considered when designing the format in which the operating procedures will be presented to the user. The layout must be created such that it facilitates the understanding of the procedures and their implementation into the completion of the task. The presentation should be designed such that the operating procedures are accessible, legible, and explicit, and the factors which affect these objectives must be considered. The criteria covered in this section addresses the question posed by Wright (1988) of "how to give" the information to the user.

4.2.1.1 Medium

Operating procedures may be conveyed to the operator via different medium. The documentation may be in the form of printed material, computer-based material, or some combination of both. Printed operating procedures provide the operator with a "hard copy" of the instructions; whereas, computer-based procedures provide an "on-line" version. Because different forms may be preferred by different users or in different circumstances, the creation and implementation of both forms would be the preferred choice.

Because the operations of the OCC operator are oriented around the use of the computer system, it follows that on-line versions of operating procedures can be easily implemented and utilized. In addition, on-line procedural aids have greater flexibility. They possess the capability of being modified to accommodate various needs and situations. Additionally, computer based aids can be presented more easily in a "leveled" form in which minimal procedures are provided on the upper levels and more detailed explanations are provided on the lower levels. For printed versions, such flexibility is not as easily attainable.

4.2.1.2 Textual and Graphical Specifications

An important portion of the development of a uniform structure in which to present the procedural information lies in the use and implementation of text and graphics. In designing the textual specification for the operating procedures, it is imperative that the font which is utilized be one which provides the operator with the easiest reading and comprehension. For applications such as this, it is generally accepted that sanserif letters be used so as to provide this ease in comprehension.

Also of importance in the selection of text is the character size. It is necessary that the operating procedures provide a font size which best facilitates operator reading while minimizing operator eye strain. This size should be chosen such that it meets these needs under various lighting and stress conditions.

The use of graphical illustrations and symbols must be decided upon for use in the operating procedures. A large number of studies conducted have concluded that the utilization of graphics or iconic symbols produce an increase in operator comprehension and response time. Osborne and Huntly (1992) found that when pilots were subjected to purely iconic flight instructions rather than the normal prose flight instructions, their comprehension improved in both quickness and accuracy. As with the use of text, the graphics should be made uniform in the response plan. For instance, certain symbols would represent specific tasks, actions, or system equipment. An operator would, thus, be able to recognize an operation or task through the icon which represents it.

Color is an important issue in procedure development and implementation, particularly in regard to computer based procedures. Determining the correct combination of colors, amount of color, and the significance of each color in order to maximize ease of operator use is crucial. Procedures and workstation display screens which do not effectively utilize color can create situations in which operator comprehension is diminished and response time is slowed. In addition to color, response plan screens must be designed such that they are also effective on monochrome displays.

The structure of the sentences to be used in the response plans is another substantial issue. It is important that this structure be uniform, thus allowing the user to easily and immediately recognize the commands in the response plan. Additionally, the actual text and graphics must be made uniform throughout the operating procedures. The operator would, therefore, be able to recognize a specific task or operation by the type of text and/or graphics present in that portion of the response plan.

4.2.1.3 Formatting Structure

In order to aid in the user understanding and readability of each of the command procedures, a standard structure for the response plans needs to be designed. This standard format will become a major factor in conveying to the user which type of task or operation must be performed and in which order. The largest structural issue deals with the organization and ordering of the material to be included in the operating procedures. The procedures must be organized such that the steps are carried out in an order which accounts for chronology, criticality, and continuity. In other words, the procedural steps must ensure that actions are taken in the appropriate time order, in the correct order of importance, and in a manner such that ongoing steps maintain continuity while other actions may be taken.

Generally, it is least effective to present procedural steps in the form of prose paragraphs. Two primary forms of organizational structures exist which are considered by most studies to be more effective. They include procedural instructions formatted as a list of numbered instructions and as a flowchart of pictorial symbols and words. Which form is best suited to be utilized in the CA/T is a determination which must be made.

Another concern regarding the structure of the operating procedures lies in the need for the layout to consist of methods of making critical operations more apparent and their acknowledgment more certain. Of the various different operations that will be performed in the completion of a task or sequence of tasks, some will be more sensitive or critical than others. In the performance of these critical operations (receipt of critical information or alarm), it may be necessary that the operator acknowledge when the task has been completed. When this is the case, it is necessary that the operating procedures reflect this safety feature. The appropriate type of acknowledgment must ensure that the operator can quickly acknowledge the task completion while maintaining a conscious understanding of the event which took place. The procedures must be organized and presented such that they guarantee that the acknowledgment does not become habitual or involuntary. Also, they must be presented such that when errors are made by the operator, the procedures are capable of facilitating the correction process.

4.2.2 Informational Content Criteria

Determining what information to include in the operating procedures begins with the important step of analyzing how they will be utilized in the OCC. Sohr (1983) makes the suggestion that in order to make the procedures useful for a diverse group of users, the instructions should be "task oriented." In their use in the OCC, the procedures are to be task oriented, for the OCC operator will actually use the procedures in performing a task. The procedures will take the form of a "response plan" which the computer will generate according to which specific task the operator must perform. In the design of procedures to function as the response plan, several considerations regarding informational content must be taken into account.

4.2.2.1 Procedural Detail
Several factors contribute to the determination of the amount of detailed operations that are to be included in the operating procedures. The first of these factors regards the ability and experience of the system user. The inherent abilities as well as the training and experience of the operator utilizing the OCC has a significant bearing on the development of operating procedures. Operators with greater experience and/or more training in the OCC system will generally possess a greater knowledge of the steps necessary to perform and complete a given task. Likewise, an operator whose abilities exceed others will be more apt at learning to perform a task without the aid of supplemental operating procedures. These factors contribute to the determination of the amount of detail of information which is included in the procedures.

The procedures can be designed with one anticipated ability/experience class of user in mind, or they can be designed in levels to accommodate different classes of users. Because it is difficult to provide procedures catered to individual user classes in printed, hard copy documents, a version which is capable of being used by all potential users must be created (Wright, 1988). Similarly, on-line documentation can be more easily manipulated to accommodate user differences and could, thus, include several levels of procedural information. In order to be particularly useful to the entire user population, the operating procedures should be designed such that the lowest (most detailed information) level is capable of assisting the most novice user of the CA/T computer system.

Another key factor in determining the amount of detail of operational steps in the procedures lies in the frequency of use of the task. Certain tasks are performed less often than others. Those rarely performed may tend to be forgotten by the operator. Although the operator may have been proficient to a certain degree at one time, infrequent use may require that the operator have access to more detailed information in order to perform the task.

Often specific amounts of detail are necessary at different times. For instance, the more critical the task, the less time the operator has to respond to prevent further increase in criticality. For this reason, the procedures must be organized such that the time spent by the operator reading the procedures is minimized while the successful outcome of the operator response is maintained. In this instance, the user would not want to read through the most detailed levels of the response plan. Instead, it would be more beneficial to the operator to have access to an upper level of less detailed information. Some method of notifying the operator of the criticality of the task (i.e.-an emergency task) should also be conveyed in the procedures.

The most useful response plan will be one that is created such that it provides several levels of detail which can accommodate a variety of user ability and experience as well as a variety in task criticality. These levels of informational detail should be organized such that they progress from a general procedural overview to a very specific instructional sequence. Green and Marsden (1992) describe a Procedures Document Database in a hierarchical organization of four levels. Each of these levels provides information pertaining to the completion of the same task, but in varying amounts of detail. Although their work pertains to industry, this concept is that which the procedural layout of the Central Artery/Tunnel follows. Figure 4.1 is an adapted illustration from Green and Marsden depicting the concept of the informational detail levels.

In this illustration, the top level, Response Plan Overview, provides the most basic elements of the operating procedures. This level is the most general, and acts as a map for the operator in maneuvering through the response plan. The second level, Expanded Information, comprises conditional statements, system manipulation information, and instructions for the use of equipment. Conditional statements (i.e.--if..., then..., else...) guide the operator to different procedural steps for different situations. The second level also provides assistance to the operator in the area of system manipulation which consists of information on which equipment to use, at what time, and in what order. Finally, the second level provides guidance on how an operator should use specific equipment. For instance, this type of information would describe to the user how to contact the Boston Fire Department via the CA/T hot-line or how to increase a ventilation zone step level.

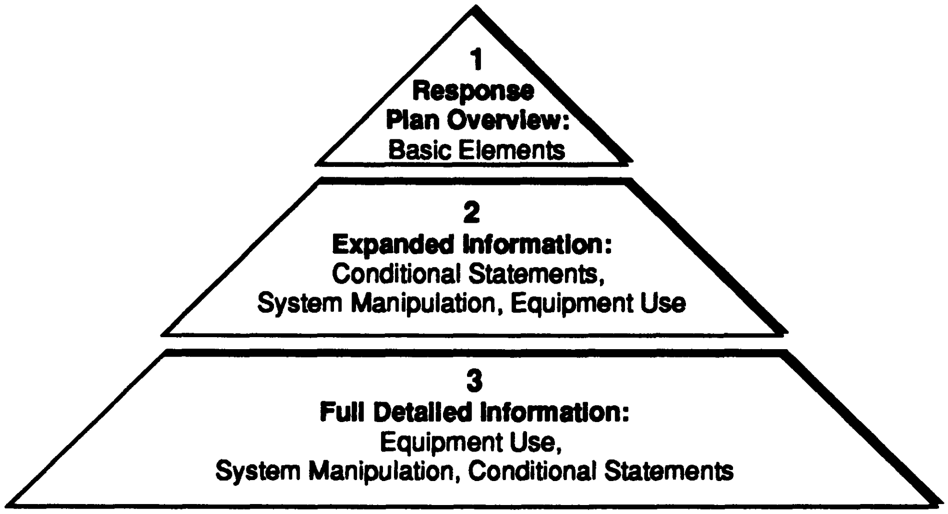


Figure 4.1: Levels of Procedural Detail

The third level, Full Detailed Information, provides the same categories of information as the second level but in different proportions. In the figure, the second level lists conditional statements first and equipment use last while the third level lists these components in reverse order. This arrangement is due to the fact that the second level contains a greater quantity of conditional statements than information regarding equipment use, and the third level contains more information on equipment use than it does conditional statements. Methods for using equipment is a skill which will generally be known by the more experienced OCC operators. The beginning, novice operators will usually be the users who require this form of assistance. Thus, equipment usage is relegated to the most detailed level. Conditional statements serve as a slightly more detailed guide through the response plan and are, therefore, found in greater quantity in the second level. These categories do not occupy mandated percentages of the second and third levels. Instead, they are guidelines for the placement of information in the operating procedures.

A great deal of research has provided evidence that procedural manuals which provide the user with briefer instructions are actually more effective than those which include longer elaboration on a subject. Reder found in 1986 that elaboration actually did not seem conceptually to improve a user's understanding of a system. In fact, Reder and Anderson (1980) found that summaries and overviews could prove more effective than the longer text they were summarizing. In regard to the OCC, response plans which consist of briefer procedural steps should be incorporated.

4.2.2.2 Task-Oriented Vs. Symptom-Oriented

Operating procedures have the capability of being utilized under several circumstances in the OCC. These include routine (normal) tasks, emergency (abnormal) tasks, and special event (off normal) tasks. Often, the operator will know the specific task which is to be performed. The response plan will need to reflect this knowledge and thus provide instructions for the specific task or event. These procedures are referred to as "task-oriented" (Sohr, 1983). Many tasks, however, may not always be immediately known to the operator. Instead, the operator will be aware of a specific abnormality or symptom. "Symptom-oriented" procedures need to provide the user with instructions which help the operator to determine the event taking place from the information known. Often, this known information is incomplete or only partially complete. These symptomatic procedures will guide the user to determining the cause of the abnormality and initiating the appropriate known emergency or special event task. For instances in which the problem cannot be so readily determined, this procedural form will also provide the operator with assistance in seeking further information as well as in "buying time" until that information is found. This concept of buying time includes the implementation of preventative measures which allow for the safe operation of the CA/T system until the source of the difficulty can be discovered and corrected. Without the inclusion of such symptomatic procedures, the possibility exists that the operator may not have the knowledge or experience to determine the specific task-oriented procedure necessary for a particular situation. Symptom-oriented procedures will help ensure the quick and accurate determination of the occurring abnormality and the proper associated task.

4.2.2.3 Flexibility

One of the most important requirements of the operating procedures for the CA/T system is that they be flexible. The system requires that the operator be able to revise and alter the system-generated response plans at any time during the task. This feature must be reflected in the final procedures. While for hard-copy manuals such alterations may be particularly difficult to formulate, on-line documentation has the capability of being changed and converged.

The ability of the operator to update response plans is important due to the unpredictable and constantly changing CA/T system. Unusual incidents not previously encountered or accounted for may frequently occur. Although hard-copy documents will have difficulty in portraying such flexibility, the computer system is capable of generating hybrid response plans. Additionally, in computer based applications the operator is also capable of modifying a response plan to apply to individual situations. In the event that a response plan requires modification, it must be conducted in a manner which response plan elements are quickly and accurately added to or deleted from the existing plan.

Another circumstance in which the flexibility of the operating procedures is necessary is found in the fact that the status of the incident will be changing on a continuing basis throughout the course of the incident resolution. Such variations in incident status have the capability of either making portions of the response plan obsolete or requiring new portions be added. Some instances will even require both the addition and deletion of response plan elements. The ability to allow modifications based on changing incident status is necessary in on-line OCC operating procedures. Additionally, the ability to update the status of the incident as well as modify the elements of the response plan is also a requirement for the successful use of operating procedures in the Operations Control Center.

The response plans must also demonstrate flexibility in their ability to work cooperatively with external agencies such as the Boston Police and Fire Departments. In instances in which the assistance of these agencies is required, the response plans need to include provisions for the communication and coordination of the external agencies with the CA/T personnel. Additionally, these stipulations should be implemented so as to prevent confusion while maintaining proper awareness of the occurring situation.

4.2.3 Evaluation and Revision Criteria

Equally important as the development stage is the evaluation stage. In fact, development is an iterative process which includes testing, evaluation, and revision. For a complex technological system such as the CA/T OCC, changes are to be expected. These changes, could be due to further system optimization, advancements in technology, modifications in operator duties, or differences on user preferences. Because the concept of traffic management systems is new, the entire realm of possible difficulties in operation or anticipated emergency incidents have not been classified. Realistically, it is not possible to ever be able to determined and classify every form of problematic occurrence for the reason that these occurrences are random and unpredictable. Thus, the ability of the system to accommodate new and previously unaccounted for incident types is necessary. Regardless of the nature of changes to be made to the system, however, these changes must be provided for in the operating procedures. It is more than likely that the operating procedures will require occasional or regular updating which accompanies the changes in the system. Methods must be incorporated into the procedures which ensure that they may be easily revised and that the operator will be aware of the revisions.

The more difficult procedures are to revise, the more costly these revisions will be, and the less eager system engineers will be to make these revisions. Another motivating factor for incorporating provisions for updating into the operating procedures lies in the fact that operators who are not aware of revisions, will not know to enact the new requirements in their response plans. Response plans which inform the operator of new information or procedural steps will ensure the accomplishment of these new tasks.

4.3 Presentation and Discussion of Operating Procedure Guidelines

This sections sets forth a set of guidelines to be used in the creation of operating procedures for the CA/T system. In order to demonstrate the use of these guidelines, the three sample incident scenarios created and presented in Chapter 3 have been used as examples. These tasks were developed such that they would correspond to a variety of operations of a critical nature; thus, each scenario incorporates various aspects of CA/T OCC operations. It is during one of these critical operations in which command and control procedures will most likely prove most beneficial. The use of the various incidents as examples, thus, provides a demonstration of the capabilities of the operating procedures under a range of CA/T traffic and facility system operations.

The operating procedure guidelines for computer-based documentation were developed into working demonstrations on a computer system through the use of VAPS software and the work of Thomas Chao. His assistance was utilized and appreciated in the development of the on-line demo and window display as well as the creation of the Helvetica vector font.

The first incident scenario, "High Carbon Monoxide Levels, Unknown Cause" is one which is "symptom-oriented." That is, the operator is alerted to a specific abnormality but is unaware of the cause of the abnormality. The operating procedures must, therefore, instruct the user in determining the nature of the disturbance and in initiating the appropriate response to the disturbance (see Figure B1 of Appendix B).

The second of the scenarios, "Vehicle Collision on Tunnel Roadway" is "task-oriented," meaning that the operator has been alerted to an incident, has confirmed the incident, and is ready to respond. The operating procedures, in this case, will provide the operator with all of the steps necessary to complete the response and resolve the incident. This particular incident will also portray the ability of the operating procedures to provide the operator with instructional steps which last the duration of the response plan (see Figure B2 of Appendix B).

Like the second incident, this scenario is also task-oriented. In this example, however, an additional abnormality occurs which requires special attention--the vehicle collision has erupted into a fire. Through the use of this scenario example, the flexibility of the operating procedures to modify the incident status and the response plan in accordance can be demonstrated. Additionally, the ability of the procedures to coordinate the response of an external agency, in this case the Fire Department, with the CA/T personnel may be demonstrated.

4.3.1 Layout and Presentation Guidelines

Guidelines which govern the presentation of the operating procedures for the CA/T OCC include specifications for the form of media used in presentation, the type of text and graphics utilized in the layout of the procedures, and the general structure in which the procedures are formatted.

4.3.1.1 Medium

In the design of operating procedures for the Central Artery/Tunnel Operations Control Center, the use of both printed instructions as well as computer-based procedures would be the most advantageous method of conveying procedural information to the operator. In this manner, the benefits of each form of media may be extracted. Such advantages were discussed in section 4.2.1 Layout and Presentation Criteria, and they include propensity for flexibility in on-line systems as well as utilization ability away from the computer for printed procedures.

Because the difference in hard copy, printed procedures and on-line, computer-based procedures transcends the specific category of "Medium," these differences are described for each category of guidelines presented in this section as well as those ensuing.

4.3.1.2 Textual and Graphical Specifications

The selection of appropriate font size and type to provide maximum operator readability and comprehension is a necessary step in designing operating procedures. In the majority of computer applications, some form of sanserif letter is generally used to facilitate user interaction. For these guidelines, Helvetica is recommended for its smooth characters and readability features.

The size of the characters used in the operating procedures is another issue which correlates to the operator's ability to read and understand information under various lighting and stress conditions. A character which is optimally sized to allow for the most possible information on a workstation screen or a piece of printed paper while minimizing operator eye strain is the goal of font size selection.

In order to determine an adequate minimum for character size in the use of on-line operating procedures, the following relation governing the minimum height of a character for operator viewing from Dhillon (1986) was utilized as a guideline:

$$h_l = (0.0022)d + c_1 + c_2$$

where h_l is the height of the letter, d is the operator viewing distance (estimated at approximately 24 inches), and c_1 and c_2 are constants relating to lighting conditions and criticality respectively. From this relation, the minimum character height was determined to be 4.77mm. Woodson (1981) provides recommendations for the height to width ratio of a character as between 5:3 and 3:2. For emphasized letters, up to a 1:1 ratio can be utilized. Thus, using the recommended ratio of 3:2, a width of 3.18 mm was calculated. Here c_1 and c_2 were specified for good lighting conditions and a critical operation.

