

# TRAFFIC ANALYSIS and DISPLAY for the SAN FRANCISCO VESSEL TRAFFIC SYSTEM

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*The Traffic Analysis and Display (TAD) subsystem for the San Francisco Experimental Vessel Traffic System has been designed to enable operators to obtain position, speed, and identification information on vessels of interest more quickly and accurately than previously possible with manual systems. It has nine computers connected together in a fourth generation architecture. Three display stations allow operators to enter and edit vessel information independently, to associate this information with a radar contact, or to make relative position or closest-point-of-approach measurements on contacts of interest. The TAD system uses a fixed display format, operator prompting cues, and computer controlled function buttons to allow the operator to work interactively with the system in a simple and quick manner. It is presently installed and operating reliably in the Coast Guard Harbor Advising Radar site on Yerba Buena Island.*

**T**HE TRAFFIC ANALYSIS AND DISPLAY (TAD) SUBSYSTEM for the San Francisco Experimental Vessel Traffic System is designed to enable operators to obtain position, speed, and identification information on vessels of interest more quickly and accurately than previously possible with manual systems. It is presently installed and operating in the Coast Guard Harbor Advisory Radar site on Yerba Buena Island.

The TAD system is unique in that it has nine computers connected together in a fourth generation architecture, which uses distributed processors and a common input/output (I/O) bus. Within this architecture is a mini-time-sharing system of three users combined with a multi-processing system. Data are received from two radar processing computers, processed, put into the files, and displayed on any or all of eight displays. Independently, operator services are processed which make use of either the radar data in the track file or the storage and editing capability of the computer. In the background an analysis program runs continually, looking for trouble spots in the traffic of interest, and reporting any adverse results to the operators.

## Requirements

The basic TAD system requirements have been discussed previously but will be briefly summarized here. A file must be maintained on all contacts held by the Automatic Detection and Tracking (ADT) subsystem. A clutter-free display must be provided, including all medium and large size contacts. The displays must have sufficient resolution to enable an operator to perform his duties easily. The operators must have the capability to identify contacts and to associate them with text data entered and held in a computer file. The system should provide geometrical navigation information on any contacts and be able to monitor vessels in nonradar contact areas (Vessel Movement Reporting System—VMRS). A multiple operator capability must be available for both high-density traffic situations and redundant backup operations.

To satisfy these requirements, the TAD system has a track file that can hold 510 contacts (including buoys); it has an identified vessel file for 30 contacts, each of which may be in radar contact, in the VMRS area or about to enter the



system. A set of vessel data services is available which allows the operator to enter the vessel data, recall it (Status), change it (Full Status Edit), and associate it with a radar contact (Identify). The system also has a set of analysis services that enable the operator to obtain Relative Position or Closest-Point-of-Approach (CPA) information on contacts and/or fixed points. A simple, flexible set of operator actions has been developed to control the system using these services.

## Categorization of Information

Three major vessel categories have been established and these, along with the unidentified radar contacts, make up the primary information which must be maintained in the files. These major categories are:

1. Radar Identified (R)—a vessel with text information in the system is associated with a radar contact.
2. Imminent (I)—a vessel with text information is about to enter either the Radar or VMRS areas, but is not associated with any radar contact.
3. VMRS (V)—a vessel with text information is active in the VMRS area.

Several subcategories have been defined which are used by the automatic processing system.

1. A Lost Identified Contact is an identified vessel for which radar contact has been lost.
2. A VMRS overdue vessel is one that is more than 15 minutes overdue at the next reporting point.
3. A Collision Warning is an alert issued when an identified vessel is on a course that will take it within 1,000 feet of another identified vessel within the next four minutes.

As the attributes change, a vessel can be transferred from one category to another by operator action or automatically by the system according to a programmed set of rules.

## Equipment Layout

The major on-line elements of the TAD system are a traffic computer, three interactive display computer/processors, five noninteractive display processors, and a disc storage unit (Fig. 1). A discussion of the hardware and software in

greater detail than is given here has been published.<sup>1</sup>

The main system control computer is the Traffic Computer. At the time this system was defined, the Coast Guard had on hand several DDP-516R computers purchased previously from Honeywell for a task which had not materialized. At APL there was considerable experience with the 516, support software was available from Honeywell in the form of real-time executive and utility programs, and an assembler was available for the 360/91 with its attendant large file and linkage edit capability. Thus the choice of the prime computer was obvious.

