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APPLICATION OF DIGITAL COMPUTERS TO AIR TRAFFIC CONTROL IN THE UNITED STATES

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Summary

Digital computers are being applied in large numbers to air traffic control operations in the United States. By the mid-1970's, all U S. en route traffic control centers and all busy terminals will be equipped with systems featuring digital computers which process flight plans and radar and beacon data into displays for air traffic controllers. Work is underway to further apply computers to such control functions as ground-based conflict prediction, sequencing and spacing, and flow control

Introduction

Digital computers are the single most important development in recent years in the operation of the air traffic control (ATC) centers in the United States The U.S. is well on the road to installation of computers for air traffic control in all of its major ATC facilities For example, by mid-1974, 20 en route control centers will have been equipped with large-scale computing systems, by mid-1973, 61 terminal-radar approach-control facilities will have been equipped with medium-scale computing systems. The Federal Aviation Administration (FAA) of the U S Department of Transportation provides, maintains, and operates these facilities.

The application of digital computers to air traffic control has evolved from two streams of development activity. One stream began in the late 1950's with the application of business-oriented computers to the non-real-time processing and distribution of flight plans The other stream evolved from military and naval air defense systems of the early 1950's. These used computers as the tracking, intercept calculation, and alphanumeric display makeup elements in radar-directed aircraft control systems The business computers were the first (as early as 1956) to be applied to en route air traffic control information handling problems in operating centers Advanced flight data processing systems are now installed in most U.S. en route centers. Radar-oriented tracking and alphanumeric display systems using digital computers are just now emerging as the key data processing tool in air traffic control, although the Great Falls Center, using air defense computer and display facilities, has been in operation since 1963 These radar-oriented systems, using real-time digital computation and character-writing displays, form the basic building blocks from which future advances in safety and efficiency in the ATC system will come

This paper will first define the operational aspects of the U S ATC system, and then describe how computing systems are applied in the control system Characteristics of these computers and computer programs will then be outlined Finally, future applications of computers in air traffic control, and in applications supporting air traffic control, will be discussed

Air Traffic Control in the United States

Aircraft operations in the United States are conducted under two forms of ATC procedures The first procedure is called Visual Flight Rules, or VFR, and the second, Instrument Flight Rules, or IFR

Visual Flight Rules: Under Visual Flight Rules, it is the responsibility of the aircraft's pilot to maintain adequate separation from other aircraft. Ground-based ATC separation services are not provided, except in the immediate vicinity of some 300 airports at which control towers are maintained and at which landing and take-off separation is provided.

Pilots flying under Visual Flight Rules may communicate, either by radio when airborne, or by telephone when not, to a network of 350 Flight Service Stations (FSS) for weather and other information pertaining to flight safety. A flight plan may be filed with a FSS giving departure airport, route of flight, estimated time en route, etc. This flight plan is forwarded from the Flight Service Station near the departure airport to one near the arrival airport and is used to alert search and rescue operations in the event an aircraft becomes overdue.

Thus far, no part of the FSS Network servicing Visual Flight Rules aircraft is equipped with computers. Research and development activities are being started, however, to investigate the use of computers for distribution of flight plans and for storage and subsequent selective retrieval of weather data and other flight safety information. For example, prior to take-off, a pilot normally contacts by telephone a Flight Service Station to file his flight plan and receive a weather briefing. In the future he would type his flight plan into a computer terminal. The computer would assure the flight plan's automatic transmission to the pilot's destination airport; additionally, the pilot automatically would receive a weather briefing for his route of flight. The proponents of such a system believe it would result in better service to the pilot and reduce costs to the government, since fewer personnel would need to be added to Flight Service Stations to handle the anticipated growth in demand.

Instrument Flight Rules. Most commercial aviation operations, all high-altitude (above 18,000 feet) operations, and some military and general aviation low-altitude operations are conducted under Instrument Flight Rules (IFR). The ground-based ATC system is responsible for providing separation among aircraft flying under IFR, although in clear weather the pilot also has a responsibility to see and avoid other traffic, since not all aircraft in most segments of low-altitude airspace will be under control of the ground system. That is, in good weather conditions some aircraft may be under IFR and some under VFR. Where the weather is below the minimum permissible for VFR, all aircraft fly IFR and are under control of the ground system

Under IFR, the departure and approach phases of flight are under control of terminal air traffic control facilities located at airports. At major terminals, these facilities are radar-equipped; these facilities are known as Terminal Radar Approach CONtrol, or TRACON, facilities. In the cruise phase of flight, between terminals, IFR aircraft are under the control of the en route ATC facilities or Air Route Traffic Control Centers (ARTCC's) Twenty-one of these ARTCC's are located within the conterminous U.S., and additional facilities are located in Alaska, Hawaii, and overseas locations

Application of Computers To Terminal and En Route Facilities

It is in the Terminal Radar Approach Control facilities and in the (en route) Air Route Traffic Control Centers that computers have had major application to air traffic control.

Automated Radar Terminal System (ARTS)

Terminal traffic control operations at busy airports are organized into two main subdivisions: first, the visually operated airport control tower, which controls landings and take-offs from the airport's runways; and second, the terminal area radar-oriented approach and departure control facilitiy, which controls traffic from the control tower's area of jurisdiction to a distance about 30 miles from the airport and to perhaps 7000 feet in altitude.

At 101 locations the terminal area facility is equipped with radar and radar beacon. The ATC Radar Beacon System consists of a ground radar-like azimuth-scanning interrogator which transmits a time-coded pulse pair at a 200-300 pulse repetition frequency on the universal microwave channel assigned to all ground interrogators. This pulse pair is received in the aircraft when it is in the ground beam, and the aircraft replies on another universal channel. When the aircraft is interrogated by the ground in the identity mode, its reply contains a 12-bit identity code. When interrogated in the altitude mode, its reply is a 12-bit altitude code. The beacon's radar-like characteristics permit measurement of aircraft azimuth and range, and the digital encoding of the down link permits reporting of aircraft identity or altitude.

At 61 locations having radars and beacons, the computer-based Advanced Radar Terminal System (ARTS) is being deployed. The principal feature of the current version of ARTS is its capability to decode identity and altitude replies from ATC radar beacon transponders and to present them on a geographic display showing relative positions, altitude, and identity of aircraft within the controller's area of responsibility.

Figure 1 shows an ARTS display. Both search radar and ATC radar beacon data are displayed on the Plan Position Indicator (PPI) in the normal manner. Alphanumeric data are superimposed on the PPI by positioning the beam to write alphanumerics during the dead time of each radar sweep (i.e., after the time required to display the maximum range of the radar).

A block diagram of the ARTS system is shown in Figure 2.

Beacon video containing a digitally encoded identify and altitude message and antenna azimuth is quantized by the "Data Acquisition Subsystem." The "Data Processing Subsystem" then determines the center azimuth of each beacon target reply train and performs an automatic tracking function. The automatic tracking associates aircraft flight number with particular beacon replies and positions an alphanumeric data block alongside its corresponding beacon video target reports. The tracking process also computes ground speed for each track.

Figure 3 shows the configuration of equipment used at Chicago's O'Hare Terminal. At this location, two radar/beacon systems feed the ARTS. In most locations, only one radar/beacon system is used, and only one input/output processor (computer) is required. Similarly, most sites use a lesser amount of memory (24,000 words) than the 40,000 words supplied to Chicago. Processor speed is approximately 250,000 instructions per second, and basic memory speed is 750 nanoseconds.

The UNIVAC Division of the Sperry-Rand Corporation is the prime contractor for ARTS, supplying the computers and computer programs; the Burroughs Corporation provides the "Data Acquisition" subsystem, and Texas Instruments, Inc., provides the "Data Entry and Display" subsystem.