As an informal verification of this relation, a sampling of font sizes was tested on the workstation screen. By viewing the computer screen and estimating the minimum of comfortable viewing size of Romans letters (the closest approximation to Helvetica font on the computer software), a size which was a factor of 0.4 of the original 32x22 point default size was found to be the lower limit. Converted into millimeters (1 point = 0.35 mm), this size is 4.48 mm in height and 3.08 mm in width. Thus, the informal test provided estimates which were very close in proximity to those calculated in the formula.

For printed procedural instructions, the minimum size of font which still provides comfortable reading for the operator should be approximately 9 point. As with the computer-based procedures, larger character sizes may be utilized and are recommended in certain circumstances. The guidelines which have been presented here simply provide a boundary for minimum character height.

Sentence structure entails the placement and inclusion of verbs, objects, and other words in the sentence. Many sources have researched this subject and made recommendations to increase operator understanding and completion time. The TVA Office of Nuclear Power provides a detailed guide which indicates that the best structure is comprised of several points, some of which are included in the following list. These structural guidelines reflect the advantage of minimum procedures over maximum explanation in the fact that all aim to simplify the information being conveyed to the operator.

- An action verb followed by a direct object.
- One verb per action.
- Verbs which indicate actual physical or mental action. Some examples include
  - START or STOP for rotating equipment that is power driven,
  - NOTIFY for steps which require operator to inform another party of relevant information,
  - DISPATCH to send an Emergency Response Team to a specified location,
  - DEPRESS and HOLD for pushbutton switches,
  - PLACE and HOLD for other types of switches,
  - OBSERVE for confirming equipment responses,
  - CONFIRM for confirming operator actions,
  - VERIFY for steps that require second operator confirmation,
  - MONITOR for continuing steps,
  - CHECK for steps which asses situation,
  - INITIATE for steps which require the start of another task, and
  - TERMINATE for steps which require the termination of the current task.
- The simplest verb to indicate desired meaning. Some examples include
  - STOP instead of IMMOBILIZE,
  - USE instead of UTILIZE, and
  - METHOD instead of METHODOLOGY.
- Omission of the understood subject, "you."
- Omission of most articles such as "a," "an," and "the."
- Composition of as few words as possible to adequately convey procedure.

Guidelines regarding the use and placement of textual items entail issues such as line spacing, margin size, category headings, procedure titles, and so on. These guidelines and recommendations are provided here.

- Use of boldface, capital, enlarged font for action verbs.
- Use of text for step numbers that match action verbs.
- Use of same size font for remaining text.
- Separation of action verbs from direct objects (see Figure 4.2).

[1] ACTION VERB	Direct Object
[2] LONGER ACTION VERB	Direct Object
[3] LONGEST ACTION VERB	Direct Object

Figure 4.2: Separation of Action Verbs from Direct Objects

- Direct objects listed separately (i.e.-separate lines) for more than one object (example in Figure 4.3).

[1] ACTION VERB	Direct Object
[2] LONGER ACTION VERB	Direct Object #1
	Direct Object #2
	Direct Object #3
[3] LONGEST ACTION VERB	Direct Object

Figure 4.3: Separate Line Listing of Multiple Direct Objects

- Indention of sub-tasks from preceding task (see Figure 4.4).

[1] ACTION VERB (1)			Direct Object
	[1.1] ACTION VERB (1.1)		
		(1.1.1) ACTION VERB (1.1.1)	
		(1.1.2) ACTION VERB (1.1.2)	
		(1.1.3) ACTION VERB (1.1.3)	
	[1.2] ACTION VERB (1.2)		
		(1.2.1) ACTION VERB (1.2.1)	
		(1.2.2) ACTION VERB (1.2.2)	
		(1.2.3) ACTION VERB (1.2.3)	
[2] ACTION VERB(2)			Direct Object
	[2.1] ACTION VERB (2.1)		
		(2.1.1) ACTION VERB (2.1.1)	
		(2.1.2) ACTION VERB (2.1.2)	
		(2.1.3) ACTION VERB (2.1.3)	
	[2.2] ACTION VERB (2.2)		
		(2.2.1) ACTION VERB (2.2.1)	
		(2.2.2) ACTION VERB (2.2.2)	
		(2.2.3) ACTION VERB (2.2.3)	

Figure 4.4: Indention of Subtasks from Preceding Tasks

Textual guidelines which are specific to computer-based procedures only include the points provided below.

- Use of lightly grayed text for steps which have been completed.
- Use of heavily highlighted or bolded text for steps which are in progress.
- Use of highlighted text for steps which are continuing.

The example depicted in Figure 4.4 raises the issue of the method of numbering of procedural steps. For this application in which the lower levels of information is limited to three or four levels deep (see Section 4.3.2 for full explanation of information levels), it is recommended that the numbering scheme which be used is as shown in Figure 4.5.

[1] MAJOR PROCEDURE STEP
A. Direct Object #1
B. Direct Object #2
C. Direct Object #3
(1.1) SUB PROCEDURE STEP
(1.1.1) SUB SUB PROCEDURE STEP
A. List Item #1
B. List Item #2
a. Sub List Item #1
b. Sub List Item #2
C. List Item #3
(1.1.1.1) SUB SUB SUB PROCEDURE STEP

Figure 4.5: Recommended Numbering Method

For any procedural steps beyond a fourth level, a string of numbers and decimals will become very confusing to the user. Attempting to restrain procedure levels to three is highly recommended to avoid as much operator confusion as possible.

When listing items in a procedural step (i.e.--a list of external agencies to be notified, or a list of direct objects upon which the action verb is being operated, etc.), the recommended notation utilizes letters (A, B, C,... and a, b, c,...) rather than numbers. By assigning the use of numbers to the task of marking procedural steps only, while letters serve the purpose of naming listed items in a procedural step, this notation attempts to reduce operator confusion even further. An example of this notation is also depicted in Figure 4.5.

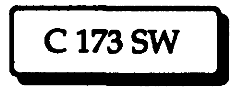
Illustrations, symbols, and pictograms must be used in a fashion which promotes uniformity and facilitates understanding. Illustrations which add confusion should not be utilized. The recommendations for the use of symbols and illustrations as provided by the TVA Office of Nuclear Power have been adapted for the specific use in the Central Artery/Tunnel. These adapted guidelines have been provided here.

- Brackets or boxes indicating procedural step numbers as illustrated in Figure 4.6.

1 or [1.1] or (1.1.1)

Figure 4.6: Procedure Step Number Symbol Notation

- Uniform symbols indicating specific items of equipment. Figure 4.7 provides an example of use in the CA/T system.



Camera Number and Direction

Figure 4.7: Equipment or Machinery Symbol Notation

- Uniform symbols indicating specific locations in the CA/T system (see Figure 4.8).

Figure 4.8: CA/T System Location Symbol Notation

- Uniform symbols which direct user to previous or future steps/sections (see Figure 4.9).

Figure 4.9: Branching Symbol Notation

The use of color coding in operating procedures, or any computer application, poses a number of challenges and disputes. While many studies and ergonomic handbooks maintain that color use is beneficial over monochrome displays, dissenting views (Appleyard and Kirwan, 1992) argue that properly used color produces approximately identical responses as the utilization of no color. In addition, properly used color also produces improved responses over improperly used color. Zwaga (1993) found that the primary method of system designers to incorporate color into applications used personal preference and very general ergonomic recommendations. The resulting computer applications were, therefore, not effective. Zwaga suggests applying color to the computer displays according to "task-oriented display specifications" as well as "application specific design."

In order to create a user-friendly operating procedure display screen, color must be properly applied. Perhaps the most important aspect relating to the use of color involves the idea that a point exists at which the addition of more colors to a screen only serves to reduce the positive effects of the utilization of color. Computer displays too cluttered with color are not only aesthetically unattractive, but they can also be confusing to the operator as well.

Although the specific design of display screens falls outside the scope of this study, several guidelines for determining how color should be used are provided here. Zwaga's approach begins with determining those informational elements relevant to the current task. In this method, important task information is displayed in a prominent manner. Information not as pertinent to the task is shown more discretely while completely irrelevant information is suppressed or not shown. By not displaying every piece of information at the same time, the informational overload of the operator is avoided. Color is then used to mark the "conceptual differences between items of information."

The second portion of the study conducted by Zwaga included applying color based upon the application of the software. While many handbooks exist which provide guidance for using color in displays, it is important to note that these guidelines are very general and must be carefully applied to each specific application. Appleyard and Kirwan (1992) experimented with a set of ergonomically constructed color coded screens in which each color had been specifically analyzed and applied to a particular item or function in the screen. This set was compared to another set containing colors chosen without such careful consideration and analysis. The first set produced quicker response times and better comprehension among operators than did the latter of the sets. Thus, in determining the color to be used in operating procedure display screens, task analysis and CA/T specific equipment configurations should be utilized in addition to general ergonomic color guidelines in order to achieve the most effective color coding.

4.3.1.3 Formatting Structure

Another primary layout and presentation issue involves the format in which the procedures are presented to the user. The method in which the material is organized and ordered in the procedure is of great importance in operator comprehension. In writing procedures, the individual steps must be organized such that each is ordered from lowest step number to highest in the chronological order necessary for the resolution of the task. For instances in which certain steps should be completed at approximately the same time, the steps should be ordered from lower to higher in order of criticality. For this reason, it is necessary that some form of ranking system be used to determine the degree of criticality of each task step relative to those other steps being performed in the same task response plan.

One example of the necessity for the determination of the criticality of each procedural step is found in Incident Scenario 2 (Figure B2 of Appendix B). In steps 2 and 4 which require the notification of external agencies, the knowledge of which agency is most critical to the resolution of the incident is necessary. Step 2 mandates the notification of the Boston Police Department as well as Emergency Medical Services. Step 4 has been reserved for the less critical external agencies such as the Regional OCC. These agencies are not as important, and even allow the inclusion of a more crucial procedural Step 3 prior to their notification. In fact, to spend time notifying these agencies of Step 4 before dispatching the appropriate CA/T Emergency Station would result in a great loss of time and, perhaps, heightening of the incident problems. Thus, by determining a system of ranking based on chronology and criticality, the fastest and most accurate response can occur.

In addition to the order of the information to be included in the response plans, the operating procedures themselves must be presented to the user utilizing some form or structure. Two major options exist in which the procedures may be formatted for presentation to the operator. The first involves a format similar to that of a numbered list. This structure is depicted in Figure 4.10 and utilizes the first incident scenario, High Carbon Monoxide Levels of Unknown Cause, as an example.

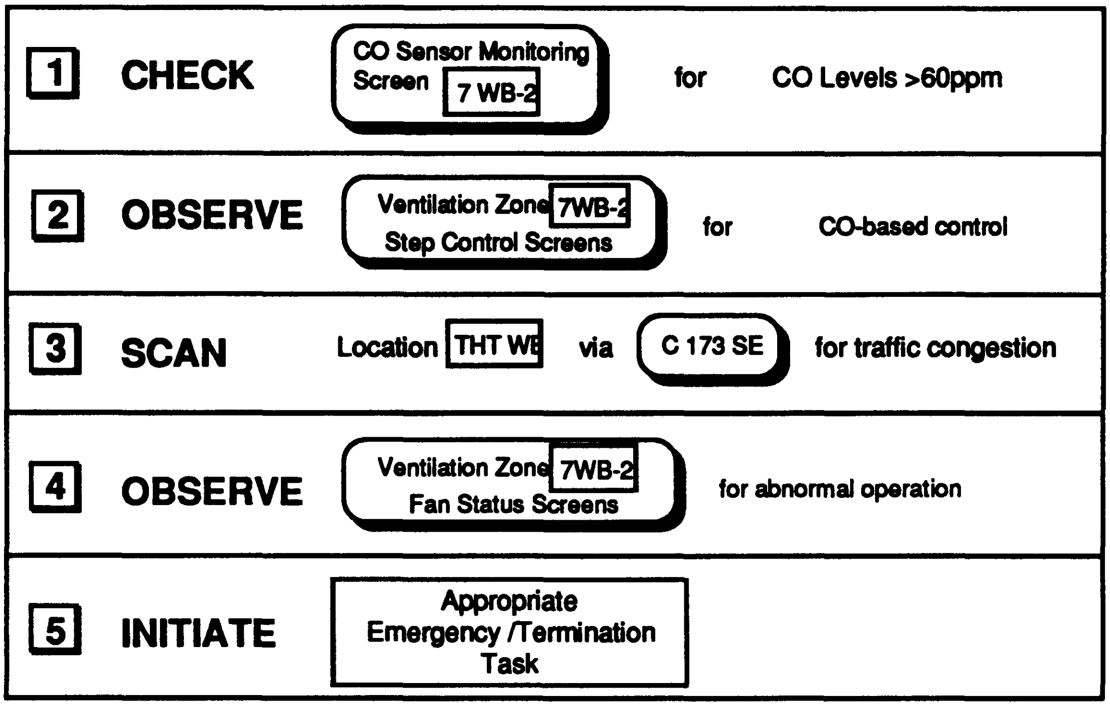


Figure 4.10: Numbered List Format (Incident Scenario 1)

The second option consists of formatting the response plan as a flow chart as portrayed in Figure 4.11. Again, the first incident scenario was used as an example in demonstrating the flow chart structure.

In each of these formats, more detailed information on lower levels would be accessible by expanding a specific task number shown.

For this particular application in the Central Artery/Tunnel, the "numbered list" format has several advantages over the flow chart method of organization. To begin with, for hard-copy documents in which the full amount of procedural information is to be provided simultaneously, the numbered list would allow for easier implementation of this expansion. The very nature of the flow chart structure does not allow for easy expansion. This flow chart expansion would have to be done by showing the entire flow chart with all of its smallest components. An expansion of this sort would include a great number of components which could cause confusion for the operator. Additionally, the information would not fit on the same page, and the format does not allow for easy page to page conversion.

This argument also holds true for on-line procedures. Although implementation of lower level expansion would be better provided for in computer based procedures, the expansion of a single block of a flow chart into a lower level flow chart does not map to human comprehension as well as the numbered list strategy. Humans are more accustomed to the numbered list formats, particularly in the use of lower level lists.

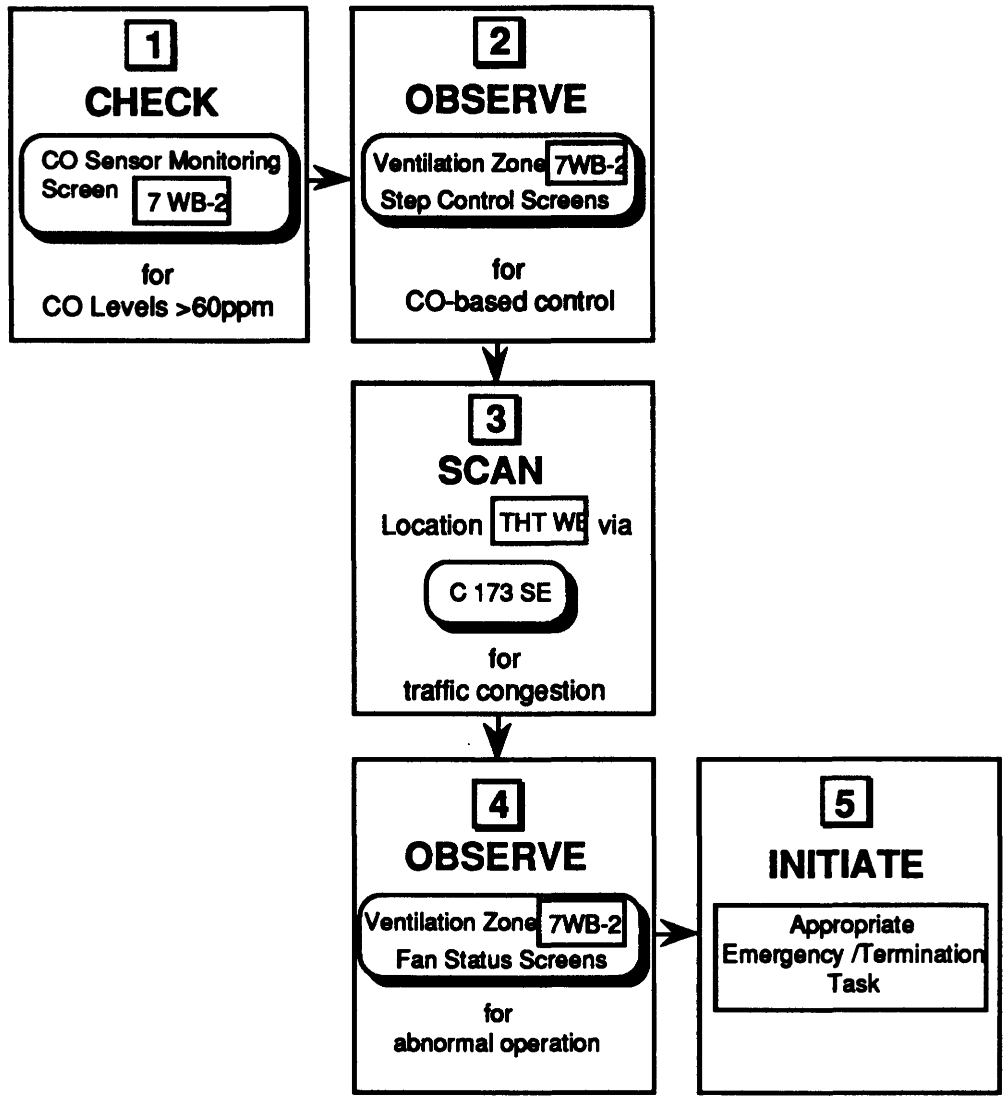


Figure 4.11: Flow Chart Format (Incident Scenario 1)

4.3.2 Informational Content Guidelines

4.3.2.1 Procedural Detail

The response plans must be created such that they allow for several levels of detail which can accommodate variation in user ability and experience and variation in task criticality. Such allowances can be accomplished in a couple of manners. For printed, hard copy material, headings and sub-headings may be used to identify major tasks and their sub tasks. Users could easily spot the primary tasks and, if necessary, utilize the sub tasks of that task. If the sub tasks are not necessary, the operator could move to the next easily identifiable primary task. The goal in creation of the primary, top level tasks would be to keep the task description to a minimum without sacrificing information. An general example of these hard-copy instructions is provided in Figure 4.12.

[1] TASK1
- (1.1) Subtask1.1
  - (1.1.1) Full Detailed Information
  - (1.1.2) Full Detailed Information
- (1.2) Subtask1.2
  - (1.2.1) Full Detailed Information
  - (1.2.2) Full Detailed Information
- (1.3) Subtask1.3
  - (1.3.1) Full Detailed Information
  - (1.3.2) Full Detailed Information

[2] TASK2
- (2.1) Subtask2.1
- (2.2) Subtask2.2
- (2.3) Subtask2.3

[3] TASK3

Figure 4.12: Printed Response Plan Format

The use of a computer system for the delivery of procedures to the operator provides an additional level of convenience. All levels of the procedure no longer have to be exhibited on the same display or at the same time. For on-line, computer based procedural response plans, it is possible to present the different levels of sub tasks to the operator separately. For instance, the top level tasks can be initially provided (see Figure 4.13). If the user then needs access to more detailed information, s/he may have the response plan expanded by clicking on the expand button of the desired procedural step. In working with Thomas Chao to implement the procedures into a functional computer application, Chao designed this expansion button to display "More...", a very accurate representation to the user of the purpose of the command button. The expansion buttons of each step are located in a column on the right hand side of the procedure window are shown in Figures 4.13, 4.14, and 4.15. The expanded window may then be closed by clicking the box notation for closure on the upper left perimeter of the window display.