However, to provide the required system performance, the memory was increased from 8K to 16K, hardware multiply and divide circuits were added, and the input/output capability was expanded by the addition of 16 direct-memory-control channels.

The three interactive computer processors serve the working displays at the two operator stations and at the supervisor's console, and the five noninteractive processors serve five satellite displays in the two traffic consoles. Considering the display requirements and the equipment available at the start of system fabrication, the use of refreshed displays was selected as the most straightforward way to provide and easily maintain good clear pictures. (High resolution storage tube techniques were seriously considered but were rejected for two reasons—the quality of the picture was not as high as was desired and there were erase problems leading to too many system complexities.) Having chosen the refreshed display system, and after examining the complexity of the pictures needed along with the high data rates for refreshing them, the decision was made to use separate computers for display purposes, rather than to rely on the traffic computer.

Each of the display computers selected have both a display processor, which refreshes a random access on X-Y monitor at a 40 Hz rate and a minicomputer from data format and manipulation. The three working display computers have 8K of core memory and provide the operator interaction with the system through the Function Buttons, Trackball, and Keyboard. The five Satellite Dis-

<sup>1</sup> R. G. King, A. J. Cote, Jr., and F. S. Gregorski, "Minicomputer Processing and Display for the San Francisco VTS," *Proc. IEEE/NBS Symposium on Minicomputer Trends and Applications*, Apr. 4, 1973, 35-44.



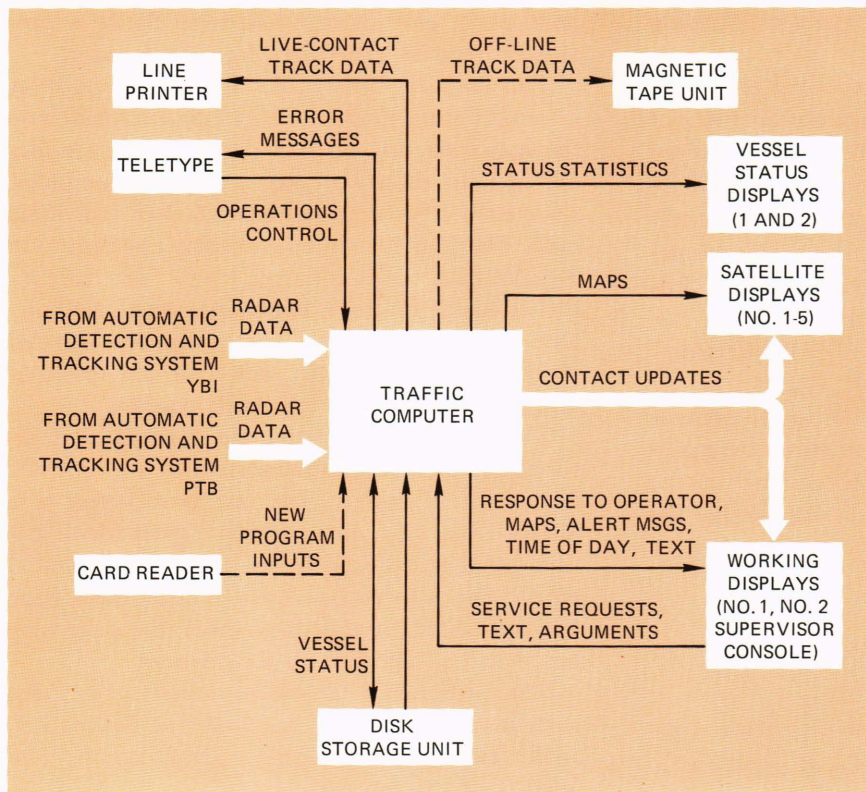


Fig. 1—TAD system flow diagram.

play Computers have a 4K of core memory and are strictly passive display devices.