ARTS has been designed as a modular system to provide for future additions of such system features as:

- Modular redundancy - the ability to sense failures and replace failed units with spare units
- Radar Tracking - the ability to perform automatic tracking of search radar data
- Metering and Spacing - the provision of control instructions to the controller to permit him to sequence approaching aircraft to obtain more optimum utilization of a runway.

En Route System

While the terminal radar approach control facility is concerned with an area immediately surrounding an airport and with altitudes below 7000 feet, say, the en route center is concerned with IFR traffic in all of the airspace between and above the terminal airspace. Thus, while a busy terminal may have some eight control positions, a future busy en route center may have as many as 80.

The U.S. is currently embarked on a program of semi-automation of its domestic en route control centers. This program of activities and equipment is called "NAS-En Route-Stage A," or – more familiarly – "NAS" (for National Airspace System).

Radar Processing and Display

As in the terminal, the principal control tool in en route centers is search radar and ATC radar/beacon. To provide the needed radar and beacon coverage over the large area covered by an en route center, some centers are scheduled to be serviced by as many as ten radars and radar/beacons. Thus, a major function in the semi-automation of the en route system, or NAS, is the processing and display of search radar and radar/beacon data and the correlation of these data with aircraft identity. This is used to form a pictorial display of the air situation in each sector of the en route center. (A control sector is a subdivision of airspace in an en route center. In future busy centers, there may be as many as 80 such sectors.) Typical NAS sector equipment is shown in Fig. 4.

Flight Plan Processing

Flight plan processing is a major function performed in the NAS en route system (but not in the ARTS system), and it requires a considerable amount of the system's capacity. Each pilot who intends to fly under instrument flight rules (IFR) must file a flight plan containing, among other items, the aircraft identity, type, speed, cruising altitude desired, departure time, and route of flight. This information is entered into the NAS en route system either from previously stored magnetic tape for most airline flights, or on-line from flight service stations or military operations offices for general aviation and military IFR flights.

The NAS computer program is designed to take the route of flight information from each flight plan and print, at each sector through which the flight will pass, at least one "flight progress strip." Based on the route information in the flight plan, as well as the departure time and speed data, a time estimate over key traffic control points in each sector is computed and printed on the "flight progress strip." The route of flight is also printed on the strip. Thus the "flight progress strip" may be used by the controller as a planning aid, since it indicates the future intention of each aircraft which will traverse his sector. The flight progress strip is also used by the controller as a handy means of recording changes to the flight route or altitude.

Within the computer program, the flight plan file is updated automatically by the automatic tracking programs so that future time estimates of position can be calculated and wind or speed errors corrected.

After a strip has been printed at a sector, Controller Updating Equipment (CUE), which consists of a display and entry keyboard, is used to pass new information such as updated time estimates from control sector to control sector. The CUE can also be used for entry of data such as route revisions and altitude reports.

NAS Equipment. Figure 5 is a block diagram of NAS. Major equipment components of NAS are the Central Computing Complex, manufactured by International Business Machines, Inc.; The Common Digitizer, manufactured by Burroughs Corporation; and the Computer Display Channel and Controller Updating Equipment manufactured by the Raytheon Company. IBM also produces the system's computer programs specified by FAA and The MITRE Corporation, and IBM performs equipment integration as well. Ralph M. Parsons Company provides architectural services and the FAA and MITRE the system engineering.

The Central Computer Complexes are parallel processing variants of the IBM 360/50 and the IBM 360/65. The IBM 360/50 variant, known as the IBM 9020A, is installed at the 11 moderately busy centers, and the IBM 360/65 variant (or IBM 9020D) is installed at the nine busier centers. Program sizes and representative computer configurations are shown in Figures 6 and 7. The 9020A has a computing capacity of approximately 500,000 instructions per second, and the 9020D approximately 1.5 million instructions per second.

The Raytheon Company Computer Display Channel (see Figure 8) has, in addition to its pictorial and tabular displays and digital-to-analog display generators, a considerable amount of both stored-program and wired computing logic. The Raytheon Computer Display Channel uses its computing capability to make up, from the total radar and track data base transmitted to it by the IBM Central Computer, tailored display data for each sector's display console. Each air traffic controller may filter the data being presented to him – for example, he may desire to see aircraft only within certain altitude limits, or he may change the geographic center or the scale of his display. The computers in the Raytheon Computer Display Channel respond to these display filtering actions and select the appropriate data for display.

The stored program computers within the Raytheon system have a memory speed of about 1.2 microseconds and an average instruction rate of approximately 250,000 instructions per second. The stored program within the display system occupies two 16,000 word memory elements of 16 bits/word. Twelve additional 16,000-word memory modules are available for data storage.

All digital elements of the NAS en route system – that is, IBM and Raytheon computing elements, input-output elements, and memories – are modular and are backed-up by redundant elements. Error checking and analysis programs are contained within both the IBM and Raytheon computing systems. These operate in conjunction with error checking hardware to automatically switch spare memories, compute elements, and input/output elements on line when error thresholds are exceeded.

Other Applications of Computers Supporting Air Traffic Control

Thus far the ARTS terminal and NAS en route systems have been described. In these applications, computers are used as part of a real-time control system. Computers have also been used by FAA for less time-critical control functions such as national flow control (allocating aircraft to terminals and routes based on traffic density and en route and terminal capacity). Computers have also been used in the maintenance of files for publication of flight planning information. Data published for pilot use is thereby kept as up-to-date and correct as possible. These files include information such as airport data (location, runway length), obstructions to navigation, terminal area procedures, holding pattern areas, and other information which would be charted for use by airmen.

The FAA maintains a large network of radars, communications facilities, landing systems, etc. Business computers are used to maintain inventories of replacement parts and maintenance records. Computers are used to reduce flight measurement data taken to calibrate and measure the performance of navigation aids.

Additionally, FAA is an organization of 50,000 people. As in other large organizations, business computers are used to maintain personnel and pay records.

Future Applications of Computers in Air Traffic Control

I have already mentioned the research and development activity underway to utilize computers to assist in handling VFR flight plans and weather dissemination by Flight Service Stations.

Lower Density Terminals

You will recall that the ARTS systems will be installed at 61 airports but that 101 are currently equipped with radar and beacons. The air traffic activity at airports that will not receive ARTS is sufficient to warrant radar, but the airports are not sufficiently busy to warrant ARTS. The advent of low-cost minicomputers has aroused interest in the FAA to determine whether a lower cost ARTS-like system for these remaining airports could be provided using these minicomputers as data processing elements. Additionally, some airports that do not have their own radars lie within the coverage area of radars serving other airports or en route centers. Minicomputers are being explored as low-cost data processors for digital remoting and display of radar/beacon data at the airports which do not now have radar service.

Conflict Prediction

I mentioned additions to the basic ARTS now being considered. These include modular redundancy, radar tracking, and metering and spacing A major system improvement to both the ARTS terminal system and the NAS en route system will be the addition of a conflict prediction (i.e., ground-based collision warning) algorithm to their computer programs. If potential conflicts are detected, the air traffic controller will be alerted by suitable alarms Since both systems track aircraft under control and thus maintain the position, velocity, and altitude of these aircraft, all of the necessary information is available to compute whether aircraft are likely to violate safe margins of separation.

Work is currently in progress to refine the algorithms. Demonstrations of early versions of these algorithms have taken place. In one demonstration, an array processor in conjunction with an ARTS-like computer was used to perform the conflict prediction. In another demonstration, the en route computer program logic was simulated and the algorithm tested against recorded actual traffic. This simulation indicates that a track-based conflict prediction algorithm can be operated successfully at predicted traffic loads utilizing perhaps 5–10% of the available en route or terminal computing time.

