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CATALOG OF FUNCTIONS FOR COMPUTER-BASED TRAFFIC SIGNAL SYSTEMS

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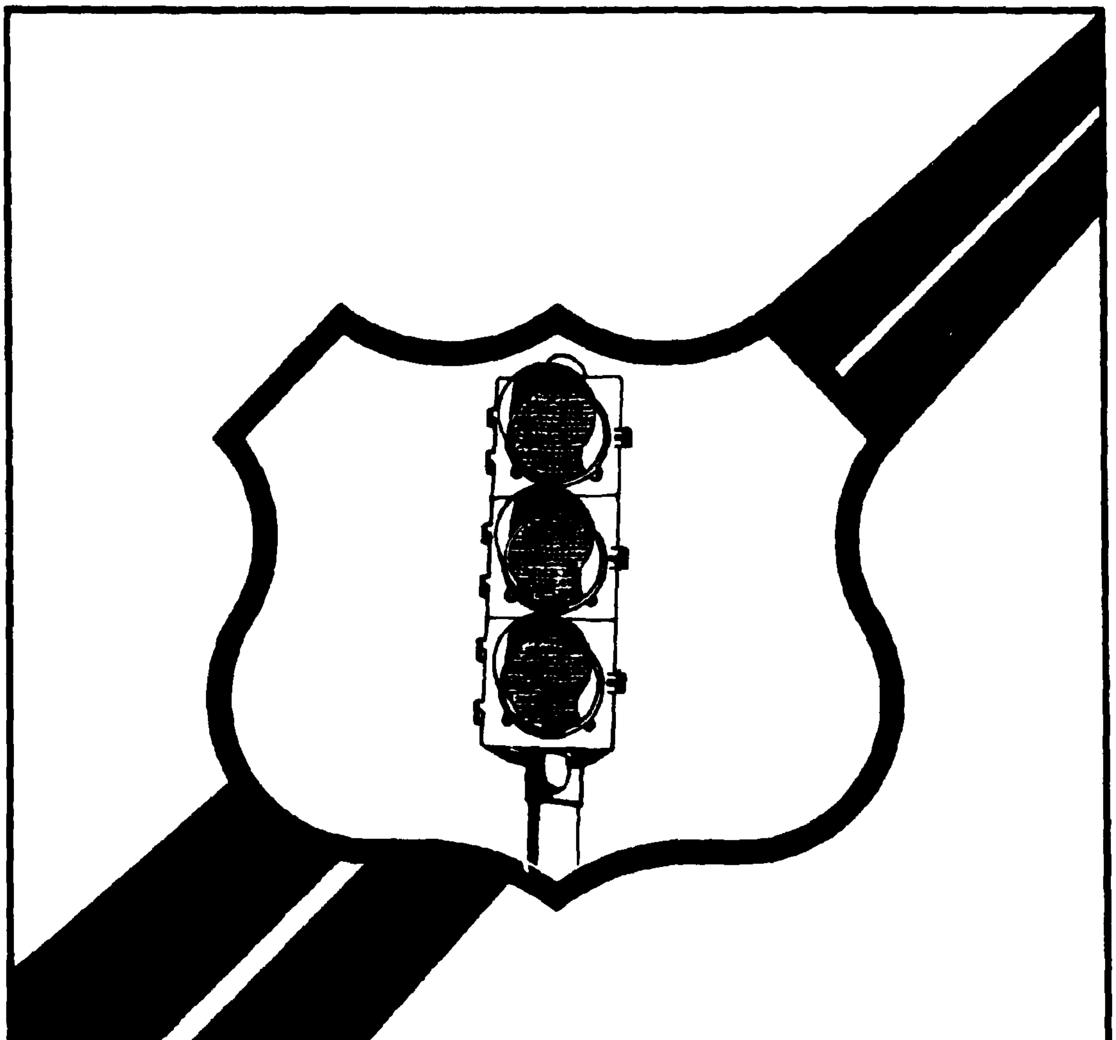

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16. Abstract

The catalog of functions includes a description of a "Basic" computer-based traffic signal system, plus a listing and description of options which can be added. Standardization of the functional requirements of the Basic system, and of the functional requirements for additional features (options), will assist planners and users in the functional design of their systems, as well as assist designers in the design of hardware and software components and modules. Standardization of performance functions, as well as compatibility of equipment that implements these functions, is a major consideration.

The catalog of functions contains:

1. A description of the Basic system, plus options
2. Traffic performance, utility considerations, and cost factors associated with each option
3. A cross-reference between the catalog of functions and the functional specifications

Functional specifications describe what functions are to be performed, parameters to be measured and/or displayed, and inputs and outputs associated with each function. The functional specifications do not define how each function is to be specifically translated into hardware or software elements.

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FOREWORD

This report provides a catalog of functions that are available in computer-controlled traffic signal systems. The functions include a complete selection of both hardware and software features. Each function is described and its advantages and disadvantages are summarized. Capital cost, maintenance, and traffic performance considerations are included. The report is organized around a "Basic" signal system with options that can be added according to specific situations and budgets.

Sufficient copies of this report are being distributed by FHWA Bulletin to provide two copies to each FHWA Region office, one copy to each Division office, and two copies to each State highway agency. Direct distribution is being made to the Division offices.

Lyle Saxton for
Stanley R. Byington, Director
Office of Safety and Traffic Operations R&D

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ORGANIZATION OF REPORT

This Catalog of Functions for Computer-Based Traffic Signal Systems is based on the principle that all signal systems contain a basic set of functions plus various options. The basic functions are necessary in all signal systems, but the optional functional modules are required only if the functions they provide are to be included in the specific control system.

Traffic control functions may be distributed to area computers or may be exercised by a single central computer (a "centralized" control system). Cost and reliability may be affected by the choice of distributed or central control, but the functions of a traffic control system can be considered independently of how the intelligence is distributed. Note, however, that the control distribution may affect how any given function is actually implemented.

There are two principal parts to this report: (A) Catalog of Functions, and (B) Specifications. Part A, defines a "Basic System" in terms of those functional modules which are normally required in all traffic control systems. Part A also contains other general introductory remarks such as definitions and examples.

Part B contains descriptions of all functions which might reasonably be included in a traffic signal system. Each description is given as a "functional module" which describes the function and its general characteristics, the input required for the function, and the output from the module. A short description of how the function works is included. A discussion of how the functional module interacts with centralized control system and with two or three level distributed systems is also included.

This report will be of interest to all persons concerned with computerized traffic control; in particular, system designers will want to study it before drawing up bid specifications. This report is the essential document for determining how various functions interact with one another and with the degree of system decentralization.

PART A: CATALOG OF FUNCTIONS

CHAPTER 1

SYSTEM FUNCTIONAL SPECIFICATIONS

1.1 DEFINITIONS

Baud: The maximum rate of transmission of signal elements, referred to the shortest signal element used.

Coordination: A definite timing relationship between traffic signals.

Digital Timing: The technique of adding relatively small and accurate segments of time to total the desired time period.

Downloading: Transmission of data from a higher level system element to a lower level system element.

Interconnect: A means of remotely controlling some or all of the functions of a traffic signal.

Local Control Unit: A microprocessor based system element that can control the operation of several local intersection controllers. Sometimes referred to as a Local Master.

Local Intersection Controller: The unit that controls the operation of traffic signals at an individual intersection, consisting of a controller unit, and all auxiliary equipment.

Measures of Effectiveness (MOE): Calculations based on information supplied by system sensors. Included are the number of stops made by vehicles approaching each instrumented intersection, average delay experienced by vehicles within each system section, average speed of vehicles over each sensor, and volume and occupancy at each sensor.

Offset: The percentage of the time cycle that the beginning of the major street green interval on a controller differs from a certain instant used as a time reference base.

Phase: A traffic movement or movements receiving simultaneous right-of-way during one or more intervals.

RAM: Originally defined as Random Access Memory, now defined as Read and Alter Memory to more properly refer to its property to quickly store and recall digital contents.

Section: A group of signalized intersections which are interconnected and have some time relationship between them.

Sequence: The order of appearance of signal indications during successive intervals of the time cycle.

Split: The percent of a time cycle allocated to a particular traffic phase.

System Sensors: Vehicle detectors placed within the controlled roadway for the measurement of free-flow traffic. Data can be returned to a central computer, a local control unit, or to an appropriately instrumented local intersection controller for MOE evaluation and traffic responsive control.

Timing Parameters: Cycle length, split, and offset.

Timing Plan: A selected set of timing parameters.

TOD/DOY: Time-of-Day/Day-of-Year criteria for selection of signal timing plans.

1.2 INTRODUCTION

Traffic control system users have differing requirements that are not necessarily related to the number of intersections that the system controls. Some small jurisdictions may have more available resources and technical sophistication than large jurisdictions; some small jurisdictions may need more complex systems because of complex jurisdictional problems within the area (for example, two or more maintaining agencies); and, finally some small jurisdictions may be more willing to accept a more sophisticated approach than a larger jurisdiction.

While system sizes may range from very few intersections to as many as several thousand intersections, the number of intersections has little, or no, relationship to the sophistication of the system. Also, in configuring distributed multilevel control systems, where functions are assigned away from central to intermediate and local levels, the number of levels of control which can be practically assigned has little relationship to the sophistication of the system.

Three types of major system types are considered: centralized, two-level distributed, and three-level distributed systems.

In the centralized system, all forms of command, monitor, display, and control are resident within the central subsystem. This implies that a highly reliable communications system be implemented in order to permit second-by-second control and monitoring of the intersection controllers and detectors. Each controller must receive its command signals at least once per second and must return its status monitor signals back to the central computer at the same rate in order to determine the reliability of control.

The amount of data transfer required limits the number of intersections which can be assigned to a communications channel, and is therefore an important factor in the cost of the communications cabling, either leased or owned.

In a two-level distributed system, the command, monitor, display, and control functions are distributed between the central subsystem and intelligent programmable local intersection controllers, or programmable local control units and intelligent programmable local intersection controllers. This may mean that the communications requirements are somewhat reduced as long as full advantage is taken of the self contained control and monitor capabilities of the second level system elements. Since timing plans, event scheduling tables and the like may be "downloaded" to the second level of intelligence, and accumulated monitor data (controller status and detector data) "uploaded" periodically to the central subsystem some savings in communications cost may be realized. The communications requirements are reduced and, therefore, communications subsystem costs reduced only if the number of bits per unit of time is reduced. In other words, if 1000 bits per second are transferred to and from the central computer under second-by-second control and 600,000 bits per ten minutes are required to be transferred under "downloading, uploading" techniques, then the rates are equal and the communications cost savings will be nil.

In a three-level distributed system, the command, monitor, control, and display functions are distributed among three programmable, intelligent units. The central subsystem would have the primary control and display responsibilities and be the repository for all timing and signal plans and all event scheduling. Each local control unit would contain all of the timing and signal plan as well as event scheduling information for the group of intersections under its control as updated by the central subsystem. Each local intersection controller would contain its particular set of timing and signal plans as well as the event scheduler as updated by the local control unit. Periodically, control data would be downloaded to the local control unit and monitor data uploaded to the central subsystem. Likewise, similar data transfer between the local control unit and the programmable, intelligent local intersection controller would take place. Generally, command data (timing or signal plan data, or event scheduling data) need only be transferred between subsystems when changes are made. Monitor data (equipment status and detector data) should be made at more frequent intervals, but five or ten minute detector data accumulations and equipment status data reported "up the line" only to report abnormal conditions may be reasonable in order to reduce the communications load.

It must be remembered that the only way to reduce the overall communications subsystem cost is to reduce the amount of data transferred per unit of time. Even in the highest level of distributed system, if the requirement exists for monitor data to be returned to central for reporting or display purposes on a near real-time basis, then the supposed communications cost advantages of a distributed system are negated.

The functional specifications which follow are not intended to describe any specific existing or planned systems. Further, they do not describe any system which is available from any particular vendor. Rather, it is intended that the user will determine the features described herein which will be beneficial in his system and use these specifications as a guide in preparing formal system specifications.

1.3 FUNCTIONAL SPECIFICATIONS

1.3.1 Basic System

For the purposes of this report, the Basic System is defined as one which provides:

- o Coordination of traffic signals
- o Monitoring of the intersection controllers to insure proper operation
- o Central control of timing plan data entry and modification
- o Unattended operation
- o Failure reporting capability
- o User friendly operator interface at two levels
  - Detailed menu-driven data entry via CRT
  - Menu override capability for experienced operators
- o Monitoring of system elements
  - On-site local control unit
  - System sensors
  - Communications

1.3.2 Optional Features

Options available for inclusion into any system include:

- o Detector data accumulation
- o Traffic responsive operation
- o Determination of Measures of Effectiveness
- o Expanded detection malfunction capability
- o Display capabilities (maps or graphic displays)
- o Preemption detection and recovery
- o Critical Intersection Control
- o Remote terminals
- o Portable terminals
- o Operator interface via control console
- o Flow trend prediction
- o Emergency vehicle detection
- o Database generation
- o Expanded detector processing and error-checking
- o Special Functions
- o Section locking
- o Uninterruptible power source
- o Timing plan development (PASSER, TRANSYT-7F, etc.)
- o Data downloading to local on command from field site
- o Data uploading to central from local intersection

1.3.3 System Configuration Requirements

In order for the prospective vendor to supply a system to suit the particular requirements, certain items must be known. The following lists items which must be specified for a basic system.

- o Number of pretimed controllers
- o Number of actuated controllers

- Number of system traffic control sections
- Number of timing plans per section
- Number of detectors at each intersection
- Method of control for pretimed controllers - interval advance or phase advance (dial supervision of electromechanical controllers)
- Will free operation be the desired mode of operation for actuated controllers when off-line?
- Number of controllers requiring more than one signal plan and number of signal plans required by these controllers
- Types of preemption (emergency vehicle, railroad, etc.)
- Number of intersections to have Critical Intersection Control imposed
- Type of interconnect

1.4 PLANNING CONSIDERATIONS

Several items must be quantified by the prospective system owner in the initial planning period. These are:

- Initial system requirements
- System expansion requirements
- Time periods for each incremental expansion

These can be described through the use of examples:

Example 1: Limited Expansion of Initial System

The most fundamental version of the Basic system may be specified with no plans to expand the system beyond adding a number of intersections to the system over a ten year period. In this situation the total number of intersections to be placed under computer control will never exceed the upper limit of the system's capacity, and the sophistication of the control strategy will not be increased.

This approach insures the lowest hardware and software costs, although not necessarily the lowest construction costs. The computer and communications hardware are minimized since drastic system expansion capabilities need not be incorporated into the initial design.

The software costs are minimal since only database updates are required to add intersections for the expected life of the system.

The construction costs may not be affected to any appreciable degree, especially if user-owned communications cable is to be installed, since wire installation is labor intensive and costs are therefore relatively independent of the size of the cable.

Example 2: Expansion of Initial System

If the fundamental Basic system is specified for initial installation but it is expected that the capability to accumulate detector data will be added within five years and traffic responsive control will be added within seven years. The total number of intersections to be brought under computer control will not exceed the upper limit of the specified system's capacity.

The capability of the ultimate system must be provided for in the initial system specifications, either as guaranteed modular expansion or as a part of the initial system purchase. The communication subsystem should be specified to be capable of handling all expected communications requirements in order to avoid the need to replace part or all of the initial subsystem or to add a second communications subsystem.

The software initially provided should contain all control algorithms and database requirements desired for the expanded system and should be fully tested before system acceptance in order to avoid costly reprogramming later.

These initially unused algorithms and database elements may be deactivated until needed. Adequate documentation must be supplied to permit activation without supplier intervention.

With this approach, construction costs may be delayed until required to implement the optional features, but extensive and expensive core system modifications are avoided.

Example 3: Expansion of the Initial System to a Higher Level of System Complexity

In this example the fundamental Basic system attributes are desired to initially control the intersections, but the desired final system capabilities extend into the domain defined by a more complex system.

If the time period in which system expansion is estimated to take place is less than five years, consideration of the Basic system for initial implementation is unwise. Again, the core computer and communications subsystems should be configured to allow for the ultimate expansion.

CHAPTER 2

PERFORMANCE CHARACTERISTICS

2.1 INTRODUCTION

In this section traffic performance characteristics are examined. Also, for each option available for all system configurations, expected utilities and associated cost factors are examined, including maintenance, operation, and construction considerations.

2.2 TRAFFIC SYSTEM PERFORMANCE

2.2.1 Basic System

While traffic performance is not a direct function of the type of signal system, it is nevertheless a function of the timing plan which is currently being imposed on the street. Studies have shown that large improvements in traffic performance are achieved in going from noncoordinated to coordinated operation, and larger improvements achieved in going from noncoordinated to computer-based operation.

A standard feature of the Basic system is the control of local intersections from a small mini or microcomputer using stored timing plans which are selected according to time-of-day, day-of-week, and week-of-year. Traffic performance is highly dependent on the quality of the timing plans. Thus, a major responsibility of the maintaining agency is to modify timing plans to reflect traffic pattern changes in its locality. Timing plans are installed and updated off-line. Temporary fine-tuning changes can be made to a number of intersections with the system on-line; however, timing plan changes which are to become permanent are made during database updates.

Traffic performance is also increased when provisions are made for malfunction detection and diagnosis capability. This capability is a standard feature of the Basic system. Malfunction detection and diagnosis and automatic status logging minimizes the time-to-repair of local hardware.

The Basic system is intended to operate 24 hours per day, unattended, with operator attention required only periodically. Operator intervention is limited to modifying timing plans, responding to malfunction alarms or indicators, and manually "fine-tuning" current timing plans.

Operator interface occurs at two levels: first, a detailed CRT menu-driven data entry process; and second, a menu-override capability for experienced operators.

User-friendliness is a major feature of the Basic system. Meaningful system-generated prompting messages allow for uncomplicated operator interface. Off-line suppo - software assists the traffic engineer in identifying the need for, and implementing, new timing plans. CRT displays and hardcopy reports monitor and record system operation. Carefully prepared documentation should provide the user step-by-step examples and procedures for system operation and maintenance.

System performance is also increased by expanded maintainability. This is achieved by system self-diagnostic capability, system modularity, utilizing fewer printed circuit boards and more plug connected equipment, minimization of preventative maintenance activities, inclusion of self-training courses, and use of standardized schematic and flow chart documentation symbols.

A major design feature of the Basic system is a provision for expandability. The system must be expandable in order to allow addition of a greater number of intersections and to allow incorporation of a larger number of features.

2.2.2 Optional Features

Features not included in the Basic system, but which should be available as options are:

Detector Data Accumulation

Detector data, in the form of volume and occupancy values for each detector instrumented, are used for Measures of Effectiveness (MOE) calculations, traffic responsive control, and for inputs to timing plan development programs. The system software error checking routines determine the acceptability of the input data by comparison with threshold values for high or low volume counts, low-occupancy values or by comparison with historical data. In order to remove short-term fluctuations from incorrectly influencing such operations as traffic responsive control or critical intersection control, detector data smoothing techniques are employed. Current volume and occupancy time period counts may be reduced by a system wide weighting factor and algebraically added to the prior count to effect the smoothing.

Traffic Responsive Operation

Because the value of the traffic responsive feature of any system varies from jurisdiction to jurisdiction, and also because, when activated, it is not always fully utilized, it is not provided as a standard Basic system feature, but is available as an option. This option will provide for processing data from system sensors and then matching stored timing plans with identified traffic patterns.

Measures of Effectiveness

Similarly, the value of a measures of effectiveness feature varies with using agencies, and when implemented, is often not fully utilized. However, this feature is normally available as an option of the Basic system.

Additional Malfunction Detection Capability

Although local controller and communications malfunction detection is provided as a standard Basic system feature, detector malfunction detection and processing is optional. It may be included, however, as part of the optional traffic responsive module.

Display Capabilities

Display maps are not a standard feature of the Basic system. However, three display options are provided: one is the traditional, large display map (wall-mounted or free standing); second, is the TV projection display; and third, the colorgraphic CRT display. Colorgraphic displays are less expensive and have supplanted maps in new systems.

Storage and Implementation of Signal Plans

Installation of microprocessor controllers at the local intersection level has made it possible for the user to change not only the timing plan (by manual, time-of-day, or traffic responsive methods) but also the local signal plan (phase sequence). (Previously, phases could be lengthened, shortened, or skipped; current microprocessor capabilities, however, allow the order of the phase sequence to be changed.) Various signal plans may now be stored and implemented locally.

Preemption Capability

A major option is preemption capability. Features may be added for fire, police, railroad, and bridge preemption events.