For the display of alphanumeric-only information, TV techniques provide good quality at a much lower price than refreshed units. Thus, for vessel status display, the system has two 9-inch TV monitors with independent storage and a display capability for 16 lines of 32 characters. The characters are approximately  $\frac{1}{4}$  inch high, which provides easy readability, both when sitting at the console or standing at a distance of several feet from it.

When several independent asynchronous machines are hooked together, the problem of who is in control becomes significant. The interfaces between traffic and display computers have been specifically designed to assure that the Traffic Computer is indeed in control of the system. The Display Computers can request data transfers and services, but the Traffic Computer directs the actual transfers, both as to type and timing.

The Disk Storage unit stores map outlines, non-current service programs, background analysis programs, and vessel text information. A teletypewriter is used for initial system start-up and for error printouts. A Line Printer is used for a

fast printout of active contact information as well as off-line printout of radar data. A Magnetic Tape unit and a Card Reader are used for off-line program input of data collection.

### Functional Allocation Among Computers

The allocation of the functions between the Traffic Computer and the Display Computers is based upon two factors:

1. Minimization of data and program transfers between computers using the common input/output bus and
2. Performing all mathematical analysis computations in the Traffic Computer.

The first factor emphasizes system reliability by minimizing the chance for error in input/output transmissions. Erroneous data transfers, giving incorrect information which might be somewhat troublesome to an operator, should not bring down the system. Erroneous transfers of operating program blocks, however, could cause the system to hang up in a mode which would require reloading programs for recovery; this is unacceptable in a limited operational system. The



I/O minimization also helps to avoid overloading the input/output system.

The second factor in the functional allocation stems from the insufficient arithmetic capability of the display computers to perform the required analyses within the available core storage. Had an acceptable display system with an expanded arithmetic capability been available, the analysis functions would have been done in that computer, thus further simplifying the input/output transfers.

The functions performed in the Traffic Computer and the working Display Computers are listed in Table 1. They reflect the fourth generation concept of distributed computers by the maximization of operator action processing in the Display Computers as well as in the display file storage there.

TABLE 1

ALLOCATION OF FUNCTIONING AMONG COMPUTERS

*Functions of Traffic Computer*

- Accept and convert radar data from both Radar Computers.
- Prepare and send contact update data to Display Computers.
- Maintain a file of current radar data.
- Merge radar data from coverage overlap areas.
- Maintain a file of Lost Identified Contacts.
- Support operator services on the Working Displays.
- Maintain a vessel information file.
- Perform periodic background analyses:
  - Collision prediction for identified vessels.
  - VMR report overdue check.
  - Transmission of alert area, alarm signals.

*Functions of Working Display Computers*

- Display the map or VMRS page.
- Display Radar Contacts.
- Receive and display service-connected displays.
- Receive and display alert messages.
- Accept and process all operator inputs.
- Generate operator control symbols.
- Transmit service requests, arguments, and data to the Traffic Computer.

*Functions of Satellite Computers*

- Display the map or VMRS page.
- Display radar contacts.

## File Structure

The major system files are the radar contact Track file, the Contact Display files, and the Vessel Information file.

The system Track file contains track information on contacts from both ADT systems. It is ordered according to radar track number and held in core memory. It contains track position, velocity, status (new report, coasting, in overlap

area, etc.), contact size, and type. Space is provided for up to 255 tracks from each radar.

The contact display files contain the display information on those contacts that are located on the map currently on that display. Separate files are kept in each working or satellite computer, since each computer may have its own individual map. The four files in each display contain up to 30 identified vessel contacts, up to 128 unidentified contacts, up to 16 blinking contacts, and any lost identified contacts. These files are updated by the Traffic Computer each time new information is received from the ADT systems.

The Vessel Information file contains text information entered into the system by the operator for up to 30 vessels. The text is recorded as a Vessel Data Page along with a Vessel Identification Number assigned by the system upon initial entry. The information on a Vessel Data Page may be edited, modified, or the entire page may be deleted at any time by the operator.

The information carried for any vessel includes such items as vessel type, origin or destination, radio call frequency, pilot identification, and VMRS data if appropriate.

The VMRS page is not a file—i.e., the information to be displayed is not held in a specific storage area. Rather, it is created from Vessel Data Page information and displayed on a satellite or working display as assigned by an operator.

