SMART CALL BOX FIELD OPERATIONAL TEST EVALUATION

SUMMARY REPORT

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REVISED DRAFT
5-1-97

ABSTRACT

Smart call boxes are an enhanced version of devices used as emergency call boxes in California. The overall system consists of a microprocessor, a cellular communications transceiver, solar power sources, data collection devices, maintenance computers, and data recording systems. The Smart Call Box Field Operational Test (FOT) evaluated the feasibility and cost-effectiveness of using smart call boxes for five data processing and transmission tasks: traffic census, incident detection, hazardous weather reporting, changeable message sign control, and video surveillance. Evaluation focused on cost-effectiveness, with effectiveness understood to include both functional adequacy and reliability and costs to include capital costs, telephone charges, and maintenance costs. Due to schedule slippage it was impossible to evaluate reliability and maintenance costs. The smart call box concept was found to be feasible but not necessarily optimal. Functional systems for traffic census, hazardous weather reporting, and video surveillance were produced. Due to high wiring installation costs, these will often be cheaper to deploy than hardwire systems but are not necessarily superior to other wireless options. Significant system integration problems were encountered. Systems produced by the FOT should be subjected to further testing and development to provide design enhancements, and to evaluate reliability and maintenance costs. Agencies considering deployment of smart call boxes should prepare detailed deployment plans to resolve such issues as ownership, financing, and provision of maintenance services. Institutional problems encountered in the FOT itself included inadequate involvement of the sponsoring agencies and potential users in system development, delays due to a lengthy vendor-selection process, and cumbersome contracting procedures; some of these might have been avoided by including of all major participants as partners in the FOT proposal.

Key words: intelligent transportation systems, field operational tests, call boxes, traffic data collection, wireless communications, institutional issues, cost-effectiveness.

EXECUTIVE SUMMARY

Smart call boxes are an enhanced version of devices used as emergency call boxes in California. The overall system consists of a microprocessor, a cellular transceiver, a solar power source, data collection devices, a maintenance computer, and data recording systems. The goal of the Smart Call Box Field Operational Test (FOT) was to demonstrate the feasibility and cost-effectiveness of using smart call boxes for five data processing and transmission tasks: traffic census, incident detection, hazardous weather detection and reporting, changeable message sign (CMS) control, and CCTV surveillance. Test systems were designed and installed by two vendors, GTE Telecommunications Systems of Irvine, California and U. S. Commlink of San Leandro, California.

Evaluation of the FOT focused on assessing the cost-effectiveness of smart call boxes as compared with a baseline system using hardwire telephone communications. System effectiveness was understood to include both functional adequacy and reliability. Costs included capital costs, telephone charges, and maintenance costs. Due to schedule slippage, however, it was not possible to adequately evaluate reliability and maintenance costs, and the evaluation was primarily based on functional adequacy and capital costs.

Functional systems were produced for traffic census, hazardous weather reporting, and CCTV Surveillance. The CMS Control subtest was canceled prior to installation of equipment in the field, in part because it was discovered that the CMSs used in California are incompatible with smart call box systems. Incident detection systems were installed in the field but did not function correctly.

Important conclusions of the Smart Call Box FOT evaluation include the following:

1. The smart call box concept is feasible but not necessarily optimal. Due to the high cost of installing wiring, smart call box systems will be cheaper than hardwire systems at many locations. On the other hand, they are not necessarily superior to other wireless options such as special-purpose systems consisting of sensors, cellular modems, and solar power supplies. One major motive for developing smart call box technology was to create multipurpose devices that could take advantage of existing call box infrastructure. The FOT demonstrated, however, that no more than two data-related functions can be supported at a single call box without external power, even if existing solar power supplies are significantly enhanced. In addition, the systems produced by the FOT experienced significant system integration problems, some of which might have been avoided by simpler systems. In particular, the call box microprocessors played little role in the systems produced by the FOT and may have contributed to the system integration problems.

2. The major technical lesson encountered in the FOT was the difficulty of system integration. This difficulty appears to be related to incompatibilities between the smart call box concept and existing commuincation system designs for traffic counters, weather sensors, and similar devices. It was also complicated by the presence of the

call box microprocessors, which added an extra communications interface, and by the presence of call box maintenance computers whose polling routines sometimes interfered with smart call box operation. Some of these difficulties could have been avoided had there been a standard communications protocol applicable to smart call boxes. Development of such a protocol as a part of the National Transportation Communications for ITS Protocol (NTCIP) is highly desirable. In order to produce standards specifically adapted to smart call boxes, the current NTCIP effort would need to be extended to include standards for smart call box higher level functionality, such as data logging and alarm reporting. Actual development and adoption of such a protocol may depend on vendor perceptions concerning the potential size and profitability of the market for smart call boxes.

3. Systems developed by the FOT should be subjected to further testing and development prior to deployment. Goals of future testing and development should be to provide design enhancements, establish system reliability, and estimate maintenance costs.

4. In retrospect, a lack of quantitative market research was a major deficiency of the FOT. The potential size and profitability of the market for smart call boxes may be fairly limited. Prior to further development of smart call box systems, prospective vendors should conduct market research.

5. Agencies considering deployment of smart call boxes should prepare detailed deployment plans to resolve issues such as ownership, financing, and provision of maintenance services. Such planning should also include careful investigation of the qualifications of prospective vendors. Deployment plans are likely to differ significantly between California, where there is a well-developed system for installing and maintaining voice call boxes, and other states.

6. Important institutional features of this FOT included control by local agencies as opposed to the California Department of Transportation (Caltrans) Office of New Technology and Research, use of a private-sector project manager, and involvement of vendors through arms-length contracts. While these arrangements were effective for the most part, some of them contributed to problems encountered in the conduct of the FOT. Major institutional problems included inadequate involvement of both the sponsoring agencies and potential users in system development decisions, a lengthy and complicated vendor selection process, and cumbersome contracting procedures. Some of these problems might have been avoided by an organizational structure that included all major participants as partners in the original proposal.

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INTRODUCTION

Smart call boxes are devices similar to those used as emergency call boxes in California. They consist of a microprocessor, a cellular telephone transceiver, and a solar power source. The purpose of the Smart Call Box Field Operational Test (FOT) was to determine whether such devices are a cost-effective means of performing specified data processing and transmission tasks. The FOT was divided into five subtests, each focusing on a particular data processing/transmission task. The five subtests were as follows:

1. Traffic Census

2. Incident Detection

3. Hazardous Weather Detection and Reporting

4. Changeable Message Sign (CMS) Control

5. CCTV Surveillance

This report presents an overview of the FOT. Detailed descriptions of each subtest are presented in a separate report (*1*).

The FOT was motivated by a belief that smart call boxes could fill an important niche in the overall ITS architecture. At the time the FOT was proposed, the one version proposed ITS architecture identified an entity called a “roadside terminal” that would be connected via bi-directional communications links to both transportation management centers (TMCs) and vehicles (*2*). It was felt that smart call boxes could serve this function.

In addition, the smart call box concept was particularly attractive in California because a well-developed voice call box system already exists. A second motivation for developing smart call boxes was to take advantage of the potential for multiple use of the existing call boxes. It was felt that the marginal cost of adding data processing and transmission features to existing call boxes would be less than deployment of special-purpose data terminals.

Beyond this, it was felt that smart call box technology possesses two important cost advantages. First, it avoids the need to provide electrical and telephone conduits to the roadside terminal. Since current California Department of Transportation (Caltrans) cost estimates for providing wiring amount to $11.00/ft for trenching, conduit, and wiring and $100/ft for jacking cables under the traveled way, elimination of wiring can result in a significant cost advantage at many sites. Second, the existing call boxes have been crash tested and approved for installation in the roadway clear zone. So long as smart call boxes do not significantly alter the weight distribution of the call box, their use avoids the tedious and expensive process of crash testing that might otherwise be required.

The goals of the FOT were to demonstrate the feasibility of using smart call boxes for the tasks outlined above, evaluate their potential cost-effectiveness, and identify institutional issues which might affect their deployment. The FOT was successful in producing functional devices for three of the five subtests. It was less successful in evaluating their cost-effectiveness because schedule slippage compromised efforts to evaluate system reliability and determine maintenance costs. Finally, a number of critical institutional issues were identified, some of which had substantial impact on the tests.

Participants

The Smart Call Box FOT was funded by the Federal Highway Administration (FHWA) and the State of California, acting through the Caltrans Office of New Technology and Research. It was carried out by a consortium (the FOT Partners) consisting of Caltrans District 11, the Border Division of the California Highway Patrol (CHP), and the San Diego Service Authority for Freeway Emergencies (SAFE).

Day-to-day management of the FOT was provided by a Project Manager. Initially, the Project Manager was the Titan Corporation; however, in March 1994 Titan sold this portion of its business to RMSL Traffic Systems, Inc. and RMSL acted thereafter as the Project Manager under subcontract with Titan. On January 1, 1996 , RMSL changed its name to TeleTran Tek Services (T-Cubed); in this report this firm will be referred to as T-Cubed throughout.

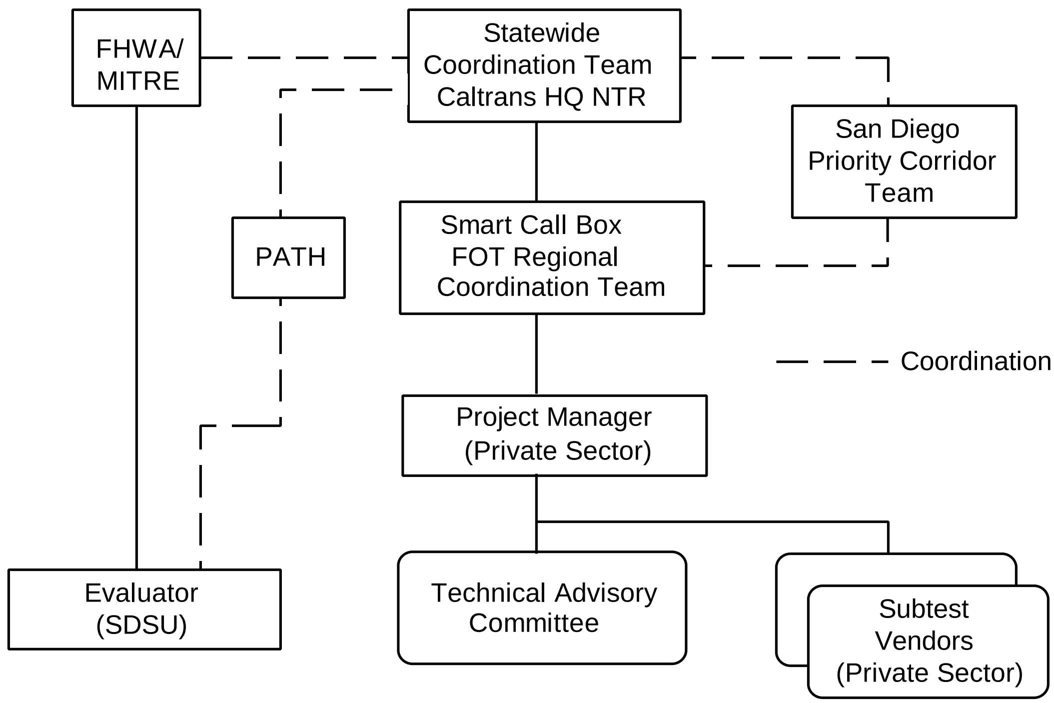
Independent evaluation of the FOT was provided by San Diego State University (SDSU), under subcontract with the California Partners for Advanced Transit and Highways (PATH) program, which served as statewide Evaluator for California field operational tests.