Critical Intersection Control

Critical Intersection Control (CIC) is imposed on certain intersections with variable demands on intersecting approaches. Most commonly used algorithms adjust the signal split at the CIC location according to traffic volumes on each approach to the intersection, while still maintaining the same cycle length as adjacent intersections in the section.

Remote Terminal Interface

The capability to add remote terminals (CRTs and/or keyboard/printers) will be provided as an optional feature. Remote terminals can be installed at other traffic engineering offices for system analysis and monitoring, or at signal maintenance shops for use by maintenance personnel.

Control Console

The Basic system's primary operator interface is via the system CRT. Optionally, an operator console may be added to enable the operator to perform all required traffic control system functions, generate reports, control the map, etc.

Flow Trend Prediction

Optional software modules will enable the traffic engineer to process stored detector data for traffic pattern analysis, traffic plan development, 24 hour, weekly or monthly traffic counts, etc.

Emergency Vehicle Detection

Capability for adding emergency vehicle detection is included as an option. This feature will enable the system operator to track emergency vehicles and/or implement emergency vehicle routing through use of special timing plans or preemption.

Database Generator

Optional database features will include on-line database changes and on-line timing plan modifications.

Increased Detector Processing

A more advanced surveillance capability will include as options: determination of individual vehicle speeds and detection of emergency and transit vehicles.

Special Functions

This optional system feature provides for issuing special function signals to the intersection controllers. These signals can be used for phase skipping, flash operation, controller test command, maximum timer selection, actuation of variable message signs, etc.

Section Locking

This feature permits coordination between adjacent control sections by imposing the same cycle length on each selected section.

Uninterruptible Power Source

This optional feature insures a continuous supply of power to the central system equipment during periods of primary power loss.

2.3 UTILITY CHARACTERISTICS AND COST FACTORS

The following identifies expected utilities and associated cost factors when adding optional features in order to increase the level of system sophistication.

Appended to each function title which follows is the Functional Module (FM) number or numbers which apply to these Basic system optional features. The Functional Modules along with a description of their composition and use are located in Part B: "Specifications".

Store and Implement Several Different Signal Plans - FM 2.3

With the advent of microprocessor controllers it has become possible to change not only the timing plan at the intersection on a manual, time-of-day or traffic responsive basis, but now also the signal plan, or phase sequence.

This capability can be very useful. For example, it may be desirable to change the order in which left turn phases appear to improve progression in one direction along a street during a certain time of the day. At a three phase intersection it may be desirable to reverse the order of two of the phases during certain times. Many times an improvement in progression can be realized that would have been impossible when it was necessary to choose between one sequence or the other for all time periods.

The capability to change phase sequence did not exist with electromechanical controllers but is designed into the software of many microprocessor controllers. Therefore when microprocessors are used in the system, the capability may already exist in the controller. Additional manpower is required to program the equipment to utilize this feature and, because more timing plans will be used during the day, additional manpower will be required to develop them.

Store Many Different Timing Plans - FM 2.1, 2.3

System architecture will determine where in the system timing plans will be stored. In centralized systems timing plans are stored in the central computer's memory or on disc. In two level systems with slave controllers plans are stored with the area master.

In two level and three level systems with intelligent local intersection controllers, timing plans are downloaded from central, or the local control units, into RAM at each intersection. In this case there is storage at two or three levels; long term in the central computer and/or local control unit and short term at the intersection.

Compute Timing Plans On-Line - FM 2.4.1.1

First generation systems use a table look-up technique to match existing traffic patterns with prestored patterns to select the best timing plan. Second generation techniques compute timing plans on-line.

One and one-half generation systems compute timing plans in the background while the system is on-line and controlling traffic with one of the previously stored plans. Current traffic data, as supplied by the system sensors, is used in the design of the plan and, when complete, is stored on disc. MOE's for the new plan, using the current traffic conditions, are compared with the MOE's for the plan actually in control. If there is an improvement, the operator can place the new plan on-line the next day.

Additional costs associated with computing timing plans on-line using the one and one-half generation approach are:

1. Cost of purchasing and installing many additional detectors (up to one per lane per approach, plus detectors on selected left turn bays).

2. Cost of purchasing additional computer hardware (e.g. memory, larger discs etc.) and software

3. Cost of maintenance associated with additional hardware and detectors

Fallback Operation - FM 1.5

Various types of fallback operation can be achieved:

1. Minimal

   a. With electromechanical pretimed controllers -- a second dial with a standby timing plan takes over command of the intersection when communications is lost.

   b. With solid state pretimed controllers -- the intersection operates as an isolated pretimed intersection when communications is lost.

   c. With actuated controllers -- The intersection operates as an actuated noncoordinated intersection when communications is lost.

2. Medium

   a. Pretimed controller (electromechanical or solid state) -- time-based coordinators, or interconnection, is provided at each intersection to maintain synchronization in the event that communications is lost. Several dials may be provided with timing plans for various times of day.

b. Actuated controller -- an auxiliary timing device (which could be a time based coordinator) is provided to maintain coordination. It may also include several standby timing plans.

3. Redundant central control -- a redundant computer or standby master is provided.

Time-based coordinators are now available which can be used as backup systems. One unit is located in each controller cabinet or programmed within the controller. This will provide the equivalent of a multi-dial, multi-offset backup system.

Large systems often have a second computer to take over when the main computer is off-line. This second computer may not be as large as the main computer and will therefore provide a degraded level of traffic service and operator interface capability. Also the display map may not be available to the operator during this time, as well as other noncritical functions.

When the backup computer is not controlling the system it can be used to develop new timing plans or for any other off-line application.

The cost of providing a backup timing system can range from relatively inexpensive to very costly, depending upon the complexity of the system.

Critical Intersection Control (CIC) - FM 2.5

It is desirable to apportion green times at critical intersections where major intersecting roadways each have variable traffic demands.

Most software algorithms adjust the signal split at the CIC controlled intersection according to traffic volumes on each approach while still maintaining the same cycle length as the other intersections in the section. Coordination is therefore maintained with adjacent intersections. This may somewhat degrade true responsive control, wherein the length of the green is determined solely by the ratio of the volumes on the various approaches. On the other hand, if coordination were not maintained, serious traffic problems could result.

Instrumenting an intersection for CIC control requires detectors be placed on all approaches to the intersection, additional communications equipment to send the detector data back to central, and more complex software.

Constants must also be selected to determine the volume and/or occupancy level at which CIC control will be instituted at the intersection as well as other weighting and smoothing factors to be used during CIC operation. These factors are usually selected by intuition and trial and error in trying to find a combination which will be most effective. This can be a very time consuming process which may, or may not, prove to be successful or worthwhile.

Detector Data Accumulation and Processing - FM 3.1, 3.2

For systems with detectors the detector data must be collected, processed in some form, and handled and stored by the computer. Preprocessing some data in the field before it reaches the computer can be cost effective. Final processing must be done at the central site or local control unit location.

Detector data are final-processed in the computer for use in calculating measurement of effectiveness parameters and for developing reports on short term traffic flow trends, daily operational reports, etc.

During final processing, volume, occupancy, and speed data will be averaged over specified time periods. Some of the data will be weighted and smoothed for use in the traffic responsive mode of operation, to update historical data lists, etc.

Traffic Responsive Timing Plan Selection - FM 2.3.3

The capability to select timing plans in traffic responsive mode of operation requires that: software becomes more complex; detectors and communications equipment must be installed in the street to send traffic data to central or the local control unit; and operating parameters -- detector weighting constants and smoothing factors -- must be selected and placed in the data base. Selection of these parameters, system calibration, and system evaluation are time consuming tasks. Additional funds for maintenance of the many additional detectors must also be provided.

It has been observed that even these systems which have traffic responsive operation are not routinely operated in this mode. Either the maintaining agency does not have the time to select operating parameters and evaluate their effectiveness, or an insufficient number of detectors are in proper operating condition, as required by the system.

Cost factors associated with traffic responsive operation and storage of selection parameters include:

1. Additional cost of purchase and installation of system detectors

2. Additional central hardware and software

3. Engineering costs associated with system calibration, and selection of weighting constants and smoothing factors

Section Locking - FM 2.3.3.1

When operating in the traffic responsive mode, it may prove advantages to implement "section locking" for adjacent traffic control sections (or groups of intersections operating under the same cycle length) when those sections are operating close to the same cycle length (determined by previously established threshold limits). Those adjacent sections for which cycle-locking is permitted will then operate under a common cycle length, insuring a smoother traffic flow across section boundaries.

Cost factors for implementation of section locking involve relatively minor software additions. These are:

1. Inclusion of a database array relating specific sections to cycle-locking (yes or no), and specific thresholds for cycle length comparisons with adjacent sections.

2. Software logic to compare cycle lengths and cycle-locking thresholds, and logic to implement section locking.

Storage of Detector Data - FM 3.1

Storage of detector data is required in systems which have the ability to operate in the traffic responsive mode and in systems where storage of traffic data is required for studies involving short term and long term traffic trends.

For traffic responsive operation it is necessary to maintain historical record files for each detector. This information is continually updated when the associated detector is functioning properly and is stored for use as backup information when the system is to operate traffic responsively but the particular detector has malfunctioned and cannot provide valid data on current traffic conditions.

Cost factors associated with storing detector data include the extra memory required, tape or disk equipment for long term storage and additional hardware and software requirements.

Determine Vehicle Volume/Occupancy - FM 3.1, 3.3

The capability to determine volume and occupancy at the site of each system detector is necessary for traffic responsive operation and for traffic studies. It is also necessary in systems where these parameters are to be used in reports and in calculating measures of effectiveness.

Volume and occupancy are the two parameters most frequently used to determine the effectiveness of timing plans which are in service. Without this information the operator has no method of determining how well a particular timing plan is responding to traffic requirements except to manually monitor the operation in the field.

Cost factors associated with determining volume and occupancy include:

1. Cost to purchase and install detectors

2. Cost of additional central hardware and software

3. Cost of detector maintenance

<u>Measures of Effectiveness</u> - <u>FM 3.4</u>

Determining measures of effectiveness requires direct measurements of volume and occupancy from each system sensor and calculation of delay, speed, number of stops, spacial averages, fuel consumption, and other parameters. This data is useful for evaluation of system performance, developing cost/benefit information, and identifying areas requiring particular attention by timing engineers.

The information is used in preparation of many of the reports produced by the system and can also be included in the End-of-Day report, if desired, and filed for future reference.

Cost factors associated with calculating measures of effectiveness include:

1. Cost to purchase and install system detectors

2. Additional hardware and software

3. Cost of detector maintenance

<u>Predict Short-Term Traffic Trends</u> - <u>FM 3.5</u>

Short term traffic trends can be predicted through an analysis of detector data over a time period of several weeks or months. This information can be used to predict imminent traffic conditions for purposes of selecting a timing plan. It can also be used to review volume counts from a previous special event, to estimate the traffic for a similar upcoming special event.

Short term traffic trends are also useful in estimating seasonal variations in traffic flow. This will allow the system operator to be more responsive to the additional traffic associated with the Christmas season, for example.

If the system already has detectors there is no real cost involved with predicting short term traffic trends except for the manpower required to analyze the information which will be available and the cost of implementing changes that are developed as a result of the analysis.

<u>Preemption</u> - <u>FM 2.2</u>

Signal preemption for purposes of railroad and bridge activities and emergency vehicle (police, fire, ambulance) routes increase safety for the public as well as for personnel responding to emergencies. Post-preemption recovery timing plans are introduced on the street to return traffic flow to normal as quickly as possible.

The additional cost factors associated with preemption are:

1. Special identification equipment mounted on the emergency vehicle or special equipment located at the bridge, rail crossing site or fire station
2. Possible preemption equipment located in the controller cabinet
3. Possible customization of local and central software and local hardware
4. Additional communications equipment
5. Additional central hardware and software
6. Development of preemption patterns and preemption recovery patterns
7. Additional equipment maintenance

<u>Storage of Special Event Plans</u> - <u>FM 2.1</u>

Storage of timing plans for special events is a low-cost and effective option. In its simplest form, it means only that several special-purpose timing plans have been created to accommodate traffic arriving at and leaving special events such as sports activities, activities at convention centers, and recreation areas, etc.

These special plans can be placed into operation manually by the system operator, scheduled automatically via the system, or can be triggered at the site of the special event.

The cost of storing and implementing special event patterns is relatively minor. The patterns are merely added to the system database and implemented on a manual or time-of-day basis. There are, of course, the engineering costs associated with pattern development and evaluation.

Determine Individual Vehicle Speeds - FM 3.6

Individual vehicle speeds can be determined by locating two detectors longitudinally in a traffic lane spaced four to six feet apart. Speed is calculated using detector spacing and the time difference between detection at the two detectors.

A second and more commonly used method is to calculate speed based upon an assumed vehicle length and the length of time that a vehicle occupies a single zone of detection. This method requires only one detector. However, since the calculation is based on an assumed vehicle length, it is not accurate. With this method the data are usually averaged over a number of vehicles to obtain average speed within the zone of detection during a certain period of time.

The two detector method is naturally more costly to implement and maintain. The accuracy of the speed information which is provided is not necessary for purposes of evaluating system or timing plan performance. Therefore, most systems use the single detector method. Average vehicle speed is sufficient when used with other measures of effectiveness such as volume, occupancy, number of stops, etc.

Additional cost when two detectors are used to determine individual vehicle speed includes:

1. Cost of the additional detectors

2. Cost of additional communications equipment

3. Cost of additional maintenance

Detect Emergency and Transit Vehicles - FM 3.7

Emergency vehicles are detected by radio or optical signals which are emitted from units mounted on the emergency vehicles themselves. The signals are received by sensors mounted near the controller cabinets. Preemption equipment located in the controller cabinet is activated to take control of the signals, or a signal can be sent to the computer to initiate preemption.

Transit vehicles can be detected using radio or optical methods, or with transponders or passive detectors mounted on the transit vehicle. The signal is received by an antenna buried in the roadway. A vehicle identification number is included in the transponder message so that each vehicle can be uniquely identified. It can then be determined if the vehicle is operating on schedule.

Vehicle identification may be required for bus scheduling systems and bus priority systems. A bus priority system, for example, may give signal priority to a bus which is behind schedule but not to one which is on schedule.

The cost per vehicle for emergency vehicle and transit vehicle detection include:

1. Equipment Cost

2. Additional central hardware and software

3. Additional equipment maintenance

Display and Reporting Subsystems - FM 4.1, 4.3, 5.2, 5.4

Display maps (either wall-mounted or free-standing), TV projection systems and colorgraphic CRT's are effective public relations devices, and may also be useful tools for the system operator. They provide a "snapshot" of what is happening in the system at any particular moment. They also can provide the first indication to the operator of trouble which has developed.

Wall maps are difficult to change as the system grows and intersections are added to the system or unforeseen roadway changes take place. Sometimes jurisdictional boundary changes occur which require extensive modifications to the artwork. Nonetheless, wall map displays have been used in the past for many large systems and have proven to be a very valuable tool to the system operator.

Projection type display maps are coming into use. There has been little experience using them in traffic control systems. Their future should be promising, however, and they have many advantages over the larger, more bulky, wall-type map.

Color graphic CRT's are becoming a popular and effective tool. The system operator can cause the geometrics of any intersection in the system to be reproduced, in color, on the screen. The current signal display, sensors, and display changes can be seen as they occur and current traffic volumes can be shown for that particular intersection along with any other group of parameters which may be desired.

Projection TV systems are currently the costliest display systems to implement, followed by the wall-mounted or free-standing units and color CRT's. Aside from the actual hardware, both TV projection and colorgraphics systems have associated software costs. In addition, memory requirements in the host computer are much greater for the TV projection and colorgraphics systems.

Printed reports and CRT status displays are a vital element in the analysis of system performance. Failure alarms, displays and reports provide maintenance personnel with the capability to react more quickly to field hardware malfunctions and then minimize component down-time. Measures of effectiveness reports provide an analysis of data collected over a period of time. System status reports and displays provide the traffic engineer with the system's current operational status. Summary reports present historical records of system operations. Database reports list actual database entries of all traffic control parameters.

Cost factors for the CRT displays and reporting subsystems include cost of the hardware and software required to generate displays and reports.

Remote Terminals - FM 5.1.3

Terminals installed at sites other than the central control room can add to the system's utility. These terminals are either CRTs or keyboard/printers and may be installed at maintenance shops for use by maintenance personnel, or at other traffic engineering offices for analysis and monitoring of system performance.

Costs associated with installation of remote terminals are:

1. Cost of terminal

2. Computer hardware -- Enough I/O multiplexor ports must be available to allow interconnection between the remote site terminal and processor. The addition of one or two ports is usually a relatively small cost compared to overall computer hardware costs.

3. Communications media -- For a remote site (i.e. another building, another part of the city, etc.) two modems will be required per terminal, as well as a leased or dial-up telephone line per terminal. If the "remote" site is as close as the office next to the processor, a long cable between the processor I/O port and the terminal may suffice.

Traffic Control Console - FM 5.1.2

The Basic system's primary operator interface is via the system CRT. Optionally, an operator's console may be incorporated into the system to enable the operator to perform all required traffic control functions. The console consists of a desk-like frame which houses the traffic control panels. A control console may be as simple as a table or desk with a table-top elevated panel containing the required pushbuttons. Or, it may be a complex command post-type console, with the control panels an integral part of the frame.

The control panels for the most sophisticated systems include the following functions: traffic system control; map displays control; malfunction indicators; status displays.

Lighted pushbutton indicators confirm operator action. Lighted bulbs display malfunctions status or indicate selected traffic parameters. Audible alarms also notify the operator of system malfunctions.

Cost factors are directly related to the desired level of control console complexity, console size, and quality of furniture.

The most basic console consists of a simple table or desk large enough to accommodate a CRT and/or keyboard/printer, plus a small table-top console with limited system control and map control functions. The most sophisticated console model includes enough space for two or more CRTs and keyboard/printers, and built-in control panels which contain all system traffic control and map control functions, as well as malfunction indicators and status displays.

<u>Database Generator</u> - <u>FM 2.4</u>

The system database is where all intersection and system timing information is stored, as well as the definition of the physical characteristics of the street network. The database is periodically accessed by the traffic control software for application of the required timing plans. Since traffic performance is highly dependent on the quality of timing plans, these must be periodically updated to reflect changes in local traffic patterns.

In the Basic system all timing plan information, as well as the geometric features of the street network, are initially entered with the system off-line. Permanent timing plan changes, and other system database updates are also performed off-line. Sophisticated database management programs allow for permanent timing plan and other changes to be performed with the system on-line.

The major cost factors associated with development of a database generator is the degree of "user-friendliness" desired. An interactive data entry process may involve many levels of operator/machine dialog. Each level will incorporate data entry error-checking, with appropriate error messages printed and/or displayed. For reasons of safe system operation, the database checking program ("editor") must validate all data entered into the database for reasonableness before actual implementation.

<u>Special Functions</u> - <u>FM 2.6</u>

Special functions which may be controlled at the local controller by the system include phase skipping, alternate phase sequence selection, selection of maximum timers, and signal flash operation, as well as actuation of illuminated signs, blank-out signs, and variable message signs.

Cost factors associated with inclusion of special function features in a system are:

1. Additional hardware costs at each intersection where a special function may be implemented

2. Additional communications costs, because of more command bits sent to the local controller, as well as status information returned to the central site or local control unit

3. Additional software costs because of expanded database requirements and additional processing by applications software to implement the special function requirements

Uninterruptible Power Source - FM 1.5.3

An uninterruptible power source (UPS) protects critical computer system elements from not only power outages, but the surges, sags, and spikes experienced on all utility power lines.

A full time UPS that constantly powers the computer system offers the best protection. The standby type of UPS system that only supplies power upon detection of a power failure does not offer the protection from power line noise that can degrade data transfer.

The cost factors associated with the inclusion of a UPS system involves the hardware cost of the system itself and the installation and maintenance costs.