From each expanded level, the operator may expand the procedures even further to access even lower levels of information. Each lower level of procedural steps can be presented to the user in the form of cascading windows (to be seen in Figures 4.14 and 4.15). The operating procedures of the first incident scenario have been used in the following figures to demonstrate the organization of information in the computer-based application.

Figure 4.14 displays an expanded version encompassing the next lower levels of the particular step for which additional information was requested. The on-line response plans can be designed such that only one additional level is accessed by each expansion. The leveled procedure windows are then presented to the user in a cascading form as seen in the figure, and the step which has been expanded is to be clearly indicated to the operator.

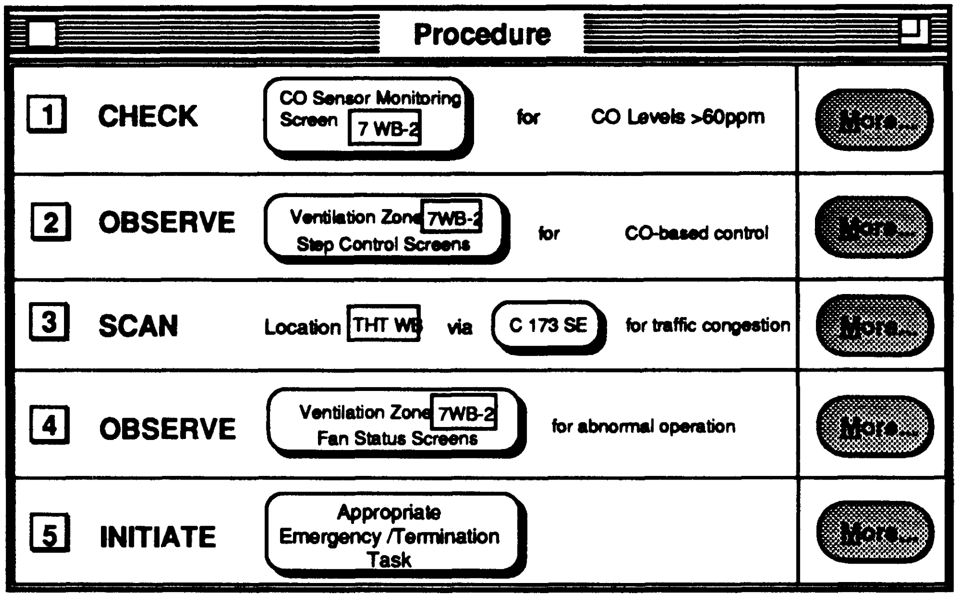


Figure 4.13: Computer Based Response Plan, Top Level

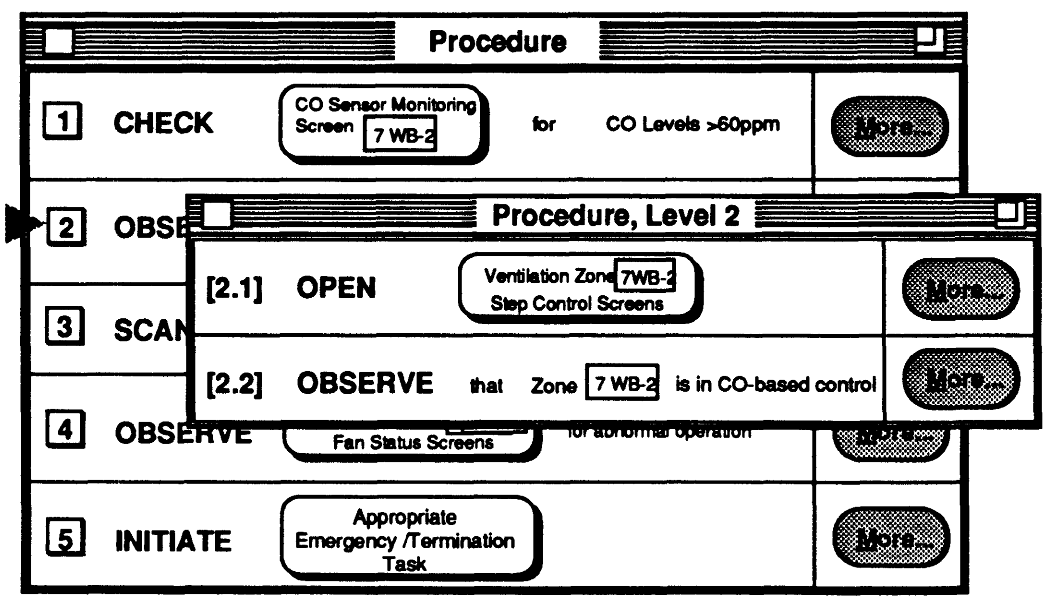


Figure 4.14: Computer Based Response Plan, Lower Level

If the operator then desires even more detailed information, s/he may access it by again selecting a specific procedural step and expanding it. Figure 4.15 displays an even further expanded version of the on-line operating procedures. Here, three levels have been cascaded with the lowest, most detailed procedural steps at the front and the highest, most general procedural steps at the back. Once the operator has completed the lower level tasks, s/he may close that lower level window and return to the higher, less detailed level.

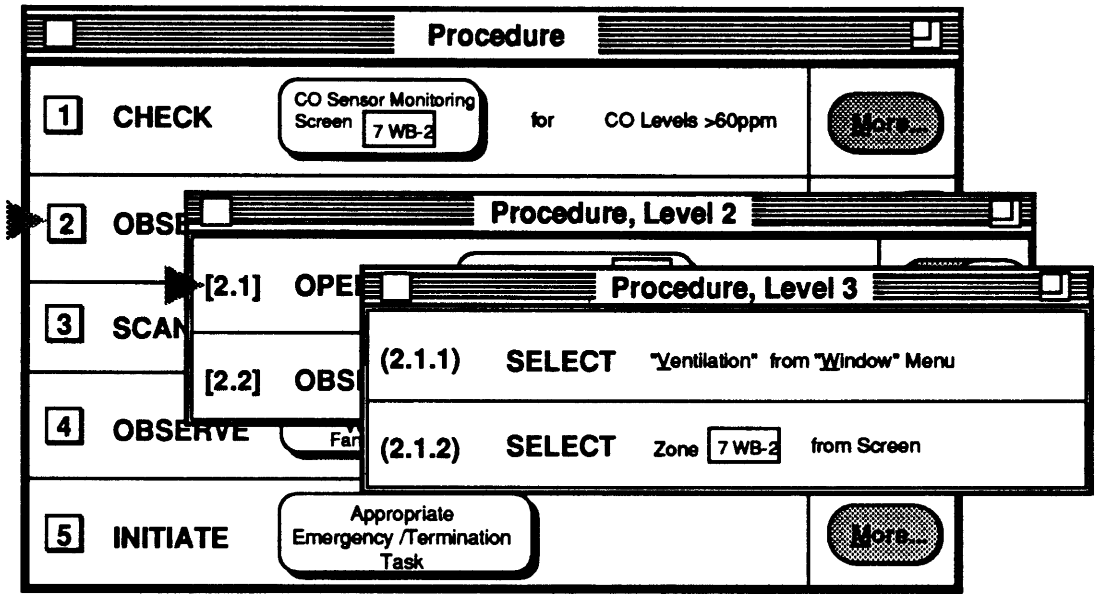


Figure 4.15: Computer Based Response Plan, Lowest Level

The illustrations of Figures 4.13, 4.14, and 4.15 as well as Figure 4.1 of the previous section, portray a system of operating procedures composed of three informational levels. Although it is possible to enact a system containing more than three levels, the greater the number of detail levels, the more confusing maneuvering through the procedures will be. For instance, a procedure which contains eleven levels of detail will pose problems to the operator when the information needed is on the eleventh level. This difficulty is particularly amplified in the on-line situation in which the operator would be required to open and close ten new windows in order to access the lowest level information. Not only is this method time consuming, but it can also be confusing to the user who must remember the primary goal of the top level step while fulfilling the requirements of the lowest level steps. Three levels are, therefore, recommended for use in the CA/T OCC application. The procedures should not, however, exceed four levels. Incident Scenario #1 has been provided as an example of a procedure which possesses four informational levels.

4.3.2.2 Task and Symptom Oriented Procedures

In order to ensure the best possible coverage of the operating procedures for all forms of CA/T system incidents, the procedures should be designed such that they may take on the form of either a task-oriented response plan or a symptom-oriented response plan. In a task-oriented response plan, the incident is known, and the response plan is used to resolve the incident and return the CA/T system to normal, routine task operations. In a symptom-oriented response plan, the incident is not known; however, the operator is aware of a specific abnormality. Thus, this form would guide the user to determine the cause of the abnormality, "buy time" until the determination is made, and then initiate the appropriate task-oriented response plan. Buying time consists of enacting stabilizing, back-up actions which may not cure the problem but assists in maintaining the safe, acceptable operation of the CA/T system until the problem is found and can be resolved. The example provided in Incident Scenario 1 would require a response plan which is symptom-oriented or symptomatic. Incident Scenarios 2 and 3 provide demonstrations in which the operator is instantaneously aware of the type of emergency and can, thus, immediately initiate the appropriate task-oriented response plan.

4.3.2.3 Flexibility

The concept of flexibility in operating procedures stems from the fact that not all incidents which occur in the operation of the CA/T system will be predetermined. In fact, a great number of incidents will more than likely involve new circumstances not previously encountered. By initially designing procedures which can react to and accommodate these changing events, a greater level of accuracy in operation can be assured even for uncertain events.

In order to provide flexibility in operation, the procedures must be designed such that they provide the system user with several accommodating features. These features include the abilities to (1) modify response plans, (2) account for changing incident status, (3) enact adequate response plans based on only partial or missing information, (4) perform system manipulation functions quickly and accurately, and (5) coordinate changing incident events.

The CA/T system necessitates the operator's ability to modify the response plan for varying tasks and incident status. As stated in points one and two in the preceding paragraph, the operator needs to be able to update the status of the incident as well as modify the elements in the response plan. According to the design specifications of DeLeuw, Cather, and Company (April, 1993), upon the occurrence of an incident, the computer system will provide the operator with a default response plan which can be accepted, rejected, or modified. This type of application is very beneficial in an ever-changing system such as the CA/T. For occurrences which do not conform to anticipated incidents, this design allows the operator the option to "tailor fit" the response to the actual incident.

The capacity to update the status of an incident is also an important element in the creation of flexible operating procedures. For example, Incident Scenario #2 is the collision of a vehicle on the roadway of a tunnel in the CA/T system. When an operator initiates a response plan to resolve this situation, the computer will produce the plan based on the currently known information regarding the status of the incident. If, after the plan has been accepted and the operator has begun fulfilling the steps of the operating procedures, a fire breaks out at the scene of the collision (Incident Scenario #3), the operator would need to update the status of the incident. In other words, the user would need to inform the computer system that the incident has changed. As a result, the operating procedures will require modification to account for the alteration in the status of the incident. For on-line computer based procedures, the computer system should have the capability of translating the incident parameters input by the operator into an appropriate response plan or response plan modification. An example of this system proficiency is illustrated in Figure 4.16, a display screen proposed as a guideline for the incorporation of both the operating procedures and the incident status in the same window.

Figure 4.16 portrays an example of a response plan window for Incident Scenario #2 which incorporates the operating procedures for the resolution of the event, all relevant information regarding the current status of the incident, and the commands to modify or update this information. Dependent upon the task, the information appearing in the Incident Status area may vary. This configuration provides the system user with all information needed in performing the task. Thus, the process of opening other windows and searching for additional information may be avoided. To have this information conveniently located for easy manipulation and modification allows faster response times and reduces operator confusion which can be caused from an overload of informational sources.

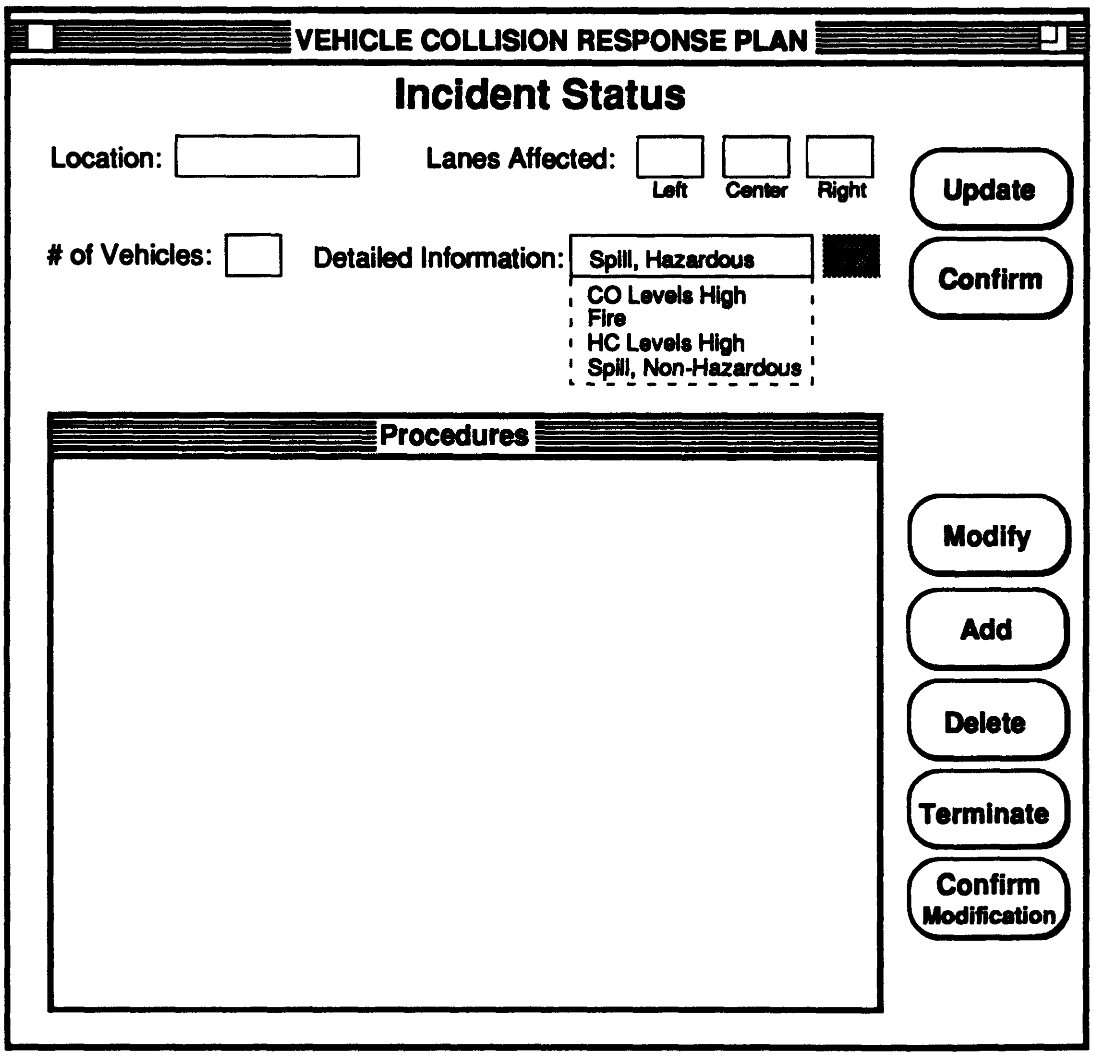


Figure 4.16: Response Plan Window Display for Flexible Procedures

In order for the operator to change the status of the incident, s/he would click the "Update" button, change the appropriate information, and click the "Confirm" button. As a method of insurance for avoiding accidental updates, a dialog box can be used upon clicking the "Confirm" button. The box would state the changes that have been made and ask the operator to either accept them or cancel them. Changes in the incident status will usually call for resulting changes in the operating procedures. Once the operator has confirmed the incident status update, the computer can generate modifications to the remaining operating procedure steps, present them to the user, ask for acceptance or modification, and incorporate them into the current operating procedures. It is important than the resulting modifications to the operating procedures do not abruptly interrupt the current response plan and cause confusion among the operator and other CA/T personnel. The changes must be appropriately incorporated into the response plan such that the operator is aware of the modifications. This can be accomplished through the use of dialog boxes indicating which steps are being altered, added, and/or deleted. It is also important that the modifications be made to only those steps the operator has not yet completed. If changes are made to previous completed steps, the operator may be unaware of the changes or may have greater difficulty in going back to previous steps rather than moving on to new ones.

If the operator chooses to make a modification to the response plan at any time, s/he may click the "Modify" button, select additional elements from a standard list, remove desired elements from the current procedures, and accept the changes by clicking the "Confirm Modification" button. If the operator simply wants to add or delete a single element, the "Add" or "Delete" button may be used respectively. As with changes in the incident status, dialog boxes may also be used in the case of changes to the operating procedure elements.

For printed instructions, these modifications of response plan and incident status cannot be accomplished in the same manner as computer based documentation. Thus, the use of a single "base" procedure for a specific task should be utilized. Instructions for the occurrence of abnormal events may be built into this single procedure. Conditional statements assist in providing the operator with a variety of possible choices to match the incident at hand. Examples of the base procedure concept are provided in Appendix B for all three incident scenarios.

The third flexibility issue involves the occurrence of incidents in which information is missing. Missing information may be particularly common in situations which have not been previously encountered. The computer would, thus, have no predetermined response plan for this occurrence. This type of partial information occurrence would, therefore, be resolved through the use of symptomatic procedures. The operator would enter all known information to the computer system which would, in turn, generate a hybrid response plan based on the partial information. This symptomatic procedure would assist the operator in enacting actions to help compensate for problems in the CA/T system that are a result of this situation. In addition, it would guide the operator through searching the CA/T subsystems for more information regarding the abnormality (see section 3.4.1 for more information on this critical operation). If the procedures are designed such that the information gathered by the operator while performing the symptom-oriented procedures is provided to the system, the computer will then be able to update incident status and reformulate the response plan to narrow the focus of the procedures and better determine the missing information. The computer will then also be more accurately able to provide the operator with necessary steps to compensate for the problems due to the situation.

One recommendation for providing the computer with updated information determined from each procedural step is the use of operator confirmation question buttons shown in Figure 4.17. The confirmation information would be provided in a single column close to the right side of the procedure window. Thus, the operator will easily be able to locate those steps which require some form of confirmation. When the operator determines the needed information of a procedural step, s/he has the option of clicking the one of two responses--a positive or a negative--in the confirmation column. The system can use this information to determine future steps necessary for the operator to take. For instance, if the operator clicked the "Yes" button for heavy traffic congestion in step three, the system may determine that certain steps associated with the step four are no longer necessary. Thus, the computer can make recommendations to the user that certain modifications be made to the operating procedures that will guide the operator to the eventual resolution of the problem.