There are three libraries of programs in the Traffic Computer system:

1. The resident system is a collection of programs permanently resident in the Traffic Computer memory when the system is in operation. It includes the basic Executive Program plus programs to process the incoming radar data, manage operator services, and provide background analyses, as well as several small support programs.

2. The operator service program library is a collection of programs stored on the disk; individual programs are loaded into the operator service overlay core area as required for operator services.

3. The background services library is a collection of programs stored on the disk, with individual programs periodically loaded into the background overlay core area for the background analyses.

The resident system is also stored on the disk and may be loaded into core by the system utility



loader to start or restart the system. It is organized so that in case of a program failure it can be reloaded and restarted while preserving previous radar contact information and access to the Vessel Information file.

## System Processing

The TAD system accepts information from the two ADT systems and analyzes and formats the data for display on the working and satellite displays. It also accepts information from the operators in the form of requests for services, designation of contact, category, or display information for performance of the services, or text information associated with a particular vessel. Figure 1 shows the data flow through the system.

The highest priority of data handling is the receipt and display of radar contact records. The Traffic Computer receives a radar contact record, converts Range, Bearing, Range Rate, and Bearing Rate to System X, Y,  $\dot{X}$ , and  $\dot{Y}$ , and stores the information in the Track file. It then performs the correlation of identical radar contacts in the overlap areas, and also constructs and sends the update records to the appropriate displays. When this has been completed, the next radar contact record is accepted and processed.

The operator consoles combine simplicity of operation with the capability to handle a broad range of situations. The six function buttons perform specific actions—three associated with the service being used, and three to call the basic system services of Normal Operating Display, Select Displays, or Alert Response. The three track ball buttons are used for Hook, Set, or Clear (Hook or Set) actions. The control keyboard is used for system control or specific map modifications (ID number-off, leader length change). The typewriter keyboard is used exclusively for entering characters in text services.

To reduce errors, buttons not used in service are disconnected. Also the separation of control functions from the typewriter keyboard enables the operator to operate the system without ambiguity. And a single level of operations for each service allows easy movement from service to service.

The operator requests a service by typing a two-number control code which brings the service into the system for the requesting console. The operator then designates the contacts of interest

or types in text; the Traffic Computer processes and stores it and sends any results back to the working display.

System response to an operator request was specified in the beginning to be one second or less. In practice the response has been much faster, even in high traffic cases. The effect is to give the operator the impression that he has almost instantaneous response.

These services were developed in conjunction with the Coast Guard Operations personnel of the 12th District (San Francisco)—those who would be actual users of the equipment. A track ball was chosen instead of a joystick or light pen to provide a system that is reliable and not tiring over a long watch period.

## Software Structure

The software is organized into three separate programs: Traffic Computer, Working Display Computer, and Satellite Display Computer.

The Traffic Computer operational program consists of the major executive program (with I/O drivers), subexecutive programs, operator service programs, background programs, and support programs.

The major executive program is the OP-16 general real-time operating system for the DDP-516R, built by Honeywell; it functions as a program scheduler to activate the required radar processing, operator service, or background programs. Program execution is on a priority basis. Interrupt code is executed whenever an appropriate interrupt occurs; otherwise a program list table determines the priority. A real-time clock and error message printing on the teletype are also provided by OP-16.

There are three subexecutive programs scheduled by OP-16. The Radar Map Management Program (RAMAP) has top priority and performs all processing associated with the radar contacts. The operator service subexecutive (OOEXEC) schedules the appropriate operator service programs for the three Working Displays, effectively providing a three-terminal time-sharing capability. The background subexecutive (BOEXEC) schedules the background analysis programs which monitor the track file for collision warning conditions and for overdue reports in the VMRS area. The background programs have the lowest priority in the system and are executed when no other program is running.



The Working Display Computer processing is primarily controlled by interrupts. An external interrupt from the Traffic Computer signals a data transfer to or from the Traffic Computer, while an internal interrupt at a 40-Hz rate starts the display processor cycle and performs other internal timing functions. During the time when the Working Display is not servicing interrupts it is under executive control. The executive is a very simple cyclic program which calls programs to perform keyboard input and control, to process data records received from and sent to the Traffic Computer, to provide the hook function, to perform sequences of actions for operator services, to display and edit keyboard characters for the text pages, and to display certain error messages to the operator.