CHAPTER 3

CROSS-REFERENCE CHARTS

The required (R) and optional (O) features for the Basic system configuration are cross-referenced to the Functional Modules (specifications) of Part B as follows:

		BASIC SYSTEM R	BASIC SYSTEM O
1.Ø	Provide for System Operational Features		
1.1	Provide for Initial Startup	x	
1.2	Provide for System Restart	x	
1.3	Provide for Unattended Operation	x	
1.4	Provide for System Shutdown	x	
1.4.1	Provide for Planned Shutdown	x	
1.4.2	Provide for Emergency Shutdown	x	
1.5	Provide for Fallback Operation	x	
1.5.1	Provide for Transfer to On-line Operation	x	
1.5.2	Provide for Transfer to Fallback Operation	x	
1.5.3	Provide for Uninterruptible Power Source		x
1.6	Provide for Demarcation Points	x	

		BASIC SYSTEM R	BASIC SYSTEM O
2.0	Time Signals		
2.1	Provide for Special Event Timing Plans		x
2.2	Provide for Preemption		x
2.3	Select Signal and Timing Plans	x	
2.3.1	Provide for Transition Timing	x	
2.3.2	Provide for Manual and TOD Modes	x	
2.3.3	Provide for TRSP Operation		x
2.3.3.1	Provide for Section Locking		x
2.4	Provide for Database Management	x	
2.4.1	Provide for Origination and Updating of Database	x	
2.4.1.1	Compute Timing Plans		x
2.5	Provide for Critical Intersection Control		x
2.6	Provide for Special Functions		x
2.7	Provide for Command and Monitor Communications	x	
2.7.1	Provide for Communications Error Detection	x	
2.7.2	Provide for Various Control Methods	x	
2.8	Provide for Street Operation Verification	x	

		BASIC SYSTEM	
		R	O
3.0	Process Detector Data		
3.1	Provide for Data Logging		x
3.2	Provide for Error Checking		x
3.3	Provide for Data Smoothing		x
3.4	Compute Measures of Effectiveness		x
3.5	Predict Flow Trends		x
3.6	Provide for Vehicle Classification		x
3.7	Provide for Emergency Vehicle Detection		x
4.0	Generate Reports		
4.1	Generate Measures of Effectiveness Reports		x
4.2	Generate Status Reports	x	
4.3	Generate Summary Reports		x
4.4	Generate Database Reports	x	

		BASIC SYSTEM	
		R	O
5.0	Provide Controls and Displays		
5.1	Provide for Primary Operator Interface	x	
5.1.1	Provide for CRT Menu Override	x	
5.1.2	Provide for Interface with Operator Console		x
5.1.3	Provide for Interface with Remote CRT		x
5.2	Provide Map Display		x
5.2.1	Communicate with Map Display		x
5.3	Provide Hardcopy Logging	x	
5.3.1	Provide an Activity Log		x
5.3.2	Provide Failure Logging	x	
5.4	Provide Graphics Capability		x
5.4.1	Provide a Color CRT		x
5.4.2	Provide Graphics		x
5.4.3	Provide Projection Displays		x

PART B: SPECIFICATIONS

INTRODUCTION

The specifications are presented in a structured format similar to the Hierarchical Input-Process-Output (HIPO) format used in structured computer programming. The HIPO format was rearranged to more adequately suit the requirements of this task. Each item within the structure is referred to as a Functional Module (FM) to further particularize this application of the HIPO philosophy.

This type of structured format was chosen to provide a logical flow of specification detail in the form of an inverted tree. The main element, or tree trunk, is termed Functional Module "0.0 Control Traffic" and serves to introduce the five major branches of the tree; 1.0, 2.0, 3.0, 4.0, and 5.0. Each of these five major branches, or major Functional Modules, serve to introduce their subordinate Functional Modules which are the actual functional specifications. Figures 1 through 9 "Functional Module Diagrams" illustrate the order and linking of the Functional Modules. The shaded blocks on the figures indicate the options which may be selected for Basic system expansion.

Each of the subordinate Functional Modules are divided into five sections. Immediately after the title (example: "1.1 Provide for Initial Startup") is at least one paragraph of descriptive material pertaining to that Functional Module. It is included in order to minimize the need to refer to other sections or other documents.

The next three sections are the specifications themselves, divided into INPUT, OUTPUT, and PROCESS segments. The Input segment details the input data, signals, or operator actions required to satisfy the requirements of the module. The Output segment describes the results of the implementation of the module. The Process segment describes what has to be implemented in order to satisfy the Output requirements, given the Input parameters. In order to maintain the functional nature of the specifications, the Process segment only states the requirements of the task, not how to instrument it.

The final section deals with system type considerations and is so titled. There are three types of systems which may be implemented. The centralized system consists of a central computer and communications network which issues command signals and requires controller status and, optionally, detector data monitor signals on at least a second-by-second basis in order to properly control the intersections. The intersection controllers may be of any type, but are normally considered to conform to the NEMA standard interface.

The two level distributed system may take two forms. The first type consists of a central computer and a field located microprocessor type local control unit that exercises direct control over the intersection controllers. The second type of two level distributed system retains the central computer, but is instrumented with programmable microprocessor controllers programmed to act as both local control units as well as intersection controllers.

The three level distributed system consists of a central computer which supervises the activity of microprocessor based local control units, which, in turn, supervise the activity of the microprocessor-based intelligent, programmable, local intersection controllers.

The terms "intelligent local intersection controller", or "programmable intersection controller" used throughout the Functional Modules refer to any type of accepted microprocessor based unit that can be programmed to provide the intent of the specifications. This implies the capability to store several timing and signal plans, a time of day/day of week scheduler, a time- based coordination implementation and the capability to accept and confirm "downloaded" data and generate "uploaded" data from and to the next higher level of intelligence (the central computer or the local control unit).

The items detailed in the System Type Considerations section of the Functional Modules are intended to provide insights into the problems and solutions of implementing the various types of systems. Once the type of system is selected, the appropriate items detailed in the System Type Considerations section should be added to the Process segment of the specifications.

As an example of the use of these Functional Modules, a traffic engineer desires a basic system that can operate unattended with an uninterruptible power source to accommodate the frequent utility power outages experienced in the area. The high school and State college athletic programs are highly supported by the population of the surrounding area, creating severe traffic problems before and after these events. A railroad's main line runs through the center of town, interrupting vehicular traffic on several main routes. The industries which support most of the area's population all start and end daily operations within minutes of each other. A centralized system using leased communications lines is considered appropriate for this installation. Although over fifty percent of the intersection controllers are actuated, the installation of additional "system" detectors is not considered economically feasible for a rather predictable traffic flow. A remote CRT terminal at the Maintenance Facility is warranted. There is no requirement for a map display or CRT graphics.

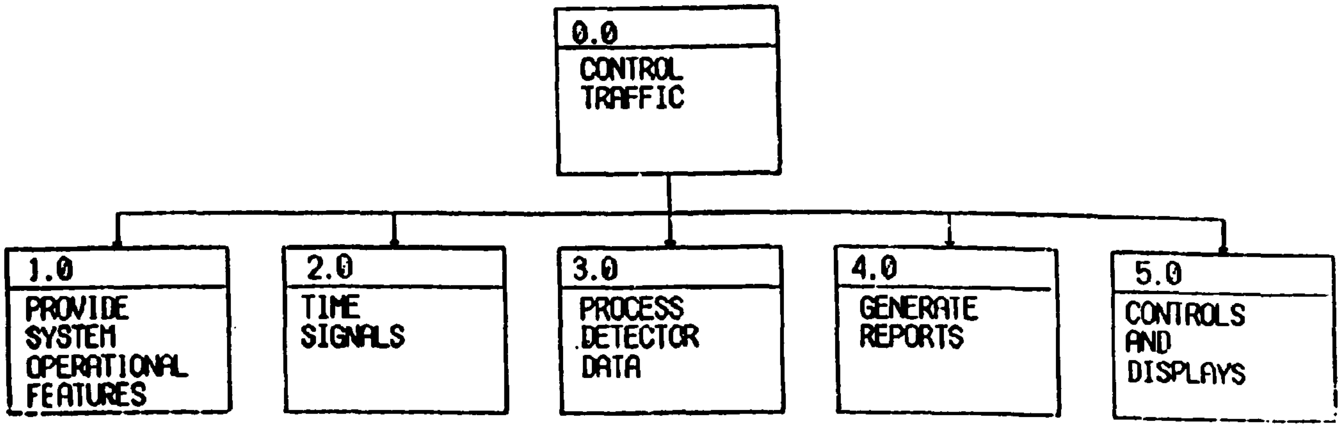
In addition to Functional Module 0.0 " Control Traffic", the following set of modules is required in order to provide all of the features desired for the example system:

1.0	Provide for System Operational Features
1.1	Provide for Initial Startup
1.2	Provide for System Restart
1.3	Provide for Unattended Operation
1.4	Provide for System Shutdown
1.4.1	Provide for Planned Shutdown
1.4.2	Provide for Emergency Shutdown
1.5	Provide for Fallback Operation
1.5.1	Provide for Transfer to On-Line Operation
1.5.2	Provide for Transfer to Fallback Operation
1.6	Provide for Demarcation Points
2.0	Time Signals
2.3	Select Signal and Timing Plans
2.3.1	Provide for Transition Timing
2.3.2	Provide for Manual and Time-of-Day Modes
2.4	Provide for Database Management
2.4.1	Provide for the Origination and Updating of the Database
2.4.1.1	Compute Timing Plans
2.7	Provide for Command and Monitor Communications
2.7.1	Provide for Communications Error Detection
2.7.2	Provide for Various Control Methods
2.8	Provide for Street Operation Verification
4.0	Generate Reports
4.2	Generate Status Reports (All but the detector status report)
4.4	Generate Database Reports
5.0	Provide Controls and Displays
5.1	Provide for Primary Operator Interface
5.1.1	Provide for CRT Menu Override
5.3	Provide Hardcopy Logging
5.3.2	Provide Failure Logging

The traffic engineer would also choose the following optional Functional Modules to particularize the system to suit the municipality's requirements:

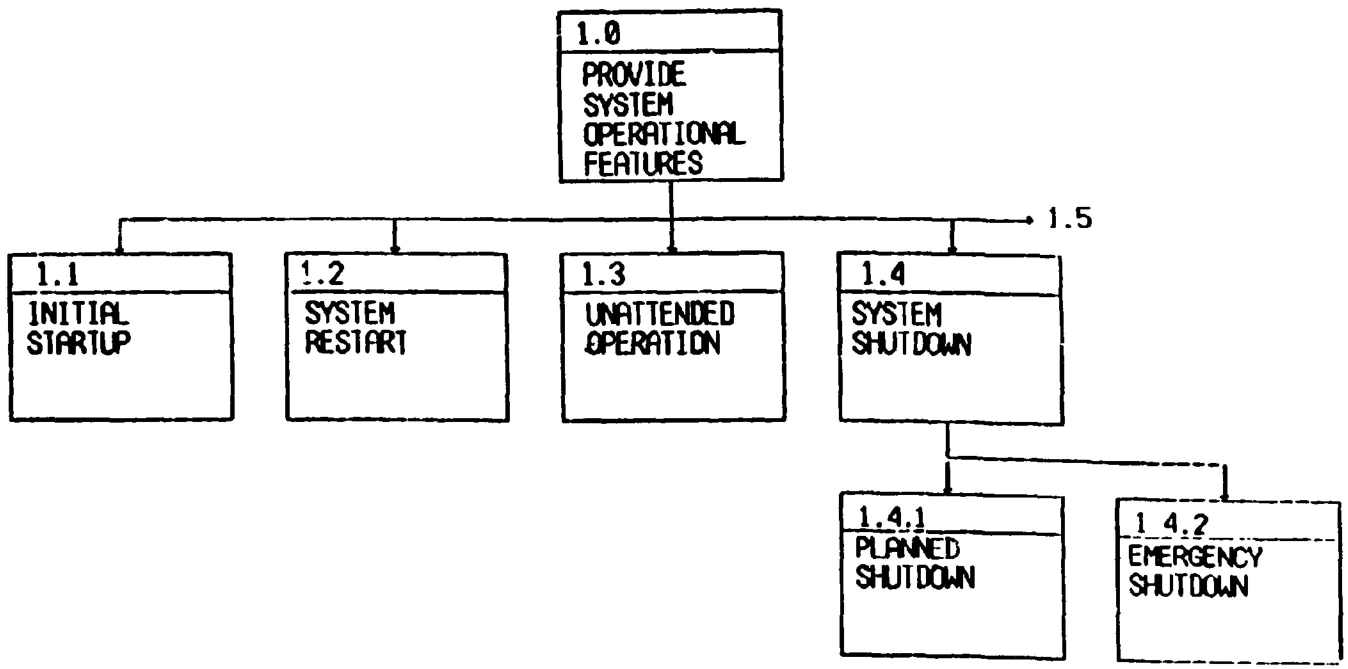
1.5.3	Provide for Uninterruptible Power Source
2.1	Provide for Special Event Timing Plans
2.2	Provide for Preemption
2.6	Provide for Special Functions
4.3	Generate Summary Reports (All but the vehicular flow report)
5.1.3	Provide for Interface with Remote CRT (Failure data and repair information only,password protected)

Using this shopping list of requirements and alternatives, a viable system can be specified for any municipality.



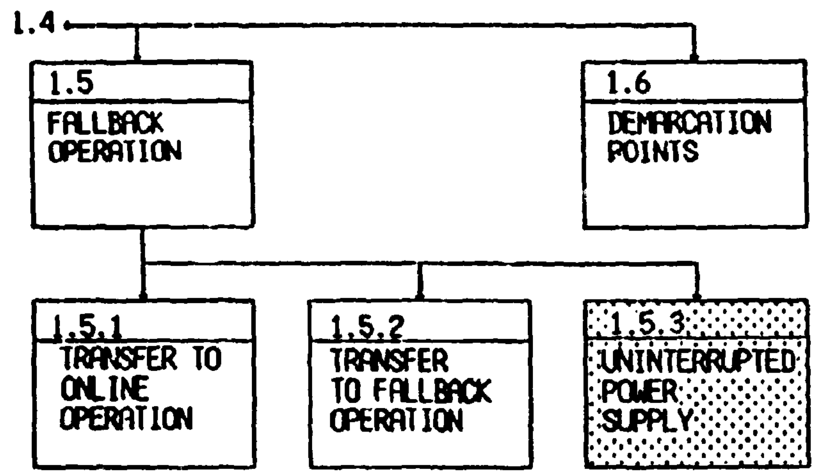
(Shaded Features are Optional)

Functional Module Diagram Figure 1



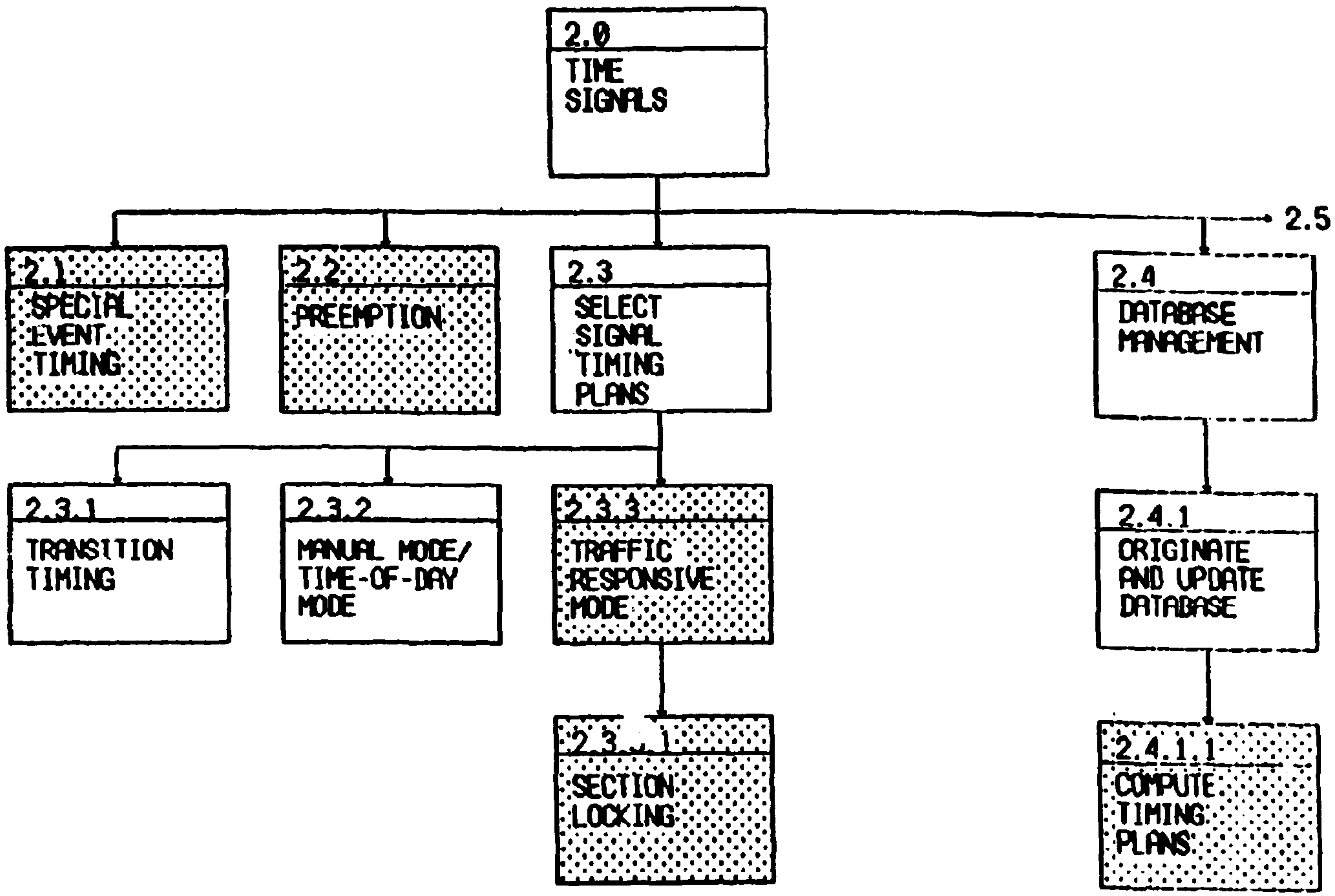
(Shaded Features are Optional)

Functional Module Diagram Figure 2



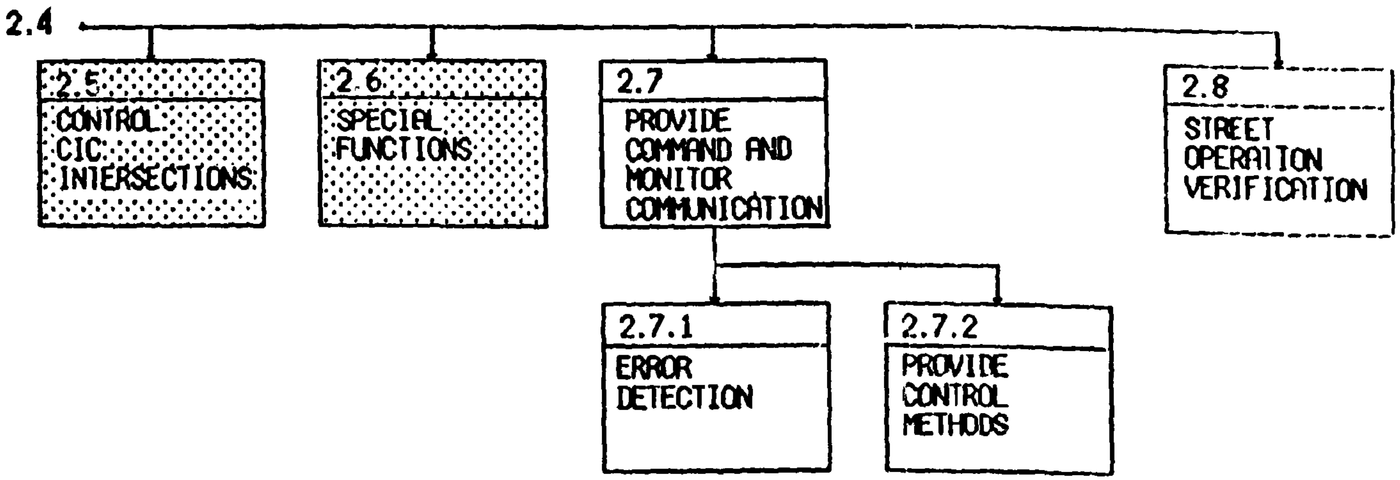
(Shaded Features are Optional)