One important feature regarding the use of the confirmation column in partial information situations is that it should not be required to be used. Knowledgeable operators who have had a great deal of experience with the system and symptomatic response plans may find that mandatory use of confirmation or even acknowledgment steps slows their progress and response time. On the other hand, unskilled or inexperienced operators may find the confirmation columns extremely helpful in providing information necessary to the discovery and resolution of the incident. Thus, this feature would be more appealing and useful to the user if it were optional rather than required.

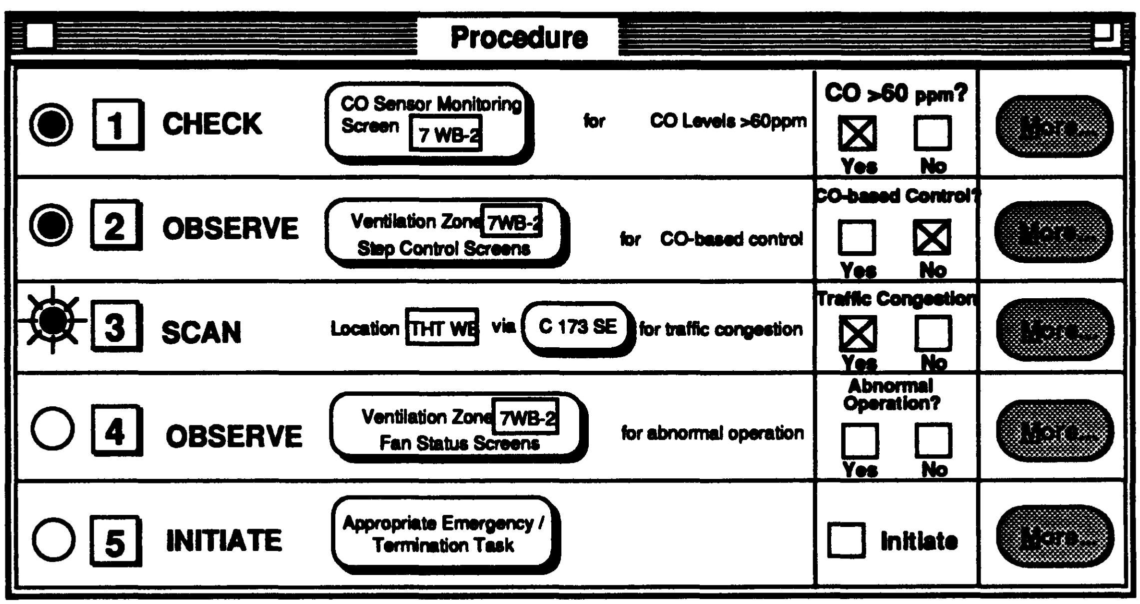


Figure 4.17: Symptom-Oriented Procedures With an Action and Confirmation Column

Points four and five are issues of flexibility which encompass the capabilities of the operating procedures to include steps by which the operator can perform functions from within the procedures. Some instances include initiating other tasks, acknowledging the completion of steps, opening additional workstation windows, and/or performing the specific duties of each task. By allowing certain functions to be performed from within the response plan window, the operator is able to save time by not having to manually perform each of these functions. Regardless of the capabilities of the response plans, however, the computer system should provide for both automatic and manual activation of each of these features.

The ability to initiate an emergency task directly from the operating procedures is one example of system manipulation which can be incorporated into the response plan window. For example, step five of Incident Scenario 1 provides the user with the opportunity to initiate an emergency task-oriented response plan by clicking on the icon labeled "Appropriate Emergency/ Termination Task." This label has the capability of changing to a specific emergency task if the operator utilizes the cascading confirmation windows to provide the system with information regarding the specific problem and necessary emergency or termination task. Other forms of initiation icons may be used as well. The selection of the "Initiate" icon could be followed by a dialog box informing the user that this operation will terminate the current response plan and asking for confirmation of the operator action.

Acknowledging the completion of a procedural step is another function which the response plan window can include. The design in this study recommends the utilization a step acknowledgment button on the left side of the procedure step numbers. Thomas Chao is credited with the implementation of this button into the on-line procedural aid. The buttons are empty circles which the operator clicks to indicate step completion. Upon clicking the button, a black dot will appear inside the circle to show that the computer is aware the step has been completed. At this time, the computer will "gray" the completed step so the operator will remain aware that step has been completed. These buttons can also be used to indicate continuing steps a black dot that flashes at a slow rate. A rate of 0.67 Hz was used in this application for the computer demonstration. Thus, while the operator works on later steps, the flashing dot will act as a reminder that this step is still continuing (i.e.-an ongoing monitoring step, for example). These acknowledgment buttons are also shown in Figure 4.17. In order to keep the procedures as flexible as possible, clicking the buttons would be optional for the user. As discussed earlier, more experienced users may decide to not utilize this option while less experienced users would probably opt to use it. If necessary for particularly sensitive steps, the selection of the "Done" command could be followed by a dialog box asking the user for confirmation that the step has been completed.

The ability to perform functions of the operating procedures from within the procedural steps is yet another example of flexibility in system manipulation. It may be easier and save time if the procedural steps could be linked to certain commands of the CA/T system. This is not to imply that all commands should be linked to the operating procedures. Some possible candidates for incorporation into the response plan window are provided here.

- The system could be programmed with the ability to contact all necessary external agencies simply by clicking a "Notify" button or icon within a procedural step. For instance, steps 2 and 4 of Incident Scenario 2 could include provisions for an operator to click a "Notify" command button which would send notification of the incident and specified details to all agencies which required notification (i.e.-Police, Fire, etc.). The agencies to which notification would be sent would be specified in a list recommended by the response plan but subject to modification by the operator. If the external agencies are linked by the computer system, this transfer of information could include all necessary, relevant files. For agencies not connected by computer, some type of automatic phone notification would be recommended. Finally, for agencies of less importance such as local radio stations, a possible form of automatic notification could be completed by phone or facsimile. The ability of the operator to simply click a button to perform all of these notification tasks which would normally require a number of personal manual phone calls could greatly reduce the response time of the operator in the resolution of the situation.

- Emergency Response Teams (ERT) could be dispatched by selecting that relating functional icon from the response plan step (see Incident Scenario 2, step 3). If the ERT is linked to the central computer system, the selection of that command would send all relevant system information to the ERT. This method would save an great amount of time while ensuring that the ERT is provided with all necessary information which could be omitted by an OCC operator during a personal phone call. The procedures would include instructions for receiving confirmation from the team that the ERT has been dispatched. The specific ERT(s) which are dispatched by the operator would be recommended by the response plan. As always, they would be subject to approval by the operator.

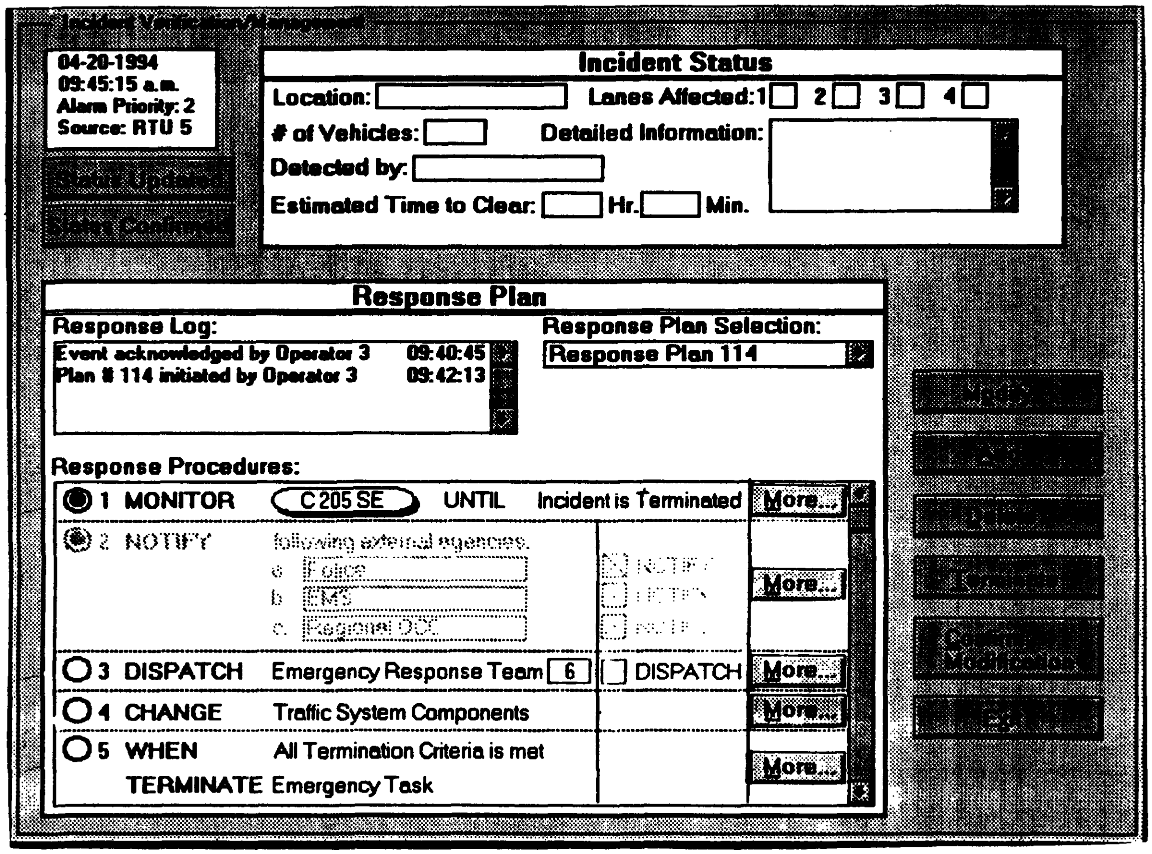
- All of the field devices could be changed directly from the operating procedures by selecting a "Change" command or icon within that procedural step (see Incident Scenario 3, step 8). The specific changes would be recommended and specified by the response plan based on incident type, traffic volume, and location of ERT which would be responding. The operator would be able to modify the changes if necessary. This incorporation of functions within the operating procedures would eliminate the need for the operator to open additional windows to activate traffic system elements and would, therefore, save time.

- The ability to open additional windows from the operating procedures by selecting the icon representing that screen in the procedural step would save operator time by eliminating the need to find the window by going through several pull down menus provided in the workstation menu bar. This incorporation would also eliminate the need to describe how to open the window via the manual menu method in the operating procedures. An example is provided in Incident Scenario 1. When an operator needs to open the Ventilation Zone Step Control Screen of step 2, the system user could simply select that icon, and the screen would open.

These commands could be performed by the operator clicking a command button located in an action column. The action column is shown in Figure 4.17 and coincides with the confirmation column. Steps whose required action is to confirm a state would fall under the category confirmation. All actions would be easy to spot by the operator. Once the operator decided to perform the action, s/he would click the box next to the command action. An "x" in the box would indicate that the action had taken place.

The final flexibility issue regards the concern over the coordination of continuing operations. The operating procedures are designed to make the operator aware of the fact that some procedural steps may continue throughout the entire length of the incident management phase. This specification can be accomplished through the use of highlighted text for the continuing procedure, step and/or the use of the acknowledgment button to indicate the step is "In progress..."

The screen compiled by Thomas Chao as an on-line demonstration of the role of the operating procedures in CA/T OCC incident management is provided in Figure 4.18. It demonstrates the use of the acknowledgment button, the "grayed out" text for completed steps, the highlighted text for current steps, and a single illustration of the "More" button for expansion. Chao's development of this figure utilized the guidelines provided in this study, the specifications set forth by DeLeuw, Cather, and Company, and the research and knowledge of Chao, himself.



by Thomas Chao

Figure 4.18: Computer Display of Operating Procedures in Incident Management

4.3.3 Evaluation and Revision Guidelines

In the use operating procedures in the CA/T OCC, it will be necessary that the procedures be evaluated and revised when warranted. Because it is the findings of the evaluation process which will provide recommendations for the revisions which are to be made, guidelines for the evaluation of the operating procedures will be discussed first.

4.3.3.1 Evaluation

The process of evaluation includes the collection of information, the analysis of the information, and the transformation of that information into useful recommendations. Likewise should the process of evaluation occur for the operating procedures in the OCC. The collection of information to be utilized in the future is the first step. This step would require the maintenance of daily operator logs for the various functions performed. Of importance in these daily logs would be the following:

- types of incidents which had occurred,
- procedures the operator had used in the resolution of each incident,
- modifications which had been made to each procedure, and
- other actions taken by the operator in the incident resolution.

The use of computer-based procedures is particularly convenient in the information collection stage. The computer system could be used to automatically maintain such logs. Maintaining manual logs for operations in which printed procedures are used would be more time costly as well as less accurate. The operator would not be able to keep the log during an emergency situation and would, therefore, be forced to wait until the termination of the event to record his or her log. In this manner, the operator may not remember or may neglect to record all information,

particularly if s/he is required to perform several emergency operations back to back before obtaining the opportunity to make an entry in the log.

The information collected in daily logs will be of great importance in the analysis of system use and in diagnosing system problems. By looking at the manner in which the system and the operating procedures were utilized in the past for specific circumstances, problems encountered in the future may be more readily understood. Additionally, resolution plans for these problems may be better implemented using the knowledge of successful and/or unsuccessful methods of the past.

Log information will also provide valuable information in the optimization of the system. For instance, the analysis of various forms of procedures utilized for the same incident may point to procedure configurations in which response time and incident resolution is quicker. In the same manner, the analysis may direct system engineers to procedural configurations in which response time is much slower.

Another beneficial use of the information obtained from operator usage logs includes the determination of which system default response plans are rarely used by the operator as well as which ones are frequently used. Additionally, default response plans which are modified most often and least often may be easily determined. Results of this type of analysis could be indicative of the fact that a default response plan for a specific incident is not as effective as a user modified version. For this reason, the operators would always modify this response plan in the event that this specific incident occurred. From this information, a recommendation could be made that the particular default response plan be changed to the modified version most used by the operators.

4.3.3.2 Revision

In order to revise operating procedures, several items must be considered. The first concerns the authority necessary to make such changes. While the operator is free to modify a response plan during the implementation of that response, these changes are temporary and do not affect the default response plan called up upon future initiation of a specific incident. The revision of procedures entails the permanent change of a default response plan or a response plan element. Because this alteration is much more crucial than operator modifications, it may be necessary to require this access to only supervisory and/or administrative personnel. This precaution could help prevent unwarranted procedure changes as well as lack of change notification to appropriate OCC staff.

For printed material, a revision log of some form should be utilized to account for all revisions. This log should be attached to the procedure manual itself and should include the date and nature of revision as well as the administrator who made the revision. Being attached to the procedural manual will allow the user to be able to note changes that have been made. Dependent upon the importance of the changes which have been made to the operating procedures, the distribution of a memo or a supervisor announcement informing OCC personnel of the changes may be necessary.

On-line operating procedures also mandate user awareness of revisions to a response plan or response plan element. As previously discussed, an OCC memo or supervisor announcement could be utilized as a means of informing operators of the changes to the response plans. Another method, however, includes the use of dialog box on each operator's computer account. When the operator logged on for a session immediately after the changes have been made, a message would appear on the screen informing the operator of the alterations. This message could include the date, the response plan or element affected, the nature of the change, and the administrator responsible for making such a change. If the OCC finds it beneficial for operator retention, this message could be designed to appear after log-in for a certain period of time after the revision has been made.

Another similar method for informing operators of revisions in on-line procedure applications includes the use of a dialog box which appears when the operator initiates the revised response plan or response plan element. This notification would be much briefer than the previously discussed notification scheme. It would simply include the nature of the changes and which specific procedure steps were affected. It would also require the operator to click a button acknowledging that s/he understands the changes. The reasoning behind this method lies in the fact that an operator may not have the opportunity to use a specific response plan for a long period of time. If a revision is made during that time period, the operator may forget the revision by the time s/he actually has a need to use this response plan again. Thus, if a brief reminder in the form of a dialog box appears on the screen the first time (or first several times) the operator initiates this response plan after the revision has been made, the operator will better remember the revisions and be able to implement them.

This type of notification could be custom designed for each operator system account. For example, an operator who initiates a revised response plan the day after the revision was made, would receive the brief dialog box at this time. If another operator did not initiate the same revised response plan until several months later, s/he would receive the brief dialog box of his or her system at that time. For even better operator comprehension, this dialog box could be used in conjunction with the log-on dialog box described above.

Chapter 5
Conclusions and Recommendations

5.1 Conclusions of This Research

5.1.1 Task Analysis Summary and Conclusions

The Central Artery/Third Harbor Tunnel system was analyzed from the human factors engineering perspective of the function of the Operations Control Center. The system objectives, modes of operation, and functions were determined and evaluated. Additionally, the equipment of the CA/T was identified and grouped according to the system functions each particular equipment configuration supported. Finally, the OCC tasks were identified, described in detail, and grouped according to type. The final task analysis was utilized in identifying critical OCC task operations and in constructing operational procedure guidelines.

The task analysis identified three primary task categories--routine, emergency, and special event. It further broke these categories down into tasks specific to the type of operator in the OCC--traffic operator, facility operator, or supervisor. From the task analysis, it is apparent that the major duties of OCC monitoring and control will fall to the traffic operators. The facility operator will have a smaller role, and the supervisor will have relatively larger role in coordinating the responses of all other operators as well as providing backup to traffic and facility operators when necessary.

5.1.2 Critical Operation Identification Summary and Conclusions

Primary sources of operator error in systems such as the CA/T OCC were identified and classified into three major categories. These error categories comprised excessive operations, absence of situational awareness, and lack of experience. Using the task analysis as a method of identifying errors, the OCC tasks which pose potential for error during performance were identified and listed according to error category. These tasks were utilized in the compilation of example incident scenarios which demonstrated circumstances prone to operational error as defined by the error categories.

5.1.3 Operating Procedure Guidelines Summary and Conclusions

Guidelines for the preparation of operating procedures for use by OCC operators during incident management were developed. These guidelines were designed based on information from the task analysis, anticipated critical operations, and human factors criteria and knowledge. Most importantly, the guidelines were developed to be utilized in situations for which the OCC has no previous experience. The guidelines were developed for the three primary aspects of procedure writing--the information included, the format of presentation, and the method of evaluation and revision.

The procedures were designed to encompass all levels of experience and knowledge; therefore, they may be utilized by a wide range of human operators. A numbered list format consisting of uniform iconic and symbolic text was designed to best assist the operator in understanding and fulfilling the duties of the procedures. This format may be implemented into both a printed, hard-copy medium as well as a computer-based medium. The evaluation and revision of the operating procedures was suggested to be completed on an iterative basis in which data from response plan use is stored in a log for later use in analyzing problems as well as strong points in the human use of the procedures.

The two major forms of procedures determined from this study include task-oriented and symptom-oriented. Task-oriented procedures provide response plans for known tasks. Symptomatic procedures provide the operator with a type of "map" to follow in order to determine the abnormality present in the system. Symptom-oriented procedures are the form that will be utilized in the occurrence of an event not before encountered. These events may be characterized by missing or partial information.