A unique feature of the Working Display Computer program is that each selected service does

not require a multitude of overlay subroutines to be transmitted, which would detract from processing time and decrease program reliability. Instead, a single program "control matrix" of 156 words is received from the Traffic Computer for each service and remains core resident until another service is requested. The control matrix sets the proper labels for the function buttons, operator instructions, and page names, and allows only the subroutines required for that service to be performed.

### Operational Sequences

One problem encountered early in the design of the operator services was that of describing the steps to be taken by the operator to operate a service and the steps necessary for the computer to respond. In solving this problem a design tool has been developed which enables the

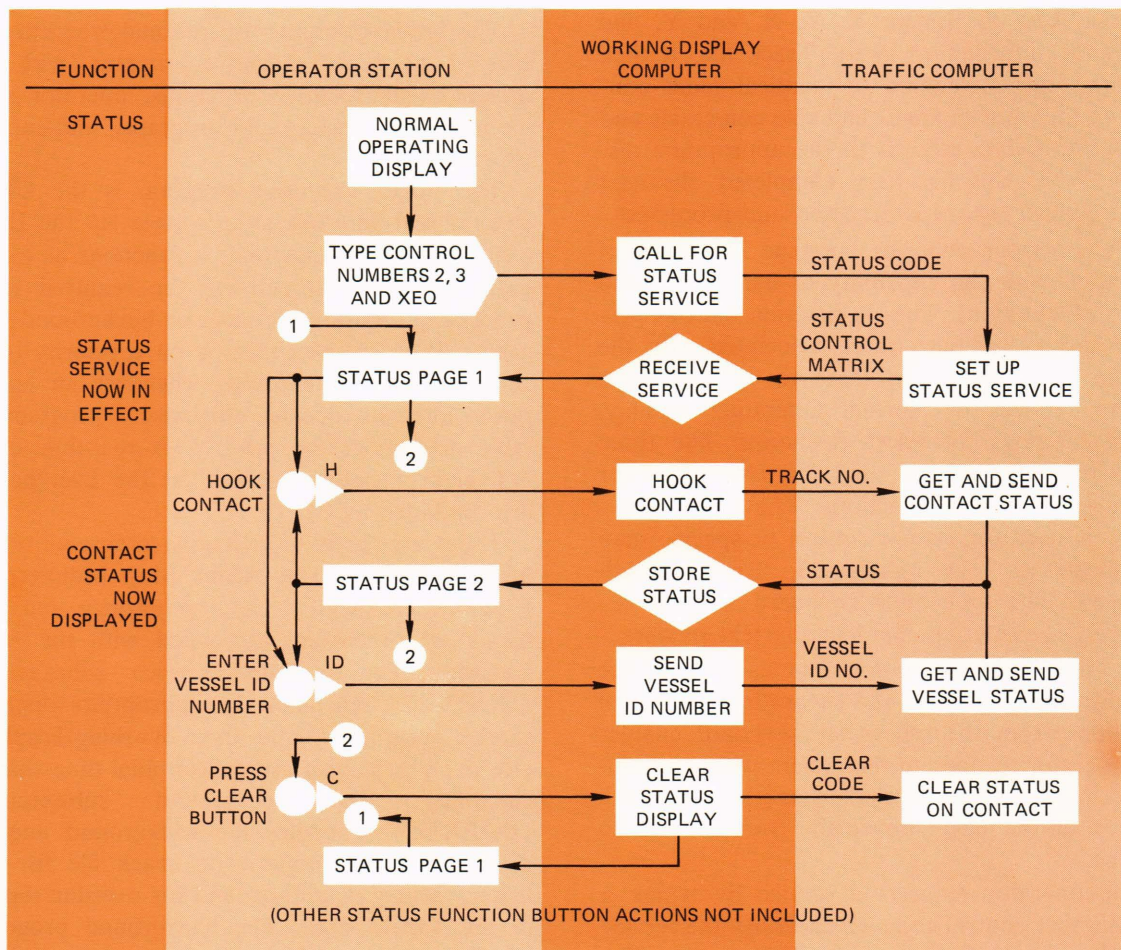


Fig. 2—Status operator sequence diagram.



system designer to functionally specify the actions required in the service, and which also enables the software designer to completely specify the program requirements, both in the Traffic and Display Computers. This tool is called the Operational Sequence Diagram (OSD).