Functional Module Diagram Figure 3



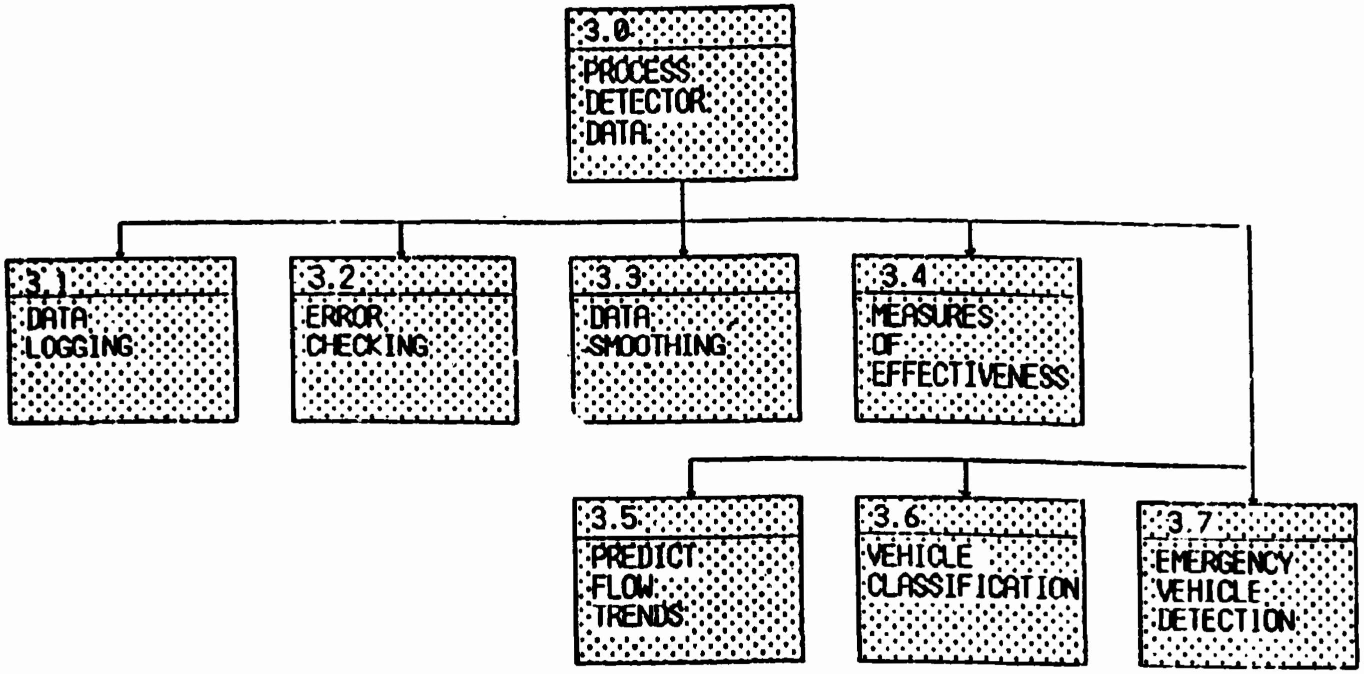
(Shaded Features are Optional)

Functional Module Diagram Figure 4



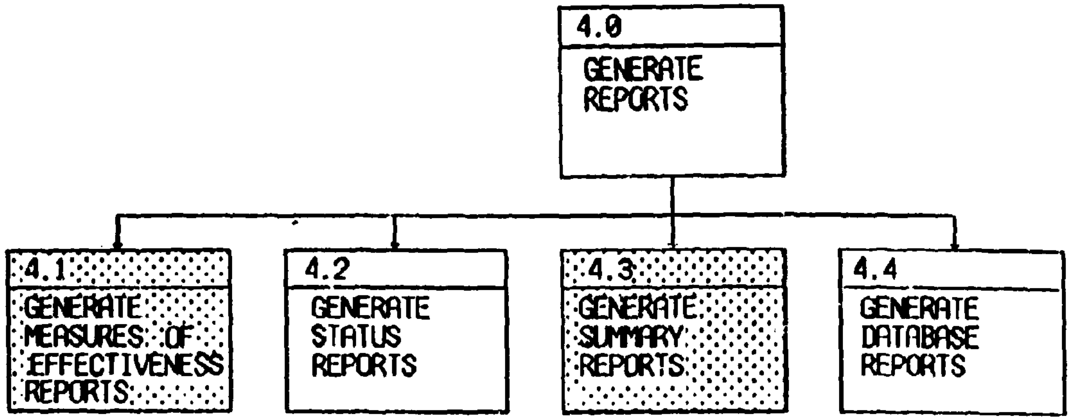
(Shaded Features are Optional)

Functional Module Diagram Figure 5



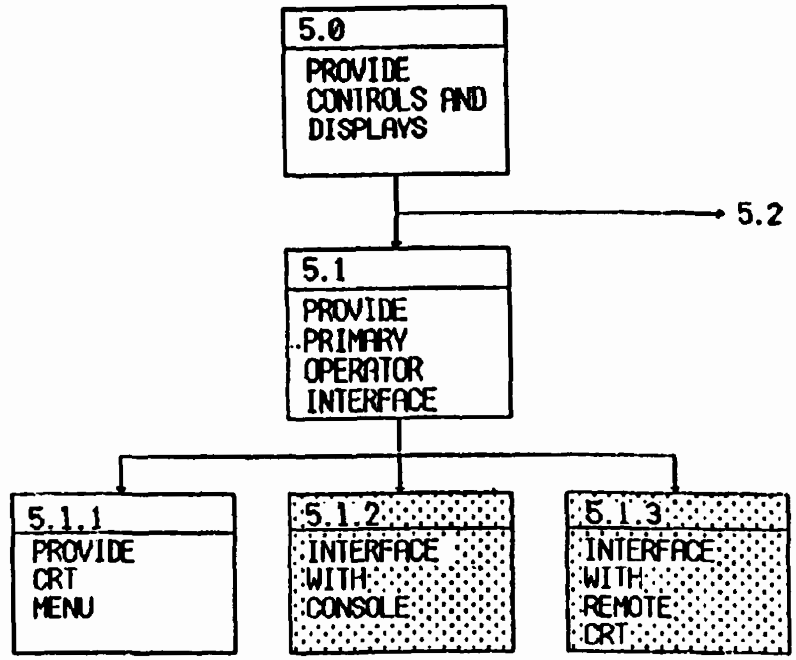
(Shaded Features are Optional)

Functional Module Diagram Figure 6



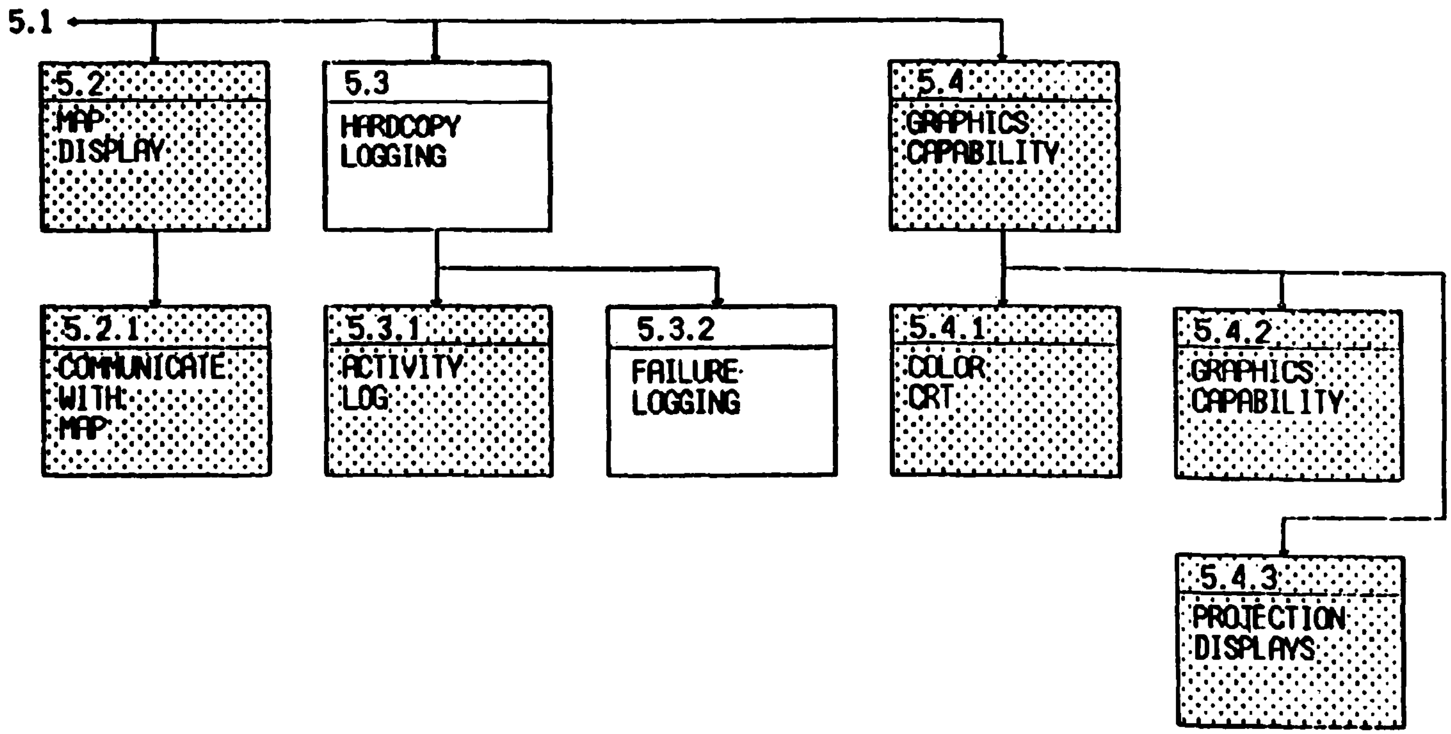
(Shaded Features are Optional)

Functional Module Diagram Figure 7



(Shaded Features are Optional)

Functional Module Diagram Figure 8



(Shaded Features are Optional)

Functional Module Diagram Figure 9

0.0 Control Traffic

A computerized traffic control system may be implemented in many ways, but still accomplish the same function: control and regulation of traffic in a manner that will optimize available roadway usage. Although the end result may be the same (illuminate the traffic signal lamps in an orderly and safe progression), and the monitor data input may be the same (vehicular detector and traffic signal monitor data as a minimum), the process of data manipulation and system control may vary radically without obvious impact upon the motoring public, but with radical differences in overall system implementation cost.

The Functional Modules which contribute to 0.0 "Control Traffic" are grouped into five major areas:

1.0 Provide for System Operational Features

2.0 Time Signals

3.0 Process Detector Data

4.0 Generate Reports

5.0 Provide Controls and Displays

All of these Functional Modules follow the format described in the Introduction section of this report.

1.0 Provide for System Operational Features

System operational features are those items of system design that indirectly affects traffic signal control and directly affects system operability and maintainability. These items include provision for:

A. Orderly startup, restart, and shutdown of the system

B. Unattended operation

C. Fallback operation

D. Demarcation points

These items are described in detail in the modules which contribute to Item 1.0, "Provide for System Operational Features":

1.1 Provide for Initial Startup

1.2 Provide for System Restart

1.3 Provide for Unattended Operation

1.4 Provide for System Shutdown

1.4.1 Provide for Planned Shutdown

1.4.2 Provide for Emergency Shutdown

1.5 Provide for Fallback Operation

1.5.1 Provide for Transfer to On-Line Operation

1.5.2 Provide for Transfer to Fallback Operation

1.5.3 Provide for Uninterruptible Power Source

1.6 Provide for Demarcation Points

All of these Functional Modules follow the format described in the Introduction section of this report.

1.1 Provide for Initial Startup

The computer-controlled traffic control system shall provide for the initial startup of the system by initializing all operational and failure arrays within the software data arrays. The initial startup routines shall be used not only at the true initial startup of the system, but whenever it is desired to restart the system without prior status information. This startup mode is particularly effective when massive power failures or communications interruptions have caused extensive entries into failure tables and it is desired to eliminate all such entries by restarting the system.

INPUT:

Operator entry at the computer console device.

OUTPUT:

System startup. Sensor data is collected and traffic controllers are monitored in preparation for being placed on-line.

PROCESS:

Following the required operations imposed by the computer operating system, minimal operator actions shall be required to startup the traffic control program. Only the program name in abbreviated form shall be entered following the necessary computer operating system entries.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

All initial startup logic shall be included in the central computer software.

Two-Level Distributed Systems:

The local control unit shall be programmed to accept initial startup commands from the central system.

Three-Level Distributed Systems:

The local control unit and the intelligent local controller shall be programmed to accept initial startup commands from the central system.

1.2 Provide for System Restart

Restarting the system becomes necessary after a power failure, off-line processing or system maintenance efforts require it. This process differs from initial system start-up in that the previously accumulated operation and failure data is loaded into the applicable data arrays rather than initializing them.

INPUT:

Power failure, automatic restart interrupts and operator inputs via the computer console device.

OUTPUT:

Reloaded and restarted traffic control applications program using pre-shutdown operational data.

PROCESS:

Upon restoration of power or operator selection of the restart mode, the traffic control applications program shall be placed into execution using the last used operational and equipment failure data.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

All system restart hardware/software logic is contained within the central computer system.

Two-Level Distributed Systems:

The local control unit(s) shall contain the power failure, automatic restart logic and all of the features shall be resident within the central system.

Three-Level Distributed Systems:

The local intersection controller shall contain the power failure, automatic restart logic and all of the features shall be resident within the local control unit(s) and the central system as defined for the two-level distributed system.

1.3 Provide for Unattended Operation

All traffic control systems should have the capability of unattended operation. The capability for scheduling all modes of operation including the capability for accepting emergency or transit preemption or priority should require no real time operator interaction.

INPUT:

Power failure automatic restart hardware/software, long-term (eight day) scheduling capability of operational modes and special events.

OUTPUT:

Power failure/power restoration interrupts, scheduling of all operational modes and methods of control.

PROCESS:

The operator shall be capable of entering all usual and special events into an all-purpose scheduler. This scheduler shall have an eight day (one day for special events), 24-event-per-day-per-section capacity. Power failure, automatic restart hardware/software features shall be included to permit additional unattended operational features.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

All provisions for unattended operation are resident in the central hardware and software.

Two-Level Distributed Systems:

Time-of-day and special event scheduling can be downloaded to the local control unit. Traffic responsive, emergency vehicle and transit preemption (or priority) may also be included in the local control unit, but usually should remain within the province of the central computer in order to maintain coordination across local control unit boundaries. Power failure, automatic restart features should be included in the requirements of all levels of control.

Three-Level Distributed Systems:

The same guidelines as described for two-level distributed systems apply, with the additional possibility of periodic downloading of time-of-day and special event scheduling to the intelligent intersection controller.

1.4 Provide for System Shutdown

The system must be periodically shutdown for a variety of reasons. Preventative or corrective maintenance of the various components (hardware or software) of the system are some of the reasons.

There are two ways to shutdown a traffic control system (stop execution of the traffic control program).

The most agreeable manner to shutdown a traffic control system, or component part of the system (in the case of a distributed system) is to permit operation to a point of neutrality -- a point where minimum disturbance to the traffic flow is reached -- before allowing reversion to a fallback operation state. (The point of neutrality is, most often, the start of main phase green.) This type of shutdown is generally termed a "planned" or "graceful" shutdown.

Occasionally, a hardware or software fault observed by the operator or sensed by fault detection systems requires an immediate shutdown process. Even a few seconds wait for a point of neutrality for all or some of the intersection controllers is more than can be tolerated. This is termed an "emergency" shutdown procedure.

INPUT:

Power failure, auto restart monitors; applications program stall monitors, operator input, maintenance considerations.

OUTPUT:

Stopping of the execution of the traffic control program and control signal communications outputs in an emergency or planned (graceful) manner.

PROCESS:

Proper processing of the input monitor states and proper reaction to the monitor inputs. Refer to subordinate Functional Modules 1.4.1 and 1.4.2.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

All shutdown logic shall be included in the central software/hardware implementation.

Two-Level Distributed Systems:
Three-Level Distributed [illegible]ems:

Shutdown logic shall [illegible] [illegible]istributed between central and the local control unit(s).

1.4.1 Provide for Planned Shutdown

The traffic control system must accommodate the planned shutdown of the primary components for scheduled preventive maintenance, data base modification (some systems), or system hardware/software modification.

The invocation of a planned shutdown routine requires that the intersection controllers receive computer control signals until the release point is reached (normally main phase green). After a predefined time has expired at the release point, the local controller is allowed to revert to fallback operation.

INPUT:

Operator input of planned ("graceful") shutdown.

OUTPUT:

Storage of traffic flow and failure data onto the mass storage device.

Exiting of the traffic control program in an organized manner.

PROCESS:

Upon operator entry (via control panel pushbutton switch or operator terminal keyboard) the traffic control program shall continue timing plan control of the intersection controllers until the release point (predefined) of each intersection controller is reached. The release point is generally "main phase green". After a predefined amount of time (generally, minimum green time) each individual controller is released to fallback operation (refer to Functional Module 1.5 and its subordinate functional modules).

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

All planned shutdown logic shall be included in the central computer software program.

Two-Level Distributed Systems:
Three-Level Distributed Systems:

Planned shutdown logic may be distributed between central and the local control unit. A local control unit may be shutdown from central control (the local control unit's intersection controllers will revert to fallback operation) without affecting the remainder of the local control units or the operation of central.

1.4.2 Provide for Emergency Shutdown

Three types of emergencies must be accommodated by the traffic control system:

A. Power failure

B. Unplanned stopping of program execution

C. Operator observation of improper operation

Computer equipment should be equipped with a power failure detection, automatic restart circuit. Impending power failures can be detected within one quarter cycle of the AC supply, providing sufficient time to store volatile register information in nonvolatile memory. Upon restoration of power, the automatic restart circuit instigates the start of a program to restart the traffic control applications program.

Periodically, any applications program can suddenly stop execution for any number of hardware or software reasons. Depending on the hardware/software configuration, this sudden ceasing of program execution could cause unsafe intersection controller operation. In any event, alarms should be enabled to alert the operator as to the problem and circuitry should insure that the communications subsystem cannot transmit erroneous data. In a one-computer configuration, this detection and alarm circuit must be external to the computer and separately powered. Outputs from the computer, such as toggling signals, are sampled by the detection and alarm circuit ("Watch Dog Timer") and its outputs control the alarm and communications disable circuit. In a dual (redundant) computer configuration, exchange of data between computers on a periodic basis can accomplish the same results, with the added benefit that the "standby" computer can be constantly updated with the latest control strategies applied, as well as the necessary traffic flow and failure data.

The operator may notice improper operation of the system to the point that immediate interruption of control of the intersections is necessary. A method for cessation of control must be implemented that will, upon activation, prevent any further transmission of control data to the street. Suitable hardware (switch hood) or software (password) protection should be provided to prevent inadvertent operation of this feature.

INPUT:

Power failure, automatic restart circuitry output signals; program execution stop detection implementation; operator input via protected switch or password protected terminal entry.

OUTPUT:

Complete stoppage of the execution of the applications program.

Complete cessation of communications control signal outputs.

PROCESS:

Once a power failure or applications program cessation is detected, or an appropriate operator entry is completed, the system shall shut down and all computer control output signals to the communications subsystem shall be inhibited.

SYSTEMS TYPE CONSIDERATIONS:

Centralized Systems:

The emergency shutdown implementation is confined to the central hardware/software system complement.

Two-Level Distributed Systems:

The central system would contain all of the above described emergency shutdown procedures. The local control unit would contain the power failure, automatic restart, and program execution stop (watchdog timer) features described above. The operator-instigated command to stop transmission of control signals to the intersection controllers relies on intact communications from central to the local control unit.

Three-Level Distributed Systems:

The same distribution of features as described for the two-level distributed system is applicable for the three-level distributed system. The power failure, automatic restart feature as well as the program stop (watchdog timer) function should be added to the local controller as well.

1.5 Provide for Fallback Operation

Every traffic control system must provide for some sort of fallback operation in cases of failure of the main elements of the system (central or local control unit, communications circuits, etc.). The level of fallback operation chosen depends upon the local traffic conditions, the importance of full-time coordination of traffic signals and the cost restrictions.

There are three levels of fallback operation:

A. Minimal fallback provisions

A.1. Pretimed controllers

Providing a "second" dial with standby timings and the circuitry necessary to switch to that dial if communications are lost.

A.2. Actuated controllers

Operation as standard uncoordinated actuated controllers when communications are lost.

B. Medium level fallback provisions

B.1. Pretimed controllers

A Time-Based Coordination unit coupled with time-of-day switching of several dials when communications are lost.

B.2. Actuated controllers

A Time-Based Coordination unit and/or an auxiliary timing unit which can provide several time-of-day selectable timing plans.

C. Maximum fallback provisions

In addition to the fallback provisions described above, redundancy of central equipments such as the primary computer equipments (computer itself and prime peripherals such as the operator interface and mass storage elements) and the central communications subsystem must be considered.