5.2 Recommendations for Future Research and Applications

The research undertaken in this investigation was contrived that it might be the basis of future human factors design elements for the Central Artery/Tunnel. Such future research can provide information and data for the further evaluation of the CA/T Operations Control Center in the following areas:

- The estimation of operator workload: The task analysis can be used as a basis in matching equipment functions with the required operator actions. By building on to this match-up, a comparison of human capabilities with equipment demands can be completed.
- The design of control and display text, signals, and layouts for the OCC workstations: The research in this study began examining the use of text, symbols, and graphics but for application to the operating procedures only. Further research can begin the design of the actual controls and displays in the OCC workstations. Task analysis and critical operation identification can point to convenient and necessary groupings of equipment, controls, or monitors to facilitate the response of the operator to OCC tasks.
- The determination of the requirements for OCC operators: The necessary skill level and training requirements of the operator can be determined with help from the task analysis. By utilizing task analysis, the duties of the operator and the skills necessary to perform these duties may be determined. These required skills may then be analyzed to determine the type and amount of training necessary. Also related would be the determination of the optimum number of staffed operators that should be present in the OCC for best results in operation.

Appendix A: Central Artery/Tunnel Task Analysis

A1 Task Description Table

1.1 Routine Traffic Operator Tasks							
		Monitoring and Detection		Incident Confirmation			
Task Name	Subtask	Status for Which to be Monitored	Devices Used to Monitor	Information to be Received	Source of Information	Methods for Verifying Incident	Non-Incident Termination Duty
1.1.1 Routine Traffic Incident Detection Task		• Warning Status or abnormality which may be indicative of or lead to a Traffic Emergency or Special Event	• Vehicle and Video Detectors via Operator workstation • External Agency or Internal CA/T Communications • CCVE	• Traffic Flow is Irregular • Potential Traffic Emergency Event has Occurred • Location of Potential Emergency Event • Number of vehicles involved	• Vehicle Loop Detectors • Video Vehicle Detectors • Incident Detection Algorithms • External or Internal Communications	• Scan Roadway of Potential Incident Location using CCVE • Determine factors in event (fire, blockage, spill, injury, false alarm, etc.)	• Notify supervisor • Notify Maintenance if necessary • Perform communication Tasks if necessary (HAR messages, agency notifications)
1.1.2 Routine Overheight Vehicle Detection Task		• Warning Status or abnormality which may be indicative of or lead to an Approaching Over-height Vehicle Emergency Event	• Overheight Vehicle Detectors • Horizontal Attenuators • External Agency Communications • Internal CA/T Communications • CCVE	• Overheight Vehicle is approaching tunnel • Location of overheight approach	• Overheight Vehicle Detectors • Horizontal Attenuators • External Agency Communications • Internal CA/T Communications • CCVE	• Scan Roadway of Potential Vehicle Location using CCVE	• Notify supervisor • Notify Maintenance if necessary • Perform communication Tasks if necessary (HAR messages, agency notifications)
1.1.3 Routine Roadway Equipment Malfunction Tasks	1.1.3.1 Routine CCVE System Malfunction Task	• Warning Status or abnormality which may be indicative of or lead to a Malfunction of the CCVE system	• CCVE via Field Data Communications • Device Status Screen via Workstation • OCC overhead monitors	• CCVE system/subsystem component has become inoperable • Location of Disturbance	• CCVE via Field Data Communications • Device Status Screen via Workstation • OCC overhead monitors	• Verify CA/T Communications • Verify using Device Status Screen	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary
	1.1.3.2 Routine Field Device Malfunction Task	• Warning Status or abnormality which may be indicative of or lead to a Malfunction in a field device	• Device Status Screen via Operator Workstation • Local Field Controller (VMS, LUS, VSLS, BOS, CS, all vehicle detection systems, horizontal attenuators.)	• Field Device is Malfunctioning or producing conflicting signal • Type of field device • Location of field device	• Device Status Screen via Operator Workstation • Local Field Controller (VMS, LUS, VSLS, BOS, CS, all vehicle detection systems, horizontal attenuators.)	• Scan location of field device using CCVE • Verify malfunction of field device using Local Field Controller and Device Status Screen	• Notify supervisor • Notify Maintenance if necessary • Perform communication Tasks if necessary • Resolve and compensate for Conflicting Status if necessary
	1.1.3.3 Routine Tunnel Lighting System Malfunction Task	• Warning Status or abnormality which may be indicative of or lead to a Tunnel Lighting System Malfunction or Difficulty	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Light(s) become(s) inoperable, Light(s) do(es) not respond to change in illumination level, and/or illumination level must be altered • Location of Light(s)	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Scan location using CCVE • Verify CA/T Communications • Verify using Device Status Screen	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary
1.1.4 Routine Congestion Control Task		• Warning Status or abnormality which may be indicative of or lead to Heavy congestion and/or an Emergency or Special Event	• External Agency and Internal CA/T Communications • CCVE • Vehicle Detection System	• Large amounts of traffic flow through tunnel and/or on roadway	• External Agency and Internal CA/T Communications • CCVE • Vehicle Detection System	• Scan Roadway using CCVE • Verify communications from internal or external source	• Notify supervisor • Notify Maintenance if necessary • Perform communication Tasks if necessary

Table A1.1: Routine Traffic Operator Task Description Table

1.1.5 Routine External Agency Communi-cations Task		• Warning Status or abnormality which may be indicative of or lead to a Traffic Emergency or Special Event	• External Agency Communications (Fire, Police, EMS, Radio, Cellular phones, etc.)	• External Agency to affect OCC operations (i.e.-Emergency Vehicle through tunnel, police to apprehend vehicle) • Incident outside OCC jurisdiction to cause potential problem to CA/T	• External Agency Communications (Fire, Police, EMS, etc.)	• Scan roadway of location of external agency operation • Verify approach of external agency • Verify possible backup on CA/T roadway	• Notify supervisor • Notify Maintenance if necessary • Perform communication Tasks if necessary
1.1.6 Routine Weather Advisory Forecast Task		• Warning Status or abnormality which may be indicative of or lead to a Traffic Emergency or Special Event due to severe weather	• External Agency Communications (Weather , Radio, Police, etc.)	• Severe weather is predicted (anticipated duration and precipitation) • Type of severe weather (Rain, snow, ice, freezing rain, tornado, hurricane, etc.)	• External Agency Communications (Weather , Radio, Police, etc.)	• Verify weather advisory communications • Determine types of potential problems to CA/T system	• Notify supervisor • Notify Maintenance if necessary • Perform communication Tasks if necessary
1.1.7 Routine Planned Special Events Task		• Warning Status of an External event which may be indicative of or lead to a Traffic Emergency or Special Event	• External Agency Communications (Radio, Event Organization, Police, Cellular phone, etc.)	• Special Traffic Event is Scheduled (anticipated duration and scope) • Type of Traffic Event (Peak Traffic Period, Maintenance, Special Vehicles in tunnel, Other(ball game, etc.)) • Location of event	• External Agency Communications (Radio, Event Organization, Police, Cellular phone, etc.)	• Verify External communications • Determine Types of potential problems to the CA/T system	• Notify supervisor • Notify Maintenance if necessary • Perform communication Tasks if necessary
1.1.8 Routine Traffic-Affected Facilities Tasks	**1.1.8.1 Routine CA/T System Power Failure Task**	• Warning Status or abnormality which may be indicative of or lead to a CA/T system Power Failure	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Power Failure has occurred • Location of Disturbance	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Scan location using CCVE • Verify CA/T Communications • Verify using Device Status Screen	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary
	1.1.8.2 Routine Tunnel Water Level Task	• Warning Status or abnormality which may be indicative of or lead to High Water Levels in the Tunnel	• RTU • Internal CA/T Communications • CCVE	• Water level in tunnel is high • Location of High water levels • Severity of high water	• RTU • Internal CA/T Communications • CCVE	• Scan location using CCVE • Verify CA/T Communications	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary
	1.1.8.3 Routine Hydrocarbon Levels Task	• Warning Status or abnormality which may be indicative of or lead to High Hydrocarbon Levels in the Tunnel	• RTU (via HC sensor) • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Hydrocarbon Levels are above normal • Location of high hydrocarbon readings • Severity of hydrocarbon levels	• RTU (via HC sensor) • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Scan location using CCVE • Verify CA/T Communications • Verify using Device Status Screen	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary
	1.1.8.4 Routine Security Intrusion Task	• Warning Status or abnormality which may be indicative of or lead to a Security Intrusion	• RTU (Intrusion Detection Control Panels) • Internal CA/T Communications • CCVE	• Intrusion by unauthorized personnel has been signaled by intrusion detectors • Location of Intrusion	• RTU (Intrusion Detection Control Panels) • Internal CA/T Communications • CCVE	• Verify CA/T Communications • Scan location using CCVE for evidence of intrusion	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary

	1.1.8.5 Routine Fire Detection Task	• Warning Status or abnormality which may be indicative of or lead to a CA/T system fire Facility Emergency	• RTU (Fire Alarm Control Panel- smoke detectors, heat detectors, manual pull stations, sprinkler system, linear heat control panels, etc.) • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Fire/Fire Related Incident has been detected • Location of Disturbance	• RTU (Fire Alarm Control Panel- smoke detectors, heat detectors, manual pull stations, sprinkler system, linear heat control panels, etc.) • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Scan location using CCVE • Verify CA/T Communications • Verify using Device Status Screen	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary
	1.1.8.6 Routine Carbon Monoxide Level Task	• Warning Status or abnormality which may be indicative of or lead to high Carbon Monoxide levels in the Tunnel	• RTU (via CO sensors) • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Carbon Monoxide Levels are above normal • Location of high CO levels • Severity of high CO levels	• RTU (via CO sensors) • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Scan location using CCVE • Verify CA/T Communications • Verify using Device Status Screen • CO Sensors (RTU)	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary
	1.1.8.7 Routine Structural Damage Task	• Warning Status or abnormality which may be indicative of or lead to Structural Damage in Tunnel	• Internal CA/T Communications • CCVE	• Structural Damage has occurred to CA/T • Location of Damage • Severity of Damage	• Internal CA/T Communications • CCVE	• Scan location using CCVE • Verify CA/T Communications	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary

1.2 Routine Facility Operator Tasks

Task Name	Subtask	Monitoring and Detection: Status for Which to be Monitored	Monitoring and Detection: Devices Used to Monitor	Incident Confirmation: Information to be Received	Incident Confirmation: Source of Information	Incident Confirmation: Methods for Verifying Incident	Incident Confirmation: Non-Incident Termination Duty
1.2.1 Routine Electrical Load Distribution System Task		• Warning Status or abnormality which may be indicative of or lead to a fault or overload in the electrical system	• Remote Terminal Unit (RTU) • Internal CA/T Communications • CCVE • Device Status Screen via Operator Workstation	• System/Subsystem Overload has occurred or System Device has become inoperable • Location of Disturbance	• RTU (Breaker, Transfer Switch, Uninterruptible Power Sup-ply System, Standby Generator, 13.8 kv Tie Lines, Battery Charger, etc.) • CA/T Internal Communications • CCVE	• Verify malfunction of equipment using Device Status Screen and info from RTU • Scan location using CCVE • Verify CA/T Communications	• Notify supervisor • Notify Maintenance if necessary • Perform communication Tasks if necessary • Resolve and compensate for malfunction if necessary
1.2.2 Routine Tunnel Drainage System Tasks	1.2.2.1 Routine Water/Refuse Tank Level Task	• Warning Status or abnormality which may be indicative of or lead to High Tank Levels	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Water or Refuse Tank Level is high • Location of Tank • Severity of high levels	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Scan location using CCVE • Verify CA/T Communications • Verify using Device Status Screen	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary
	1.2.2.2 Routine Pump Operation Malfunction Task	• Warning Status or abnormality which may be indicative of or lead to the Malfunction of a Drainage Pump	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Sump Pump and/or Oil Water Separators have become inoperable • Location of Disturbance	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Scan location using CCVE • Verify CA/T Communications • Verify using Device Status Screen	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary
1.2.3 Routine Communi-cation System Malfunction Task		• Warning Status or abnormality which may be indicative of or lead to a Traffic Emergency or Special Event	• Network System • Internal CA/T Communications • Device Status Screen via Operator Workstation	• System element becomes inoperable (Workstation Video/ Voice Recording System, Direct Link Communication System, Highway Advisory Radio, etc.)	• Network System • Internal CA/T Communications • Device Status Screen via Operator Workstation	• Verify CA/T Communications • Verify using Device Status Screen	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary
1.2.4 Routine Network System Malfunction Task		• Warning Status or abnormality which may be indicative of or lead to CA/T system facility emergency	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• System Device has become inoperable (RTU, RTU Cabinet Fan, Backbone Network Manager, Backbone Node, etc.) • Location of Disturbance	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Verify CA/T Communications • Verify using Device Status Screen	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary
1.2.5 Routine Fiber Optic Backbone System Malfunction Task		• Warning Status or abnormality which may be indicative of or lead to a malfunction of the fiber optic backbone and a Facility Emergency	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Fiber Optic Backbone System or system element has become inoperable • Location of Disturbance	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Verify CA/T Communications • Verify using Device Status Screen	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary

Table A1.2: Routine Facility Operator Task Description Table

1.2.6 Routine Planned Facility Events Task		• Warning Status or abnormality which may be indicative of or lead to a Facilities Emergency or Special Event	• Internal CA/T communications (maintenance, etc.)	• Special Facility Event is scheduled (anticipated duration and scope) • Type of Event (cleaning, maintenance, testing, etc.) • Location of Event	• Internal CA/T communications (maintenance, etc.)	• Verify CA/T Communications • Determine potential problems to the CA/T system	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary
1.2.7 Routine Security System Malfunction Task		• Warning Status or abnormality which may be indicative of or lead to malfunction in the Security System Equipment	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Intrusion Detection Device (Intrusion Detection Control Panel, Access Panel, etc.) has become inoperable • Location of Device	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Verify CA/T Communications • Verify using Device Status Screen • Scan location using CCVE for evidence of intrusion	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary
1.2.8 Routine Fire Systems Malfunction Task		• Warning Status or abnormality which may be indicative of or lead to a malfunction of the fire detection system	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• System Device has become inoperable (Fire Pump System, Heat Tracing System, Sprinkler System, Carbon Dioxide System, etc.) • Location of Problem	• RTU • Internal CA/T Communications • CCVE • Device Status Screen via Workstation	• Verify CA/T Communications • Verify using Device Status Screen	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary
1.2.9 Routine Fan & Ventilation Zone Malfunction Task		• Warning Status or abnormality which may be indicative of or lead to the malfunction of a ventilation fan	• Internal CA/T Communications • CCVE • Device Status Screen via Workstation • Programmable Logic Controller (PLC)	• Fan has become inoperable and/or ventilation step cannot be maintained • Location of disturbance	• Internal CA/T Communications • CCVE • Device Status Screen via Workstation • Programmable Logic Controller (PLC)	• Verify CA/T Communications • Verify using Device Status Screen • Verify using PLC	• Notify supervisor • Notify Maintenance if necessary • Perform resolution/ communication Tasks if necessary

Task Name	Monitoring and Detection: Status for Which to be Monitored	Monitoring and Detection: Devices Used to Monitor	Incident Confirmation: Information to be Received	Incident Confirmation: Source of Information	Incident Confirmation: Methods for Verifying Incident	Incident Confirmation: Non-Incident Termination Duty
1.3 Routine Supervisor Tasks						
1.3.1 Routine Traffic and Facility Systems Task	• Warning Status or abnormality which may be indicative of or lead to a Traffic and/or Facility Emergency or Special Event	• Internal CA/T Communications • CCVE • Device Status Screen via Workstation • Other Traffic and Facility Monitoring Systems	• A traffic and/or facility warning status has occurred • Severity of warning signal	• Internal CA/T Communications • CCVE • Device Status Screen via Workstation • Other Traffic and Facility Monitoring Systems	• Determine if Operators are available to assume responsibility for warning	• Determine if follow-up actions should occur • Supervise operator responsibilities for non-termination duties
1.3.2 Routine Alarm and Operator Incident Queue Task	• Warning Status or abnormality which may be indicative of or lead to a Traffic and/or Facility Emergency or Special Event	• Supervisor's Display Alarm Queue Screen • Supervisor's Display Incident Queue Screen	• Warning in Alarm or Incident Queue has reached a certain priority level without being responded to • Priority of Warning	• Supervisor's Display Alarm Queue Screen • Supervisor's Display Incident Queue Screen	• Determine if Operators are available to assume responsibility for warning	• Determine if follow-up actions should occur • Supervise operator responsibilities for non-termination duties
1.3.3 Routine Device Configuration Notification Task	• Warning Status or abnormality which may be indicative of or lead to the reconfiguration of system devices	• CA/T Internal Communications • Response Plan Element Requirement	• Request has been made to reconfigure a system device (Operator Profile, Overhead Monitor(s), Variable Message Sign, System Wide Display Screen, HAR Message) • Priority of Reconfiguration Request	• CA/T Internal Communications • Response Plan Element Requirement	• Determine necessity of changes • Schedule time to reconfigure	• Determine if follow-up actions should occur