Technical supervision of the FOT was the responsibility of a Regional Coordination Team (RCT) consisting of voting representatives of the Partners and non-voting representatives of the Project Manager and the Evaluator. In addition, non-voting representatives of FHWA, the Caltrans Office of New Technology and Research, and PATH sometimes attended RCT meetings.

Design and installation of test systems was carried out by two vendor teams under contract with the Partners. One of these teams was led by GTE Telecommunications Systems of Irvine, California. The other was led by U. S. Commlink of San Leandro, California. A complete list of vendors included in the two teams is documented in Appendix A. Input into the management of the FOT by the vendor teams (and, in theory, by any other interested individuals or firms) was provided by means of a Technical Advisory Committee (TAC).

Figure 1 is a schematic diagram showing the formal lines of authority and reporting among the participants in the Smart Call Box FOT.

Figure 1. Formal Lines of Reporting for the Smart Call Box FOT.



Goals and Objectives

Goals and objectives of the FOT are documented in the FOT Evaluation Plan (*3*) and in Individual Test Plans (*4*,*5*). Goals of the FOT evaluation were:

1. To evaluate the cost-effectiveness of smart call boxes.

2. To document and discuss the institutional issues encountered in the Field Operational Test.

Objectives related to the first of these goals were:

1.1 To determine (where feasible) the relative effectiveness of smart call boxes and a baseline system consisting of conventional telephone lines and Model 170 controllers for the tasks involved in the Field Operational Test, with effectiveness to include the functional adequacy, accuracy, and reliability of the data processing and data transmission provided.

1.2 To determine the projected life-cycle costs of smart call boxes and the baseline system.

1.3 To determine tradeoffs between smart call boxes and the baseline system in carrying out the tasks involved in the Field Operational Test and to determine which system is best for each task.

Objectives related to the second goal were:

2.1 To determine whether any institutional issues encountered in the Field Operational Test have a potential for affecting the performance of similar systems if widely deployed.

2.2 To determine the perceptions of participants in the Field Operational Test regarding the administration of the Field Operational Test, any other significant institutional issues encountered, and the effect of institutional issues on similar systems if widely deployed.

Subtest Descriptions

The Smart Call Box FOT consisted of five subtests. For purposes of scheduling, these subtests were grouped into three subphases. As originally scheduled, Subphase 1 was to have included the Traffic Census and Hazardous Weather subtests, Subphase 2 was to have consisted of the CCTV Surveillance subtest, and Subphase 3 was to have included the Incident Detection and CMS Control subtests. This proposed staging was based on the perceived difficulty of the system development tasks involved in each subtest. In September 1995, this phasing was altered to move the CCTV Surveillance subtest to Subphase 3 and the Incident Detection subtest to Subphase 2. This change was made because the FOT was lagging seriously behind schedule. It was based on the relative amount of field data collection time expected to be required for these two subtests. Later, the CMS Control subtest was canceled because changes in the design of the test and technological advances independent of the FOT were judged to have undermined its usefulness, and the scopes of other subtests were altered because it appeared that vendors would not be able to meet deadlines for installation of equipment. In addition, a "Subphase 0," a preliminary communications test, was scheduled to be conducted immediately after the initiation of the FOT. The five main subtests were as follows:

Subtest 1: Traffic Census

The objective of this subtest was to evaluate the cost-effectiveness of smart call boxes for processing and transmitting traffic census data. Eight smart call box units were tested. These included a total of five different test system configurations developed by the two vendor teams. The team headed by GTE designed and installed two units. One of these employed a standard inductive loop traffic counter external to the call box and the other a loop counter mounted in the call box cabinet. The other team, headed by U. S.

Commlink, designed and installed six units. Four of these employed standard inductive loop counters external to the call box, one employed an inductive loop counter mounted in the call box cabinet, and one employed an infrared detector counter. All traffic census installations except the U. S. Commlink infrared detector system used existing induction loops. All GTE installations involved modification of existing call boxes, but all U. S. Commlink call box units were specially installed.

Subtest 2: Incident Detection

The objective of this subtest was to evaluate the cost-effectiveness of smart call boxes for processing and transmitting incident alarms. In the course of planning for the subtest, it was decided to limit the test to detection of congested traffic, as indicated by specified speed thresholds, rather than trying to distinguish between recurrent congestion and incident congestion.

Eight smart call box units were tested. These included a total of three different test system configurations developed by the two vendor teams. The team headed by GTE designed and installed six units, all of which employed inductive loop traffic counters mounted in the call box cabinet. The other vendor team, headed by U. S. Commlink, designed and installed two units. One of these employed a standard loop counter external to the call box and the other employed an infrared detector. All traffic census installations except the U. S. Commlink infrared detector system used existing induction loops. This complicated evaluation of the subtest, because none of these loops were located in places where alternative sources of speed data were available (for instance, speed estimates from ramp meter volume and occupancy counts). All GTE installations involved modification of existing call boxes, and all U. S. Commlink call boxes were specially installed.

Subtest 3: Hazardous Weather Conditions Detection and Reporting

The objective of this subtest was to evaluate the cost-effectiveness of smart call boxes for processing and transmitting hazardous weather alarms. Four smart call box units were tested. These included a total of three different test system configurations developed by the two vendor teams. The team headed by GTE designed and installed two units using sensors to detect fog or other low visibility conditions. The other team, headed by U. S. Commlink, designed and installed two units. One of these was a low-visibility detection system similar to that developed by GTE. The other consisted of a call box connected to a Davis Weather System, which was used to provide wind speed alarms. All weather sensors used in this subtest were specially installed, as were the U. S. Commlink call boxes. All GTE installations involved modification of existing call boxes.

Subtest 4: Changeable Message Sign Control

The objective of this subtest was to evaluate the cost-effectiveness of smart call boxes for controlling changeable message signs (CMSs). It had been proposed to test four smart call box units. Due to problems encountered with system designs for this subtest and development of other technologies independent of the FOT, this subtest was canceled prior to the installation of equipment.

Subtest 5: CCTV Surveillance

The objective of this subtest was to evaluate the cost-effectiveness of smart call boxes for controlling video cameras and transmitting video signals. Three smart call box units were tested. These included two different test system configurations developed by the U. S. Commlink team. The three units included two monochrome fixed-field-of-view (FFOV) units and one FFOV color system that incorporated a pan-tilt-zoom (PTZ) camera (that is, the camera had PTZ capability but could not be controlled remotely, because the vendor was unable to resolve the communication and system integration problems involved). All units transmitted slow-scan video images. The vendor team led by GTE had also expected to participate in this subtest but was unable to meet the RCT's deadline for installation of equipment. All equipment used in this subtest was specially installed.

Test Sites

Tables 1 and 2 give configurations for all the test sites ultimately used. Figure 1 is a map showing their locations. It should be noted that the site numbering systems were developed by the vendors independently of one another, and are somewhat different. U. S. Commlink conducted tests at six sites, each of which was intended to be used for more than one subtest simultaneously; these were simply numbered consecutively, and numbers were retained when sites were relocated during the planning phase (as happened with Site 6). GTE, on the other hand, did not plan to conduct more than one test at a time at its sites, and actually numbered subtests, rather than sites. Consequently, in two cases, GTE sites were assigned two different numbers. These sites were designated as 2 and 3 for the Traffic Census subtest and 13 and 14 for the Incident Detection subtest. In addition, GTE did not retain site numbers when sites were relocated or subtests canceled; as a result, GTE site numbers are not consecutive. In Tables 1 and 2, the abbreviation "PM" stands for "post mile."

TEST CHRONOLOGY

Organizational Phase

Figure 3 shows an overall time line for the Smart Call Box FOT. The FOT proposal was submitted in response to an RFP for IVHS field tests issued by FHWA on July 20, 1992. The initial proposal was submitted on October 19, 1992 and was approved for funding in late September 1993.

Table 1. Site Configurations for U. S. Commlink Test Sites.

Site No.	Site	Subtest			
		Traf. Cen.	Incid. Det.	Weather	CCTV
1	I-5, PM NB 36.826	Ext. Det.	--	Jaycor	B/W
2	I-805, PM NB 28.526	Ext. Det.	Ext. Det	--	Color
3	I-805, PM NB 18.296	Ext. Det	--	--	--
4	SR-163, PM NB 5.498	Ext. Det.	--	--	B/W
5	I-8, PM EB 39.300	Int. Det.	--	Davis	--
6	I-15, PM NB 12.957	Infrared	Infrared	--	--

Table 2. Site Configurations for GTE Test Sites.