Further in the future will be the introduction of Intermittent Positive Control (IPC). This control concept will be used in airspace where the traffic densities or speeds of aircraft are not sufficiently high to warrant requiring all aircraft to fly IFR, but in which there is a considerable mix of VFR and IFR traffic. In this concept, all aircraft in the IPC airspace are tracked, and conflict resolution instructions may be transmitted via a data link in the event the NAS or ARTS computer detects a conflict. The tracking is made reliable and the data link made possible through the use of a Discrete Address Beacon System, or DABS. The principal feature of this new beacon system is that each aircraft can be discretely addressed from the ground. Hence, control messages can be transmitted via the beacon's data link, and aircraft responses can be similarly transmitted on the beacon return link. Additionally, the system is compatible with existing airborne beacon equipment, although Intermittent Positive Control cannot be provided for aircraft equipped with the older beacon transponders. In one type of ground interrogator of the Discrete Address Beacon, an electronically steerable phased-array antenna is employed; in another type, a rotating antenna will be used. It is anticipated that a digital computer at the beacon ground interrogator site will be used for performing the tracking required for the phased-array antenna beam steering or for transmitting via the rotating antenna.

Telephone Switching System

An extensive voice telephone system exists within and between the NAS en route centers and from the en route centers to ground/air radio transmitter/receiver sites. Specifications have been written to procure a computer-controlled switching system for all en route center voice communication. This is yet another example of the application of digital computers to air traffic control applications.

Conclusion

I have attempted to show the present wide-spread application of digital computers to air traffic control. The potential future application of computers and digital logic to air traffic control will probably have an even greater impact on system safety and efficiency than the computer-based building blocks now being implemented in the United States

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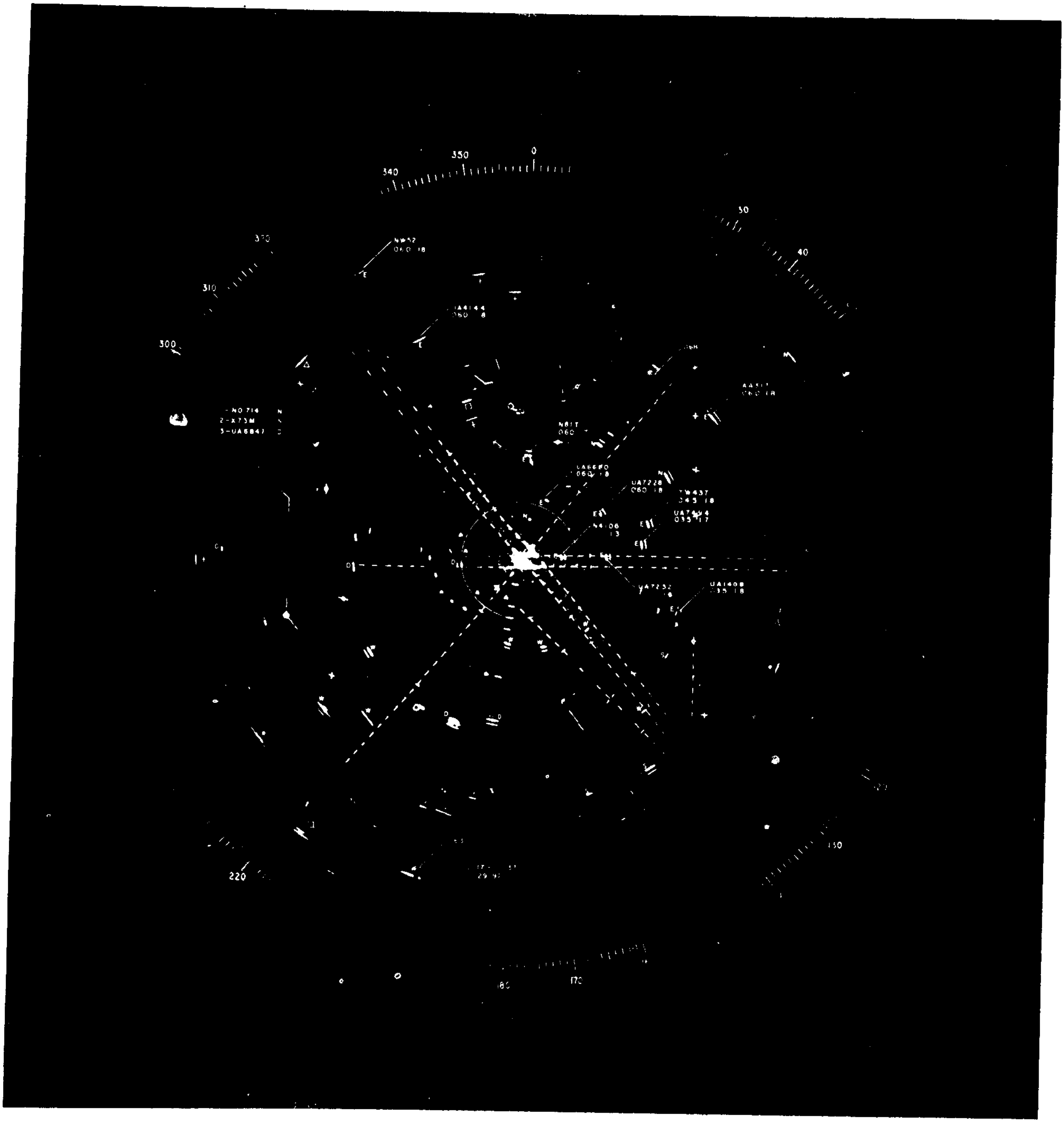