Table A1.3: Routine Supervisor Task Description Table

2.1 Emergency Traffic Operator Tasks

Task Name	Subtask		Response &	Termination	
		Sources Used to Monitor Emergency	Action(s) to be Controlled	Means to Control Action(s)	Criteria for Completion
2.1.1 External Agency Emergency Tasks	2.1.1.1 Vehicle in Tunnel to be Apprehended by Police Emergency Task	• CCVE • Communication with external agency • CA/T Internal Communication	• Motorist safety such that they are aware of an emergency situation and can respond accordingly	• Field Devices (VMS, BOS ,sirens) warn motorists of danger • External agency to stop vehicle outside of tunnel • CCVE for operator to monitor vehicle movement • HAR message	• Vehicle has been prevented from continuing further on the CA/T system or vehicle has passed through the CA/T system
	2.1.1.2 Emergency Vehicle Passing Through Tunnel Emergency Task	• CCVE • Communication with external agency • CA/T Internal Communication	• Motorist safety such that they are aware of an emergency situation and can respond accordingly	• Field Devices (VMS, BOS ,sirens) warn motorists of danger • External agency to assist • CCVE for operator to monitor vehicle movement • HAR message	• Vehicle has passed through tunnel
2.1.2 Approaching Overheight Vehicle Emergency Task		• CCVE • Communication with external agency • CA/T Internal Communication • Overheight Vehicle Detectors • Horizontal Attenuators	• Route of the vehicle such that it does not enter the tunnel	• Field Devices (VMS, BOS ,sirens) warn motorists of danger • External agency to stop vehicle prior to tunnel entry • CCVE for operator to monitor vehicle movement • HAR message	• Vehicle has been prevented from entering the tunnel
2.1.3 Traffic-Affected Facilities Emergency Task	2.1.3.1 CA/T System Fire Emergency Task	• CCVE • CA/T Internal Communication (continuous) • Device Status Screens (Fan/Zone screens) • Fire Alarm Control Panel • External agency communications • Vehicle Detection System	• Fire to be Extinguished • Safe Air Environment to be maintained • Appropriate Drainage of Water from fire fighters to be maintained • Traffic to be routed around or away from dangerous facilities event/incident	• Ventilation Fans to control air intake/ output • CCVE to monitor emergency progress • External Agency (Fire, EMS, Police) to assist • CA/T Personnel to assist • Field Devices (VMS, BOS ,LUS, closure signals, sirens) warn motorists to avoid certain lanes or prepare to stop • HAR message • Toll Booths to control traffic flow	• Fire has been extinguished • Environment is safe for motorists and workers • Drainage System operating normally
	2.1.3.2 Abnormal Carbon Monoxide Levels Emergency Task	• CCVE • CA/T Internal Communication (continuous) • Device Status Screens (Fan/Zone screens) • CO Sensors (via RTU) • External Agency Communications • Vehicle Detection System	• Carbon Monoxide levels to be reduced • Safe Air Environment to be maintained/ reestablished • Traffic to be routed around or away from dangerous facilities event/incident	• Ventilation Fans to control air intake/ output • CCVE to monitor emergency progress • External Agency to assist • CA/T Personnel to assist • Field Devices (VMS, BOS ,LUS, closure signals, sirens) warn motorists to avoid certain lanes or prepare to stop • HAR message • Toll Booths to control traffic flow	• CO Levels have been reduced • Environment is safe for motorists and workers
	2.1.3.3 Abnormal Hydrocarbon Levels Emergency Task	• CCVE • CA/T Internal Communication (continuous) • Device Status Screens (Pump/Drainage Device screens) • HC Sensors (via RTU) • External Agency Communications • Vehicle Detection System	• Hydrocarbon levels to be reduced • Safe Environment to be maintained/ reestablished • Appropriate Drainage to be maintained	• Pumps to control drainage • CCVE to monitor emergency progress • External Agency to assist • CA/T Personnel to assist • Field Devices (VMS, BOS ,LUS, closure signals, sirens) warn motorists to avoid certain lanes or prepare to stop • HAR message • Toll Booths to control traffic flow	• HC Levels have been reduced • Environment is safe for motorists and workers

Table A1.4: Emergency Traffic Operator Task Description Table

	2.1.3.4 **Unauthorized Personnel Emergency Task**	• CCVE • CA/T Internal Communication (continuous) • Intrusion Detection Control Panels/Access Panels via workstation • External Agency Communications • Vehicle Detection System	• Person(s) to be apprehended and removed from tunnel building • Safe Environment to be maintained/reestablished • Traffic to be routed around or away from dangerous facilities event/incident	• CCVE to monitor emergency progress/intruder position • External Agency to assist • CA/T Personnel to assist • Device Status Screen (Intrusion Detection and Access Control Panels) • Field Devices (VMS, BOS ,LUS, closure signals, sirens) warn motorists to avoid certain lanes or prepare to stop • HAR message • Toll Booths to control traffic flow	• Person(s) has/have been apprehended and/or no longer a threat • Environment is safe for motorists and workers
	2.1.3.5 **CA/T System Power Failure Emergency Task**	• CCVE • CA/T Internal Communication (continuous) • Device Status Screens (Power Source screens) • External Agency Communications • Vehicle Detection System	• Alternate Power source to be engaged • Primary Power source to be recovered • Safe Environment to be maintained/reestablished • Traffic to be routed around or away from dangerous facilities event/incident	• Pumps to control drainage • CCVE to monitor emergency progress • External Agency to assist • CA/T Maintenance Personnel to assist in repairs • Field Devices (VMS, BOS ,LUS, closure signals, sirens) warn motorists to avoid certain lanes or prepare to stop • HAR message • Toll Booths to control traffic flow	• Primary Power Source has been recovered • Environment is safe for motorists and workers
	2.1.3.6 **CA/T System Structural Damage Emergency Task**	• CCVE • CA/T Internal Communication (continuous) • External Agency Communications • Vehicle Detection System	• Structural Damage to be repaired • Safe Structural Environment to be maintained/reestablished • Traffic to be routed around or away from dangerous facilities event/incident	• Pumps to control drainage • CCVE to monitor emergency progress • External Agency to assist • CA/T Maintenance Personnel to assist in repairs • Field Devices (VMS, BOS ,LUS, closure signals, sirens) warn motorists to avoid certain lanes or prepare to stop • HAR message • Toll Booths to control traffic flow	• Structure has been repaired • Environment is safe for motorists and workers
	2.1.3.7 **Abnormal Tunnel Water Level Emergency Task**	• CCVE • Communication with external agency • CA/T Internal Communication (continuous) • Device Status Screens (Pump/Drainage) • Vehicle Detection System	• Water Level in tunnel to be reduced to an acceptable level • Safe environment to be maintained/reestablished • Appropriate Drainage to be maintained • Traffic to be routed around or away from dangerous facilities event/incident	• Pumps to control drainage • Field Devices (VMS, BOS ,LUS, closure signals) warn motorists to avoid certain lanes or prepare to stop • External agency assist • Emergency Platform/Station to assist • CCVE to monitor progress • HAR message • Toll Booths to control traffic flow	• Water levels have returned to normal • Traffic Flow has returned to normal • Environment is safe for motorists
2.1.4 **CA/T Roadway Traffic Incident Emergency Task**	**2.1.4.1** **Blocked Lane or Vehicle Breakdown Emergency Task**	• CCVE • CA/T Internal Communication (continuous) • Vehicle Detection System • External agency communications	• Roadway to be cleared of disabled vehicle or debris • Traffic to be routed around blocked lanes if possible • Safe environment to the maintained for motorists	• Field Devices (VMS, BOS ,LUS, closure signals) warn motorists to avoid certain lanes or prepare to stop • External agency assist (EMS, Fire, Police, etc.) • Emergency Platform/Station to assist • CCVE to monitor progress • HAR message • Toll Booths to control traffic flow	• Disabled vehicle or debris has been cleared • Traffic flow has returned to normal • Environment is safe for motorists

	2.1.4.2 Vehicle Accident Emergency Task	• CCVE • CA/T Internal Communication (continuous) • Vehicle Detection System • External agency communications	• Roadway to be cleared of disabled vehicle or debris • Traffic to be routed around blocked lanes if possible • Safe environment to the maintained for motorists	• Field Devices (VMS, BOS ,LUS, closure signals) warn motorists to avoid certain lanes or prepare to stop • External agency assist (EMS, Fire, Police, etc.) • Emergency Platform/Station to remove wreckage, vehicle, debris • CCVE to monitor progress • HAR message • Toll Booths to control traffic flow	• Wreckage has been cleared • Traffic flow has returned to normal • Environment is safe for motorists
2.1.5 Roadway Equipment Emergency Task	2.1.5.1 Field Device Malfunction Emergency Task	• CCVE • CA/T Internal Communication • Device Status Screens (Field Devices • External Agency Communications • Local Field Controller • Vehicle Detection system	• Field Device to be repaired • Safe Environment to be maintained/ reestablished • Traffic flow to be maintained	• Device Status Screens • Local Field Controller • External Agency to assist if necessary • CA/T Maintenance Personnel to assist in repairs • Alternate Traffic directing method to be employed if necessary	• Field Device System has been repaired • Environment is safe for motorists and workers • Traffic Flow has returned to normal
	2.1.5.2 CCVE System Malfunction Emergency Task	• CCVE • CA/T Internal Communication • Device Status Screens (CCVE components) • External Agency Communications	• CCVE System component to be repaired (cameras, demultiplexers, multiplexers, etc.) • Safe Environment to be maintained/ reestablished • Roadway Monitoring Compensation to be provided	• CCVE Working Cameras to compensate for down camera(s) • External Agency to assist • CA/T Maintenance Personnel to assist in repairs	• CCVE System has been repaired • Environment is safe for motorists and workers
	2.1.5.3 Tunnel Lighting System Malfunction Emergency Task	• CCVE • CA/T Internal Communication • Device Status Screens (Lighting components) • External Agency Communications • Vehicle Detection System	• Lighting system component to be repaired • Safe Environment to be maintained/ reestablished • Appropriate illumination to be maintained/ reestablished • Traffic flow to be maintained	• CCVE to monitor emergency repair progress • External Agency to assist • CA/T Maintenance Personnel to assist in repairs • Compensate for down lighting with alternate lighting source	• Tunnel Lighting System has been repaired • Environment is safe for motorists and workers • Traffic flow has returned to normal
2.1.6 CA/T Roadway Debris or Spill Emergency Task	2.1.6.1 Non-Hazardous Debris or Spill Emergency Task	• CCVE • CA/T Internal Communication (continuous) • Vehicle Detection System • External agency communications	• Debris/spill to be removed • Traffic to be routed around debris/spill if possible • Safe environment to the maintained for motorists	• Field Devices (VMS, BOS ,LUS, closure signals) warn motorists to avoid certain lanes or prepare to stop • External agency assist (EMS, Fire, Police, etc.) • Emergency Platform/Station to assist • CCVE to monitor • HAR message • Toll Booths to control traffic flow	• Debris has been cleared • Traffic flow has returned to normal • Environment is safe for motorists
	2.1.6.2 Hazardous Debris or Spill Emergency Task	• CCVE • CA/T Internal Communication (continuous) • Vehicle Detection System • External agency communications	• Debris/spill to be removed • Traffic to be routed around debris/spill if possible • Safe environment to the maintained for motorists • Spread of hazardous material to be prevented(ventilation, drainage)	• Field Devices (VMS, BOS ,LUS, closure signals) warn motorists to avoid certain lanes or prepare to stop • External agency assist (EMS, Fire, Police, etc.) • Emergency Platform/Station to • CCVE to monitor • HAR message • Toll Booths to control traffic flow • Ventilation Fans, Drainage Pumps to control excess material	• Debris has been cleared • Traffic flow has returned to normal • Environment is safe for motorists

2.2 Emergency Facility Operator Tasks

Task Name	Subtask	Response & Termination			
		Sources Used to Monitor Emergency	**Action(s) to be Controlled**	**Means to Control Action(s)**	**Criteria for Completion**
2.2.1 Abnormal Water/Refuse Tank Levels Emergency Task		• CCVE • CA/T Internal Communication (continuous) • Device Status Screens (Pump/Drainage Device screens) • Tank Level Indicators • External Agency Communications	• Tank Levels to be drained to acceptable level • Safe Environment to be maintained/ reestablished • Appropriate Drainage to be maintained	• Pumps to control drainage • CCVE to monitor emergency progress • External Agency to assist • CA/T Personnel to assist	• Tank Levels have been reduced • Environment is safe for motorists and workers • Drainage system operating normally
2.2.2 CA/T Roadway Hazardous Spill or Debris Decontam-ination Emergency Task		• CCVE • CA/T Internal Communication (continuous) • Device Status Screens (Pump/Drainage and Fan/Zone Device screens) • External Agency Communications	• Spread of hazardous material to be prevented (drainage, ventilation) • Safe Environment to be maintained/ reestablished • Appropriate Drainage and Ventilation to be maintained	• Pumps to control excess material drainage • Ventilation Fans to control excess material • CCVE to monitor emergency progress • External Agency to assist • CA/T Personnel to assist	• Hazardous debris has been cleared of system • Environment is safe for motorists and workers • Drainage system operating normally • Ventilation System Operating normally
2.2.3 Facility Equipment Malfunction Emergency Task	**2.2.3.1** Electrical Load Distribution System Malfunction Emergency Task	• CCVE • CA/T Internal Communication • Device Status Screens (Power components) • External Agency Communications	• Electrical System component to be repaired • Safe Environment to be maintained/ reestablished	• CCVE to monitor emergency repair progress • External Agency to assist • CA/T Maintenance Personnel to assist in repairs	• Electrical Load System has been repaired • Environment is safe for motorists and workers
	2.2.3.2 Security System Malfunction Emergency Task	• CCVE • CA/T Internal Communication • Device Status Screens (Security System components) • External Agency Communications	• Security System component to be repaired • Safe Environment to be maintained/ reestablished	• CCVE to monitor emergency repair progress • External Agency to assist • CA/T Maintenance Personnel to assist in repairs	• Security System has been repaired • Environment is safe for motorists and workers
	2.2.3.3 Network System Malfunction Emergency Task	• CCVE • CA/T Internal Communication • Device Status Screens (Network System components) • External Agency Communications	• Network System component to be repaired (RTU, RTU cabinets, network backbone, computers) • Appropriate control to be maintained/ reestablished	• CCVE to monitor emergency repair progress • External Agency to assist • CA/T Maintenance Personnel to assist in repairs • Compensate for down network (move to BOCC is necessary)	• Network System has been repaired • Environment is safe for motorists and workers
	2.2.3.4 Fiber Optic Backbone System Malfunction Emergency Task	• CCVE • CA/T Internal Communication • Device Status Screens (Backbone components) • External Agency Communications	• Fiber Optic Backbone system component to be repaired • Safe Environment to be maintained/ reestablished • Appropriate control to be maintained/ reestablished	• CCVE to monitor emergency repair progress • External Agency to assist • CA/T Maintenance Personnel to assist in repairs • Compensate for down backbone (move to BOCC is necessary)	• Fiber Optic Backbone System has been repaired • Environment is safe for motorists and workers
	2.2.3.5 Communications System Malfunction Emergency Task	• CCVE • CA/T Internal Communication • Device Status Screens (Communications components) • External Agency Communications	• Communications System Component to be repaired • Safe Environment to be maintained/ reestablished • Appropriate communications to be maintained	• CCVE to monitor emergency repair progress • External Agency to assist • CA/T Maintenance Personnel to assist in repairs • Compensate by using back-up communications	• Communications System has been repaired • Environment is safe for motorists and workers
	2.2.3.6 Drainage System Malfunction Emergency Task	• CCVE • CA/T Internal Communication • Device Status Screens (Drainage components) • External Agency Communications	• Drainage system component to be repaired (Pumps, Oil/ Water Separator Unit, Settling Tank, Sump Pit, Refuse Oil Tank, HC Sensors, etc.) • Safe Environment to be maintained/ reestablished	• CCVE to monitor emergency repair progress • External Agency to assist • CA/T Maintenance Personnel to assist in repairs	• Drainage System has been repaired • Environment is safe for motorists and workers

Table A1.5: Emergency Facility Operator Task Description Table

	2.2.3.7 Fire Protection/ Detection Systems Emergency Task	• CCVE • CA/T Internal Communication • Device Status Screens (Fire system components) • External Agency Communications	• Fire system component to be repaired (Fire Pump, heat tracing, sprinkler, carbon dioxide, heat detection, smoke detection systems, manual pull stations, alarms, heat control panels, etc.) • Safe Environment to be maintained/ reestablished	• CCVE to monitor emergency repair progress • External Agency to assist • CA/T Maintenance Personnel to assist in repairs	• Fire System has been repaired • Environment is safe for motorists and workers
	2.2.3.8 Ventilation System Malfunction Emergency Task	• CCVE • CA/T Internal Communication • Device Status Screens (Ventilation components) • External Agency Communications	• Ventilation system component to be repaired (Fans, Programmable Logic Controllers, CO sensors, etc.) • Safe Air Environment to be maintained	• CCVE to monitor emergency repair progress • External Agency to assist • CA/T Maintenance Personnel to assist in repairs • Compensation with additional fans	• Ventilation System has been repaired • Environment is safe for motorists and workers

2.3 Emergency Supervisor Tasks		
Task Name	**Response and Termination** **Sources Used to Monitor Emergency Situation**	**Criteria for Completion**
2.3.1 Emergency Incident Handling Supervision Task	• Supervisor Device Status Screens of all components utilized in response plan • CA/T Internal Communications (i.e.-with operator in charge especially)	• Incident is no longer active • Operator has terminated incident • Supervisor opinion that incident was handled/terminated correctly • Or incident priority allows for placement in Alarm or Incident Queue

Table A1.6: Emergency Supervisor Task Description Table

3.1 Special Event Traffic Operator Tasks

Task Name	Subtask	Response & Termination: Sources Used to Monitor Special Event	Response & Termination: Action(s) to be Controlled	Response & Termination: Means to Control Action(s)	Response & Termination: Criteria for Completion
3.1.1 Peak Traffic Flow Periods Special Event Task		• CCVE • CA/T Internal Communication (Toll Data) • Vehicle Detection System • External agency communications • System Device Status Screens	• Safe environment to the maintained for motorists • Continuous flow of traffic to be maintained	• Field Devices (VMS, BOS ,LUS, closure signals) warn motorists to avoid certain lanes or prepare to stop • External agency assist (EMS, Fire, Police, etc.) • Emergency Platform/Station to assist • CCVE to monitor flow • HAR message • Toll Booths to control traffic flow • Device Control and Status Screen to control facility system components	• Peak Flow data indicates that peak flow is over • Significant reduction of traffic through tunnel • Environment is safe for motorists and workers • Facility System components are operating normally
3.1.2 Special (Non-Emergency) Vehicle in or Passing Through Tunnel Task		• CCVE • CA/T Internal Communication • Vehicle Detection System • External agency communications	• Safe environment to the maintained for motorists • Traffic flow to be routed around/away from special vehicle if possible	• Field Devices (VMS, BOS ,LUS, closure signals) warn motorists to avoid certain lanes or prepare to stop • External agency assist (EMS, Fire, Police, etc.) • Emergency Platform/Station to assist • CCVE to monitor flow • HAR message • Toll Booths to control traffic flow	• Traffic Flow has returned to normal • Special vehicle has left tunnel and/or CA/T system
3.1.3 Facility Maintenance or Cleaning Affecting Traffic Flow Task		• CCVE • CA/T Internal Communication • Vehicle Detection System • External agency communications • Device Status Screens	• Safe environment to the maintained for motorists • Continuous flow of traffic to be maintained • Traffic flow to be routed around/away from facility event	• Field Devices (VMS, BOS ,LUS, closure signals) warn motorists to avoid certain lanes or prepare to stop • External agency assist (EMS, Fire, Police, etc.) • Emergency Platform/Station to assist • CCVE to monitor flow • HAR message • Toll Booths to control traffic flow	• Facility Event is complete • Traffic Flow has returned to normal • Environment is safe for motorists
3.1.4 External Event Affecting Traffic Flow Task		• CCVE • CA/T Internal Communication (Toll Data) • Vehicle Detection System • External agency communications • Device Status Screens	• Safe environment to the maintained for motorists • Continuous flow of traffic to be maintained	• Field Devices (VMS, BOS ,LUS, closure signals) warn motorists to avoid certain lanes or prepare to stop • External agency assist (EMS, Fire, Police, etc.) • Emergency Platform/Station to assist • CCVE to monitor flow • HAR message • Toll Booths to control traffic flow	• External event is over • Significant reduction is traffic flow • Environment is safe for motorists
3.1.5 Hazardous Weather Conditions Task	**3.1.5.1** Heavy Rain or Flooding Special Event Task	• CCVE • CA/T Internal Communication • Vehicle Detection System • External agency communications (weather advisory, etc.)) • System Device Status Screens (Drainage, etc.)	• Safe environment to the maintained for motorists • Continuous flow of traffic to be maintained • Drainage System to remove excess water without becoming overloaded	• Field Devices (VMS, BOS ,LUS, closure signals) warn motorists to avoid certain lanes or prepare to stop • External agency assist (EMS, Fire, Police, etc) • Emergency Platform/Station to assist • CCVE to monitor flow • HAR message • Toll Booths to control traffic flow • Device Control and Status Screens • Drainage Pumps to control water flow	• Severe weather is over • Traffic flow has returned to "normal" • Environment is safe for motorists and workers • Facility System Components (drainage System) operating normally