Site No.	Site	Subtest		
		Traf. Cen.	Incid. Det.	Weather
2,13	I-8, PM EB 0.214	Ext. Det.	Int. Det.	--
3,14	I-8, PM EB 1.450	Int. Det.	Int. Det.	--
4	I-5, PM SB 35.200	--	--	Jaycor
5	SR-75, PM NB 17.600	--	--	Jaycor
7	I-805, PM NB 17.380	--	Int. Det.	--
21	I-805, PM NB 25.300	--	Int. Det.	--
22	I-805, PM NB 26.430	--	Int. Det.	--
23	I-805, PM NB 20.888	--	Int. Det.	--

Figure 2. Map Showing FOT Field Test Sites

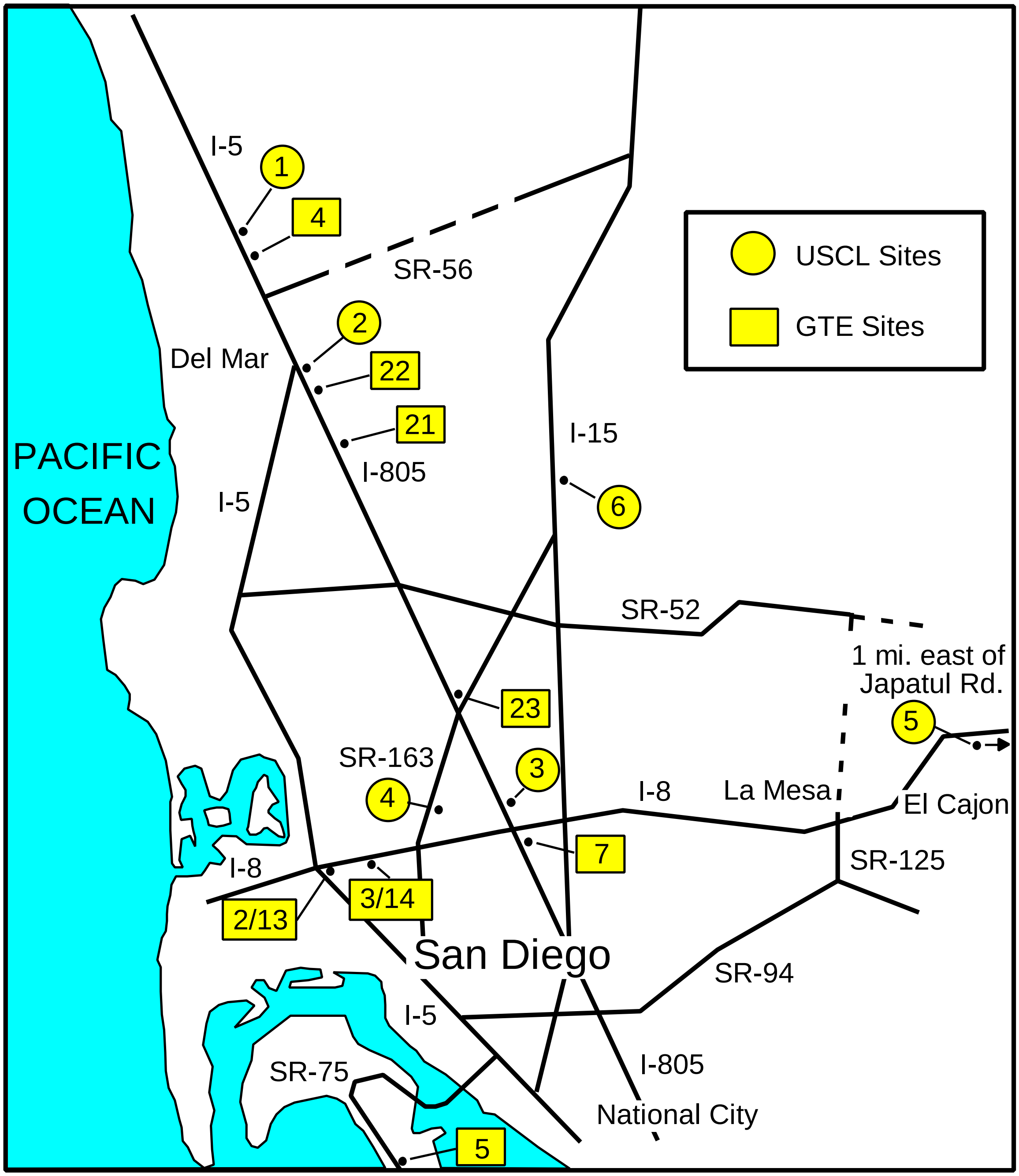
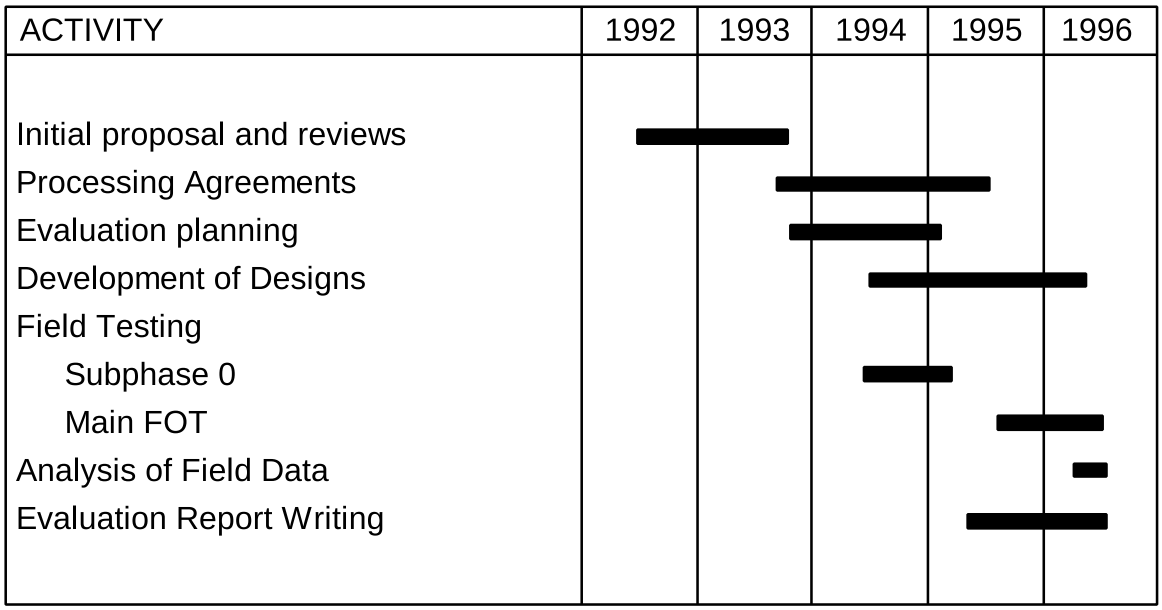


Figure 3. Time Line for Major FOT Activities.

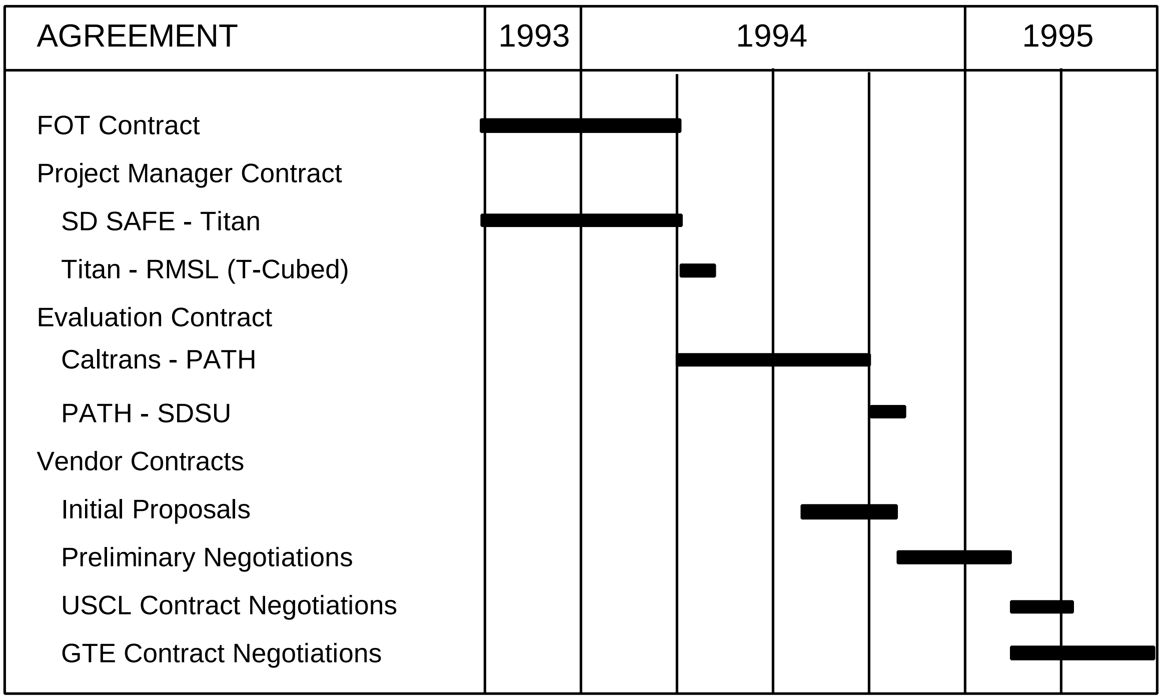


The FOT agreement between the State of California and San Diego SAFE (acting as agent for the FOT partners) went into effect in early April 1994. The evaluation contract between Caltrans and the California PATH program was finalized at the end of September 1994; the evaluation subcontract between PATH and SDSU was issued on November 1, 1994. Contracts with the prime vendors, U. S. Commlink and GTE, were finalized on April 6, 1995 and June 26, 1995 respectively. Figure 4 shows a detailed time line for the negotiation and processing of the FOT agreements.

Field Testing

Field testing of equipment began in September 1995 and was completed in June 1996. Figures 5-8 are detailed time lines for the four subtests for which equipment was actually installed (the CMS Control subtest was canceled prior to the installation of equipment). They show periods of time for each test site for which equipment was operational, operational with errors or problems, or not operational. In addition, a preliminary communications test referred to as “Subphase 0” was conducted between July 1994 and March 1, 1995. Highlights of Subphase 0 and the various subtests were as follows.

Figure 4. Time Line for Negotiation and Processing of FOT Agreements.