An Uninterruptible Power Source (UPS) should be considered a necessity to not only provide a source of power to override utility power outages, but to minimize the failure rate of the computer and the prime peripherals as well as the communications subsystem by providing effective isolation from the surges, sags, and spikes present on all utility power.

INPUT:

A planned, operator-instigated, or emergency, hardware/software-instigated drop to fallback operation. Also, an operator-instigated or automatic method of attaining on-line operation.

OUTPUT:

Transfer of traffic signals from on-line control to fallback operation and the reverse.

PROCESS:

Any of the methods and implementations described above and in subordinate Functional Modules 1.5.1, 1.5.2, and 1.5.3.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

Maximum fallback operation provisions are normally required to insure maximum operability of the system.

Two-Level Distributed Systems:

Fallback operation provisions must be distributed between the central system components as well as the local control unit and the intersection controller.

Three-Level Distributed Systems:

The same considerations as described for the two-level distributed system applies, but the inclusion of an intelligent local controller permits a higher level of fallback operation at the local intersection controller and thereby permits less sophistication at the local control unit and the central system.

1.5.1 Provide for Transfer to On-Line Operation

The system shall provide for an orderly transition from fallback operation to computer control to minimize any disturbing effect on the traffic flow.

INPUT:

Controller status data

OUTPUT:

Computer-selected controller timings

PROCESS:

The intersection controllers shall be transferred to computer control at the start of main phase green. Once the controller is "captured" in main phase green, the process of transitioning shall take place. The number of cycles taken to achieve the transition from fallback to on-line computer control depends on the number of seconds difference between the actual and desired offset time settings and the particular method chosen to accomplish the transition ("brute force", "n" cycles, etc.). (Refer to Functional Module 2.3.1)

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

The central processor controls all of the processes involved in providing for the transfer for intersection controllers to on-line (computer control) operation. Regardless of the option chosen for transition, the central computer shall control the entire operation.

Two-Level Distributed Systems:

The central processor shall issue the command to the local control units to transfer the local intersection controllers to the on-line condition.

Three-level Distributed Systems:

The process is the same as for the two-level distributed system described above.

1.5.2 Provide for Transfer to Fallback Operation

When any part (or all) of the system is to be placed off-line (not under computer control), a graceful transition to the fallback operation shall be provided to insure minimal disturbance to traffic flow.

INPUT:

A nonemergency, operator-instigated, command to cease computer control for an intersection, a series of intersections ("sections") or the entire system.

OUTPUT:

A programmed removal of computer control signals from the selected units.

PROCESS:

The computer software shall continue to provide computer control signals under the current signal timing plan(s) imposed until the start of coordinated phase green is detected by the computer for any of the intersection controllers to be returned to the fallback operation condition. The computer shall then remove those computer control signals and permit the intersection controllers to revert to their previously entered local timings.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

All fallback logic shall be included in the central computer software program.

Two-Level Distributed Systems:

For the two-level distributed systems that involve only the usually instrumented NEMA controllers, fallback logic must be distributed between the central computer and the local control unit. One intersection controller under control by a local control unit may be commanded to be placed into the fallback operation condition for any number of reasons (maintenance, local control, time of day schedule). The local control unit, having been issued the command(s) to place intersection(s) under fallback control by the central computer shall proceed with the same preprogrammed operation as described in PROCESS above.

If the central computer issues the command to place an entire local control unit's complement of intersections under fallback control, then the entire set of intersections being controlled by the local control unit shall revert to the fallback control conditions as described in the PROCESS section above.

Three-Level Distributed Systems:

For the three-level distributed system, fallback logic can be distributed between the central computer, the local control unit and the intelligent controller. The one main difference between this type system and the two-level distributed system is that the intersection controller may have its own, internal, time-based coordination hardware and/or software.

1.5.3 Provide for Uninterruptible Power Source (OPTIONAL)

An uninterruptible power source (UPS) protects critical computer system elements from not only power outages, but the surges, sags, and spikes experienced on all utility power lines.

An uninterruptible power source subsystem, where the utility AC power is converted to DC, with batteries "floated" across the DC output, and the DC inverted to AC, provides the best protection for the equipment placed across the inverted AC load terminals. Failure of the utility power will not influence the operation of the critical components of the computer subsystem connected to the uninterruptible power source until the batteries fall below a certain charge level. The discharge time need not be be greater than 15 minutes to accommodate over 99 percent of the utility power outages in most parts of the country. (At least 24 hours of recharge time must be allowed for each 15 minutes of discharge time.)

INPUT:

Utility power.

OUTPUT:

Protected AC power for predetermined period of total outages.

PROCESS:

The utility supplied AC power shall be converted to DC. The DC voltage shall be used to:

1. Charge and maintain charge of the batteries.

2. Provide input power to the AC inverter.

The AC inverter shall change the DC input to the regulated AC output power for the critical computer elements.

The AC output power requirements shall include at least a 10 percent excess power requirement.

The switchover time from utility to battery supply shall be less than 50 percent of the computer power failure detection circuitry detection level.

The minimum battery capacity required for the uninterruptible power source shall provide 15 minutes of stable AC output power. The maximum battery recharge time shall not exceed 24 hours. A diesel generator "extra backup" subsystem may have to be considered for locations where utility power outages are significantly greater than the battery capacity and its recharge time.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

The central processor(s) and the primary peripherals (disk storage unit(s), operator video display unit(s) and central communications equipments) must be considered for uninterruptible power source connection. Other central equipment may be considered for inclusion dependent upon the importance placed upon their operability under adverse conditions.

Two-Level Distributed Systems:

The same considerations should be made as per the centralized systems described above. In addition, serious consideration should be paid to the inclusion of uninterruptible power systems to the local control unit also. In most cases, "on-board" rechargeable battery units to maintain memory contents will be sufficient for overall system operation.

Three-Level Distributed Systems:

The same comments as stated for the two-level distributed systems apply for the three-level distributed systems. The intelligent intersection controllers must have "on-board" battery installations for memory content protection. Any additional power interrupt protection must survive serious cost/utility/benefit ratio studies.

1.6 Provide for Demarcation Points

Demarcation points must be provided for utility company connections and other interfaces such as the police panel at the intersection controller and the communications lines.

INPUT:

Results of a study to determine the optimum location for such demarcation points.

OUTPUT:

Specifications for the location of the demarcation points.

PROCESS:

Determine the optimum points for the entry of utility power lines and the communications lines field wiring to permit necessary isolation, ease of maintenance, and minimum interference to operating personnel.

When the communications lines are to be provided by the local utility, only the end points (connections at central and at the intersection) shall be considered. For customer-owned lines, intermediate interconnection points shall also be detailed.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

Demarcation points must be defined for the control center as well as the intersection controller cabinets.

Two-Level Distributed Systems:

Demarcation points must be defined for the control center, the local control units as well as the intersection controller cabinets.

Three-Level Distributed Systems:

Same considerations as for the two-level distributed system.

2.0 Time Signals

A very basic function of a computerized traffic control system is timing the intersection traffic control signals to properly control the flow of vehicular traffic throughout the controlled area. Many signal timing plans can be developed and entered into the system, via the database, to respond to changing traffic requirements throughout the day, week, and year.

The following shall be required to be input to the system from the database:

A. Time-of-Year/Day-of-Year (TOY) Clock

B. Control Panel and/or Keyboard Commands

C. Traffic Data for Traffic Responsive Operation

D. Preemption Commands

These items are described in detail in the modules which contribute to Item 2.0, "Time Signals":

2.1 Provide for Special Event Timing Plans

2.2 Provide for Preemption

2.3 Select Signal and Timing Plans

2.3.1 Provide for Transition Timing

2.3.2 Provide for Manual and Time-of-Day Modes

2.3.3 Provide for Traffic Responsive Operation

2.3.3.1 Provide for Section Locking

2.4 Provide for Database Management

2.4.1 Provide for the Origination and Updating of the Database

2.4.1.1 Compute Timing Plans

2.5 Provide for Critical Intersection Control

2.6 Provide for Special Functions

2.7 Provide for Command and Monitor Communications

2.7.1 Provide for Communications Error Detection

2.7.2 Provide for Various Control Methods

2.8 Provide for Street Operation Verification

All of these Functional Modules follow the format described in the Introduction section of this report.

2.1 Provide for Special Event Timing Plans (OPTIONAL)

Any municipality possessing a popular sports stadium, whether high school, college or professional, or a convention or exhibition hall of any importance may require special signal and/or timing plans to accommodate unusual traffic flow patterns during special events, parades, etc.

INPUT:

Inputs from various authorities requesting special event timing.

OUTPUT:

Special event signal and/or timing plans to accommodate the special event demands.

PROCESS:

Special event signal/timing plan changes shall be implemented by the system operator in accordance with a Time-of-Day/Day-of Year schedule, or can be "triggered" by a contact closure (manual switch, or one or more detectors) at, or near, the site of the special event. A software call for the planned signal/timing plan generated and stored for the particular special event, including a call for the transition routine, shall be scheduled. Upon completion of the special event, signal and/or timing plans that correct for the disrupted traffic flow shall be imposed by prior stored signal and/or timing plans.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

Complete flexibility in all control and monitor situations exist since all control and monitor capabilities are concentrated within the central computer subsystem.

Two-Level Distributed Systems:

Careful consideration must be paid to the method of implementation of special event timing. The central computer subsystem must have time to download sufficient data to the local control units to appropriately implement the special event timings or provisions must be made to store the special event patterns in the local control unit.

Three-Level Distributed Systems:

As per the comments recorded above for the two-level distributed system, the degree of data distribution must extend to the intelligent local intersection controller.

2.2 Provide for Preemption (OPTIONAL)

Emergency vehicle preemption requirements are applicable to virtually every municipality. Bridge opening and railroad crossing preemption requirements are applicable to many, if not most, municipalities.

INPUT:

Preemption signals input to the traffic control system from any of the preemption sources.

OUTPUT:

Modification of the applied signal and timing plans to accommodate the type of preemption.

PROCESS:

The preemption input signals shall be sampled by the computer at a rate commensurate with the expected demand for signal and/or timing plan modification to accommodate the preemption demand. Upon reception of the preemption command, the traffic control system shall immediately transition to the preemption signal and/or timing plan previously implemented into the database for this preemption event. Upon completion of the preemption event, the system shall provide the capacity for post preemption timing plans before returning to the pre-preemption or scheduled post-preemption mode of operation.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

The process of system-wide preemption is somewhat simplified in a centralized system since all input/output data relative to the system operation becomes resident within the central computer subsystem.

Two-Level Distributed Systems:

Although some type of preemption activities may be localized to one local control unit's area of influence, the probability that more than one local control unit may be required to react to the preemption demand is great enough to require coordination by the central computer resident preemption routine.

Three-Level Distributed Systems:

As per the entry above for the two-level distributed system, preemption signal and/or timing plans must be also resident within the intelligent local intersection controller in order to implement preemption plans with minimum data transfer.

2.3 Select Signal and Timing Plans

One of the basic functions of a signal system is to select the signal plan and timing plan which is to be implemented in each section (integral group of intersections) of the system. In many systems the signal plan is fixed for each intersection by virtue of the intersection controller which is incapable of providing more than one sequence of phases. Newer microprocessor controllers do provide this capability, however, thereby providing greater system flexibility.

Timing plan selection is related to the entire section. Only one timing plan can be implemented in a section at one time. The timing plan can be selected by the operator (Manual mode), by time clock (Time-of-Day/Day-of-week mode), or by the system itself, when operating in the Traffic Responsive mode.

INPUT:

Operator, or system, input to determine the mode of operation for each section of the system.

Monitor data (controller status and detector data) sufficient to determine the adequacy of control.

OUTPUT:

A timing plan selected for each section, a signal plan selected for each intersection based on the selected timing plan, and both implemented in the street.

Command signals sufficient to effect the level of control desired.

PROCESS:

The timing plan for each section of the system shall be selected by referring to the database to determine first, in which mode of operation each section is scheduled to operate for the current Time-of-Day/Day-of-Year, and second, which timing plan is scheduled for each section for the current time.

The scheduled mode of operation for each section for the current time shall be Manual, Time-of-Day or Traffic Responsive. If Manual, the operator must select the timing plan for each section that is desired to be put into effect through the operators console or keyboard. If Time-of-Day operation is scheduled, the system shall automatically initiate the scheduled pattern. If the Traffic Responsive mode of operation is selected and the system is initially brought on-line (or after particular equipment failure), a Time-of-Day plan shall be automatically initiated until sufficient detector data have been accumulated from each section.

The database shall also contain the signal plan that is to be implemented at each intersection for each timing plan. Once the timing plan has been selected for each section the proper signal plan shall automatically be implemented at each intersection.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

Since all intelligence is concentrated within the central computer subsystem, division of intersections into sections, preparation and storing of signal and timing plans for retrieval at appropriate times, as well as control mode implementation, are functions of the central subsystem alone.

Two-Level Distributed Systems:

In order to capitalize on the prime advantage of a distributed system, reduction of the communications loading between the central subsystem and the local control units, the signal and timing plans associated with the group of intersections associated with each local control unit should be resident within the local control unit. Commands for change of operating mode from the central computer subsystem may then be an abbreviated code rather than detailed set of timing data. Database downloading capability must be included in the system specifications in order to accommodate the capability for signal and/or timing plan data updates.

Three-Level Distributed Systems:

The signal and timing plans for each intersection controller should be resident in those particular intelligent intersection controllers. "Copies" of these plans should be resident in the local control units as well as the central computer subsystem in order to provide adequate backup capabilities.

2.3.1 Provide for Transition Timing

Two types of transitioning methods may be employed when imposing a new timing plan on an intersection controller. The first method can be termed the "brute force" method. The controller is held at the start of a phase (usually main phase green) until that point in time is coincident with that of the new timing plan. The second method type consists of changing the value of the current offset with respect to the cycle clock by increasing or decreasing the cycle length until the offset corresponds to that designated by the new timing plan. The number of cycles over which the transition is accomplished may vary according to the design of the system. This second method is the type generally employed in computerized control systems since it results in the least disruptive effects upon the vehicular flow, and is the transition timing method considered herein.

INPUT:

Indication of an impending timing plan change.

Maximum and minimum cycle lengths allowable for each intersection controller.

New offset point for each controller.

OUTPUT:

Control signals to each intersection controller which are timed by the transition algorithm within the restrictions as to minimum timings.

PROCESS:

Each transition cycle shall be either increased to the maximum allowable (system selectable) or decreased to the minimum allowable (the summation of the minimum timings) except for the final transition cycle, where the time increase or decrease is limited to that necessary to achieve the new offset. The decision to increase or decrease the intersection controller cycle length shall be made independently for each intersection controller.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

All transition timing is made directly by the transition timing routine resident within the central computer.

Two-Level Distributed Systems:

Transition timing algorithms should most properly be resident within the local control units in order to minimize the communications load between the central computer and the local control unit.

Three-Level Distributed Systems:

Transition timing algorithms should most properly be resident within the intelligent local intersection controllers in order to minimize the communications load between the local control unit and the intersection controller as well as between the central computer and the local control unit.

2.3.2 Provide for Manual and Time-of-Day Modes

The Manual mode of system operation allows the selection of the pattern to be implemented in each section via the operator's console (pushbutton control panel or CRT keyboard).

The Time-of-Day/Day-of-Year mode of system operation allows the advance scheduling of the signal plan and timing plan which is to be implemented in each section.

INPUT:

Manual Mode:

Operator request for Manual mode of operation for designated groups of intersections (sections).

Operator request for particular timing plans to be applied to each group of intersections.

Time-of-Day/Day-of-Week Mode:

Database entry of timing plan event times and sections affected.

Operator selection of the Time-of-Day/Day-of-Week mode of operation.

OUTPUT:

A signal plan and timing plan shall be selected for each section which is to operate in Manual mode, or Time-of-Day/Day-of-Year mode, and shall be implemented in the street. Transitioning from one timing plan to another shall occur in Manual mode only when commanded by the operator, and in Time-of-Day/Day-of-Year mode as scheduled in the database.

PROCESS:

For Manual operation, the operator shall select the timing plan to be implemented for any section, or all sections within the system, via the console or the keyboard. The system then refers to the database to obtain the timing parameters for that timing plan.

For Time-of-Day/Day-of-Year operation, the system shall select the proper timing plan to be implemented in each section by noting the time from the Time-of-Year (TOY) clock and referring to the database to determine which plan has been scheduled for that period. The timing parameters are then obtained from the database for the timing plan to be implemented in each section. Timing plans may be selectable on a 15-minute interval with a resolution of one minute.

A mixture of modes of operation among the sections which make up the controlled system shall be possible. The order of mode priority shall be: #1 Manual mode, #2 Time-of-Day mode.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

Since all control and data elements reside within the central computer subsystem, implementation of these modes of operation are made somewhat easier.

Two-Level Distributed Systems:

In order to minimize the communications load between the central computer and the local control units, all timing plans and Time-of-Day/Day-of-Week table content associated with each local control unit should be made resident within each local control unit.

Three-Level Distributed System:

In addition to the system considerations described for the two level distributed system, at least a subset of the local control unit's intersection specific timing plans and Time-of-Day/Day-of-Week event tables should reside in each intelligent local intersection controller.

2.3.3 Provide for Traffic Responsive Operation (OPTIONAL)

The traffic responsive mode of system operation requires installation of system detectors throughout the system which will report traffic conditions that are representative of the traffic flow conditions throughout a particular area of control. This information is used by the system to select and impose the timing plan for each section that will be most responsive to traffic requirements in that section.

INPUT:

Inputs required from the database include:

- Timing plans that are candidates for selection in the traffic responsive mode for each section.

- The smoothing factors, detector weighting constants and occupancy factors which have been selected for traffic responsive operation.

- The volume and occupancy thresholds which have been selected for changing timing plans. Separate thresholds are required to enter a timing plan from a lower traffic level than from a higher traffic level. This provides hysteresis in the system which prevents oscillation from one pattern to another.

- The times of the day which have been defined for each section to operate in the traffic responsive mode.

- The selection of master and slave sections which have been defined for section locking.

- Historical detector data, or the assignment of an alternate detector, for each detector which is to be used during traffic responsive operation, in lieu of actual detector data in the event of detector failure.

OUTPUT:

A signal plan and timing plan selected for each section which is to operate traffic responsively. Transitioning from one timing plan to another shall occur automatically as changes in traffic conditions develop and the predesignated thresholds are detected.

PROCESS:

A timing plan for each section shall be selected by analyzing detector data inputs. The pattern of current traffic conditions, derived from the system detectors, is compared with prestored conditions. The traffic responsive strategy shall then select the timing plan that most closely matches the current traffic conditions.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

System-wide traffic responsive operation is easier to implement since all data is resident within the central computer subsystem.

Two-Level Distributed Systems:

The primary responsibility for effective traffic responsive control must reside within the local control unit in order to preserve the minimal communications level to and from the central subsystem that makes the distributed system cost effective. The major intercommunications task must be limited to the coordination between local control units in order to provide coordination between local control units' areas of influence.

Three-Level Distributed Systems:

The primary responsibility for effective traffic responsive control must be divided between the intelligent intersection controllers and the local control units in order to preserve the minimal communications level to and from the central subsystem that makes the concept of a distributed system economically attractive.

2.3.3.1 Provide for Section Locking (OPTIONAL)

When operating in the traffic responsive mode, groups of intersections being controlled by a proscribed timing plan (a "section") may be operating within a few seconds of the cycle length of other adjacent or crossing sections. Once a specified threshold limit is reached, it may be operationally advantageous to have the applications program choose timing plans for the affected sections that have the same cycle length.

INPUT:

Software implemented "flags" for those sections operating in the traffic responsive mode of operation that are candidates for sectional locking, priority listing for sectional ordering, plus threshold values for section locking.

OUTPUT:

Timing plan changes for the selected sections providing that timing plans exist for the selected cycle length.

PROCESS:

At a specified time period (end of cycle, start of master time period or end of 15-minute period -- system design dependent) the sectional locking flags shall be examined and if "positive" (sectional locking is permissible), the section cycle time differences are compared with the threshold values. If the result is positive (sectional locking is desired, the threshold value is exceeded and appropriate cycle length timing plans exist for all designated sections) then new timing plans shall be applied to the "slave" sections.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

Since all control elements and database quantities are resident within the central computer configuration, the degree of control throughout the system is relatively unlimited.

Two-Level Distributed Systems:
Three-Level Distributed Systems:

Careful consideration must be paid to the communications timing between the central computer and the remote units in order to accommodate the data transfer required to accomplish timely sectional locking.