Table A1.7: Special Event Traffic Operator Task Description Table

3.1.5.2. Snow, Blizzard, or Ice Special Event Task	• CCVE • CA/T Internal Communication • Vehicle Detection System • External agency communications (weather advisory, etc.) • System Device Status Screens (Drainage, etc.)	• Safe environment to the maintained for motorists • Continuous flow of traffic to be maintained • Drainage System to remove excess water without becoming overloaded • Snow/Ice to be removed from and/or prevented from forming on road	• Field Devices (VMS, BOS ,LUS, closure signals) warn motorists to avoid certain lanes or prepare to stop • External agency assist (EMS, Fire, Police, etc) • Emergency Plat-form/Station to assist • CCVE to monitor flow • HAR message • Toll Booths to control traffic flow • Device Control and Status Screens • Drainage pumps to control water flow • Crew to remove snow/ice	• Severe weather is over • Snow/ice is no longer a threat to motorists • Traffic flow has returned to "normal" • Environment is safe for motorists • Facility System components (Drainage System) operating normally • Snow/Ice has been removed
3.1.5.3 High Speed Winds, Tornadoes, Hurricanes Task	• CCVE • CA/T Internal Communication • Vehicle Detection System • External agency communications (weather advisory, etc.) • System Device Status Screens (Drainage, etc.)	• Safe environment to the maintained for motorists • Continuous flow of traffic to be maintained • Drainage System to remove excess water without becoming overloaded	• Field Devices (VMS, BOS ,LUS, closure signals) warn motorists to avoid certain lanes or prepare to stop • External agency assist (EMS, Fire, Police, etc.) • Emergency Plat-form/Station to assist • CCVE to monitor flow • HAR message • Toll Booths to control traffic flow • Device Control and Status Screens • Drainage pumps to control water flow	• Severe weather is over • Traffic flow has returned to "normal" • Environment is safe for motorists • Facility System components (Drainage System)

3.2 Special Event Facility Operator Tasks

Task Name	Subtask	Response & Termination			
		Sources Used to Monitor Special Event	Action(s) to be Controlled	Means to Control Action(s)	Criteria for Completion
3.2.1 Facility Maintenance or Cleaning Special Event Task		• CCVE • CA/T Internal Communication • External agency communications • System Device Status Screens	• Facility System to be repaired or cleaned	• External agency assist (EMS, Fire, Police, etc.) • Emergency Plat-form/Station to assist • CCVE to monitor repair progress	• Facility system has been repaired • Environment is safe for motorist and workers
3.2.2 Facilities Equipment Testing Special Event Task		• CCVE • CA/T Internal Communication • External agency communications • System Device Status Screens	• Facility System to be tested (i.e.- Fire systems, etc.)	• External agency assist (EMS, Fire, Police, etc.) • Emergency Plat-form/Station to assist • CCVE to monitor testing progress	• Facility system has been tested • Environment is safe for motorist and workers

Table A1.8: Special Event Facility Operator Task Description Table

3.3 Special Event Supervisor Tasks					
		Response & Termination			
Task Name	Subtask	Sources Used to Monitor Special Event	Action(s) to be Controlled	Means to Control Action(s)	Criteria for Completion
3.3.1 Special Event Handling Supervision Task		• Supervisor Device Status Screens of all components utilized in response plan • CA/T Internal Communications (i.e.- with operator in charge especially)			• Event is no longer active • Operator has terminated incident • Supervisor opinion that incident was handled/terminated correctly • Or incident priority allows for placement in Alarm or Incident Queue
3.3.2 Special System Device Configuration Task	3.3.2.1 Highway Advisory Radio Configuration Task		• A new HAR message to be recorded and/or a live HAR Announcement to be made	• Supervisor Highway Advisory Radio Screen	• The transmission has ended for the Live Announcement and/or the Recording has ended for the Record Message
	3.3.2.2 Variable Message Sign Configuration Task		• A message displayed by the Variable Message Sign needs to be added, deleted, and/or changed • Message to be assigned to a particular VMS	• Supervisor VMS message configuration screen • Supervisor VMS control screen	• The new VMS configuration has been accepted
	3.3.2.3 System-Wide Display Configuration Task		• The current settings for the System-Wide Display are to be modified (Alarm Displays, Device Status Displays, System Status Displays)	• Supervisor Alarms, Device Status, and System Status Screens	• The new system-wide display configuration has been accepted
	3.3.2.4 Overhead Monitor Configuration Task		• The current camera displays for the Overhead Monitors are to be modified	• Supervisor Overhead Monitor Selection Screen	• The new camera selection has been accepted and the screen has been exited
	3.3.2.5 User Profile Configuration Task		• Operator/user capabilities require modification	• Supervisor Profile Configuration Screen	• The profile modifications have been accepted

Table A1.9: Special Event Supervisor Task Description Table

A2 CA/T OCC Expanded Task Analysis

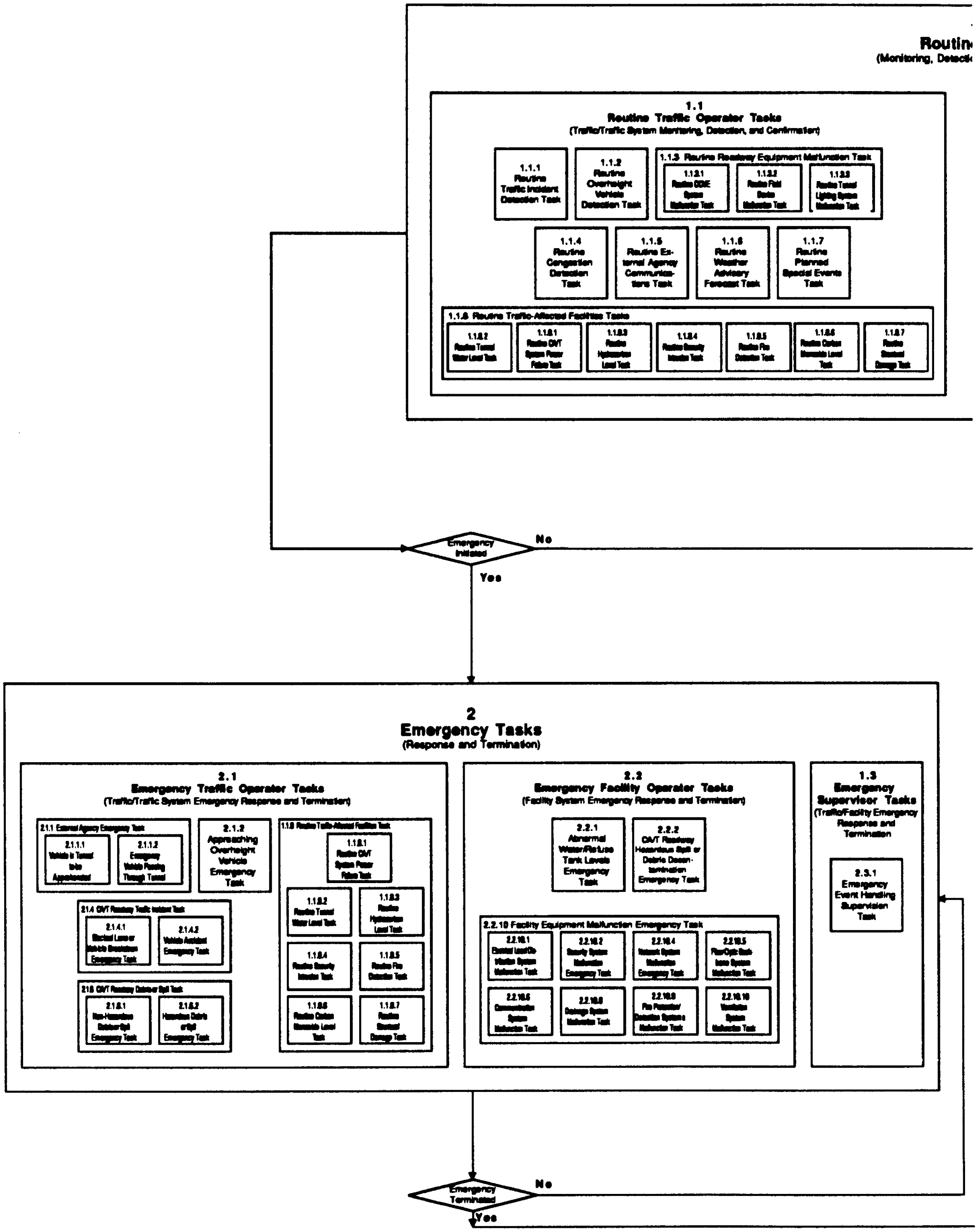
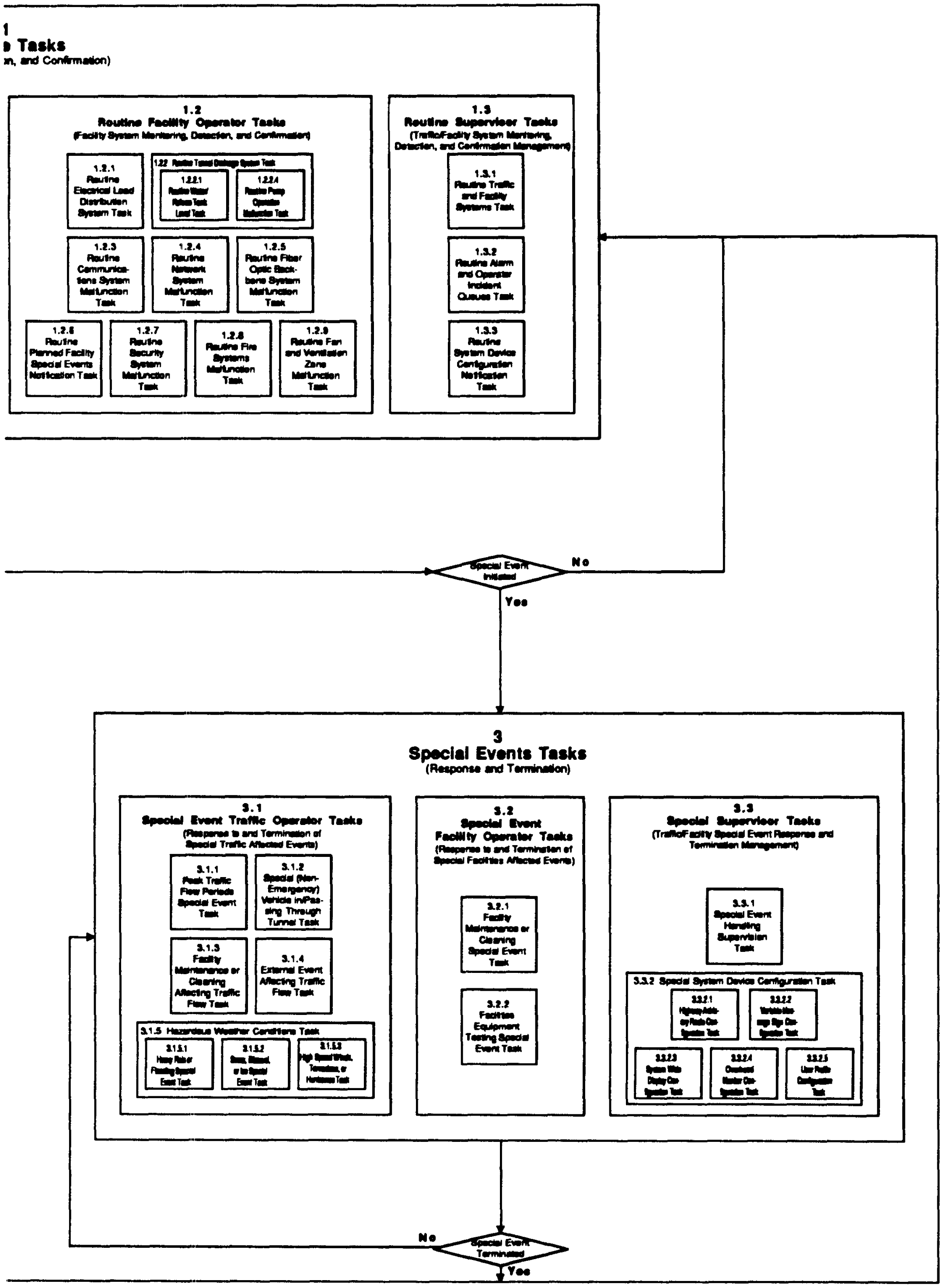


Figure A2.1: Central Artery/Tunnel Operations



Control Center Expanded Task Analysis

A3 Operator Functional Action-Decision Diagrams

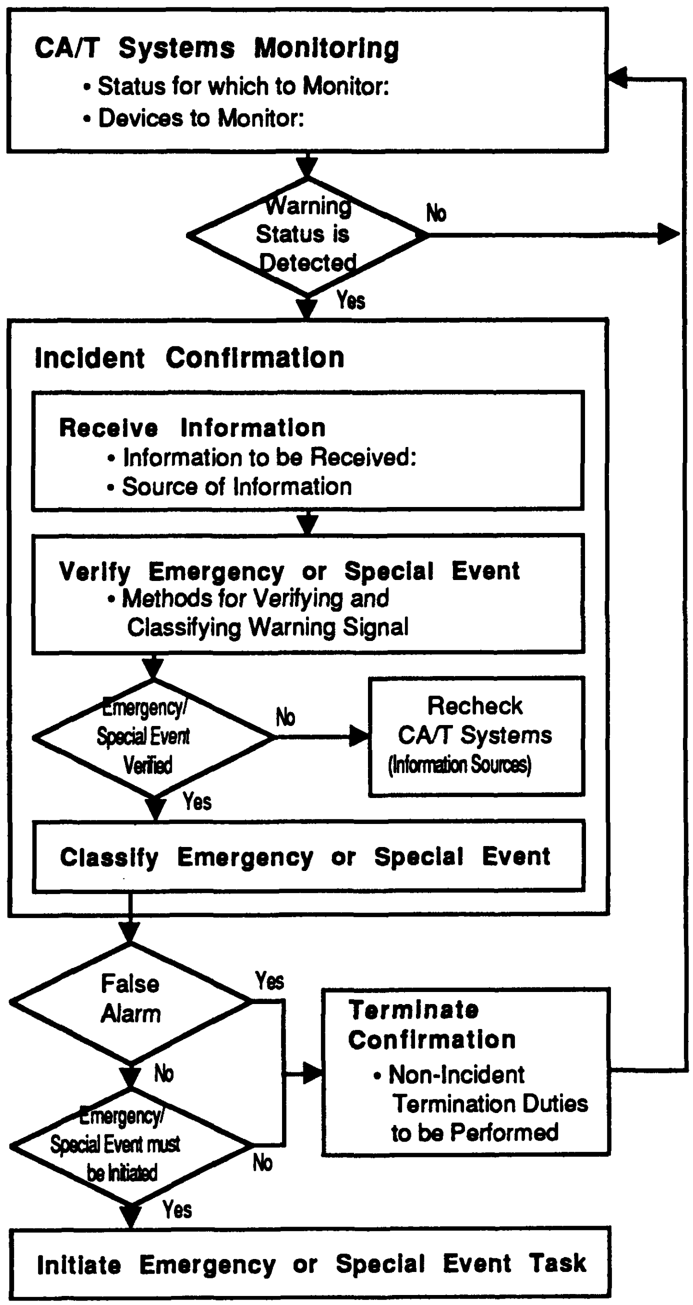


Figure A3.1: Routine Traffic and Facility Operator Functional Action-Decision Diagram