Subphase 0

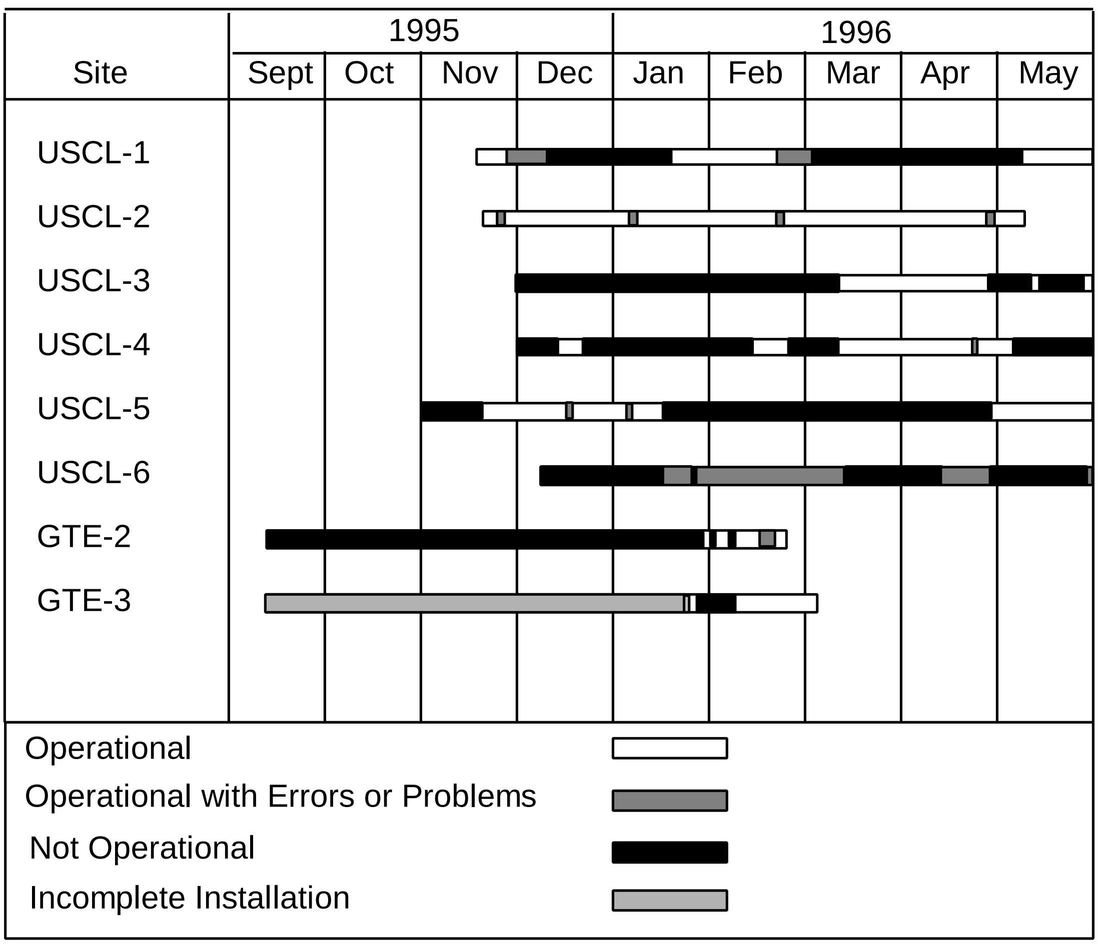
Subphase 0 was a preliminary communications test intended to demonstrate the feasibility of transmitting sensor data from a call box to an evaluation site. GTE was selected to carry out this test in June 1994, prior to the release of the RFP for the full FOT to prospective vendors. Due to a variety of institutional problems, equipment was not installed until late October 1994, and was not fully connected until December 1. Following this, there were a number of equipment failures and system integration problems, which were finally resolved at the end of January 1995. Data collection continued successfully through February 1995, and the test was terminated on March 1.

Traffic Census Subtest

GTE systems were installed in September 1995. Due to a variety of problems, neither was operational until late January 1996. In the case of GTE Site 3, there was a delay in hooking up with the existing loop detectors that was not resolved until late January. These sites were converted to incident detection sites (employing a different model of traffic counter) in late February and early March 1996. U. S. Commlink systems were installed in November and December 1995. The external-counter systems (U. S.

Commlink Sites 1-4) were operational almost immediately, but all units except that at Site 2 later experienced extended periods of down time. Problems included software problems and disruption of external A/C power supplies. The internal-counter system (U. S. Commlink Site 5) was installed in November 1995 and functioned successfully until early January 1996. Thereafter, it was down until late April 1996 due to failure of the cellular phone and the traffic counter. The infrared-detector system (U. S. Commlink Site 6) was installed in December 1995 but never functioned correctly, due to a variety of problems.

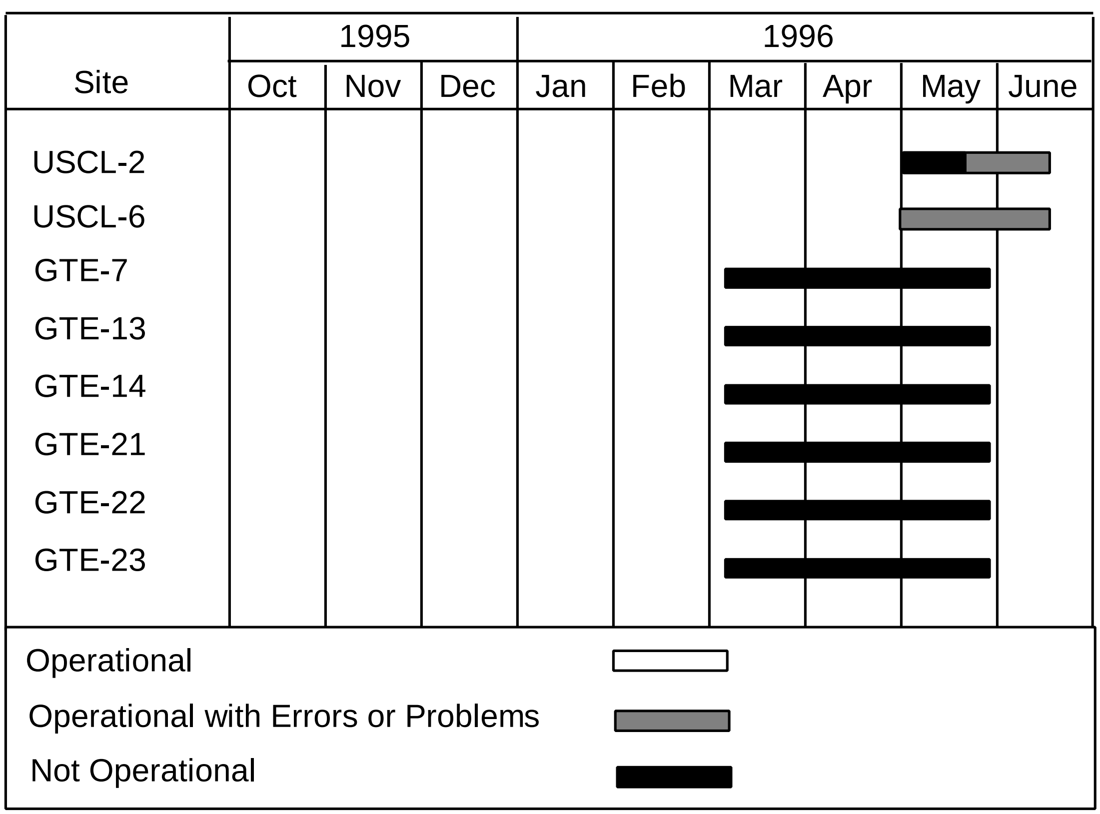
Figure 5. Time Line Showing Operational Status of Equipment at Traffic Census Field Test Sites.



Incident Detection Subtest

GTE systems were installed in early March 1996 but never functioned correctly. Only one alarm was ever received from the field. Also, these units were supposed to provide for downloading of traffic data during a predetermined time windows, but they became inaccessible due to the GTE call box maintenance computer resetting the time windows for communication unpredictably. The U. S. Commlink external-detector system (U. S. Commlink Site 2) was installed around the beginning of May 1996 and began to transmit alarms about three weeks later. Numerous alarms were transmitted, but it was subsequently determined that the unit was not always transmitting alarms when congestion was present. The U. S. Commlink infrared-detector system was converted to incident detection use around May 1, 1996, and transmitted numerous alarms, but never functioned accurately.

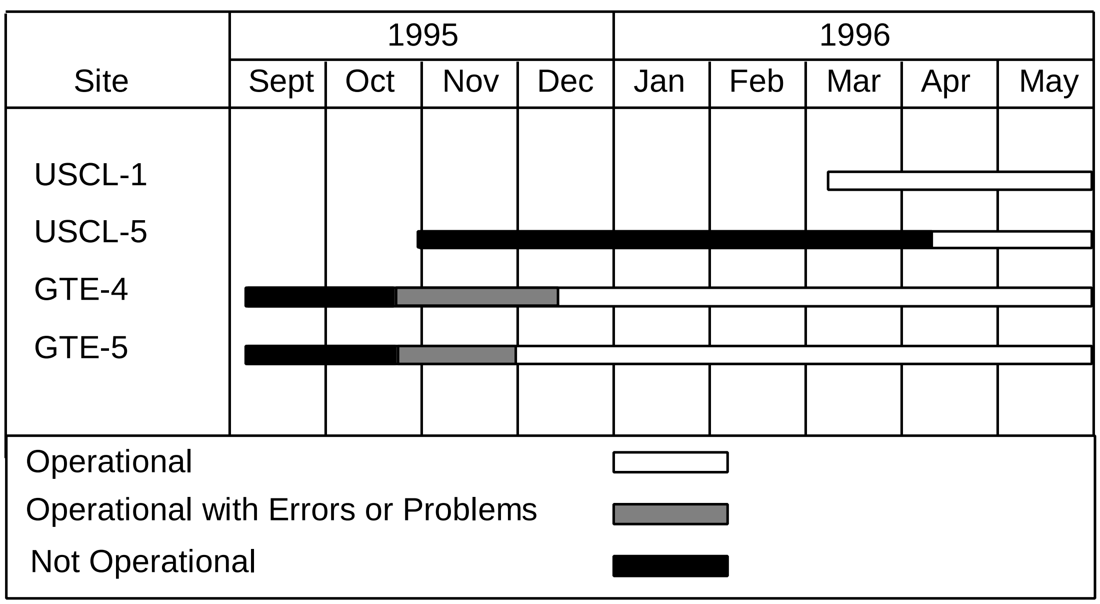
Figure 6. Time Line Showing Operational Status of Equipment at Incident Detection Field Test Sites.



Hazardous Weather Detection and Reporting Subtest

GTE's visibility alarm systems were installed in September 1995. Although there were problems with equipment malfunctions and system integration initially, by November 1995 they were successfully transmitting alarms. Following correction of software problems in November and December, they functioned continuously for the remainder to the FOT. The U. S. Commlink Davis weather station system (U. S. Commlink Site 5) was initially installed on November 1, 1995. Shortly thereafter it was damaged when its anemometer was accidentally broken off the pole by a motorist. Later, this site was down due to problems with the cellular phone. It finally became operational in early April 1996. By this time, wind speeds were insufficient to produce alarms at the original threshold of 30 MPH; once the alarm threshold was lowered to 20 MPH numerous alarms were transmitted. U. S. Commlink also installed a visibility alarm system in March 1996. While no "real" alarms were transmitted by this system, presumably because fog was no longer present at this time of year, artificially induced alarms were reported.