Figure 1. Arts Display

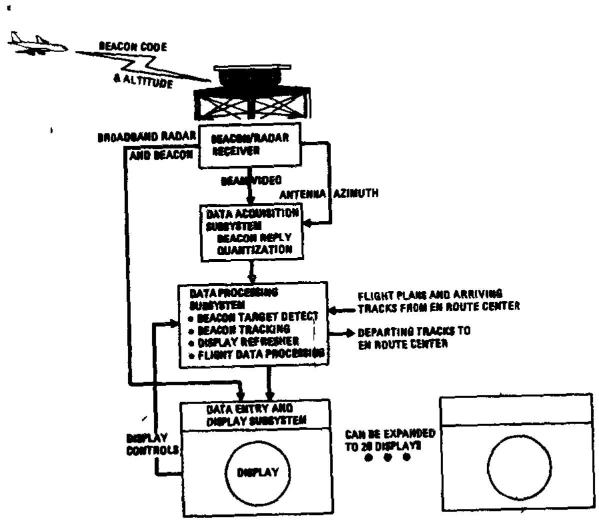

Figure 2. Arts Block Diagram

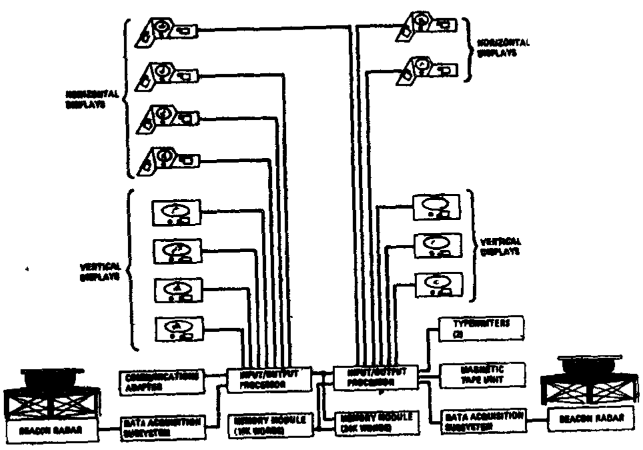

Figure 3. O'Hare Arts Configuration

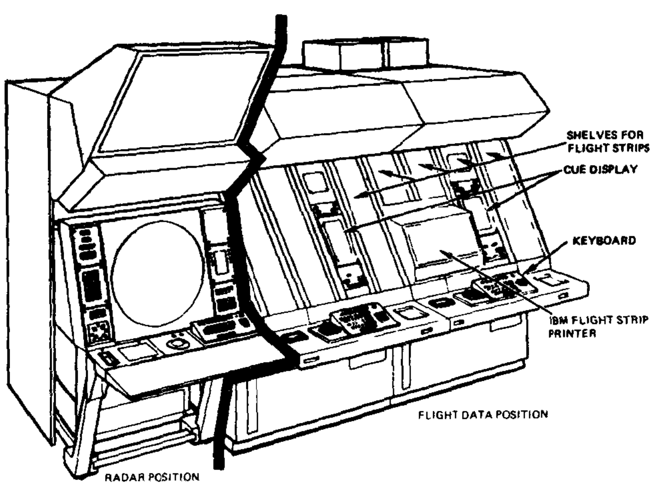

Figure 4. NAS Sector Equipment

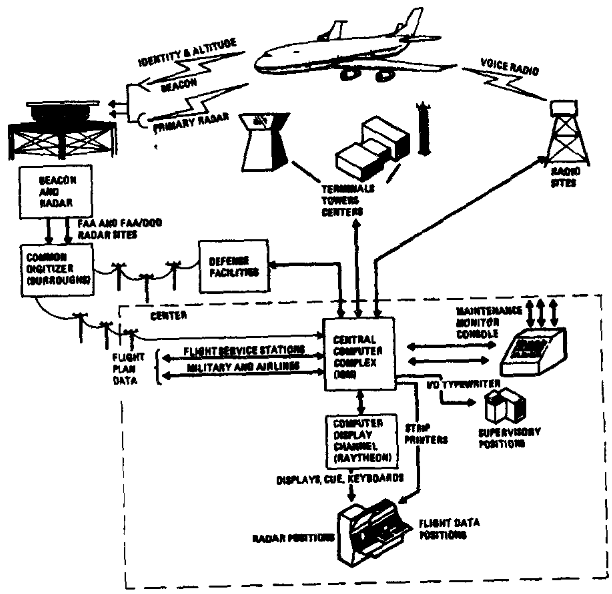

Figure 5. NAS En Route Block Diagram

FUNCTION	STORAGE (32 BIT WORDS)	COMPUTE ELEMENT (% OF AVAILABLE 55 MIPS)
RADAR BEACON TRACKING		
PROGRAM	44,000	18%
DATA	33,000	
FLIGHT DATA HANDLING		
PROGRAM	127 000	9%
DATA	237,000	
CONTROLLER INPUTS AND DISPLAYS	129 000	12%
MONITOR	57,000	5%
	627,000	44%