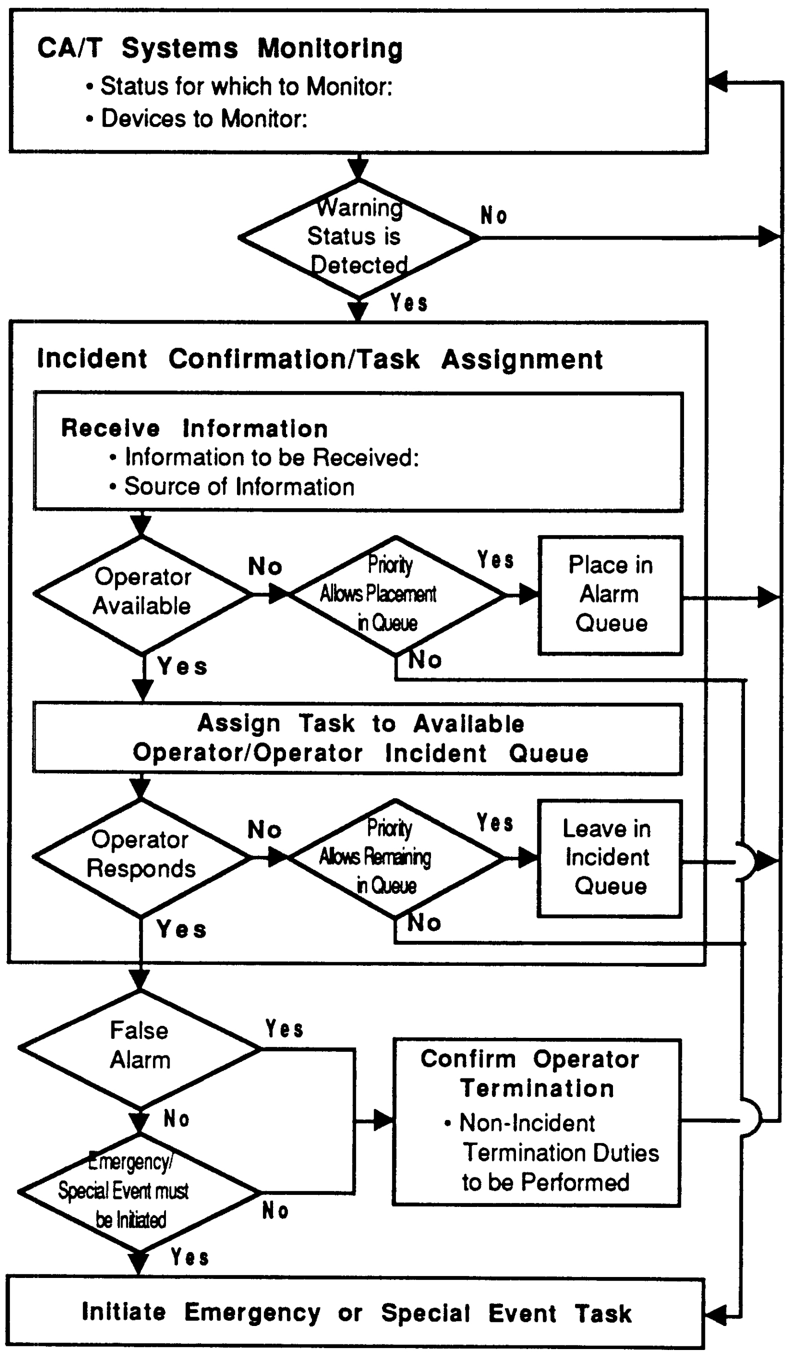


Figure A3.2: Routine Supervisor Functional Action-Decision Diagram

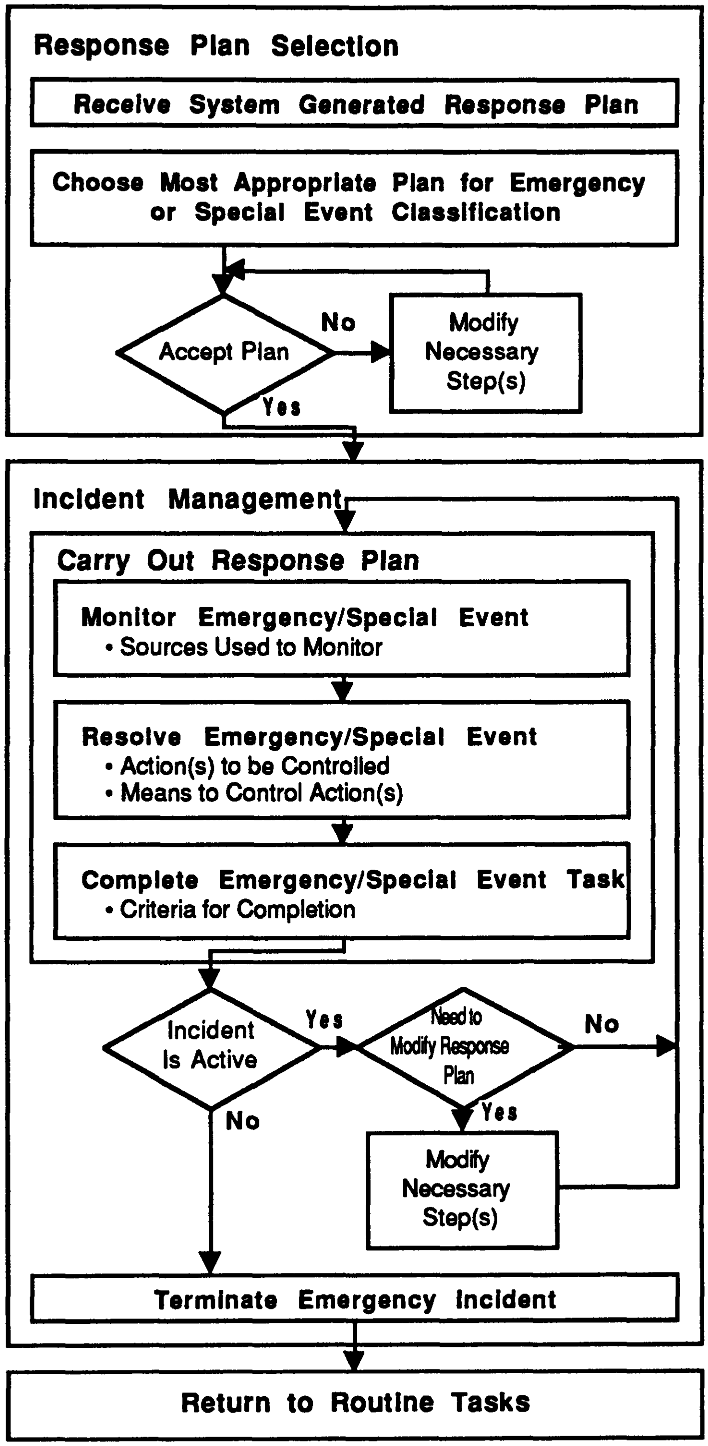


Figure A3.3: Emergency or Special Event Traffic and Facility Operator Functional Action-Decision Diagram

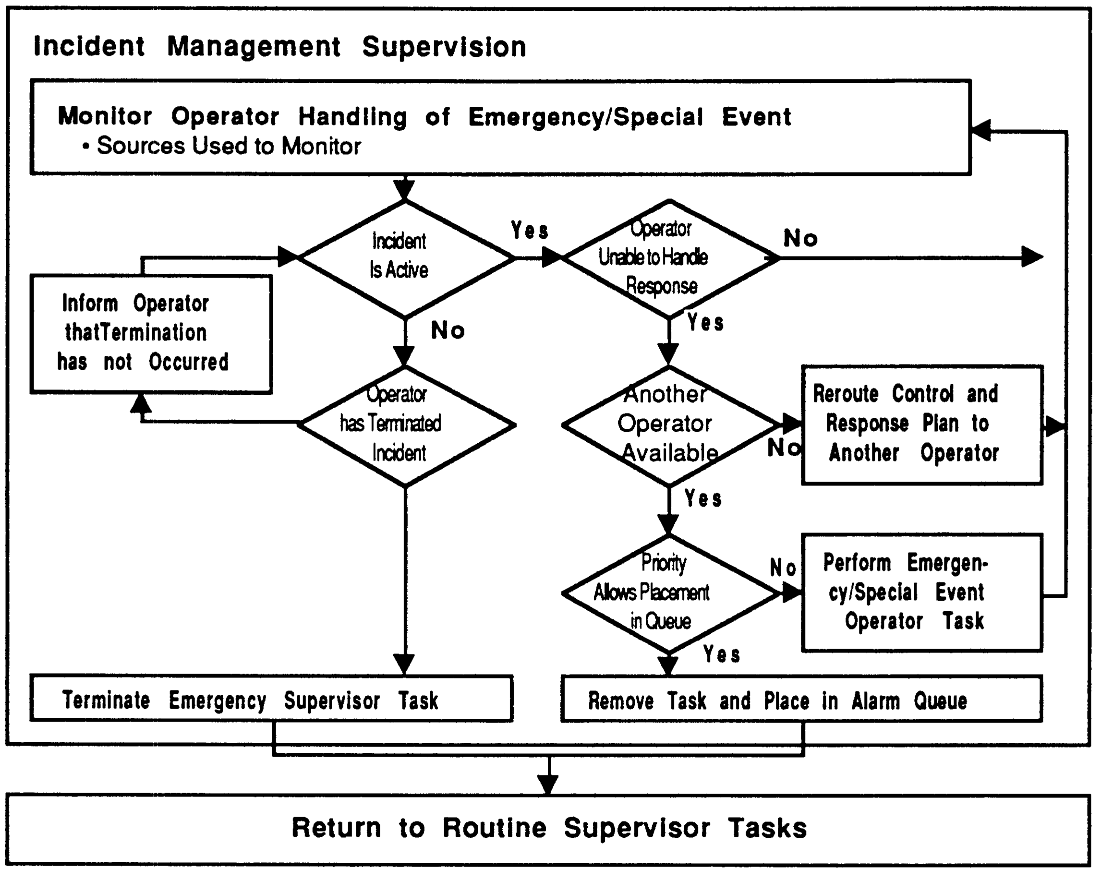


Figure A3.4: Emergency or Special Event Supervisor Functional Action-Decision Diagram

Appendix B: Central Artery/Tunnel Operating Procedures

B1 Incident Scenario 1: High Carbon Monoxide Levels (Symptom-Oriented)

1	CHECK	CO Sensor Monitoring Screen 7 WB-2	for CO Levels >60ppm
2	OBSERVE	Ventilation Zone 7WB-2 Step Control Screens	for CO-based control
3	SCAN	Location THT WB via C 173 SE	for traffic congestion
4	OBSERVE	Ventilation Zone 7WB-2 Fan Status Screens	for abnormal operation
5	INITIATE	Appropriate Emergency /Termination Task	

Figure B1.1: High Carbon Monoxide Levels, Unknown Cause (Top Level)

[1] CHECK CO Sensor Monitoring Screen [7 WB-2] for CO Levels >60ppm

- **[1.1] OPEN** CO Sensor Monitoring Screen [7 WB-2]
  - **(1.1.1) SELECT** "Ventilation" from "Window" Menu
  - **(1.1.2) SELECT** "CO Sensor Monitoring Panel" from "Devices" Menu
  - **(1.1.3) SELECT** Zone [7 WB-2] from Menu
- **[1.2] CHECK** CO Levels => 60ppm
  - **(1.2.1) IF** CO Levels => 60ppm
    THEN GO TO Step [2]
  - **(1.2.2) IF** CO Levels < 60ppm
    THEN NOTIFY Supervisor & Maintenance of CO Sensor Alarm Malfunction

[2] OBSERVE Ventilation Zone [7WB-2] Step Control Screens for CO-based control

- **[2.1] OPEN** Ventilation Zone [7WB-2] Step Control Screens
  - **(2.1.1) SELECT** "Ventilation" from "Window" Menu
  - **(2.1.2) SELECT** Zone [7 WB-2] from Screen
- **[2.2] OBSERVE** that Zone [7 WB-2] is in CO-based control

Figure B1.2: High Carbon Monoxide Levels, Unknown Cause (Lowest, Most Detailed Level)

(2.2.1) **IF** Zone [7 WB-2] is in Auto CO control

THEN GO TO Step [3]

(2.2.2) **IF** Zone [7 WB-2] is NOT in Auto CO control

THEN
OBSERVE Supply & Exhaust Steps have been appropriately adjusted

(2.2.2.1) **IF** Supply & Exhaust Steps have been adjusted

THEN GO TO Step [3]

(2.2.2.2) **IF** Supply & Exhaust Steps have NOT been adjusted

THEN
PLACE Zone [7 WB-2] in Manual Control

(2.2.2.3) **PLACE** Supply & Exhaust Steps at appropriate level

(2.2.2.2) **IF** Supply & Exhaust Steps CANNOT be maintained

THEN GO TO Step [4]

[3] **SCAN** Location [THT WB] via (C 173 SE) for traffic congestion

[3.1] **VIEW** (C 173 SE) on Workstation Screen

(3.1.1) **SELECT** "CCVE" from the "Window" Menu

(3.1.2) **SELECT** (C 173 SE) from the Menu

[3.2] **IF** Heavy Congestion exists

THEN **SCAN** Adjacent Locations [THT EB] & [I-90 WB] for Source of Congestion

and GO TO Step [5]

[3.3] IF NO Heavy Congestion exists

THEN GO TO Step 4

4 OBSERVE Ventilation Zone 7WB-2 Fan Status Screens for abnormal operation

[4.1] OBSERVE Fan 7SF-1 7SF-6 7EF-1 7EF-2 7EF-10 Status Screens for abnormal operation

(4.1.1) SELECT "Ventilation" from the "Window" Menu

(4.1.2) SELECT Fan Status Screen from the "Devices" Menu

(4.1.3) SELECT Fans 7SF-1, 7SF-6, 7EF-1, 7EF-2, and 7EF-10

[4.2] IF Fan is malfunctioning

THEN NOTIFY Supervisor & Maintenance of Malfunction

[4.3] IF Fan is in "Off" mode

THEN START Fan

and RETURN TO Step 2.

5 INITIATE Appropriate Emergency /Termination Task

B2 Incident Scenario 2: Vehicle Collision on Tunnel Roadway (Task-Oriented)

1	**MONITOR**	Location THT WB via C 205 SE
	until	Incident is Terminated
2	**NOTIFY**	the following external agencies: a. Police b. EMS
3	**DISPATCH**	Emergency Response Team 6
4	**NOTIFY**	the following external agencies: a. Regional OCC b. Radio Station
5	**MONITOR**	Communications with Emergency Response Team
	until	Incident is Terminated
6	**CHANGE**	Traffic System Components to direct traffic flow
7	**CONFIRM**	Incident Status Information is correct
8	**WHEN**	All Termination Criteria is met
	TERMINATE	Emergency Task

Figure B2.1: Vehicle Collision on Tunnel Roadway (Top Level)

1 MONITOR Location [THT WB] via (C 205 SE)

until Incident is Terminated

- **[1.1] VIEW** (C 205 SE) on Workstation Screen
  - **(1.1.1) SELECT** "CCVE" from the "Window" Menu
  - **(1.1.2) SELECT** (C 205 SE) from the Menu
- **[1.2] MONITOR** Location [THT WB] for Incident Status

2 NOTIFY the following external agencies:

a. [Police]

b. [EMS]

- **[2.1] SELECT** "Boston Police Dept." from "Hot-Lines" Menu
  or
  DEPRESS (F7 key) on keyboard
- **[2.2] SELECT** "Medical Team" from "Hot-Lines" Menu
  or
  DEPRESS (F9 key) on keyboard

3 DISPATCH Emergency Response Team [6]

- **[3.1] NOTIFY** Emergency Response Team [6]
  via Telephone
- **[3.2] VERIFY** Emergency Response Team [6]
  Has been dispatched

Figure B2.2: Vehicle Collision on Tunnel Roadway (Lowest, Most Detailed Level)

4 **NOTIFY**	the following external agencies: a. Regional OCC b. Radio Station	
[4.1]	**SELECT** "Other Hot-Lines" from "Hot-Lines" Menu **and** **SELECT** "Regional OCC"	
[4.2]	**SELECT** "Other Hot-Lines" from "Hot-Lines" Menu **and** **SELECT** "Radio Stations"	
5 **MONITOR** **until**	Communications with Emergency Response Team Incident is Terminated	
6 **CHANGE**	Traffic System Components to direct traffic flow	
[6.1]	**CHANGE**	All (LUS) in [Left] lane [900] feet downstream of reference LUS [476 WB]
[6.2]	**CHANGE**	All (VMS) between Location [THT WB3] and Emergency Response Station [6] to [Left Lane-Emergency Vehicle Use Only]
[6.3]	**CHANGE**	All (VSLS) [900] feet downstream of Location [THT WB3] to [Prepare to Merge]
[6.4]	**BROADCAST**	(HAR) Message # [17 "Lane Collision"]

7 **CONFIRM** Incident Status Information is correct

[7.1] IF Incident Status Information is correct

THEN GO TO Step **8**

[7.2] IF Incident Status Information is NOT correct

THEN
SELECT **Update** button

and
CHANGE Necessary Information

8 **WHEN** All Termination Criteria is met

TERMINATE Emergency Task

[8.1] IF The following criteria have been met

a. Vehicle has been cleared from roadway
b. Emergency Response Team cleared
c. External Agencies cleared of roadway
d. Traffic Flow returned to acceptable level
e. Environment has returned to safe level

THEN
TERMINATE Vehicle Collision Emergency Task

(8.1.1) SELECT **Terminate** button

[8.2] IF Criteria of [8.1] has NOT been met

THEN Step **1** RETURN TO

B3 Incident Scenario 3: Vehicle Collision with Fire on Tunnel Roadway (Task-Oriented)

1	MONITOR	Location THT WB via C 205 SE
	until	Incident is Terminated
2	NOTIFY	the following external agencies: a. Fire Department b. Police c. EMS
3	PLACE	Ventilation Zone 7WB 2 in Response Plan Control
4	DISPATCH	Emergency Response Team 6
5	NOTIFY	the following external agencies: a. Regional OCC b. Radio Station
6	MONITOR	Fire Department Hot-line
	until	Incident is Terminated
7	MONITOR	Communications with Emergency Response Team
	until	Incident is Terminated
8	CHANGE	Traffic System Components to direct traffic flow
9	CONFIRM	Incident Status Information is correct
10	WHEN	All Termination Criteria is met
	TERMINATE	Emergency Task

Figure B3.1: Vehicle Collision with Fire on Tunnel Roadway (Top Level)

1 MONITOR Location THT WB via C 205 SE
until Incident is Terminated

- **[1.1] VIEW** C 205 SE on Workstation Screen
  - **(1.1.1) SELECT** "CCVE" from the "Window" Menu
  - **(1.1.2) SELECT** C 205 SE from the Menu
- **[1.2] MONITOR** Location THT WB for Incident Status

2 NOTIFY the following external agencies:
a. Fire Department
b. Police
c. EMS

- **[2.1] SELECT** "Boston Fire Dept." from "Hot-Lines" Menu
  or
  DEPRESS F6 key on keyboard
- **[2.2] SELECT** "Boston Police Dept." from "Hot-Lines" Menu
  or
  DEPRESS F7 key on keyboard
- **[2.3] SELECT** "Medical Team" from "Hot-Lines" Menu
  or
  DEPRESS F9 key on keyboard
- **[2.4] IF** External Agency requires Response Plan control
  THEN
  UPDATE Incident Status Information
  and
  MODIFY Response Plan

Figure B3.2: Vehicle Collision with Fire on Tunnel Roadway (Lowest, Most Detailed Level)

3 PLACE Ventilation Zone 7WB 2 in Response Plan Control

- **[3.1] OPEN** Ventilation Zone 7WB-2 Step Control Screens
  - **(3.1.1) SELECT** "Ventilation" from "Window" Menu
  - **(3.1.2) SELECT** Zone 7 WB-2 from Screen
- **[3.2] PLACE** Ventilation Zone 7 WB-2 in Response Plan Control
  - **(3.2.1) SELECT** Response Plan Control from Screen

4 DISPATCH Emergency Response Team 6

- **[3.1] NOTIFY** Emergency Response Team 6 via Telephone
- **[3.2] VERIFY** Emergency Response Team 6 Has been dispatched

5 NOTIFY the following external agencies:

a. Regional OCC

b. Radio Station

- **[4.1] SELECT** "Other Hot-Lines" from "Hot-Lines" Menu **and SELECT** "Regional OCC"
- **[4.2] SELECT** "Other Hot-Lines" from "Hot-Lines" Menu **and SELECT** "Radio Stations"

6 **MONITOR** Fire Department Hot-line

until Incident is Terminated

7 **MONITOR** Communications with Emergency Response Team

until Incident is Terminated

8 **CHANGE** Traffic System Components to direct traffic flow

[8.1] **CHANGE** All (LUS) in [Left] lane [900] feet downstream of reference LUS [476 WB]

[8.2] **CHANGE** All (VMS) between Location [THT WB3] and Emergency Response Station [6] to [Left Lane-Emergency Vehicle Use Only]

[8.3] **CHANGE** All (VSLS) [900] feet downstream of Location [THT WB3] to [Prepare to Merge]

[8.4] **BROADCAST** (HAR) Message # [17 "Lane Collision"]

9 **CONFIRM** Incident Status Information is correct

[9.1] **IF** Incident Status Information is correct

THEN GO TO Step [8]

[9.2] **IF** Incident Status Information is NOT correct

THEN
SELECT (Update) button

and
CHANGE Necessary Information

10 **WHEN** All Termination Criteria is met

TERMINATE Emergency Task

[10.1] IF The following criteria have been met

a. Vehicle has been cleared from roadway

b. Emergency Response Team cleared

c. External Agencies cleared of roadway

d. Traffic Flow returned to acceptable level

e. Environment has returned to safe level

THEN
TERMINATE Vehicle Collision Emergency Task

(10.1.1) SELECT **Terminate** button

[10.2] IF Criteria of [8.1] has NOT been met

THEN Step **1** RETURN TO

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