Figure 7. Time Line Showing Operational Status of Equipment at Hazardous Weather Reporting Field Test Sites.



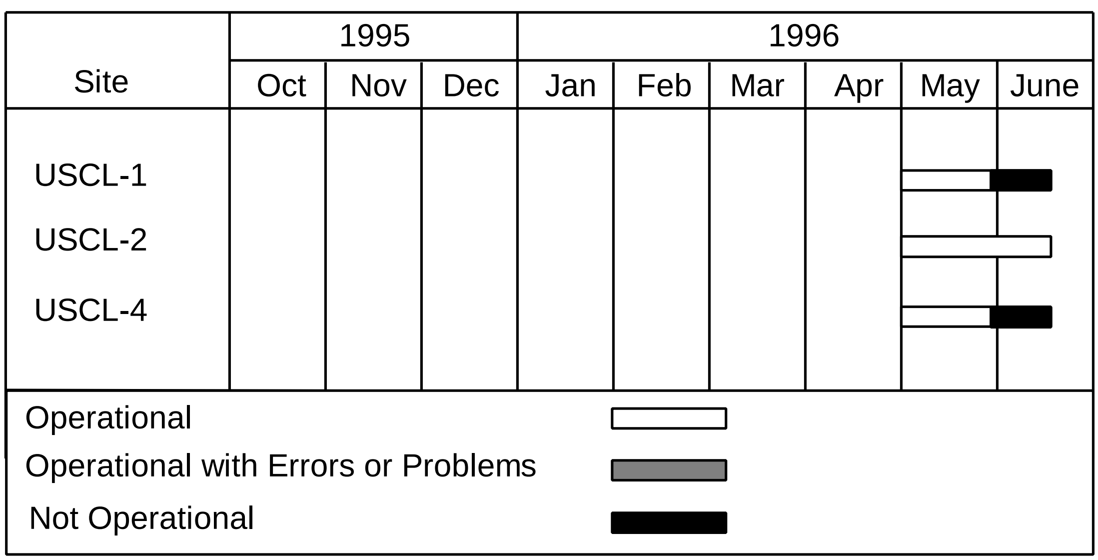
CMS Control Subtest

No equipment was ever installed for the CMS Control subtest. U. S. Commlink did make serious efforts to design a CMS control system, but in the course of these it was discovered that the design of the CMSs used in California was incompatible with control by a smart call box. On March 21, 1996, the RCT decided to cancel this subtest. Reasons included the incompatibility of the CMS design with the smart call box concept, the independent development of cellular communications links for CMS control systems, and considerations related to the FOT budget and schedule.

CCTV Surveillance Subtest

U. S. Commlink CCTV surveillance systems were installed at the beginning of May 1996. The color system functioned adequately following adjustments to improve image quality. The monochrome units functioned adequately following adjustments to improve image quality, but failed after about three weeks. The cause of this failure was never determined, as the project was terminated shortly afterwards.

Figure 8. Time Line Showing Operational Status of Equipment at CCTV Surveillance Field Test Sites.



Other FOT Activities

Analysis of field data took place primarily during May and June 1996. Other activities, such as evaluation planning, development of test system designs, and writing of evaluation reports were conducted simultaneously with processing of agreements and field testing.

Follow-Up Activities

The FOT was terminated on June 30, 1996. As the its completion approached, there were discussions of possible follow-up activities, including the potential deployment of some of the systems involved in the FOT. In the San Diego area, this resulted in a decision to prepare a proposal for pilot deployment of selected smart call box systems as a part of the Southern California Priority Corridor Showcase Project.

This proposal calls for small-scale deployment of smart call box systems for traffic census, low-visibility detection, wind-speed monitoring, and verification of CMS messages by CCTV. The proposed pilot deployment is intended to provide for further testing and system development (as recommended elsewhere in this evaluation report) and to increase confidence in eventual decisions to deploy (or not deploy) full-scale systems. The pilot deployment proposal calls for integration of all proposed systems into the District 11 TMC; in the cases of the low-visibility and wind-speed alarm systems, this also involves developing or installing display systems at the TMC. In addition, the proposal for pilot deployment of the low-visibility alarm system calls for establishment of a network of sensors in an area with a high incidence of visibility-related accidents. At the time of this writing, it is not known whether this proposal will be funded or not.

Elsewhere in California, smart call projects are currently underway in the San Bernardino-Riverside area, and in Sutter County. The San Bernardino-Riverside project was actually underway before the Smart Call Box FOT, and involves traffic census and weather warning systems. The Sutter County project, which has just recently begun, involves traffic census and low-visibility detection systems. In addition, planning is underway for smart call box projects in the Los Angeles County-Ventura County area, and in the San Francisco Bay Area.

In addition to activities related to further testing or potential deployment, the RCT sponsored a workshop on July 17 that was attended by about fifty persons from public agencies and private firms. The goal of this workshop was to publicize the results of the FOT.

EVALUATION METHODOLOGY AND CONSTRAINTS

As initially planned, the technical portion of the Smart Call Box FOT evaluation was to compare the cost-effectiveness of smart call boxes with that of hardwire communications systems used for similar purposes. Effectiveness was seen as involving the functional adequacy, accuracy, and reliability of data processing and transmission. Cost comparisons were to be in terms of life-cycle costs; these, in turn, were expected to consist of capital costs, monthly telephone charges, and maintenance costs.

Functional Adequacy

As initially conceived, the functional adequacy and reliability of the test systems were defined in terms of sets of performance standards, which were adopted by the RCT for each of the subtests. These performance standards are documented in Appendix B. They were intended to reflect the needs of potential users of smart call boxes, and were based on input from Caltrans District 11 traffic operations personnel. Ideally, they would have been developed very early in the FOT and would have provided guidance for system design as well as evaluation. As it turned out, however, they were not issued until just before proposals were due from the vendors. As a result, they had little influence on basic system design concepts, many of which dated back to the original FOT proposal; rather, they represented an elaboration of these concepts in certain matters of detail.

As the FOT proceeded, it became clear that evaluation of functional adequacy required more than merely comparing the functioning of the test systems with the written performance standards. There also needed to be a critique of the extent to which the test system designs addressed and solved the basic design problems posed by the smart call box concept -- and, indeed, of the extent to which the FOT, as actually structured, required that these be addressed. For example, the FOT proposal clearly envisioned smart call boxes as multipurpose devices, but the FOT was structured as a series of independent subtests, which meant that test systems need not provide multiple data processing and transmission capabilities.

In addition, it was realized late in the evaluation process that in order to really evaluate the smart call box concept, the FOT should have compared smart call boxes with other wireless systems as well as with hardwire communications systems. Since such comparisons were not envisioned in the FOT proposal, and were never performed, the evaluation could only speculate about the merits of smart call boxes relative to other wireless systems.

Much of the evaluation of the functional adequacy of the test systems focused on the viability of the underlying system concept and the extent to which the test systems demonstrated it. In addition, each test system was evaluated in terms of the performance standards. This evaluation consisted of two stages. The first evaluated the extent to which the designs provided by the vendors were *intended* to meet the performance standards (in some cases the vendors simply disregarded particular standards); the second compared the *actual* functioning of the test systems, as demonstrated by the FOT, with the performance standards.

In coming to an overall assessment of functional adequacy, it was also necessary to consider the appropriateness and adequacy of individual performance standards. In some cases, it was decided that performance standards were too rigid (for example, specification of exact data record sizes for traffic census systems). In other cases, the RCT waived standards because they proved to be unrealistic (for example, requirements that weather alarm systems be able to download alarm thresholds remotely). Finally, in some cases it was discovered that the performance standards had failed to address important issues (for instance, the need for all-clear signals to reset weather system alarms). Thus, the overall assessment of the performance of each test system had to consider not only whether it met stated performance standards but also whether, on the whole, it could perform the function for which it was intended.

Accuracy

The necessity for evaluating the accuracy of data collected by the smart call box systems was debated during the planning of the evaluation. Originally, the position of the evaluator had been that the data collection devices (traffic counters and weather sensors) were existing technology, whose accuracy had (presumably) already been demonstrated. After considerable discussion, however, it was decided that this might not always be true, and that even where it was, data accuracy should be checked wherever possible.

Unfortunately, it was rarely possible. In the case of the low-visibility alarm systems, it had originally been planned to provide verification of alarms by means of a CCTV system. This system involved a monochrome FFOV camera focused on a series of paddles installed at known distances from the camera, which would have allowed visibility to be determined directly. This system would have allowed verification of alarms actually received and identification of false alarms. On the other hand, there was never any practical way to eliminate the possibility that sensors were failing to respond to conditions that warranted alarms.

As it turned out, even verification of the alarms actually received was not possible, due to schedule slippage and a lack of coordination between the hazardous weather reporting subtest and the CCTV subtest. The CCTV system was eventually deployed at one site, but by the time it came on line in May 1996, weather conditions were such that low-visibility alarms were not to be expected. This meant that evaluation of low-visibility alarms was confined to noting whether they occurred at times that were plausible. A similar situation existed with regard to the wind speed alarms, except that in this case no direct means of verification was ever proposed.

In the case of traffic census data and congestion alarms produced by the incident detection systems, it had been intended to compare data from the smart call box installations with data from nearby ramp metering or traffic census sites equipped with hardwire data transmission systems. Only very limited comparisons could be performed because most FOT test sites were not located near sites where alternative sources of data were available: detailed comparisons were possible at only one of the traffic census sites and at none of the incident detection sites. Also, a CCTV installation was used to verify congestion episodes at one of the incident detection sites, but this could provide only a qualitative assessment of traffic conditions.

This situation resulted from the fact that test sites were selected by the vendors in consultation with the Caltrans District but without the direct participation of the evaluator. Numerous factors were considered in selecting sites. Considerations related to safety (such as the availability of adequate work space on the side of the roadway) or the basic functioning of the test systems (such as the availability of external power for most of the U. S. Commlink sites) tended to prevail over data collection considerations. Even in cases where the same site was used for both a smart call box installation and a regular traffic census installation, data were not collected by both systems at the same time. In some cases this may have been impossible, since the loops could not be connected to both systems at the same time.