2.4 Provide for Database Management

The database is the mechanism by which all system activities, intersection timing information and the geometric characteristics of the street network are stored for use by the applications program.

The database must be easily modified to incorporate system changes that will occur on a periodic basis.

INPUT:

Geometric and timing plan data. The capability shall exist to enter and process such data in the background mode of the computer operations and to incorporate such data into the permanent data base while the system remains in the on-line mode of operation. Examples of the type of data which must be entered are:

- Signal plans for each controller
- Timing plans for each section
- Activity scheduler for each section
- Historical data for each detector
- Detector activity reasonableness data
- Parameters for Traffic Responsive operation
- Display map indicator data
- Street network geometrics
- Reporting schedule

OUTPUT:

The database entries shall be packed into the many arrays required and used by the applications program to control and monitor the intersection controllers and any special equipment incorporated into the system.

PROCESS:

Each intersection and detector in the system shall be identified by a unique number. The reports and database operations that are intersection- or detector-specific shall also be identified with this number. Selected intersection reports shall include the intersection name in addition to its number.

The database management system shall permit updating the database while the system is operating. Database parameters may be specified to be loaded through any input device, but CRT keyboard entry shall be the prime input consideration. Database entry formats shall be designed for ease of data entry.

Appropriate safeguards shall be incorporated to prevent dangerous or undesirable intersection operation. These safeguards shall include edit checking of input parameters requiring operator confirmation, and transferring of updated data only after verifying that all criteria have been met.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:
Two-Level Distributed Systems:
Three-Level Distributed Systems:

Sufficient main and mass storage memory space must be allocated for the database preparation program and the database arrays themselves.

2.4.1 Provide for the Origination and Updating of the Database

The accuracy of the contents of the database is the most important part of the system implementation. Each intersection's "geometric" characteristics must be entered along with the timing and signal plan data. Also, Time-of-Day/Day-of-Week event scheduler data must be entered. Special event data entry is also part of the database.

Filling the database with the required entries must be made as "user friendly" as possible with data entry error checking at multiple points in the data entry program. All data entry values along with error messages inserted line-by-line should be capable of being output as hard copy printout for off-line analysis. The error messages should be "ignorable" if, after data analysis, the data entry is determined to be valid for that intersection under particular circumstances.

INPUT:

All data input shall be made by CRT keyboard entry. Punch card data entry shall not be used. The data entry values include:

- Type of controller
- Number of intervals (pretimed controller)
- Number of phases (actuated controller)
- Stop bar to stop bar distances between controlled intersections
- Stop bar to detector location distances
- Minimum or fixed interval (phase) timings
- Timing plan data relative to the timing plan interval (phase) durations.
- Historical detector data
- CIC intersections
- Special function commands

OUTPUT:

Software applications program data arrays shall be filled with data relative to the geometrics and intersection timing and signal plans developed.

PROCESS:

The database editor shall validate all data entered into the database for reasonableness prior to implementation. The following checks shall be made:

- All controller intervals shall be checked to insure that their sum does not exceed the total cycle length.
- The total of the "green" intervals for each phase of each controller shall be at least the minimum green time specified for the phase.
- The total of intervals which are variable for transitioning purposes, plus the fixed green intervals, shall not violate minimum green times.
- All controllers and detectors in the system shall be assigned a unique number, without duplication.

c Checks shall be made to assure proper format, data field content, and that data are within allowable ranges.

An edit report shall list all input data errors. The error message shall indicate the incorrect data field and the reason for the error.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

Since all of the data base resides within the main and mass storage memory capacity of the central system, complete control of the data entry and storage is well controlled.

Two-Level Distributed Systems:
Three-Level Distributed Systems:

Consideration must be paid to the accurate downloading of data to the remote locations.

2.4.1.1 Compute Timing Plans (OPTIONAL)

The computation of timing plans, if not done on a second computer, must be accommodated by any computerized traffic control system either in the off-line, background, or on-line modes of operation. In the off-line mode, the intersection controllers are placed in the fallback mode of operation.

In the background mode of operation, timing plan generation programs are loaded into areas of computer main memory that are not utilized by the traffic control program from areas of mass memory that are also not used by the applications program. In this way, computation of new timing plans may be made while the old timing plans are being applied to the problem of intersection control. At some point in the system operation (outside of peak operation hours), the newly generated timing plans would be loaded into the database.

In the on-line mode, new timing plans are generated and analyzed while the system is on-line, but the approved timing plans are placed into the on-line database without the need to place any part of the system off-line.

INPUT:

Traffic flow data, both through flow and turning count data. Block lengths, number of lanes for each approach, etc., as required by the timing plan generation program.

OUTPUT:

The individual intersection timings required.

PROCESS:

Traffic flow data and geometric data shall be input to the chosen timing plan generation program. The quantities and types of data shall be dependent upon the timing plan generation program chosen for the application. The output shall be timing data for timing plan database input.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:
Two-Level Distributed Systems:
Three-Level Distributed Systems:

Regardless of the type of system employed, timing plans must be generated and updated periodically in order to accommodate the variations in traffic flow. Provisions must be made for the periodic inclusion of new timing plans into the database.

2.5 Provide for Critical Intersection Control (OPTIONAL)

Critical intersection control algorithms are by nature only suitable for those intersections that have relatively long term, but less than timing plan change interval, variable traffic demands on all approaches. The demand measured during one cycle is compensated for during the next cycle within the constraints of sectional offset and cycle length.

Each approach to the intersection must be adequately instrumented with detectors to properly report the intersection approach demand to the computer.

INPUT:

The intersections shall be designated as qualified for critical intersection control by database entry. All approach detectors shall be, by software error detection routines, determined to be operable. Critical intersection control shall be implemented by either the TOD/DOY scheduler, or by operator command.

OUTPUT:

Each phase shall be given a time duration proportional to its green demand time as constrained by the minimum phase limits and the total cycle time.

PROCESS:

The green demand time for any approach shall be computed by factoring the vehicle release rate and the occupancy and volume determined by the cycle-by-cycle smoothed detector data. The split times for the next cycle shall be computed and entered into the timing arrays.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

All input data, critical intersection algorithm processing, and output control data is under the same program control.

Two-Level Distributed Systems:

The command to initiate critical intersection control should originate from the central processor, but not necessarily in real time. The command may be transmitted from the central computer weeks or days ahead of the scheduled event. The local control unit must have the capability to store the commanded events and implement them at the appropriate times.

Three-Level Distributed Systems:

Most of the critical intersection control algorithm intelligence should be resident in the intelligent local intersection controller. This distribution of algorithm allocation must be carefully controlled in order to preserve overall system synchronization.

2.6 Provide for Special Functions (OPTIONAL)

The system should be capable of controlling special functions and displays in the field. Possible special functions include:

- control of illuminated signs, blankout signs, and variable message signs
- phase skip
- maximum timer selection
- signal flash
- alternate phase sequence

All special functions should be controllable by commands within TOD/DOY timing plans and by operator input.

INPUT:

Special function commands shall be incorporated in the database and operator command input enabled from the console or keyboard.

OUTPUT:

Initiation of special functions with associated change in displays to the motorist or changes in signal timing and/or phasing.

PROCESS:

Each timing plan shall provide for the automatic setting of the on/off state of each special function command at each controller. Once initiated, the special function(s) shall remain in effect until changed by a subsequent timing plan, TOD/DOY command, or operator command.

Any special function command shall be set to the on, or off, state by operator command or a TOD/DOY command, irrespective of any other on/off state that may be defined by the current timing plan. The database shall, however, contain safeguards which shall prevent the operator or TOD/DOY commands from controlling certain restricted intersection specific special functions. Special function status monitor returns shall be monitored by the software and compared with the commanded status.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

The extent of the special functions implemented is limited by the time constraints and memory capacity of the central computer and by the communications message content capacity.

Two-Level Distributed Systems:
Three-Level Distributed Systems:

In addition to the considerations described for the centralized system, careful consideration must be paid to the time lapse between communications message transfer between the various intelligent components of the system.

2.7 Provide for Command and Monitor Communications

Reliable, continuous communications between all control components of a traffic control system is essential for proper, reliable system operation. The type and nature of the communications system chosen depends upon many factors, the most important of which are cost per unit and required performance.

The two major types of communications techniques are:

- Time Division Multiplexing (TDM)
- Frequency Division Multiplexing (FDM)

Time division multiplexing refers to the allocating of time "slots" for each unit to be communicated with. Frequency division multiplexing refers to the allocating of different frequencies for each unit to be communicated with. To further confuse the issue, both techniques can be combined under certain circumstances. Under most circumstances, TDM equipment requires far less physical space than FDM equipment to accomplish the same functions.

Within the TDM and FDM communications domain, frequency shift keying (FSK) and phase shift keying (PSK) can be applied, but generally only FSK is used for FDM. In elemental terms, FSK means that one frequency is used to designate a digital "one" and another frequency is used to designate a digital "zero". Also in elemental terms, PSK means that the phase of a particular frequency designates a digital "one" or "zero".

INPUT:

Monitor data from each controlled intersection, system monitored detector and special function unit.

OUTPUT:

Command data to each controlled intersection and special function unit from the data base via the intersection control software algorithms.

PROCESS:

Output data shall be accumulated from the various software arrays designated for the various control functions into message characters as designated by the system design.

Input data shall be distributed to fill the designated software arrays with the various monitor functions as designated by the system design.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:
Two-Level Decentralized Systems:
Three-Level Decentralized Systems:

Regardless of the type of system chosen for installation, any type or mixture of communications types can be accommodated.

2.7.1 Provide for Communication Error Detection

No communications subsystem of any extent can be considered error proof. There are many error detection schemes. Some of the simpler, and therefore, least expensive are,

- Parity
- Framing
- Overrun

which can generally be implemented within an integrated circuit chip. A parity bit is appended to each character whose state is dependent on the number of "one's" in the character. The receiving unit effectively counts the number of "one" bits in the received character and compares the count (even or odd number of one's) with the parity bit state. A framing error is generated if the stop bit is in the start bit state. An overrun error is generated if the data string is greater than specified within the character.

Of greater expense in communications time and equipment expense are other data security techniques, some of which are:

- o Data redundancy
- o Checksum characters
- o Error correction codes

Data redundancy techniques involve the multiple transmission of the same data a specified number of times with the receiver either selecting the majority match or, upon detection of data differences, rejecting the entire group and requesting another transmission. Checksum characters are generally referred to as longitudinal parity checking. A preceeding set of data characters are added and the truncated summation is transmitted as the last character of a message. The receiver performs the same summation and compares its result with the transmitted value. An unequal result results in the rejection of the message. Error-correcting codes add enormously to the communication time overhead and have never been considered seriously for traffic control systems.

INPUT:

The error detection parameters.

OUTPUT:

Error detection "flags" to indicate the type and severity of the error and the number of occurrences per time period.

PROCESS:

The type of error detection chosen shall be resident in all of the devices in the system. Deviations from the chosen message format or error detection format shall result in the rejection of the entire message content. The number and type of errors shall be reported by the central computer in the following formats:

- o Immediate operator alarms and reports.

- o Tabulation for periodic reporting.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

The immediacy of communications error reporting is one of the features of a centralized system. All of the error detection features are determined by the central computer resident system design.

Two-Level Distributed Systems:
Three-Level Distributed Systems:

It is generally more practical to preserve the same communications error detection scheme throughout a system. In a multilevel system, however, it is not required, or perhaps, not desired, if known communications media problems demand exotic error detection and/or correction schemes. In that case, the more elaborate error detection/correction schemes may be employed on only certain segments of the system.

2.7.2 Provide for Various Control Methods

The software should provide for direct computer control of several different types of controllers. Major functions should include transferring a controller from fallback to on-line, advancing the controller through predetermined intervals and phases, and transferring the controller from on-line to fallback.

The software provided should differentiate between pretimed controller and actuated controller operation in all aspects, including physical and timing plan database entries.

INPUT:

Timing plan data containing interval (pretimed controllers) or phase (pretimed or actuated controllers) timings.

OUTPUT:

Interval or phase advance commands transmitted to each individual controller.

PROCESS:

Pretimed Controllers

Either or both phase advance and interval advance control shall be provided as dictated by the user.

Phase advance control controls the dial (either real or programmed) of pretimed controllers. The system issues an advance command which allows the controller dial to cycle to the next dwell point. Clearances are timed locally as the timing dial advances.

Interval advance control is used for direct control of the (real or programmed) controller camshaft. With this method, advance commands are issued to advance the camshaft to each interval in the cycle.

Actuated Controllers

Actuated controllers shall be controlled by issuing hold-on-line, yield and force-off commands. The hold-on-line command takes the controller out of the fallback mode and places it on-line.

Force-off commands terminate minor phases which have been extended by vehicle actuations. Separate force-off commands shall be issued by the software for each ring of dual ring controllers.

The yield command, which may be a separate command or a momentary drop of the hold-on-line command, shall cause the controller to terminate the coordinated nonactuated phase providing there is a vehicle or pedestrian call on one of the actuated phases. The yield command creates a permissive period that allows the controller to yield to demand on an actuated phase, whether the demand occurred during, or before the beginning of the permissive period.

For systems where the communications and controller hardware include the capability for phase omit commands, the software shall extend the permissive period by selectively inhibiting phases that shall not be serviced during the cycle. This capability shall also include a pedestrian service omit feature.

The software shall provide for variable phase sequencing, variable coordinated phases and preferred service. When demand exists for a preferred phase and sufficient time remains in the cycle, the software shall allow the controller to service that phase.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

Careful attention must be paid to the capability and capacity of the central computer selected to insure that adequate main and mass memory capacity exists and that the processing power is sufficient to accommodate all of the requirements within the time constraints imposed by the system design.

Two-Level Distributed Systems:

The demands upon the central subsystem are somewhat reduced because of the somewhat less constraining communications requirements. (The same amount of data must be transferred to the local master, but the time allotted for that transfer may have less time dependent constraints.) The capacity and capability of the local control unit will have to be increased in order to accommodate any increase in control method capability.

Three-Level Distributed Systems:

The same logic stated above for the two-level distributed system applies to the three-level distributed system, except that the required increase in capacity and capability of the local control unit is partially transferred to the intelligent intersection controller.

2.8 Provide for Street Operation Verification

Verification of system operation must be incorporated in any computerized traffic control system. Operation of all street equipment must be monitored and malfunctions reported in real-time.

Controller operation is checked by monitoring the phase returns from each controller to insure that the controller is remaining in step with the computer and the other signals in the system. Detector activity is checked to determine if the data being reported are reasonable. Communication security checks, such as byte parity bits and/or message checksum characters must be included in the overall communications design to insure integrity of the operation of the communications equipment.

INPUT:

Inputs which shall be provided so that the system can monitor the operation of street equipment are as follows:

- Current phase information from each controller
- Current phase information from the stored database for the timing pattern being applied
- Activity of each system sensor
- Information from the database which indicates the range of values that is considered to be reasonable activity for each system detector
- Parity checks, checksum tests and/or other provisions to insure accurate communications data transfer

OUTPUT:

When malfunctions are identified, the error condition shall be brought to the attention of the operator and logged in the daily log.

PROCESS:

Controllers, detectors, and communications equipment shall be monitored during on-line as well as stand-by operation. Any detected error condition shall be logged. Error conditions shall be stored in a coded form that specifies the type, date, and time of the error.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

Since the central computer is in constant, second-by-second, communication with every item in the traffic control system, verification of field-installed equipment operation is real-time accumulated and real-time accessible.

Two-Level Decentralized Systems:

The real-time data accumulation and analysis should be incorporated into the design of the local control unit. Compacted data should be transmitted to the central computer on a "priority level" basis. For example, the failure of a detector may be relegated to a scheduled inquiry by the central computer for status data. An intersection controller in the "flash" state because of the conflict monitor determination of a failure should precipitate an immediate transmission of status data to the central computer.

Three-Level Decentralized Systems:

The intelligent local controller should have the capability to determine the status of the field equipments connected to it. It should also have the capacity to determine the need to institute the immediate request for status interrogation by the local control unit or to wait for the scheduled request. The local control unit design should incorporate the techniques stated for the two-level decentralized system above.

3.0 Process Detector Data

Vehicular flow information is an important part of any traffic control system. It provides the "performance feedback" real-time type of information which can, if used properly, contribute to the success of the system.

Provisions should be made for the extended time logging of detector data, raw, smoothed, and/or combined with historical data. No detector and associated electronics can be expected to operate error free, therefore, error-detection algorithms must be incorporated into the system design.

Although real-time -- moment by moment -- detector data may be of interest, especially for the observer of a display map instrumented to display real-time detector actuations, this type of information is of minor importance for the overall improvement of traffic flow. Smoothed and/or averaged data are of far greater importance.

These items are described in detail in the modules which contribute to Item 3.0, "Process Detector Data":

3.1 Provide for Data Logging

3.2 Provide for Error Checking

3.3 Provide for Data Smoothing

3.4 Compute Measures of Effectiveness

3.5 Predict Flow Trends

3.6 Provide for Vehicle Classification

3.7 Provide for Emergency Vehicle Detection

All of these Functional Modules follow the format described in the Introduction section of this report.

3.1 Provide for Data Logging (OPTIONAL)

For proper generation of new timing plans, detector data must be accumulated and properly analyzed. In order to accommodate this analysis, detector data must be logged in two types of data storage:

- o Disk storage for one or two days data storage.
- o Magnetic Tape storage or high density floppy disks for archival purposes.

Generally, because of the cost/benefit trade-off analysis, only one day's detector data storage is allowed on the on-line disk data storage subsystem. This data is generally stored as 15-minute accumulated data. At the end of the day, midnight, the usually implemented process is to transfer the past day's data onto magnetic tape or high density floppy disks.

INPUT:

Detector data with appropriate "flags" set as to the algorithm's determination of acceptability.

OUTPUT:

Storage of detector data in specified time increments (generally, 15-minutes) in short-term main memory storage, each 15-minute accumulation onto disk files, and each day's data onto magnetic tape storage or high density floppy disks.

PROCESS:

Detector data, in the form of volume and occupancy values for each detector instrumented, shall be stored in the computer's main memory in the form of smoothed values covering a fifteen minute period. Every quarter hour, this data shall be output to mass (disk) storage. At the midnight point of each day, the program shall have the capability to transfer this data to magnetic tape or high density floppy disks (if provided) for archival purposes. This archival data storage capability shall be operator selectable. Also operator selectable, shall be the capability to output the day's detector data to the line printer.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

Since all detector data is returned to the central computer in real-time, the accumulation of this data and its storage is merely a function of the computer and storage capacity which can be defined in the implementation specifications.

Two-Level Decentralized Systems:

The local control unit must assume the responsibility for accumulated detector data short-term storage. The amount and type of detector data to be transferred to the central computer must be carefully considered in order to prevent overloading of the communications subsystem thereby negating one of the most important positive characteristics of a decentralized system.

Three-Level Decentralized Systems:

The intelligent intersection controller must accomplish the detector data accumulation and data verification before data transfer to the local control unit. The local control unit, in turn, further processes this data for data compaction purposes before periodic data transfer to the central computer.

3.2 Provide for Error Checking (OPTIONAL)

Detector data may not always be representative of the true vehicular data flow. The most common error conditions are detector "chatter" whereby the detector output appears to be an extremely high volume with very low occupancy and detector "hang-up" whereby the detector output appears to be a vehicle parked over the detector (this is also the detector electronics failure condition). These are rather easy errors for a computer program to detect. Two threshold values are employed in the detector data analysis routine: too high a volume and too long an occupancy value.

For more sophisticated systems that employ historical data updating with actual vehicular flow data, appropriately smoothed, a comparison of real-time detector data with the appropriate time-of-day interval historical data may be employed. Again, threshold values must be employed to discriminate between normal variations in traffic conditions and abnormal data. However, in this case, at least three threshold values must be employed and an additional error check added to the detector error check routine. Using the UTCS Enhanced software specifications as an example, the threshold values are:

- o A systemwide proportionality constant for establishing the tolerance band of acceptability.
- o A systemwide additive constant for establishing the tolerance band of acceptability.
- o A systemwide maximum volume count constant.

These constants are additively and subtractively combined with the realtime and historical detector data to produce the following three classifications:

- o Acceptable detector data.
- o Marginal detector data.
- o Failed detector data.

(Refer to FHWA-TS-79-228 for the actual equations.)

INPUT:

Detector data

OUTPUT:

Detector error data by unit number and time of failure.

PROCESS:

Input detector data shall be examined and compared to threshold values. The results shall be reported as acceptable, or unacceptable.

SYSTEM TYPE CONSIDERATION:

Centralized Systems:

Since all detector data are directly input to the central computer system, all detector error determinations belong in the detector input software routines.