Figure 6. En Route Computer Utilization: Boston Center - 1975

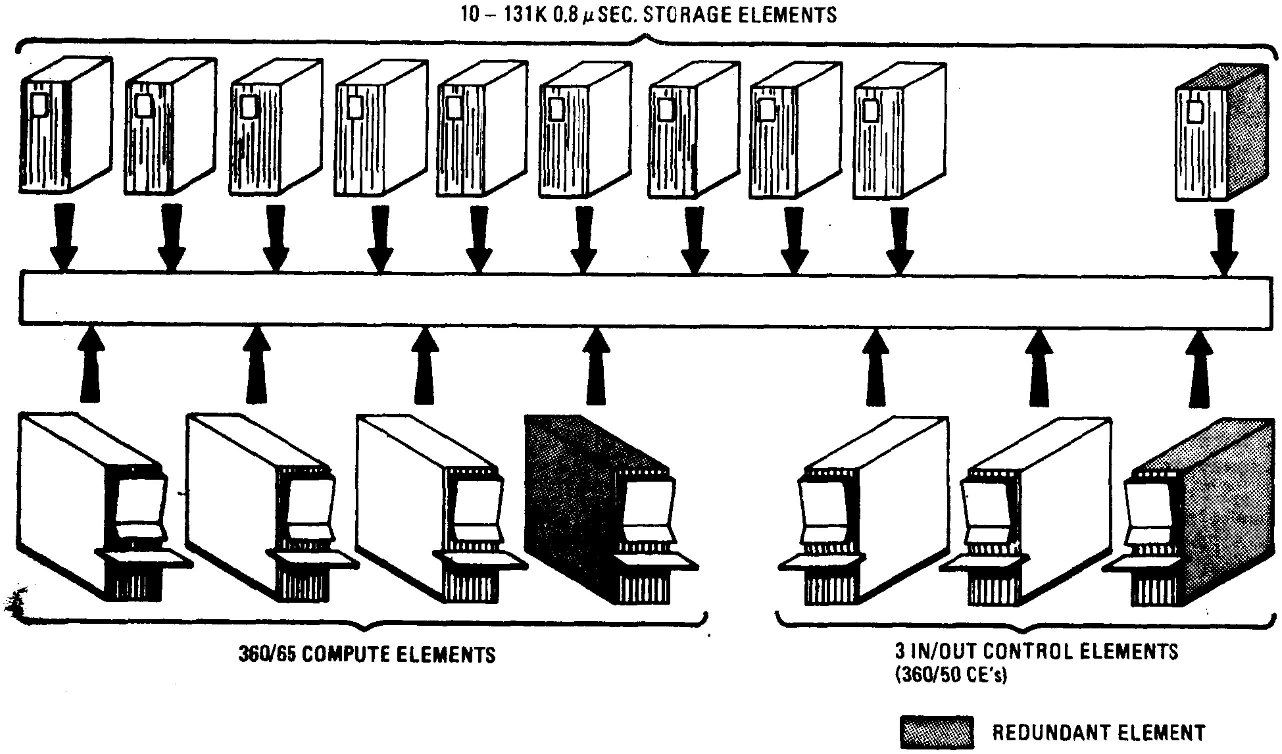

Figure 7. En Route Computer - IBM 9020D

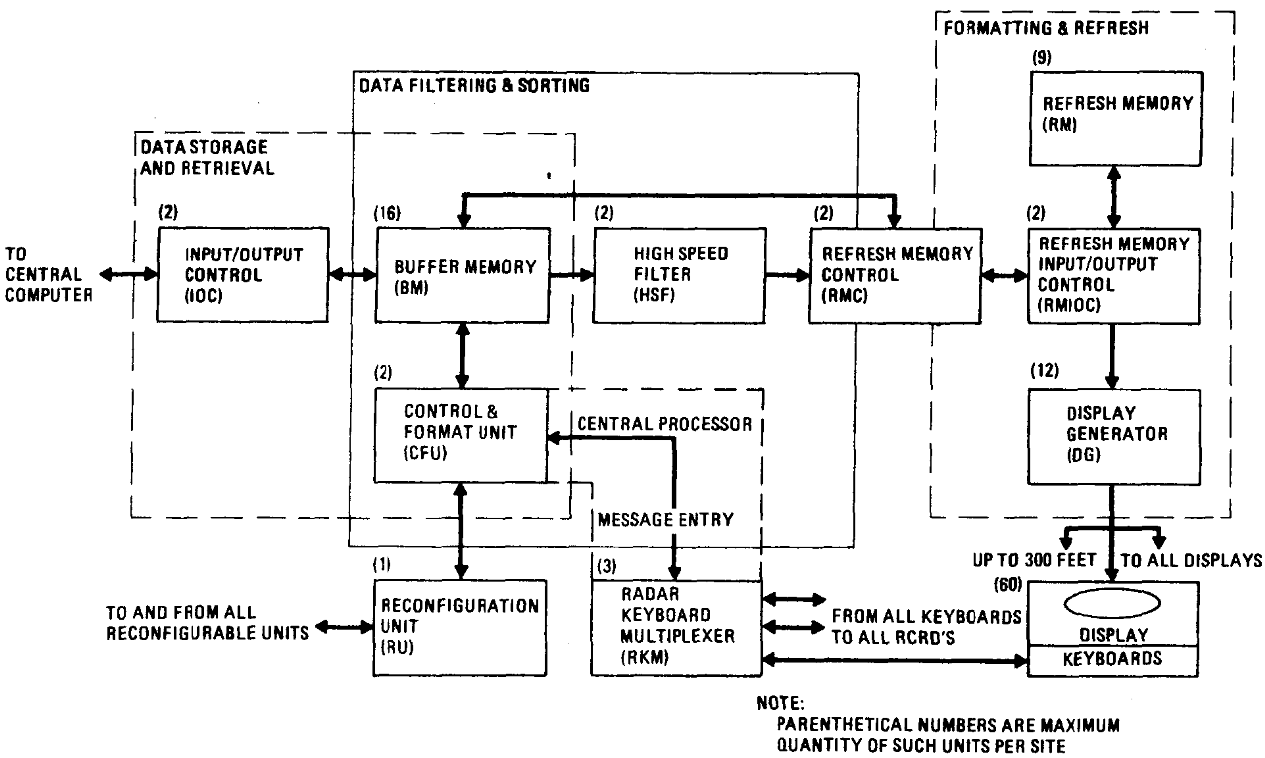

Figure 8. Raytheon Computer Display Channel Block Diagram

TRAFFIC CONTROL SYSTEM ON HANSHIN EXPRESSWAY

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Abstract

The Hanshin Expressway Public Corporation, Osaka, Japan has been operating its traffic control system since the begining of EXPO '70, that is, March 15, 1970 on its whole expressway systems in Osaka and Kobe. The total length of the Hanshin Expressway is now 79.6 KM and is expected to become 128 KM by 1975. This report presents some features of the control system putting emphasis on its hardware system. This system has a digital computer, FACOM 270-30, with 65 KW core memory, various peripherals, more than 200 detectors, more than 70 variable information indication devices along the expressway and TV monitoring systems at present. It is shown that the control system on Hanshin Expressway is quite capable and flexible towards future expansions and modifications.

Introduction

It seems to be common to many countries that the demand of road traffic always exceeds the supply, that is, the capacity of the road network. Then efforts have been made in various places in various forms to cope with the confronting and expecting traffic jams. Almost all efforts to this type of problem are for urban streets and avenues. The control in urban area depends greatly upon the traffic signal system at intersections such as vehicle-actuated or synchronized signal systems. In some cities, computer control systems have been employed to cover the wide urban area in order to optimize, in some respects, the total traffic parameters. On the other hand, only few systems for urban expressway traffic control systems have been reported. In the urban expressway traffic control system, the access to the expressway is limited to the on-ramps along the expressway and there is no traffic signal on the through way. Therefore, one of the most significant differences between the control systems for urban streets and for expressways is that the expressway traffic control systems can control the inflow traffic to the expressway system while it is impossible for the systems of urban strret traffic. The inflow traffic control system on the expressway is a very important because the smooth traffic flow can be assured and the traffic congestion can be eliminated with in a short time in the expressway.

As one of the efforts to cope with urban expressway traffic, the Special Committee of Traffic Control System was established by the Foundation of Express Highway Research under the chairmanship of Professor Eiji Kometani of Kyoto University in 1967. After two years of study at this committee, The Hanshin Expressway Public Corporation started to realize its traffic control system according to the reports by the committee in 1969 in order to be in time for the begining of EXPO 70.

The average number of cars flowing into the Hanshin Expressway in one day is about 320,000 at present. The construction expenditure for the traffic control system is about 15,000 Japanese Yen per one meter, that is, about 80,000 U. S. Dollars per one mile. This amount of money is negligible compared with the construction expenditure for the expressway. This traffic control system should be ranked as one of the largest and most capable expressway traffic control systems in the world and has been influential to the other expressway traffic control systems.

The essential parts of the specifications on the software and hardware systems in this traffic control system has been studied by the members of the aforesaid special committee. This report is to explain the contributions of the members to the control system.

Method of Traffic Control on Expressway

The method of traffic control in the traffic control system on Hanshin Expressway has, roughly speaking, two phases according to the state of traffic flow in the expressway system. One is inflow traffic control phase which is for a stationary traffic flow and the other is emergency control phase for unstationary flow such as a flow when an accident takes place. These two phases are not independent of each other but are strongly related with each other. Especially, when an accident takes place among a heavy traffic, the relation between two phases is very important.

Inflow control (L.P. control)

In the phase of inflow control, the volume of inflow traffic at every on-ramp of the expressway is controlled in order to maximize the total number of incoming cars to the expressway under the condition that no traffic jam takes place in any section of the expressway, that is, the number of cars going at any section of the expressway system does not exceed the capacity of that section. In this phase of control, the origined distribution (OD) of the traffic in the expressway should be derived. OD in the expressway system is far easier to derive than that in general road networks. This, however, does not mean that it is easy to derive the OD in expressway system. As we do not have any way of deriving OD at any instance as an on-line information, we have to estimate it with off-line analyses and on-line data available.

In order to keep the accuracy of the estimation of OD, it is required to apply our estimation only when the traffic flow can be assumed to be stationary. As on-line data for the estimation, traffic volumes of inflowing cars at all on-ramps and outgoing cars from all off-ramps are employed. It is known that the entropy method is a powerful tool to estimate OD from the number of incoming and outgoing cars to and from every entrance and exit of the road network.(1) In the entropy method, there are three parameters which should be determined by off-line analyses. The real OD has been investigated actually by the Hanshin Expressway Public Corporation several times by asking the drivers of incoming cars to answer the questions concerning their trip on the expressway on *enquête* basis. Using these data, three parameters in the entropy method are derived. These parameters are revised at least once a year. This estimation is so far very accurate judging from the estimation error recorded in the system.

With the estimated OD and the volumes of inflow traffic at each on-ramp and outgoing traffic from each off-ramp, traffic volume in each section of the expressway is estimated. Let denote the estimated traffic volumes in the expressway sections by a vector X. As a matter of cource, X does not coincide with the set of data of inflow and outgoing traffic generally. This is due to the estimation errors, where the main contribution to the estimation error is by the fact that the time required for a car entering an on-ramp to go to a certain section of the expressway is neglected in the estimation. Let e denote an error vector for the estimation, that is, by denoting the measured volumes in every section as Y, we have,

$$Y = X + e.$$

The vector e is estimated and then inflow traffic is limited so that no traffic jam takes place at any section. Therefore, by denoting the capacities of every section in a vector form as C, we have to control the inflow traffic with

$$X + \breve{e} \leq C, \qquad [1]$$

where $\breve{e}$ is an estimation of e. Under the condition that the inflow traffic is controlled so that the traffic volume at any section does not exceed the traffic capcity of that section, that is, under the condition [1], the number of inflow cars to the expressway should be maximized. This type of maximization can be reduced to a Linear Programming problem. This is the reason why this type of inflow control is called as L. P. control.

This type of control is powerful when OD does not vary widely within a short duration. For the case where the above stationarity of the OD is not expected, as in the case of traffic accident, it is required to shift the control phase to the emergency control.

Emergency control (Sequential control)

When an accident takes place at an on or off-ramp or at a section, the traffic volume of certain sections may exceed their traffic capacities and the steady flow on the expressway may not be expected any longer. In this case, the inflow traffic at the on-ramps which are in the upstream of the point where the jam is originated from should be controlled so that the jam may be dissolved as soon as possible. This type of inflow control starts from the on-ramp nearest to the origin of the jam and propagates sequentially to the next to the nearest and so on. This is the reason why this type of inflow control is called as Sequential control.