Reliability

The performance standards were also intended to provide a basis for evaluation of system reliability. In most cases, reliability was defined in terms of system availability, with 90 per cent availability being the usual standard. This definition of reliability assumed that the systems tested would be identical to those eventually deployed, that maintenance practices would be similar to those for deployed systems, and that enough time would be available to establish the availability rate with some degree of confidence.

As the FOT progressed it became apparent that none of these assumptions was entirely valid. The systems tested were actually prototypes, and still had initial design flaws that needed to be rectified; hence, they were not representative of what would eventually be deployed, and the rate of system failures experienced in the FOT was greater than what would be expected for a deployed system (assuming eventual correction of the design flaws). Moreover, neither vendor was locally-based and neither had a resident maintenance staff assigned to the FOT. This meant that repairs were sometimes not made in a timely fashion, which reduced system availability. Also, because these were prototype systems, spare parts were unavailable. This meant that faulty components had to be repaired rather than replaced, which also reduced system availability.

Finally, in several cases there was inadequate time to establish availability rates. Initial schedules had assumed that the smart call box systems would be tested in the field over extended periods of time. Periods allocated for field testing varied depending on the subtest, but were at least three months for all test systems. As the FOT progressed, however, schedules slipped.

The first major delay in the FOT (once the FOT contract was in place) resulted from underestimation of the time required for the writing and review of vendor proposals and the negotiation of vendor contracts. Once field testing was underway, there were further delays due to unexpected technical problems with the first systems installed. As a result of these delays, the RCT revised the FOT schedule in August 1995 and January 1996. These revisions were intended to provide adequate time for data collection for the evaluation, although by January 1996 scheduled field testing the last subphase of the FOT had been reduced to two months (an equipment installation deadline of March 15, 1996 and a May 15 deadline for completion of data collection).

Despite these schedule revisions and the issuance of notices to cure default to both vendors in January 1996, delays continued to occur. In the end, the U. S. Commlink wind speed alarm system was installed in mid-April 1996 and its incident detection and CCTV surveillance systems at the beginning of May. To partially compensate for these delays, data collection for the evaluation was extended to June 15, 1996. This allowed evaluation of the functional adequacy of the U. S. Commlink wind speed alarm, incident detection, and CCTV surveillance systems, but did not allow adequate time to evaluate their reliability.

Costs

Cost comparisons required estimates of capital costs, monthly telephone charges, and maintenance costs. Capital costs were estimated by having Caltrans structure bids for smart call box installations similar to those used in the FOT and then asking the vendors what they would charge to provide these systems in quantity. For items not supplied by the vendors, costs were derived from standard unit prices used by Caltrans. This allowed reasonable estimates of what it would have cost to provide baseline systems at the test sites, as well as an estimate of the cost of providing the smart call box systems as a part of a deployment effort. Wiring costs tended to dominate estimates for the baseline systems. Since these were highly site-specific (due to varying access distances to telephone and/or external power supply systems), estimated cost differences between smart call box and baseline systems also varied widely. Thus, it was possible to establish the relative capital costs for the sites actually used, but there was no way to know whether these would be typical of all potential sites.

Telephone charges were estimated based on those currently paid by San Diego SAFE for the voice call box system and Caltrans District 11 for existing hardwire data systems. It had been intended to estimate maintenance costs based on the maintenance efforts of the vendors. This proved impractical, however, for reasons similar to those discussed in connection with the evaluation of test system reliability: neither the systems nor the vendors' maintenance efforts were typical of what would be expected in a deployed system, and in several cases there was inadequate time to establish the amount of maintenance that would be required.

TECHNICAL RESULTS

The Smart Call Box FOT involved the design and testing of smart call box systems to carry out various data processing and transmission functions. The technical results of the FOT include both the design and functioning of these systems. Evaluation objectives related to the technical performance of the test systems included the following:

1.1 To determine (where feasible) the relative effectiveness of smart call boxes and a baseline system consisting of conventional telephone lines and Model 170 controllers for the tasks involved in the Field Operational Test, with effectiveness to include the functional adequacy, accuracy, and reliability of the data processing and data transmission provided.

1.2 To determine the projected life-cycle costs of smart call boxes and the baseline system.

1.3 To determine tradeoffs between smart call boxes and the baseline system in carrying out the tasks involved in the Field Operational Test and to determine which system is best for each task.

The section on System Design that follows summarizes the vendors' approaches to key design issues and evaluates the extent to which these were resolved. It also evaluates the extent to which test system designs conformed to the performance standards and other specifications established by the RCT. The section on System Performance evaluates the extent to which test systems performed as designed. It is followed by a discussion of the most significant of the technical issues and their impact on the viability of the smart call box concept.

System Design

The basic concept of a smart call box is that it is a multipurpose data processing and transmission system involving an independent solar power supply and wireless communications. Figure 9 is a block diagram showing the architecture of a generic smart call box. The overall system includes a microprocessor, a cellular telephone transceiver, a solar power supply (solar collectors and a storage battery), field data collection devices, call box maintenance computers (used to periodically check the operating status of call boxes), and some type of data handling system at a central location such as a TMC.

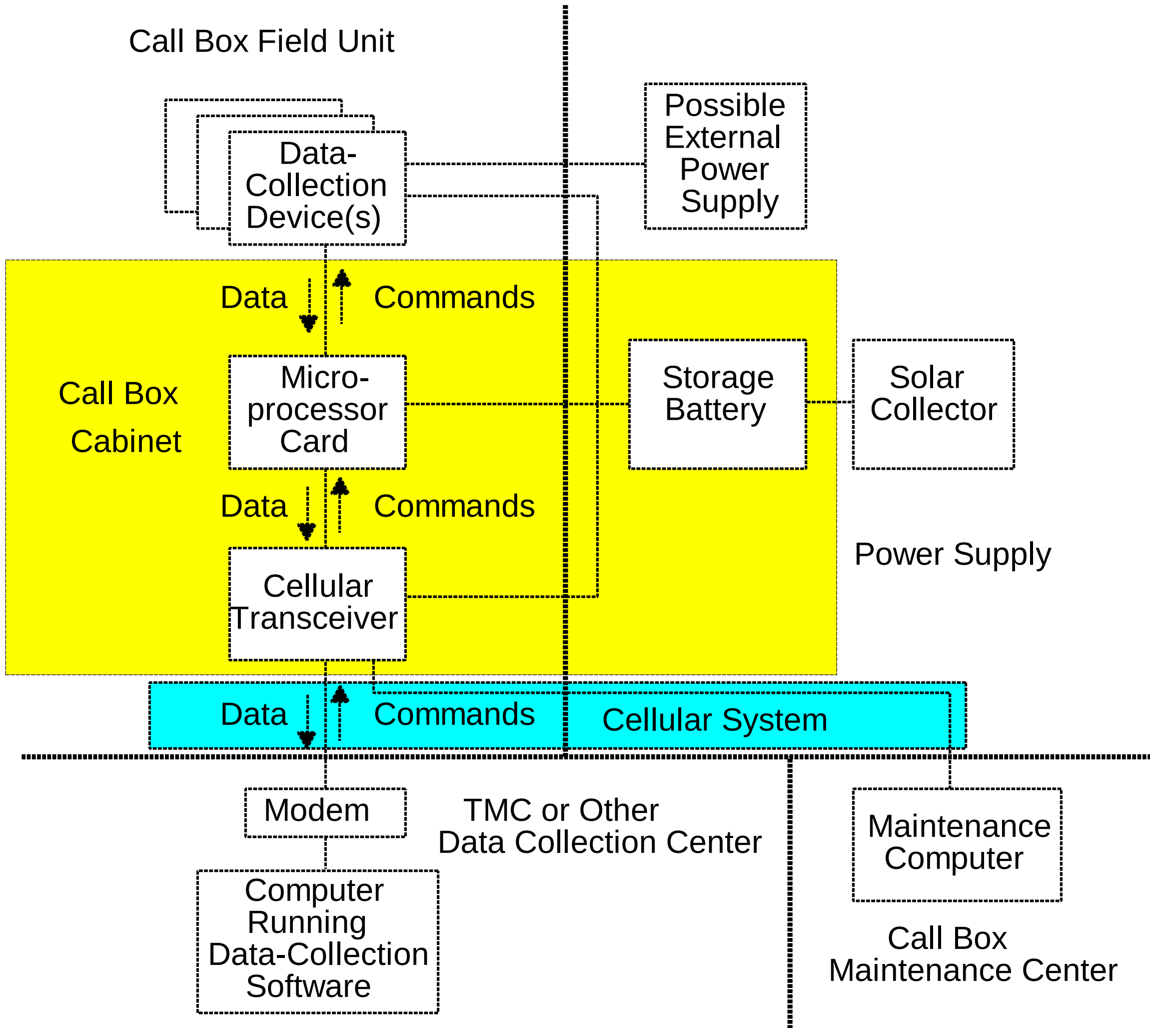
The key features of the ideal smart call box system include: 1) it should serve multiple functions, to include voice transmission and possibly several types of data transmission and 2) it should be able to function without an external power supply. In addition, several of the tasks included in this FOT also required that the TMC be able to access the field unit at any time.

Key Design Issues

Key design issues resulting from these requirements include:

- *System architecture*. A major issue is that of which data processing tasks are to be performed by which components. One of the assumed advantages of smart call boxes is that call box microprocessors possess surplus computing capacity that can be exploited for other purposes. This was emphasized in some of the early literature produced by proponents of the FOT, which refers to the call boxes as "computers on a stick." On the other hand, existing counters and weather sensors already have considerable data processing capability. The issues here are whether the call box microprocessors really have significant additional capacity and whether, if they do, there is any need for it.

Figure 9. Generic Smart Call Box System Architecture.



- *System integration*. Smart call box systems consist of a number of components which were not originally designed to work together. How to get these components to work together is a major system design issue. In particular, integration of systems of this type is apt to involve numerous software, hardware, and system compatibility problems.

- *Power supply*. A critical feature of all smart call box system designs is how to provide the necessary data processing and transmission functions with the limited power supply provided by solar collectors and storage batteries. The need for continuous accessibility increases the demand for power, as does the need to power multiple auxiliary devices such as sensors or video cameras. Power supply is thus a major limitation on the potential complexity and effectiveness of smart call box systems. Potential solutions are to design components and system operation to minimize power consumption, increase solar power supplies, or compromise the objective of independent power supply by designing systems that require external A/C power.

- *Physical connectivity*. If smart call boxes are to serve as multipurpose devices, it is necessary to be able to connect the various components. This requires that call box microprocessor cards be designed to accommodate multiple ports. It also poses a problem of designing connections in such a way that all the necessary wiring can be accommodated in the confined space provided by the call box cabinets, which are much smaller than those used for signal controllers and similar devices.