Two-Level Distributed Systems:

The local control units should have the major detector error determination role. The detector data returned to the central computer must contain "flags" to indicate marginal or failed detector data.

Three-Level Distributed Systems:

The intelligent local intersection controller serves as the first or only level of detector error determination. The local control unit may provide a higher level of detector error determination based upon comparison with historical or multiple intersection detector data analysis. The central computer may usurp part of the local control unit's software responsibilities, depending upon the communications data transfer rate and content.

3.3 Provide for Data Smoothing (OPTIONAL)

Detector data smoothing is generally required to prevent short term fluctuations from incorrectly influencing such operations as traffic responsive and/or critical intersection control algorithms. Not only are the immediately derived detector data of volume and occupancy (vehicle count and time-over-the-sensor) candidates for data smoothing, but the other Measures of Effectiveness (MOE's) as described in Functional Module 3.4.

INPUT:

Detector data with a resolution sufficient to determine volume and occupancy within 10 percent when standard sized vehicles are progressing at a speed of 45 miles per hour.

OUTPUT:

Smoothed volume and occupancy values per specified time period.

PROCESS:

Detector data individual vehicle counts, or short-term accumulated counts of volume and occupancy shall be introduced into the smoothing algorithms. Current time period counts shall be reduced by a systemwide factor and algebraically added to the prior count.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

In a centralized system, since all data input is completely controlled by the central computer timing, restrictions as to data accumulation and/or smoothing timings are minimal.

Two-Level Distributed Systems:
Three-Level Distributed Systems:

Serious consideration must be paid to the location (central or remote) at which partial, or all of the data smoothing is to take place. The consideration is dependent upon the data reporting schedule of the noncentral processors to the central computer system.

3.4 Compute Measures of Effectiveness (OPTIONAL)

Measures of effectiveness (MOE) reports permit the traffic engineer to gauge the effectiveness of the system operation. The generally accepted MOE's include:

- Unsmoothed, smoothed, and accumulated volume
- Unsmoothed, smoothed, and averaged occupancy
- Unsmoothed, smoothed, and averaged calculated speed
- Unsmoothed, smoothed, and averaged queue estimates
- Unsmoothed, smoothed, and accumulated calculated stops
- Unsmoothed, smoothed, and accumulated calculated delay
- Unsmoothed and averaged calculated demand
- Accumulated number of congested cycles

The unsmoothed occupancy (presence time) of individual vehicles is used to continually maintain an estimate of the queue size. Queue size is estimated by the examination of the detected occupancy values of the vehicles entering a detector zone and is adjusted based on the unsmoothed speed determination. Stops and delay are derived from the estimated queue size.

An unsmoothed MOE data file should be maintained for each detector in the system for a 24-hour period. At the end of each 24-hour period, the option should be provided to unload this data onto a magnetic tape or high density floppy discs for archival storage.

INPUT:

Detector data with a resolution sufficient to determine volume and occupancy within 10 percent when standard sized vehicles are progressing at a speed of 45 miles per hour.

OUTPUT:

Smoothed, unsmoothed, accumulated, and/or averaged measures of effectiveness.

PROCESS:

Unsmoothed MOE's of volume, occupancy, speed, queue, stops, and demand shall be calculated on a cycle-per-cycle or defined-time basis. The unsmoothed MOE values for each detector in the system shall be stored in a disk file for a 24-hour period in order to gain access to this data for recording or data smoothing purposes.

Smoothed MOE's shall be computed by combining a portion of the prior reporting period data with the current data. The portion of the prior data to be combined with the current data is a constant (between 0.0 and 1.0) multiplied by that prior data. The constant and the time period over which the data are to be smoothed shall be systemwide operator-specified values.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

In a centralized system, since all data input is completely controlled by the central computer timing, restrictions as to data accumulation and/or smoothing timings are minimal.

Two-Level Distributed Systems:
Three-Level Distributed Systems:

Serious consideration must be paid to the location (central or remote) at which partial, or all, of the MOE quantities are to be computed in real-time. The consideration is dependent upon the data reporting schedule of the noncentral processors to the central computer system.

3.5 Predict Flow Trends (OPTIONAL)

In order to enable a level of traffic flow prediction capability, an analysis must be made of detector data by hour-of-day and/or day-of-week. To manually pore over the usual periodic reports of detector data to detect any trends can be a monumental effort for any but the smallest size system.

In terms of data storage requirements, an economical way to determine traffic flow trends is to store accumulated volume by section and direction for a user-selectable time period per day-of-week. At the end of the selected time period, a comparison is made between last week's accumulated volume and the current accumulation. The percentage difference is calculated and added to the previous percentage. In this way, short-term fluctuations are ignored. Once a threshold value is exceeded, the trend is reported as part of the daily report.

INPUT:

Detector data for the duration of time specified.

OUTPUT:

Hard copy report (appended to the daily report) of threshold exceeded percentage increase or decrease in traffic volume.

PROCESS:

Accumulated traffic volume data over the time period specified (all day, 6am to 6pm; Monday through Friday, every day) for each section and direction within the section shall be compared each day with data from the corresponding day of the prior week. The percentage difference shall be computed and algebraically added to the prior two weeks computation. Once an operator-specified threshold value is exceeded, the percentage, along with section and direction description, shall be reported in the daily report.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:
Two-Level Distributed Systems:
Three-Level Distributed Systems:

Sufficient disk storage space must be allocated for the added files, along with main memory and processor time considerations.

3.6 Provide for Vehicle Classification (OPTIONAL)

Roadway vehicles may be classified by length by a "speed trap" loop configuration, whereby a pair of loops in a lane are installed a fixed distance apart and the detector amplifiers outputs are fed into an electronic circuit that will determine the speed of the vehicle (time duration from the vehicle detection of the first loop to the second loop) and the occupancy time of either loop (time duration of vehicle presence). Knowing the speed and occupancy time of a vehicle will give a fairly accurate (within 30 percent) determination of the vehicle length.

INPUT:

Vehicle classification by lengths of vehicles.

OUTPUT:

Data relative to the predominate types of vehicle types (by length) on a particular roadway for input into an offset optimization algorithm.

PROCESS:

Data originating from the vehicle classification elements shall be accumulated by the local processor unit and transmitted to the control computer for application to the responsive control algorithms and/or the reporting structures for vehicular flow analysis.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:
Two-Level Distributed Systems:
Three-Level Distributed Systems:

Vehicle classification data may be considered only for the "historical" data files, where these data accumulations are stored for eventual analysis of roadway usage. Under this consideration, reportage of vehicle classification data may be made at any convenient and non-time dependent interval.

3.7 Provide for Emergency Vehicle Detection (OPTIONAL)

Emergency vehicle detection schemes have been implemented, or envisioned, using either radio frequency or flashing light transponders. The flashing light transponders have been, by far, accepted as the standard means by which emergency vehicles are detected and given priority over other vehicles at signalized intersections. This type of system has one great advantage as far as maintenance is concerned. No intensive technical training is required to determine the operability of the vehicle-mounted transmitter. It either flashes or it does not. The receiver, however, can be a maintenance problem since it has to be maintained in a properly oriented position, or detection of the emergency vehicle can be completely missed, or detected too late for timely preemption.

The proposed radio frequency based type of systems consist of low power transmitters installed on the emergency vehicles with receivers installed at or near the signalized intersection. The receiver antenna may be imbedded in the roadway, much like a vehicle detection loop, or be attached to a lighting or utility pole.

INPUT:

Realization by the traffic control system of the detection of an emergency vehicle.

OUTPUT:

A green indication on the phase being preempted by the emergency vehicle as soon as safely possible.

PROCESS:

The emergency vehicle detectors shall be sampled at a rate at least equal to that of the highest priority monitoring function. Upon the detection of an emergency vehicle, the traffic control program shall immediately react by imposing minimum timings on all active phases, if possible, eliminate other phases in an effort to drive the controller to the green indication for the emergency vehicle.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

Centralized systems have a slight advantage over distributed systems in that emergency vehicle preemption-detector activation inputs can be acted upon without the communications delay inherent in distributed systems.

Two-Level Distributed Systems:
Three-Level Distributed Systems:

Special communications protocols must be provided in order to alert adjacent local control units as to the possibility of pending emergency vehicle preemption. The local control units should have the capability to report to central each and every emergency vehicle preemption.

4.0 Generate Reports

Reports are a vital element in the analysis of system performance. Failure reports may enable maintenance personnel to effect repairs before they are obvious to the motoring public. Performance reports enable the traffic engineer to evaluate the performance of the system and institute improvements.

The reporting formats to be considered are:

A. Measures of Effectiveness Reports

B. Status Reports

C. Summary Reports

D. Database Reports

These items are described in detail in the modules which contribute to Item 4.0, "Generate Reports":

4.1 Generate Measures of Effectiveness (MOE) Reports

4.2 Generate Status Reports

4.3 Generate Summary Reports

4.4 Generate Database Reports

All of these Functional Modules follow the format described in the Introduction section of this report.

4.1 Generate Measures of Effectiveness (MOE) Reports (OPTIONAL)

Measures of effectiveness reports provide an analysis of data collected over an exactly specified period of time. These reports may be segregated into the following categories:

A. Detector History Report

Each detector may have its historical volume and occupancy data stored for specific periods of time for usage during the times of detector failure. These items of data may be manually input and manually updated, or manually input, but dynamically updated after a data smoothing algorithm effort. The detector history files are usually, but not necessarily, stored in 15-minute increments.

An operator should be able to request detector history reports by detector number, detectors associated with a particular intersection, detectors associated within a section of intersections, as well as all of the detectors instrumented within the entire system.

B. Detector Analysis Reports

Past detector performance is summarized in this report. The operator specifies the period of time over which the summarization is to take place. The operator may specify a detector, all the detectors at a location, all the detectors in a section, or all of the detectors in the system. Volume, occupancy, speed, queue, stops, delay, demand, and congestion may be included in the report.

C. Traffic Performance Summary Report

Current detector performance is summarized in this report. The operator specifies the time period over which the summarization is to take place. The report is printed at the end of the time period specified. The operator may specify a detector, all of the detectors at an intersection, all of the detectors in a section, or all of the detectors in the system. The same parameters as listed above should be included in the report.

D. Split Monitor Report

The split monitor report records, in real time, the time of each controller phase or interval. The operator specifies the controller or controllers to be monitored and the period of time over which the monitoring is to take place. The report can take the form of a table, graph, or time-space diagram.

INPUT:

Operator entry of the type of report desired, the time span for the report and the detector or controller entries as required.

OUTPUT:

Printouts of the measures of effectiveness reports requested.

PROCESS:

Data storage of sufficient size shall be be allocated for the quantities to be available for report access. The software routines prepared shall offer the operator an unambiguous menu selection list and/or permit string inputs with consistent delimiters.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

All data to be considered for inclusion in the measures of effectiveness must be accessible by the reporting routines.

Two-Level Distributed Systems:
Three-Level Distributed Systems:

Consideration must be paid to the accessibility of real-time data from the remote intelligent units. The trade-off to be considered is the requirement for real-time data from more than a limited number of field units versus the communications subsystem economies expected in a distributed system.

4.2 Generate Status Reports

Operator-requested and/or scheduled system status reports are an absolute requirement for any traffic control system. It is through these reports that an operator and/or traffic engineer is informed about the operational status of the system. Status reports are "snapshot" views into system performance. They contain data available at the time of the request.

The format and content of these status reports can vary widely and still present the system owner with the required information needed for system performance monitoring. The generally accepted report format and content are as follows:

A. System Status Report

The system status report lists, by section, the desired and actual modes of operation, the timing plan number in effect, the number of controllers and detectors declared failed, and the time and date of the report, as a minimum. A system status report should be callable, by operator input, by section, or by total system.

The operator should be capable of requesting a single (snapshot) report, or an updatable report at a defined update interval, (usually, 15 minutes).

B. Intersection Report

The operator requests this report by system intersection number, section number (all the intersections in a section), or entire system (all of the intersections within every section in the system. The report should print the intersecting street names, as well as the pertinent intersection data such as, the section number within which the intersection has been assigned, the intersection's offset, cycle length, on-line or off-line status, interval data such as phase designation, fixed or variable interval, and nominal and minimal time durations. Intersection-assignable detector data, including phase, direction, volume, occupancy, speed, queue, stops, and delay should also be included as appropriate to the system design and intention.

C. Time-of-Day Plan Schedule Report

The time-of-day plan schedule report records the current time-of-day, day-of-week command assignments for each section within the system.

D. Intersection Status Report

The operator should be able to specify an intersection status report from an individual intersection, all of the intersections within a section, or all of the intersections in the system. This report should indicate the intersection status (on-line, off-line, critical intersection control, failed), control mode (time of day, traffic responsive, standby) cycle length, timing plan number imposed, controller type (pre-timed, actuated), etc.

E. Detector Status Report

The detector status report records the status of all detectors in the system. Various criteria can be assigned to the evaluation of detector performance. One such set could be acceptable detector data, software-determined marginal detector data, software-test-determined failed detectors, and operator-declared off-line detector status.

F. Failure Status Report

The failure status report records the frequency and number of controller, detector, and communications failures. Such a report should list the individual equipment condition status change by time and condition as well as the number of failures and the mean time between failures.

INPUT:

Operator request for a particular report and any subset of the generic report. Also, the output destination of the display of the report.

OUTPUT:

A CRT or line printer display of the contents of the requested report.

PROCESS:

In response to the operator input requests, data relative to the required report content shall be assembled and formatted in accordance with the requirements of the report. All data specified for inclusion in the reports shall be accessible while the applications program is in the real-time, traffic control, mode of operation.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

All data designed to be accessible while the applications program (traffic control) is being executed, may be considered for inclusion in one or more of the status reports.

Two-Level Distributed Systems:
Three-Level Distributed Systems:

Consideration must be paid to the time-dependent constraint of requiring the uploading of possible additional status data from the remote units in order to meet the requirements of the detailed status reports specified.

4.3 Generate Summary Reports (OPTIONAL)

Summary reports present historical records of system operations. These reports are generally referred to as "end-of-day" reports since they are usually programmed to be output at midnight. It is usually prudent to include the option to selectively omit any or all of these reports, to minimize paper and energy wastage.

The summary reports may include the following:

A. Equipment failure listings ordered by equipment type, equipment number, and time of failure.

B. Vehicular flow reports by section number, and detector number within the section. The contents of these reports can include volume, occupancy, and average calculated speed and such quantities as stops, delays, queue, and demand.

C. System activity log listing, by time of day, all operator and system scheduled events. Nonscheduled events such as power failures and resultant system recoveries, preemption events, and prolonged inactivity on actuated phases should also be recorded.

INPUT:

Software implemented end-of-day scheduling of reporting events. An option shall be the operator-instigated request for intermediate summary reports of start-of-day to current time reports.

OUTPUT:

Printed summary reports of equipment failures, vehicular flow data, and event logging.

PROCESS:

Data shall be collected and assembled into the desired formats and reporting sections. Optional operator inputs shall delete all or any one of the reports, or shall call for partial summary reports.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

Since all data are originated and returned to the central computer system, the only restrictions to the extent and content of the summary reporting requirements are the time of printout and the length (and utility) of the report(s).

Two-Level Distributed Systems:
Three-Level Distributed Systems:

The restriction as to summary data report content is concerned directly with the amount of data that can be "uploaded" to the central computer for data collection and formatting.

4.4 Generate Database Reports

Upon operator request, printed reports of the database contents must be enabled. Each report must list the database parameters as decimal numbers in units associated with a traffic control function, the time and date of the printout and headings that identify the specific function defined by each parameter. The operator should be able to request these database reports by subsystem as well as systemwide.

INPUT:

Operator command via the primary operator interface.

OUTPUT:

Printed reports listing the database parameters associated with the function requested.

PROCESS:

The operator input command structure shall be such as to permit selection of all or any part of the database. Each report shall be dated and contain sufficiently descriptive header data to permit examination of the data entries without need to refer to other documentation.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:
Two-Level Distributed Systems:
Three-Level Distributed Systems:

Regardless of the type of system, the entire database should be resident in the central computer or be readily obtainable by uploading from the remote units.

5.0 Provide Controls and Displays

Some measure of control and display implementation is required in every operator interactive system, be it a traffic control system or any other type of process control system. Several levels of control and display must be considered in any system design. Some of these decisions are:

A. Is a CRT (Video Display Unit--VDU) and/or a custom control panel required/desired?

B. Are multiple levels of operator control desired?

C. Is a panel board map display required?

D. Is there a genuine requirement for graphics CRT displays?

E. Is there a genuine requirement for a projection TV type of graphics display?

F. Are remote CRT's required for optimum operation, control, management, and maintenance of the system?

G. Is a color display actually required for proper systems operation/management?

H. What kind of hardcopy reporting devices are required?

These items are described in detail in the modules which contribute to Item 5.0, "Provide Controls and Displays":

5.1 Provide for Primary Operator Interface

5.1.1 Provide for CRT Menu Override

5.1.2 Provide for Interface with an Operator Console

5.1.3 Provide for Interface with a Remote CRT

5.2 Provide a Map Display

5.2.1 Communicate with the Map Display

5.3 Provide Hardcopy Logging

5.3.1 Provide an Activity Log

5.3.2 Provide Failure Logging

5.4 Provide Graphics Capability

5.4.1 Provide a Color CRT

5.4.2 Provide Graphics Capability

5.4.3 Provide Projection Displays

All of these Functional Modules follow the format described in the Introduction section of this report.

5.1 Provide for Primary Operator Interface

The primary operator interface with the traffic control system consists of some sort of data entry device, a display device that will temporarily indicate confirmation of data entry and a hard copy printer for permanent records of operator and system action as well as system performance.

The data entry device can be either the keyboard of a CRT terminal (Video Display Unit) or the pushbutton switches of a control panel. The temporary display device can be the display screen of a CRT terminal or an alphanumeric (or numeric only) illuminated indicator on a control panel. The hard copy printer can usually be a relatively inexpensive dot matrix character printer, or, for high-volume printing, a formed character line printer.

INPUT:

Operator entry for system, display, and reporting control.

OUTPUT:

System, display, and reporting control.

PROCESS:

The required CRT operator entry format shall accommodate two types of formats:

A. An "operator friendly" menu-driven format that shall guide an operator through the maze of selections available and permittable.

B. A menu-override capability that shall permit an experienced operator to circumvent the tedious menu-driven format (after entry of an appropriate control character) with abbreviated, in-line, directives that are consistent within and without the directive levels [example: DE (detector) and SE (sensor) shall not be interchangeable without definite differentiation], [example: CO (controller) and CONT (controller) type variations shall not be permitted in any of the data entry requirements].

The control panel pushbutton switch depression entry process shall be configured in a logical "top-down", "major-minor" format. Positive feedback must be provided by "Error", "Wait", "Enter/Ready", and alphanumeric or numeric readouts of data entry.

The hard copy printouts shall be callable by two methods:

1. Operator request for failure reports, performance reports, and activity reports.

2. End-of-day reports of all pertinent system data (selectable by operator input).

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:
Two-Level Distributed Systems:
Three-Level Distributed Systems:

Regardless of the type of system employed to control traffic, an operator input, feedback display, and hardcopy printout is essential. The time delay between action and reaction can vary widely depending on the the communications rate between elements of the system. With a centralized system, the time delay can be one second or less. With a two- or three-level distributed system, the delay can be seconds, minutes, hours, or days depending upon decisions reached as to data update rates.

5.1.1 Provide for CRT Menu Override

Software resident operator guidance through the maze of possible commands for control of the traffic system by selection from a detailed menu list must be implemented for the newly trained operator. However, once an operator reaches the skilled plateau, this "operator friendly" approach to system operation becomes obnoxiously burdensome. An "override" menu capability can aid immeasurably to the efficiency of system operation by permitting an in-line, shorthand type of command entry. Instead of choosing numbered choices (1= System, 2 = Section, 3 = Controller; then, 1 = On Line, 2 = Off Line), a skilled operator can enter "SY", "ONL" to accomplish the same result with far less effort.

This type of CRT menu override capability can result in greater operator efficiencies than possible with a pushbutton control panel since the system control intentions are formulated before the data entry and not as a "mindless" button-pushing reaction.

INPUT:

Recognition of CRT menu override-input format.

OUTPUT:

System control via CRT menu-override commands.