Criteria to decide when and how many ramps should be closed or limited are derived by various off-line analyses and simulations. According to the criteria, the computer system tells when and where this type of control starts.

Together with the sequential ramp control, it should be recommended or ordered, if necessary, to the drivers on the expressway to go out of the expressway from certain off-ramp. This does not happen in all cases, because in some cases, the accident which is the cause of the jam may be cleared in a short time. This type of outflow control is very important and is closely related to detour control in the road networks. In this case, it is very helpful to have powerful controlling strategy if it is possible to estimate the time required to clear the accident. After long, wide and profound discussions and some investigations, it is concluded not to estimate the time required to clear an accident because it will bring the control system a very large variance of estimation errors.

As is shown to this point, the features of the controlling method in the system of Hanshin Expressway are; (i) the OD is estimated from the inflow and outgoing traffic volumes at every on- and off-ramps, (ii) traffic volume in each section of the expressway is estimated from the estimated OD, (iii) total number of inflowing cars to the expressway is maximized under the condition that the traffic volume at any section does not exceed its capacity, (iv) when and where the sequential ramp control starts are derived by the computer system also. Among these, from (i) to (iii) are for the stationary flow and (iv) is for the unsteady flow. The detail of the controlling method is obtained from the Reports of Study on Technical Research for Traffic Control on Hanshin Expressway, the Foundation of Express Highway Research, Tokyo, 1968 (2) and 1969 (3). An English translation of (2) is obtained from the Hanshin Expressway Public Corporation but it is strongly recommended to investigate (3) together with (2) because many modifications to (2) are made in (3).

Hardware System

The hardware system of the traffic control system on Hanshin Expressway is divided into detector system, detector information transmission system, information processing system, information display system, control information transmission system, traffic control device system (variable information indication devices) and closed circuit TV system. This traffic control system is one of the largest and most advanced one in the world, and has been under construction from 1969. Though the final construction of the expressway network will be completed by 1975, the control system will have its final capability within the fiscal year of 1972. Fig. 1 shows the final system in a block diagram. The main differences between present system and the final system are; (i) external drum memory is not installed yet, (ii) off line large scale simulation is not possible, (iii) full sysytem back up against electric power source failure is not installed yet.

Fig. 2 shows a map of the Hanshin Expressway (distorted) together with the installation diagram of detectors, TV cameras. The locations of the control center and sub-centers are also indicated in Fig. 2.

Detectors and detector information

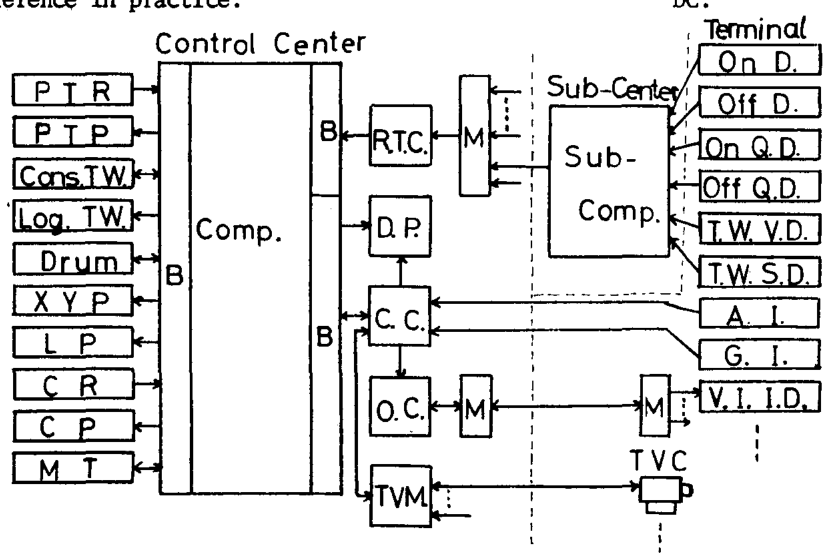
Detectors employed in this system are loop detectors (including short loop detectors, multiple loop detectors and long loop detectors) and ultra sonic detectors (Doppler detectors and pulse detectors). The installation of these detectors is shown in Fig. 2. At present, there are 235 detecting points in the system. Among them, 88 detectors detect traffic volume and time occupancy and 14 detectors detect traffic volume, occupancy and speed. As the map of Fig. 2 is distorted, the installation of devices may have slight difference in practice.

Inflow traffic is measured at each booth of on-ramps with very high accuracy. The number of on-ramps is 50 and the number of off-ramps is 50, at present. The average number of booth in one on-ramp is about 2.5. Around the on- and off-ramps, inflow or outgonig traffic volumes and queue length are measured. While on the through way traffic volume, average speed and time occupancy are measured at some sections. A section is a road between two successive merging points, branching points, on-ramp and/or off-ramp. That is, within one section there is only one entrance and one exit. The number of sections is 125 at present and the average number of lanes in a section is about 2.5. By 1975, the total number of sections will be about 150, number of on-ramps will be 80, number of off-ramps 80 and number of detectors will be about 1600. All sections will have detectors in the final contruction stage.

Information transmission system

The information transmission system has two sub systems. One is the detector information transmission system and the other is the control information transmission system. Except the detector information from the Loop line, all the detector informations are transmitted to the subcenter with DC data transmission link and then the detector informations are converted from analogue signal to digital signal and stored in the buffer memory of the subcenter. Transmission between subcenter and the control center is performed with 200 baud FS link. The detector information from the loop line is transmitted directly to the control center. throuh DC links.

Control informations are transmitted over 50 baud data link to the variable information indicating devices. Booth attendant instruction information is transmitted from the conter to subcenter with 200 baud FS and from subcenter to each booth with DC.



On D.: On-ramp detector
Off D. : Off-ramp detector
On Q.D. : On-ramp queue detector
T. W. V. D. : Through way volume detector
T. W. S. D. : T. W. speed detector
A. I. : Accident Information
G. I. : General Informacion
V. I. I. D. : Variable information indicating device
M : Modem.
TVC : TV camera
TVM : TV monitor
O. C. : Output controller
C. C. : Control console
D. P. : Display panel
R. T. C. : Real time controller

Cons. TW. : Console typewriter Log. TW. : Logging typewriter

Figure 1. Schematic diagram of the control system of Hanshin Expressway (Hardware system).