Figure 2 shows the basic OSD for the Status service. The Function column shows the service described and provides a space for comments. The Operator column shows both the operator action and the system displayed response. The appropriate actions for both the Working Display Computer and the Traffic Computer are shown in the designated columns.

Using this type of diagram, the designer can show each action and specify the system response. For instance, to obtain the Status service, the operator types control numbers 2 and 3. The only action taken is for the Working Display to show the numbers. When the XEQ button is pressed, however, the Status service code request is generated by the Working Display and sent to the Traffic Computer, which sends the Status Control Matrix to the Working Display and also initializes the Traffic Computer.

Two points should be noted here. The first is that there are two separate actions by the Working Display Computer: the first, upon receiving the XEQ signal, and the second upon receiving the Control Matrix. The designer has freedom to choose those actions which he desires; in this case the XEQ action merely calls for the service, while initialization of the service in the Working Display is done upon receipt of the Control Matrix. In this way the designer assures the operator that when he sees the page name Status (sent as part of the Control Matrix) he knows that the whole system has responded and is now set for the Status service. If the page name had not changed he would know that the service request was not recognized, and that he should try again. (This rarely, if ever, happens but the system design can handle it.)

The second point is that the designer can choose how to handle a contact which was "hooked" (designated by the operator) prior to the call for the Status service. He can cancel it out or allow it to be recognized. In this case it is recognized and the track number is sent as an argument to the Traffic Computer just as if the operator had performed the operations in the

reverse manner. Upon receipt of the track number, the Traffic Computer provides the vessel course and speed, and also, if it is an identified vessel, the name, destination, and any VMRS information.

In this manner the designer can proceed to specify all actions and responses, with appropriate functional allocations, to the Working Display and the Traffic Computer as desired. The escape or exit from the service can also be specified.

The program designer can then take this diagram and expand it to a flow chart of the program required to perform the required functions. Program names can be shown, and the program functions can be specified; it is but a simple matter to design and code the program from this point on.

Developing the OSD diagrams for all the services to the first level and then examining them for common functions leads to common subprograms for use by various services. By this method the Working Display Program has been efficiently designed, and maximum use of common subroutines has been made.

## Conclusion

The TAD System is now installed and operating in the Coast Guard Vessel Traffic Center on Yerba Buena Island, San Francisco. While experimental in nature, and thus without redundant features to insure a maximum of availability, it is operating reliably for periods up to days at a time. While the capability for three operators to independently operate the system has been demonstrated, it has also been demonstrated that one operator can monitor the vessel traffic under most conditions, and with a confidence not previously achieved. The background monitoring concept has been demonstrated to be viable. The system has both radar automatic tracking and VMRS tracking; the mere addition of a position updated display of VMRS vessels would provide a capable dead reckoning system.

The architecture used in this system has also demonstrated that fourth generation system concepts are valid. With computer equipment containing common I/O structures, wired-program CPU's and multiport memories now appearing, systems using asynchronous processors performing their own specialized functions in conjunction



with a large common data base can now be specified and designed with confidence. The principles used in the TAD portion of the VTS—manageable functional allocation, common I/O

system operations, a maximum of processing in the distributed units, and a minimum of data transfers—are those which will be used in future systems using minicomputers.

## PUBLICATIONS

Compilation of principal recently published books and technical articles written by APL staff members.

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## ADDRESSES

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- W. Seamone, "Upper Limb Prosthetic Devices," *Langley Colloquium Series, Langley Research Center, Hampton, Virginia*, January 14, 1974.
- J. R. Kuttler, "Sloshing Frequencies by Finite Differences," *American Mathematical Society, San Francisco*, January 17, 1974.
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