- *Sequencing of transmissions.* In the case of multipurpose smart call box systems, situations can arise in which there are conflicting demands for use of the cellular transceiver. Potential conflicts include those between voice and data transmissions, between different types of data transmissions, and between control commands being uploaded to the field unit and data being downloaded from it. Besides the potential conflict between voice and data communication, the most obvious such conflict is that between video signals and control signals for PTZ video systems.

- *Integration with the TMC.* A final design issue relates to the integration of data from smart call boxes into the data systems and operational routines of TMCs. The complete system has to be integrated all the way from the sensor or other field device to the ultimate user. This involves consideration of how data are to be displayed and used, so that data can be provided in a useful form.

Test system designs for the Smart Call Box FOT approached these key design issues as follows:

System Architecture

With one exception, neither vendor produced system designs in which key data processing functions were carried out by the call box microprocessor. Rather, both took maximum advantage of the data processing capabilities of the weather sensors and traffic counters. This appears to have been a result of both the limited additional computing power of the call box microprocessors and the inefficiency of having to write software for functions the sensors could already do. In only one case was a call box microprocessor used for a function involving more than minimal logic. U. S. Commlink's external-counter incident detection system did use the call box card to prompt data bursts from a Peek SOH counter and to evaluate current speed to determine whether a threshold had been crossed. Even in this case, this arrangement was something of an afterthought. The original plan had been to use a Peek ADR-3000 to send the alarms; the SOH (which was an obsolete model) was substituted only after the Peek Traffic Systems staff was unable to get the ADR-3000 to send the alarms. Otherwise, the only essential tasks performed by the call box microprocessors, other than those related to the call boxes themselves, appear to have been sending the FAX messages used in the alarm systems.

In other matters, the two vendor teams followed somewhat different approaches to system architecture. For instance, GTE did not attempt to design multipurpose smart call boxes. That is, each GTE system was designed to provide voice communications and one additional function such as traffic census or hazardous weather alarms. U. S. Commlink, on the other hand, redesigned its call box microprocessor card to be able to provide four ports for external devices, such as weather sensors, traffic counters, or video compression units. All U. S. Commlink sites were originally intended to test multipurpose systems, and all but one actually did so.

The U. S. Commlink decision to redesign its call box microprocessor resulted in considerably more advanced designs than would have otherwise been possible but also contributed to delays in installing field equipment. These delays, in turn, meant that several of the “successful” U. S. Commlink systems (for instance the wind speed alarm system and the CCTV surveillance systems) received less thorough evaluation than would have been desirable. Also, the delays in installing field equipment probably contributed to the failure to diagnose and correct accuracy problems experienced by U. S. Commlink’s external-loop-based incident detection system.

System Integration

All test system designs involved integration of external field devices such as traffic counters, weather sensors, or video compression units with the call box microprocessors and the microprocessors, in turn, with equipment and/or software at the data collection center. The simplest design was that for the alarm systems, in which the call box relayed a FAX message to the data collection point. Those for the traffic census and CCTV systems also involved integration with software running on computers at the data collection center. System integration failures were a major problem in the performance of the test systems.

Power Supply

The two vendor teams took a somewhat different approach to dealing with power supply constraints. GTE placed major emphasis on providing systems with independent power supplies, but (partly because of the power constraints) was unable to provide either multipurpose systems or continuous accessibility. GTE did propose to provide continuous accessibility by keeping the call boxes on very low-power standby and using a commercial page service to transmit a signal to cause them to power up to receive incoming calls. Although such capability was absolutely required by the CCTV Surveillance and CMS Control subtests, GTE never installed any equipment for either of these. The CMS Control subtest was canceled at the option of the RCT, and GTE missed the deadline for equipment installation for the CCTV Surveillance subtest.

U. S. Commlink, on the other hand, took the approach of redesigning its call box card to reduce power consumption and was able to provide both continuous receive mode capability and limited multipurpose capability with a somewhat augmented solar power supply. U. S. Commlink was able to operate both traffic census and hazardous weather alarm systems at its Site 5 without external power, but was not able to provide for downloading of weather data over the entire 24 hour period each day. U. S. Commlink expects to be able to provide 24-hour capability for both these functions at a single site by further reductions in the power requirements of its components. Otherwise, U. S. Commlink did not place a great deal of emphasis on the goal of providing independent power supplies, concentrating instead on providing more sophisticated sensors, multiple-function sites, and continuous receive-mode capability. For instance, several of the sensors used by U. S. Commlink, such as the infrared detector and the color CCTV system required external power for their operation. As a result, five of the six U. S. Commlink sites did require external power.

Physical Connectivity

As previously mentioned, GTE did not pursue designs that would provide for more than one external device at a time to be connected to a call box. U. S. Commlink was able to provide ports for up to four additional devices.

Physical connectivity issues were also central to the decision to cancel the CMS Control subtest. As originally envisioned, the CMS subtest had been intended to test communications between one call box equipped with sensors and another controlling a CMS. It had been assumed that automatically-posted CMS messages (in response to a hazardous weather alarm, for instance) would be acceptable and that the CMS could be controlled from a call box. It turned out, however, that the Caltrans TMC was unwilling to use automatically-posted messages.

In addition, research into the functioning of the CMS signs used in California revealed that their operation was incompatible with control by a smart call box. The Model 500 CMS used in California lacks the internal capability to switch the lights to form the message. Rather, this function is performed by an external controller, such as the Model 170 traffic controller, which has to be connected to the sign by a large number of conductors. Messages are transmitted as a series of on/off signals for the individual pixels in the sign, and these are generated by software running on a computer at the TMC. Since the call box did not have the capacity to handle the number of conductor connections required, and no intelligent device in the field was required to set the pixels, the call box could only serve as a communications link. Meanwhile, however, Caltrans had independently acquired the ability to use cellular telephone links with the CMS controllers. Consequently, there did not seem to be much value in continuing the test, and it was canceled.

Sequencing of Transmissions

All system designs provided for priority of voice transmissions over data transmissions, although this feature was never actually tested in the FOT. Neither vendor was able to solve the problem of providing for remote control of a PTZ camera.

Integration with the TMC

Design of portions of the system to be located at the TMC was considered to be outside the scope of the FOT. As a result, system designs either employed existing data collection components or employed the simplest possible means. In the case of the Traffic Census and CCTV Surveillance subtests, existing data collection software developed for particular counters or video compression systems was used. In the case of the alarm systems, FAX transmissions were used because they were simple and resulted in a permanent record of the transmission. One result is that the alarm systems are of little immediate usefulness, because there is no way of recording the alarms in electronic form or entering them into an alarm display system.

The decision to ignore integration with the TMC may also have contributed to some of the other system integration problems encountered in the FOT. Equipment located at the data collection point was owned and operated by the project manager, but ran software provided by the vendors. When there were system integration failures involving this software, it was not always clear whether these were due to basic incompatibilities in the system or to lack of familiarity with the software on the part of the project manager's staff. Some of this uncertainty (and the resulting delays in correcting the problems) might have been avoided had the vendors been responsible providing end-to-end systems, including TMC data collection hardware and software.

Detailed Design

In addition to these major design features, test system designs involved a number of details related to their intended tasks. Evaluation of these detailed design features was based on performance standards adopted by the RCT (see Appendix B) and specifications published in the RFP distributed to potential vendors.

The performance standards were based on input from Caltrans operational personnel and were intended to ensure that test systems would meet their needs and be compatible with existing TMC equipment and procedures. For the most part, they provided a reasonable basis for design and evaluation of the test systems; however, in several cases, they overlooked issues that later turned out to be of practical significance. This was particularly true of descriptions of alarm procedures for the Incident Detection and Hazardous Weather Reporting subtests. These assumed (but did not actually state) that vendors would design devices to provide notification every time a threshold was crossed either to or from an alarm condition and that alarms would be transmitted in a form that could be automatically recorded in a computer file or otherwise manipulated. In fact, the systems actually designed only provided FAX transmissions and did not always provide "all clear" signals.

In retrospect, the performance standards would probably have provided a better basis for evaluation had a wider range of people been involved in their development. In particular, participation by representatives of the vendors, the sponsoring agencies, and operational personnel from outside Caltrans District 11 would have been useful. Also, their effectiveness as an evaluation tool would have been enhanced by better communication with the vendors during the development of the test systems, so that unrealistic or inadequate standards could have been identified and revised.

For the most part, the designs provided by the vendors did conform to the performance standards. Detailed comparisons may be found in an appendix to the subtest reports (*1*).

One exception was the infrared-sensor system designed for the Traffic Census subtest. The memory and time-keeping system of this counter are inadequate for normal traffic census use. In addition, this system is limited to one lane per counter, so that no more than four lanes can be counted from a single call box, given U. S. Commlink's current call box design.

Also, although the weather alarm systems met the performance standards, the standards for these systems were somewhat inadequate. In all cases, the usefulness of these systems could be increased by adding more alarm levels. In the case of the GTE visibility-alarm system, an all-clear signal and the ability to download sensor data would also be useful.

System Performance

Adequacy

Functional adequacy was evaluated by determining the extent to which the actual functioning of the test systems met the performance standards. As in the case of system designs, detailed comparisons may be found in an appendix to the subtest reports (*1*).

Traffic census systems based on loop detectors appeared to function adequately, although at most sites it was not possible to verify the accuracy of the counts due to the lack of comparable data. The infrared-detector-based system did not function adequately, however, in that the detector never produced consistently accurate volume counts or speeds. In this case the inaccuracy of the counts was obvious; for instance, there were either zero or very small counts during times when substantial traffic volumes were to be expected.

The hazardous weather alarm systems functioned satisfactorily to the extent that they did send alarms at times that appeared reasonable. A possible exception is the U. S. Commlink visibility sensor system, which was installed after the fog season and never sent a "real" alarm.

None of the incident detection systems functioned adequately. The GTE system only sent one alarm over a period of three months. The problems in this case were apparently related to system integration, since GTE reported that the counter did produce the correct alarm pulse after it was installed in the field. The loop-detector-based system at U. S. Commlink Site 2 sent numerous alarms, some of which appeared to be valid, but it also sometimes sent alarms in illogical sequences. Also, it produced considerably fewer alarms than had been expected, in view of the degree of congestion believed to exist at the site. By using a CCTV system that had been installed at this site, it was eventually possible to verify that the incident detection system sometimes failed to transmit alarms when congestion was present. The infrared-detector-based system at U. S. Commlink Site 6 also produced numerous alarms. In this case, however, the time patterns appeared to be unreasonable; also, the system failed to provide all the specified alarm levels.