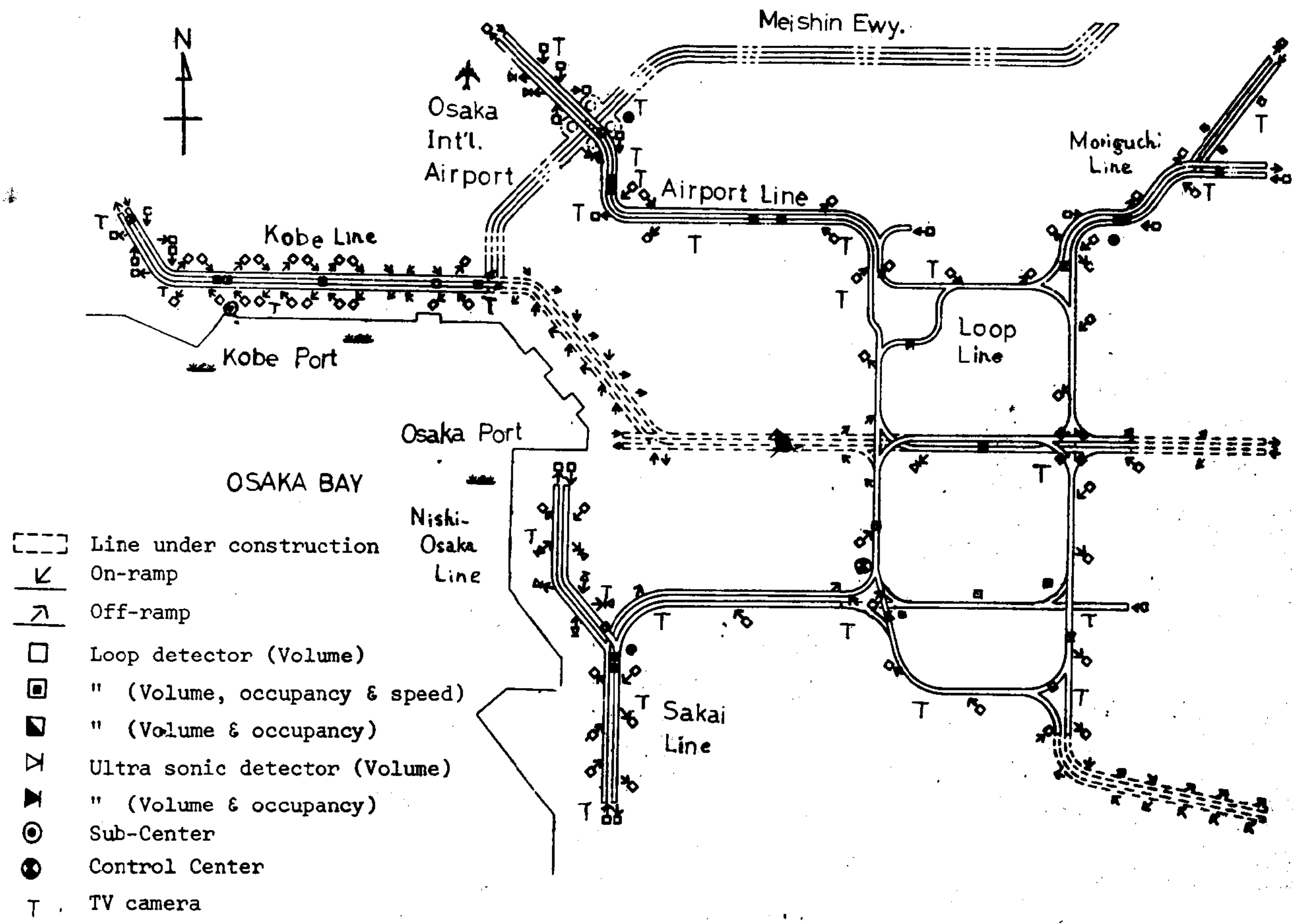


Figure 2. Hanshin Expressway map (distorted) and TV and detector installation map.

Any brand new technique for the information transmission system is required for the traffic control system. Conventional methods are quite sufficient. Fig. 3 shows a block diagram of information flow from the control center. Traffic informations from the broadcasting stations to the drivers are very useful as one of the auxiliary traffic control media.

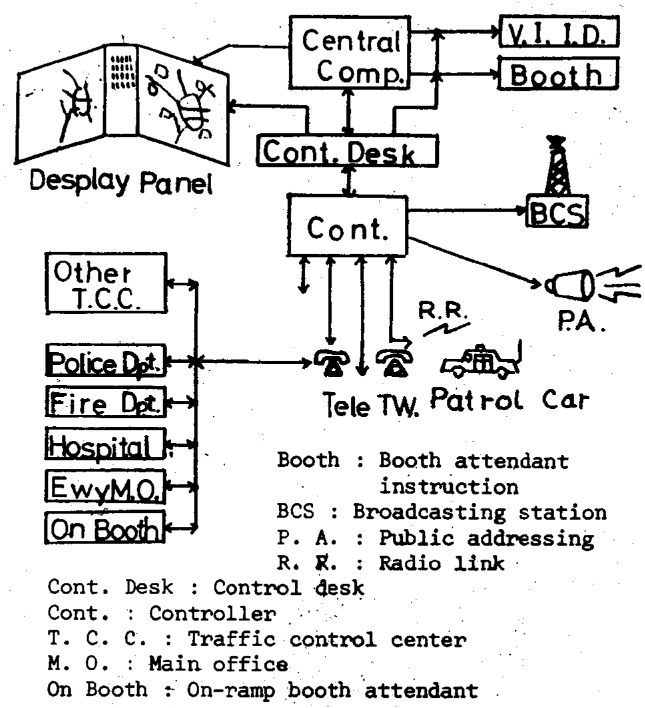


Figure 3. Information flow from control center.

Control center

The functions of the control center are summarized as follows; (i) data collection and processing for traffic control, (ii) reception of emergency call and its processing, (iii) automatic traffic control, (iv) manual traffic control, (v) exchange of information with the other traffic control systems, (vi) monitoring of whole traffic control system, (vii) maintenance of the system, (viii) transmission of instructions and publicity, (ix) modification and improvement of the traffic control system, (x) others.

As shown in Fig. 1, control center consists of information processing system, information display system, CCTV system and traffic controller system. Fig. 4 shows the information display panels and control console in the control center. Fig. 5 shows the computer room in the control center.

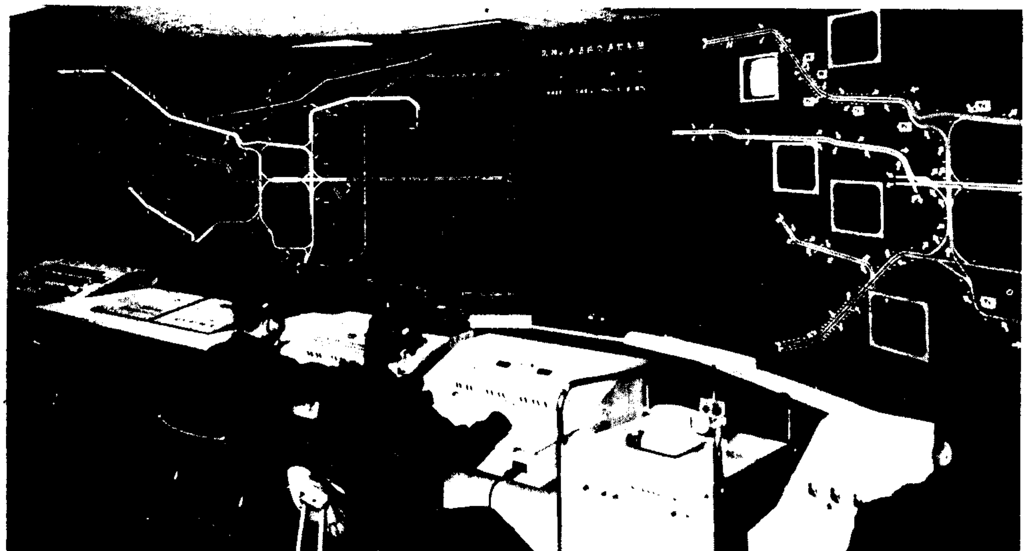


Figure 4.
Information display panels and control console in Control Center. (1970)

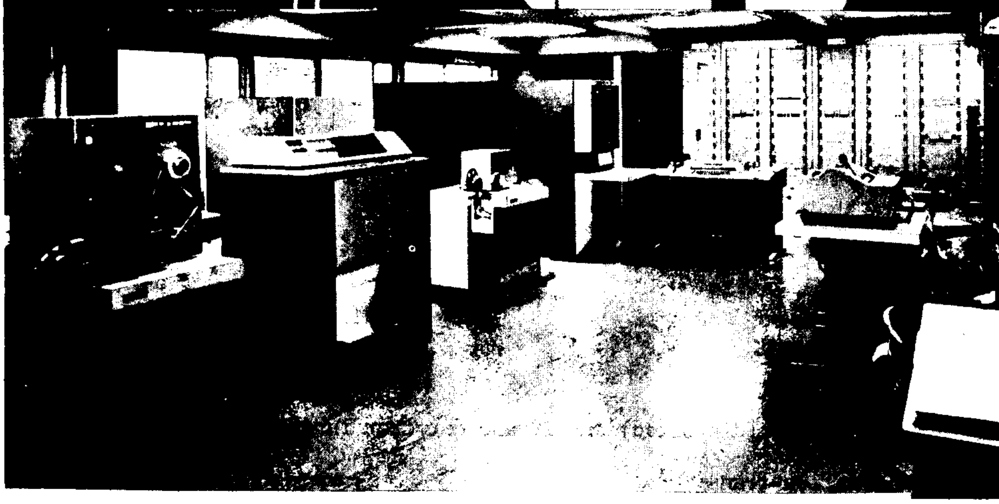


Figure 5.
Computer room in Control Center.