PROCESS:

Via a keyboard entry, the operator shall choose the menu-driven or menu-override format of data command entry. Strict rules of command and data entry shall be imposed when menu-override entry is chosen. The rules and format shall be consistent. Abbreviations for control entry shall not vary for differing types of formats.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:
Two-Level Distributed Systems:
Three-Level Distributed Systems:

The CRT menu-override structure procedure does not vary in functional specification, regardless of the type of system to be implemented.

5.1.2 Provide for Interface with Operator Console (OPTIONAL)

An operator console shall be defined as a pushbutton panel for the operation of any one or all of the following:

A. Virtually every system operation

B. Display operations

C. Emergency operations

A pushbutton control console must, of necessity, be a custom-made device (no two installations have the exact system requirements). A CRT terminal operational backup capability must be provided if extensive system downtime must be avoided.

INPUT:

Traffic control system interface software with control console reaction time constraints

OUTPUT:

Control of system operations and reports

PROCESS:

Depression of a pushbutton switch shall activate a unique input to the computer so to be properly interpreted by the computer to implement the designated command. The execution of such a pushbutton activation input shall be the same as the corresponding input of an operator CRT terminal keyboard input entry.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:
Two-Level Distributed Systems:
Three-Level Distributed Systems:

Regardless of the type of system employed to control traffic, the command input structure remains the same. A "top-down" hierarchy must be maintained to preserve an orderly and easily understood command structure.

5.1.3 Provide for Interface with Remote CRT (OPTIONAL)

A CRT terminal is termed "remote" when it is not physically located within the confines of the computer or system control room areas and is not primarily used for system control, but rather for status and performance monitoring. A remote CRT may be located in the Traffic Engineer's office for immediate access to the various reports available from the system to gauge system performance in real-time. A remote CRT may also be installed in the maintenance facility for easy access to failure reports. An interface may also be provided for the use of radio and television station traffic reporting.

System operational protection must be provided whenever remote terminals are considered. The following points must be considered whenever remote terminals are proposed for incorporation into the system:

A. What level of access shall be permitted

B. Shall system control be permitted

The Traffic Engineer should have all reports concerning system performance and equipment failures available on a request basis. The level of system control provided depends upon the number and competency level of the system operators.

The personnel at the maintenance facility may be restricted to access to equipment failure reports only, with no system control capabilities. However, the ability to declare a reported failed equipment unit as "repaired" or to declare an intermittent failure as a permanent failure (in order to de-clutter the real-time log failure table) can aid immeasurably to the system maintenance effort.

The radio and television terminal interface shall provide no system control capabilities and shall permit access to only overall traffic performance reports. A special report structure is worthy of consideration (instead of the usual traffic engineering MOE quantities, Low, Medium, or High levels of congestion may be reported).

INPUT:

Password protected or special software per terminal interface access to system command, monitor, and MOE data.

OUTPUT:

Report displays appropriate for the user.

PROCESS:

Report and system control access shall be operator changeable password protected under limited conditions (reasonable assurance is provided that the passwords will be kept confidential). Otherwise, separate software packages shall be provided for each remote terminal which will reject all requests for unauthorized actions. Any modification to these separate software packages to allow expansion of the monitoring and control activities shall remain the province of the prime system programmer to minimize the impact on the system operation.

Remote CRT terminal display data updates shall not be greater than twice the prime terminal update periods in order to provide real-time aspects.

Sufficient terminal "ports" and modems, if required, shall be provided to accommodate each and every CRT terminal.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:
Two-Level Distributed Systems:
Three-Level Distributed Systems:

The type of system employed does not affect the decision to use remote CRT terminals. The data update rate or the command effective time is dependent upon the communications subsystem polling rate of the remote units. Therefore, progressively slower remote CRT update rates must be expected as the degree of decentralization increases.

5.2 Provide Map Display (OPTIONAL)

A panel board map display provides a "snapshot" display of system performance that can be far more revealing than printed reports. Vehicle concentration levels, signal display indications, and equipment failure locations and extent can be viewed and understood far more quickly via a panel board map display. (A large scale CRT graphics display can present the same "immediate" data. See FM 5.4.2.)

The immediacy of data presentation depends upon a number of factors:

A. Central computer time line capability to update the map after completing other, higher priority tasks

B. Communications polling rate of the remote units

C. Type of system: Centralized, Two- or Three-Level Distributed.

Generally, the central computer capabilities to "have the time" to update the map is of minor importance. Today's computers (exception: some microcomputers) can easily accommodate the map display update requirements.

The communications polling rates of the remote units are of prime importance. It is a needless effort to update the map display with "old" data. The map display update rate must be equal to or less than the data accumulation rate which is dictated by the communications polling schedule.

In order to capitalize upon the communications cost advantage of a two- or three-level distributed system, a corresponding, significant, decrease in map display data update period must be expected.

INPUT:

Data relative to the type and number of display elements required.

Size, power, and environmental restrictions on the map display.

OUTPUT:

A map display commensurate with the requirements and restrictions of the system design.

PROCESS:

The number of data elements desired shall be carefully enumerated. Each data element, an intersection, for example, may require 16 or more individual indicators for complete display of all intersection states (all vehicular signal displays plus walk/dont-walk displays). Vehicular detector data display at each intersection adds to the requirements.

Since the map display can only (accurately) display the data returned to the central computer by the communications subsystem, the display limitations are tied to the communications subsystem capabilities. The communication subsystem capabilities are tied to the type of system desired (centralized or distributed) and the economically practical remote component polling rate.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

The number of display elements and the display update rate is entirely dependent upon the central/remote communications update rate and the cost/benefit ratio derived to accommodate the display requirements.

Two-Level Distributed Systems:

Since the main benefit of a distributed system is a reduction of communications costs (communications between central and the local control units can be at a reduced rate or more remote units per communications line), any map display configured for such a system must have a slower update rate.

Three-Level Distributed Systems:

The same guidelines apply as stated for two-level distributed systems except that the display map update rate must be correspondingly slower.

5.2.1 Communicate with the Map Display (OPTIONAL)

A map display requires unidirectional communications. That is, only outputs from the computer (and some bidirectional "handshaking" signals) are required to illuminate the display devices employed. An indicator, whether it is a sensor indicator, or one state of a traffic signal controller, or one segment of a numerical display, is referred to as a data point. Each data point requires one bit of information from the computer to define its "on" or "off" state. "Address" information may also be required to define the exact location of the data point, or sets of data points. The indicator "drivers" may be resident within the central computer vendor's hardware, may be supplied by the map vendor, or may be supplied by another source.

The display update requirements imposed depend upon the communications update rate between the central computer and the remote units. The display update requirements cannot exceed the slowest of these communications rates.

INPUT:

Data relative to the "on" and "off" status of each of the map display's data points.

OUTPUT:

Illumination, or the extinguishing, of each of the map display's data points upon command of the central computer.

PROCESS:

The central computer applications program shall collect the relevant data, organize the data elements in the format required and output this data via appropriate hardware elements to the map display.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

The map display can be updated at a rate commensurate with the central/remote communications polling rate. The data displayed on the map may include any or all of the data received from the communications units or generated by the central equipments status data.

Two-Level Distributed Systems:

The update rate of the map display must be limited to the ordinary communications polling rate between the central computer and the local control unit. Extraordinary conditions may permit the display of the status states of a particular local control unit at a higher rate (to the detriment of the other local control unit status display) in order to closely examine the operation of the particular local control unit.

Three-Level Distributed Systems:

The map display update rate must be further restricted over that of a two-level distributed system in order to maximize the advantages of a communications cost advantage of a three-level distributed system. A single local intersection controller's state may be displayed in real-time.

5.3 Provide Hardcopy Logging

Hardcopy (printed) reports are required for detailed review by system analysts and maintenance personnel. The capability to produce operator-requested and system-scheduled activity logs, and system component failure listings will appreciably enhance overall system performance.

INPUT:

Operator-requested or system-scheduled operational events. System-determined component failures.

OUTPUT:

Continuous activity reports and continuous or operator-requested failure reports.

PROCESS:

Central computer storage of operator activities, system-scheduled operational activities, and system determined-component failures. Operator-selectable continuous or on-demand printout.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:
Two-Level Decentralized Systems:
Three-Level Decentralized Systems:

All types of systems require printed reports of system activity and component failures for proper system performance analysis and maintenance.

5.3.1 Provide Activity Log (OPTIONAL)

A system activity log includes all system-involvement-operator actions or system-scheduled actions. A printed (hardcopy) system output is a valuable analysis vehicle to determine operator and system efficiency. (A non-system-involvement operator action is defined as operator initiated request for reports, display of various display map functions, etc.)

INPUT:

Appropriately edited operator- or system-scheduled events or equipment failure data from the appropriate software routines.

OUTPUT:

A printed, continuous, real-time, report of all operator-instigated or scheduled system actions in chronological order.

PROCESS:

Each operator or predefined, scheduled system operation shall be listed in chronological order. The operator actions to be deleted from this report shall be those actions related to report requests, display requests, and any other such actions which do not directly affect the intersection controllers.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:
Two-Level Distributed Systems:
Three-Level Distributed Systems:

All types of traffic control system implementations require a hardcopy activity log in order to properly evaluate system or operator reaction to events.

5.3.2 Provide Failure Logging

Printed ("hardcopy") failure log reports are an essential part of any traffic control system. The usual method of hardcopy presentation is chronological by failure event. An attractive alternative (or additive) report structure is to provide a callable report listing the failures by equipment type in chronological order. That type of report can add immeasurably to the maintenance effort by reducing the manual data reduction time.

INPUT:

Formatted outputs of the failure analysis routines.
Operator selectable options as to printout timings.

OUTPUT:

Printed reports of failure events.

PROCESS:

Operator selectable options shall be provided to permit real-time printouts, callable chronological printouts or callable failure-type chronological printouts. A remote (maintenance facility) printout shall be initiated by remote keyboard entry or by system-operator-instigated command.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

Real-time failure data acquisition is possible for all components of the system.

Two-Level Distributed Systems:

In order to obtain the cost benefits of a distributed system, real-time failure data should not, in totality, be available to the central system. If the system design depends upon periodic polling of the local control units, then the failure data can only be reported during these polling periods. Communications economics may dictate that two or more polling periods may expire before the total equipment failure list is completed. If the system design permits "unsolicited" responses from the local control units, a failure of a major component (a predefined critical intersection controller) may be reported between central polling periods. The central polling periods must be on the order of hours before this option is cost-effective.

Three-Level Distributed Systems:

The same philosophy applies to three-level distributed systems as was ascribed to two-level distributed systems. In three-level distributed systems, however, an additional delay in failure reporting will be caused by the polling time between the local control unit and the intelligent local intersection controller.

5.4 Provide Graphics Capability (OPTIONAL)

Electronic graphics can considerably enhance the reporting and system analysis capability of a traffic control system.

Three types of graphics display are considered in Functional Modules 5.4.1, 5.4.2, and 5.4.3. The first Functional Module considers the provision of a color CRT for the display of standard alphanumeric reports and "enhanced" reporting structures such as pie charts and bar graphs as well as the display of "static" geometric intersection data. The second Functional Module discusses the provision of dynamic graphical displays of real-time traffic flow conditions as well as the display of real-time traffic controller status. The third Functional Module is concerned with the large screen display of the other two Functional Modules.

INPUT:

Data relative to the report or graphics display desired.

OUTPUT:

A display which is meaningful and appropriate to the traffic control problem solution.

PROCESS:

Software routines and hardware interfaces shall be provided to permit the transmission of data for the type of display required. Refer to subordinate Functional Modules 5.4.1, 5.4.2, and 5.4.3. Error checking shall be included in order to prevent erroneous and uninterruptible displays.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:
Two-Level Distributed Systems:
Three-Level Distributed Systems:

The addition of color-coded displays, although at additional cost over monochrome displays, add to the interpretation and utilization of the traffic control system regardless of system architecture.

5.4.1 Provide Color CRT (OPTIONAL)

Color graphics can add dynamism to any display. Pie charts, bar graphs, and alphanumeric reports take on a new dimension when different colors are used to stress the importance of items.

Equipment failure reports, for example, usually contain many items of minor significance. Using various colors to denote the relative importance of each failure event adds immeasurably to the readability of the report and speeds the maintenance response time.

Static intersection geometry displays are enhanced by the judicious use of color since items of interest can easily be discerned without ponderous effort. A cost/benefit decision which must be considered is whether stylized or actual intersection geometry displays are sufficient for the application. Stylized graphics are decidedly less expensive.

Multiple intersection displays are often required in order to gain a full appreciation of traffic flow conditions. The degree of detail must be sacrificed in order to "fit" a number of intersections on any but the largest and highest resolution CRT displays.

INPUT:

Appropriate traffic performance and equipment status data plus the command to output the proper format.

Static Intersection Geometry data:

Data relative to the number of lanes on each approach, the width of the lanes on each approach, left turn lane length and width, bus stop locations, bus stop lane length and width, location of traffic signals and their controller and the angle of interception of the cross streets.

OUTPUT:

Color graphics CRT displays of "standard" reports as well as pie charts, bar graphs, and intersection geometrics.

PROCESS:

Routines shall be provided in the software package that will permit the operator entry of desired parameters and the desired report format.

For intersection geometrics, software routines shall be provided that will permit the entry of geometric information and the storage, retrievability and display of such information.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:
Two-Level Distributed Systems:
Three-Level Distributed Systems:

A color CRT can be added to the equipment requirements of any traffic control system as long as the data update requirements are not specified to exceed the normal command and monitor communications input/output data rate.

5.4.2 Provide Graphics (OPTIONAL)

Providing graphics capability on a systemwide basis is considerably different than the task of providing a graphic symbolization of an intersection. Many cost/benefit questions must be answered. Some of these are:

A. Are static displays sufficient?
   1. Are intersection geometry displays sufficient?
   2. Are stylized or actual intersection geometry displays sufficient?

B. Are dynamic displays required?
   1. How much intersection phase status data must be displayed?
   2. How many intersections must have dynamic phase data updated at a near real-time data update rate?
   3. What kind of vehicle sensor data is to be displayed? (Real-time vehicle actuations, smoothed data, unitary or multiple intersection data.)
   4. What minimum data update rate can be tolerated?

Dynamic graphical electronic displays offer advantages:

A. Configuration changes do not necessarily require hardware revisions (unless memory expansion, screen size, or data update speed requirements change significantly).

B. Incandescent or other type (LED, for example) lamp burnout does not cause erroneous interpretation of the resultant display.

C. The capability for "zooming in" to examine a particular problem area, in real-time, may have a priceless advantage.

Dynamic graphical electronic displays, however, have serious disadvantages:

A. One video path component failure can cause the failure of from one-third to the total effectiveness of the display.

B. The total system costs of a system wide real-time electronic graphic display can reach a factor of 40 to 200 times that of a panel board map.

INPUT:

Static geometrical information (roadways, intersection definitions).

Dynamic data input "pointers" to permit dynamic data "overlay" of intersection and vehicle data display.

Minimal time and memory requirements on the prime traffic control computer.

OUTPUT:

Real-time display of system geometry plus dynamic intersection status and vehicular status information.

Option: Selectable displays on each instrumented operator console.

PROCESS:

The graphics subsystem shall have the capability to store all of the static and dynamic "pointer" information in inverse proportion to the expected time and memory requirements of the prime traffic control computer. Ideally, the prime traffic control computer need only to output the dynamic intersection status and vehicular MOE data with the corresponding "pointer" information to the graphics subsystem.

The graphics subsystem shall merge the static data contained within itself with the dynamic data periodically transmitted to it from the prime traffic control computer and produce a readable display. The graphics subsystem shall be capable of producing multiple displays with independently varying demands depending upon the number of system operators involved in the traffic control operation.

SYSTEM TYPE CONSIDERATION:

Centralized Systems:

The design logic is simplified since all interfacing is accomplished directly through the central computer.

Two-Level Distributed Systems:

If universal real-time display of traffic controller and vehicular status information is a requirement, then the advantages of a distributed system is invalidated. If periodic (1 to 5 or more minutes, depending on the polling rate) updating of field data on the graphic display is deemed permissible, then the inclusion of such a subsystem is worthy of consideration.

Three-Level Distributed Systems:

Same considerations as for the two-level distributed system.

5.4.3 Provide Projection Displays (OPTIONAL)

Projection graphics displays are, generally speaking, of three types:

A. Magnifying lens in front of a standard TV set.

B. Magnifying lenses in front of three color TV CRT tubes, each projecting a primary color.

C. Single optical path light valve system.

The first two projection graphics types demand the use of a special high reflectivity, lenticular screen and, at least, a semidarkened room for acceptable viewing. The acceptability of the viewed presentation depends upon the viewer's distance from the focal point of the lenticular screen.

The third type system can produce an up-to-20-foot-wide picture with only a 30-foot separation between the projector and the screen (which need not be more than is required for acceptable home slide projection viewing).

Projection displays can, of course, be capable of black and white only, or color display. Only color displays can be considered acceptable for traffic engineering situation displays.

INPUT:

NTSC-encoded signals or separate RGB signals.

NOTE: MUST BE COMPATIBLE WITH THE GRAPHICS PACKAGE

PROVIDED. (Refer to Functional Modules 5.4.1 and 5.4.2.)

OUTPUT:

A visual presentation of a geographic area with at least one picture element (pixel) per identifiable quantity.

PROCESS:

The output of the graphics capability package shall permit the addition of a graphics display that shall duplicate the presentation of any of the selected operator display(s). An option shall be the capability to separately choose the type of display to be presented on the projection display subsystem. The choice of operator display, or special display, shall be by their graphics capability package operator input console selection.

SYSTEM TYPE CONSIDERATIONS:

Centralized Systems:

As in all systemwide display installations, a centralized system offers the only real-time display capability. The choice of a projection display capability must be considered within the cost/utility framework.

Two-Level Distributed Systems:

In a two-level distributed system, the choice of a projection display system can be considered if the display is to echo the operator's display, or is to provide overall, smoothed operational data.

Three-Level Distributed Systems:

Same considerations as for a two-level distributed system.

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FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH, DEVELOPMENT, AND TECHNOLOGY

The Offices of Research, Development, and Technology (RD&T) of the Federal Highway Administration (FHWA) are responsible for a broad research, development, and technology transfer program. This program is accomplished using numerous methods of funding and management. The efforts include work done in-house by RD&T staff, contracts using administrative funds, and a Federal-aid program conducted by or through State highway or transportation agencies, which include the Highway Planning and Research (HP&R) program, the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board, and the one-half of one percent training program conducted by the National Highway Institute.

The FCP is a carefully selected group of projects, separated into broad categories, formulated to use research, development, and technology transfer resources to obtain solutions to urgent national highway problems.

The diagonal double stripe on the cover of this report represents a highway. It is color-coded to identify the FCP category to which the report's subject pertains. A red stripe indicates category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, and green for category 9.

FCP Category Descriptions

1. **Highway Design and Operation for Safety**
   Safety RD&T addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act. It includes investigation of appropriate design standards, roadside hardware, traffic control devices, and collection or analysis of physical and scientific data for the formulation of improved safety regulations to better protect all motorists, bicycles, and pedestrians.

2. **Traffic Control and Management**
   Traffic RD&T is concerned with increasing the operational efficiency of existing highways by advancing technology and balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, coordinated signal timing, motorist information, and rerouting of traffic.

3. **Highway Operations**
   This category addresses preserving the Nation's highways, natural resources, and community attributes. It includes activities in physical maintenance, traffic services for maintenance zoning, management of human resources and equipment, and identification of highway elements that affect the quality of the human environment. The goals of projects within this category are to maximize operational efficiency and safety to the traveling public while conserving resources and reducing adverse highway and traffic impacts through protections and enhancement of environmental features.

4. **Pavement Design, Construction, and Management**
   Pavement RD&T is concerned with pavement design and rehabilititation methods and procedures, construction technology, recycled highway materials, improved pavement binders, and improved pavement management. The goals will emphasize improvements to highway performance over the network's life cycle, thus extending maintenance-free operation and maximizing benefits. Specific areas of effort will include material characterizations, pavement damage predictions, methods to minimize local pavement defects, quality control specifications, long-term pavement monitoring, and life cycle cost analyses.

5. **Structural Design and Hydraulics**
   Structural RD&T is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highway structures at reasonable costs. This category deals with bridge superstructures, earth structures, foundations, culverts, river mechanics, and hydraulics. In addition, it includes material aspects of structures (metal and concrete) along with their protection from corrosive or degrading environments.

9. **RD&T Management and Coordination**
   Activities in this category include fundamental work for new concepts and system characterization before the investigation reaches a point where it is incorporated within other categories of the FCP. Concepts on the feasibility of new technology for highway safety are included in this category. RD&T reports not within other FCP projects will be published as Category 9 projects.