Figure 6. Variable information indication device indicating "Airport line is now congested by an accident".

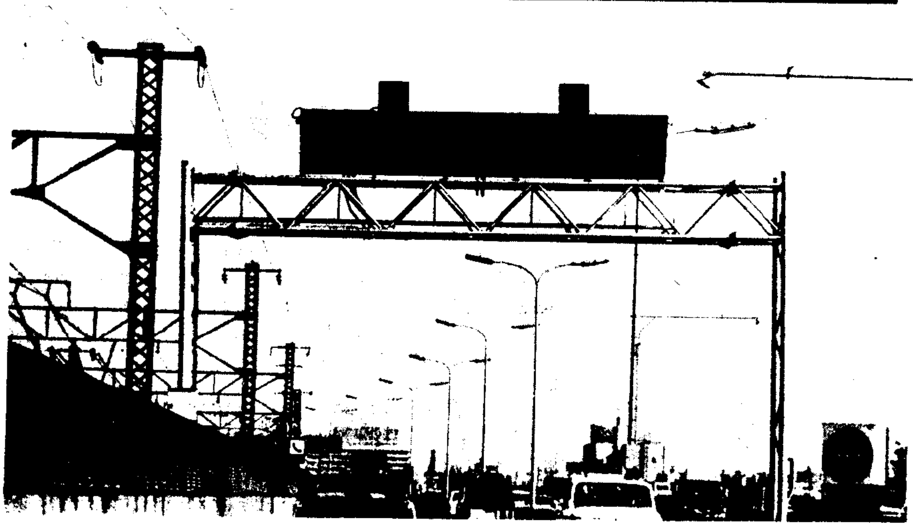


Figure 7. Variable information indication device and ultra sonic detector along expressway.

(All photographs by courtesy of Tateishi Electronics Co. Ltd., Kyoto, Japan.)

The central part of the information processing system with a digital computer FACOM 270-30 with 65 KW core memory and various peripherals. The information display system consists of graphic panel, digital information panel and TV monitor and communication panel. The graphic panel displays the qualitative aspects of the traffic in the whole expressway lines by changing the color of the sections according to the time occupancies. The quantative information is displayed on the digital information panel. On the graphic panel, existance of queue at on or off-ramp, traffic situations on the related streets and expressways with the Hanshin Expressway, the phase of control on the Hanshin Expressway, road informations and weather conditions.

On the digital information panel, time occupancies, traffic volumes and average speed of the sections which have the largest five time occupancies are shown with their section numbers automatically. As a matter of course, the above three parameter values of any section can be shown manually for up tp ten sections. This panel also shows queue length, rate of inflow traffic control at on-ramps and speed limit.

TV monitor and communication panel has 6 monitor TV's and lamps which indicate the place where emergency calls come from. This system covers only expressway lines in Osaka. For Kobe line, Kobe subcenter has its own TV and communication monitor system with 4 TV cameras and 3 monitor TV's and small digital information panel. Kobe subcenter is a miniature of the control center in Osaka and the information on Kobe line is sent on off-line basis now, but the Kobe subcenter and Osaka center will be connected when Osaka-Nishinomiya line is completed. 12 TV cameras are installed in Osaka district. Panning, tilting and zooming of the TV cameras are controlled from the control center through the control console.

Control information indication system

As there is no traffic signal on the through way of the Hanshin Expressway, the control of the cars on and near the expressway should depend on on-ramp inflow control and on the guidances or orders given to the drivers through the information indication devices. Table 1 shows the contents of indicated informations and the places of installation along and around the Hanshin Expressway.

Location / Content	On-ramp	Thru way	Exit	Street
Waiting time	X			
Rate of inflow control	X			X
Closed exit	X	X	X	
Congestion on thru way	X			X
Speed limit		X		
Lane control		X		
Detour guid	X	X	X	X
Signal	X		X	
Lane indication		X		
Congested streets			X	
Visibility	X	X		
Frozed road	X	X		
Snow	X	X		
Wind & rain	X	X		
Slippery rd.	X	X		
Accident	X	X		X
Construction	X	X		X
Fire	X	X		X
Merging traf.		X		
Curve		X		
On-ramp guid				X

Table 1. Contents and locations of information given by variable or fixed information indicator.

The variable information indication devices are controlled automatically and manually if necessary from the control center. Some of them may be controlled manually at the devices. Fig. 6 shows a variable information indication device indicating "Accident, Airport line is now congested." Fig. 7 shows an actual sight of the device installation together with an ultra sonic detector. When information is being indicated, two flash lights on top of the device are flashing.

The special feature of the hardware system of the traffic control system on Hanshin Expressway may summarized in this way. That is, the central computer does not perform the fixed routine jobs such as A-D conversion of the detector signal or calculations of occupancy, traffic volume and average speed except for the Loop line, but the sub-computers perform these jobs. This lessen the load of the central computer tremendously and results that the information processing system has very high capability, reliability and flexibility against the modifications and extensions of the system.

Conclusion

This report has presented a rough sketch of the control system on Hanshin Expressway putting emphasis on hardware system. There are some other aspects of the control system which are not stated here. They are; relations between other traffic control systems such as area traffic control systems in Osaka and Kobe, and traffic control system of Meishin Expressway (inter city expressway which connects Nagoya and Kobe), Kinki Motorway and Chugoku Motorway (both are also inter city expressways), reliability of the hardware system, reliability of data from detectors, maintenability of the hardware system, and so on.

Problem on the co-operation with the other traffic control systems has been studied by the members of the other committees, where almost all members of the committees for Osaka area traffic control system and for the inter city expressways around Osaka are same with the members of the Special Committee for the Hanshin Expressway, except for the committee for the area traffic control system in Kobe. This fact makes this type of co-operation very easy and powerful.

Reliability of the hardware system is one of the most important points for the traffic control. Since the initial installation of the hardware system, efforts have been made by the members of the Hanshin Expressway Public Corporation and the members of the Technical Committee for Traffic Control of the Hanshin Expressway Public Corporation under the chairmanship of Professor E. Kometani, also. The availability of the system has been improving up to very high score. The maintenability is also very high with the assistance of the hardware monitor installed in the computer room of the control center.

Under the direction of the above Technical Committee of the Hanshin Expressway, reliability of information from the detectors were thoroughly inspected in the fiscal year of 1971. The accuracy of the loop detectors on the through way is more than 98% after proper compensations and the accuracy of the ultra sonic detectors is more than 96%, when they are detecting time occupancy. The traffic volume detector at on-ramps are more accurate than those in the through way. This may be over quality for the traffic control. That accuracy, however, is required because the detectors at on-ramps are also checking the money collected at the on-ramp booth, though this dual use of the inflow volume detectors is not desirable for the traffic control system.

The detail of the hardware system on the traffic control system on Hanshin Expressway is also described in the Reports of Study on Technical Research for Traffic Control on Hanshin Expressway, the Foundation of Express Highway Research, (2) and (3).

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