The CCTV systems functioned adequately, except that the lack of PTZ capability and the slow refresh rate limited the usefulness of the color system intended for incident verification. Initial assessments by District 11 TMC personnel were that image quality at two of the sites was inadequate; however, after adjustments to improve image quality, TMC representatives reported that they were pleased with image quality, particularly for the monochrome systems. The TMC representatives judged the color system to be of limited usefulness due to the slow refresh rate. They noted, for instance, that it was difficult to tell whether given vehicles were present in more than one frame.

System Reliability

Test system reliability was evaluated based on the fraction of time each system was available. The timelines presented in Figures 5 - 8 show periods during which the various systems were functional, not functional, or functional with errors or problems, thus providing a sense of their availability.

As explained in the section on Evaluation Methodology and Constraints, in several cases periods of observation were too short to allow availability rates to be established with confidence. Systems for which this was true included the U. S. Commlink incident detection, weather alarm, and CCTV surveillance systems. All these systems functioned without known equipment failures, with the exception of the monochrome CCTV system and the infrared-detector-based incident detection system. In the case of the monochrome CCTV system, the system failed after about three or four weeks of operation, but the cause of failure was never determined. The infrared detector equipment, which was also used for the Traffic Census subtest, experienced numerous failures.

Of the systems for which adequate periods of observation were available, only the GTE visibility alarm systems appeared to function reliably. Otherwise, the only installation that functioned reliably over an extended period of time was the traffic census unit at U. S. Commlink Site 2. All other traffic census installations experienced extensive down time, and the GTE incident detection system never functioned at all. As explained in the

Evaluation Methodology and Constraints section, this evidence of reliability problems should be interpreted with caution. Many of the problems experienced were due to initial design flaws. In addition, some of the down time resulted from circumstances peculiar to the FOT, such as the vendors' lack of a resident maintenance staff, the lack of spare components to replace those that failed, and the extra time required to diagnose the problems of a new system.

Table 3 summarizes the evaluation of the individual test systems. The evaluations of functional adequacy refer to whether performance standards related to functionality were met. Those in the column headed "Design" refer to the extent to which the design provided by the vendor conformed to the performance standards; those in the column headed "Performance" refer to the extent to which the actual performance of the system met the standards. Evaluations of reliability refer to system availability; the notation "insufficient data" refers to cases in which there were no known equipment failures, but the period of observation was judged to be too short to adequately establish the availability rate.

Cost

Capital costs of deployed call box systems were estimated and compared with costs of hardwire telephone systems. Caltrans structured bids for smart call box installations similar to those used in the FOT. The vendors were then asked what they would charge to provide these systems in quantity. For items not supplied by the vendors, costs were derived from standard unit prices used by Caltrans. Based on these, it appears that at most sites all types of smart call box systems have significant capital cost advantages over hardwire systems. This cost advantage is due primarily to the extra costs of trenching, wiring, and jacking of conduit under the traveled way that are involved in hardwire systems. Even where external A/C power was required, the cost advantage was substantial, because distances to the nearest access points for the telephone system tended to be greater than those to the power system; however, the greatest cost advantages were for systems that did not require A/C power.

Table 4 gives the capital costs for test and baseline systems at each test site. Costs in Table 4 are based on the estimated cost of all systems installed at each site; consequently, it overstates the costs of individual systems where multiple subtests were conducted at a single site. Detailed cost estimates for each test site may be found in the subtest reports (*1*).

Differences between the capital costs of the test and baseline system at each site depended on differences in equipment required at the site and on telephone access distances for the baseline system. Test and baseline systems were assumed to require identical on-site equipment (such as traffic counters, weather sensors, video cameras, and on-site wiring), except that the test system required the call box itself ($2,400) and the baseline system required a Model-334 cabinet ($3,500) to house external power connections, external traffic counters, and telephone communications equipment. Test systems that did not require external power or external traffic counters thus had an advantage in on-site capital costs of $1,100. Test systems that did require external power or external traffic counters also required a Model-334 cabinet and thus had a $2,400 disadvantage in on-site capital costs. Otherwise, capital cost differences were dependent on telephone access costs, which were estimated by Caltrans to amount to $11/foot for trenching and wiring and $100/foot for jacking conduits under the traveled way.

Table 3. Test System Functional Adequacy and Reliability.

	Functional Adequacy			
System	Design	Performance	Reliability	Remarks
Traffic Census				
GTE External	Yes	Yes	No	
GTE Internal	Yes	Yes	No	
USCL External	Yes	Yes	No	
USCL Internal	Yes	Yes	No	
USCL Infrared	Marginal	No	No	
Incident Detection				
GTE Internal	Yes	No	N/A	
USCL External	Yes	No	Insuff. data	
USCL Infrared	Marginal	No	No	
Weather				
GTE Visibility	Yes	Yes	Yes	Standards inadequate
USCL Visibility	Yes	No data	Insuff. data	
USCL Wind	Yes	Yes	Insuff. data	
CMS Control	No	N/A	N/A	Test canceled
CCTV Surveillance				
USCL B/W	Yes	Yes	No	
USCL Color	Marginal	Yes	Insuff. data	

Table 4. Estimated Capital Costs for FOT Test Sites.

Test Site	Baseline System Capital Cost	Test System Capital Cost	Cost Difference, Baseline System-Test System
USCL-1	$77,480	$44,130	$33,350
USCL-2	67,500	57,800	9,700
USCL-3	29,000	23,060	5,940
USCL-4	28,300	26,850	1,450
USCL-5	110,915	7,815	103,100
USCL-6	156,620	75,920	80,700
GTE-2/13	22,790	10,710	12,080
GTE-3/14	14,595	7,230	7,365
GTE-4	84,900	4,900	80,000
GTE-5	32,400	4,900	27,500
GTE-7	51,150	10,400	40,750
GTE-21	77,510	10,410	67,100
GTE-22	24,140	10,410	13,730
GTE-23	56,830	10,410	46,420

Table 5 summarizes capital costs for individual test systems. The first column gives estimated total capital cost of providing the equipment used for each type of system for each subtest. In this case, if sites were used for more than one subtest, separate cost estimates are given for each subtest. The other column gives estimated costs, exclusive of the cost of providing external power and, where applicable, costs of providing loop detectors. These costs vary a great deal depending on the site, so their inclusion may distort the relative costs of the different systems. Variations in costs for individual systems are due to differences in on-site wiring costs or differences in equipment such as towers for mounting video cameras and weather sensors.

Life cycle costs were calculated on an annual cost basis. Besides annualized capital costs, they included telephone charges and maintenance costs. Current charges paid by Caltrans for conventional telephone service and San Diego SAFE for cellular service are $14.00 per month per line for conventional service and $10.00 per month per line for cellular service. To the extent that these prices are typical, smart call boxes appear to have a slight advantage; however, this difference is not very significant compared with the potential differences in capital costs and maintenance costs.

Table 5. Estimated Capital Costs for Test Systems.

System	Approximate Capital Cost	Capital Cost, Exclusive of A/C Power and Loops
Traffic Census		
GTE Systems	$7,000 - $10,000	$3,500 - $4,000
USCL External	$23,000 - $50,000	$6,000 - $10,500
USCL Internal	$7,500	$6,000
USCL Infrared	$76,000	$17,700
Incident Detection		
GTE Systems	$10,000	$3,600
USCL External	$50,000	$10,000
USCL Infrared	$76,000	$17,700
Weather		
Jaycor Systems	$5,000	$5,000
Davis Systems	$3,000	$3,000
CCTV Surveillance		
Monochrome	$8,000 - $20,000	$4,000 - $5,000
Color	$36,000	$13,500

For reasons discussed in the Evaluation Methodology and Constraints section, it was not possible to make reasonable estimates of maintenance costs; as an alternative, maximum break-even differences in maintenance costs between smart call box and hardwire systems were calculated as a function of interest rates and access distances to the conventional telephone system.

Break-even maintenance cost differences were calculated by comparing telephone charges and capital costs for each type of system. Overall annual costs for each system are

$$A_B = T_B + M_B + \text{CRF}(i, n) \times C_B$$

and

$$A_T = T_T + M_T + \text{CRF}(i, n) \times C_T$$

where

A	=	Annual cost
T	=	Annual telephone charges
M	=	Annual maintenance costs
C	=	Capital cost
CRF(i,n)	=	Capital recovery factor for an interest rate of i and a period of n years.

and the subscripts B and T stand for the baseline and test systems respectively. At break-even, annual costs of the two systems are equal, so

$$T_B + M_B + \mathrm{CRF}(i,n) \times C_B = T_T + M_T + \mathrm{CRF}(i,n) \times C_T$$

or

$$M_T - M_B = (T_B - T_T) + \mathrm{CRF}(i,n) \times (C_B - C_T) \ .$$

Tables 6 and 7 give break-even annual maintenance costs as a function of assumed interest rates and telephone access distances. A useful life of 10 years and no salvage value was assumed for all systems. Table 6 is for test systems not requiring Model-334 cabinets, including all GTE test systems and the U. S. Commlink internal counter traffic census system and weather reporting systems. Table 7 is for test systems that did require Model-334 cabinets, including the U. S. Commlink external counter and infrared counter systems used for traffic census and incident detection, and the CCTV surveillance systems.

Table 6. Break-Even Maintenance Cost Differences for Test Systems Not Requiring Model-334 Cabinets

Access Distance for	Max. Difference in Annual Maintenance Costs (Call Box - Baseline) for Given Interest Rate		
Baseline System, Ft.	5%	7.5%	10%
100	$333	$369	$406
200	$475	$529	$585
500	$903	$1,010	$1,122
1,000	$1,615	$1,811	$2,018
2,000	$3,039	$3,414	$3,809
5,000	$7,313	$8,222	$9,181
10,000	$14,435	$16,235	$18,135

Table 7. Break-Even Maintenance Cost Differences for Test Systems Requiring Model-334 Cabinets.

Access Distance for Baseline System, Ft.	Max. Difference in Annual Maintenance Costs (Call Box - Baseline) for Given Interest Rate		
	5%	7.5%	10%
100	- $120	- $141	- $164
200	$22	$19	$15
500	$449	$500	$553
1,000	$1,162	$1,301	$1,448
2,000	$2,586	$2,904	$3,239
5,000	$6,860	$7,712	$8,611
10,000	$13,982	$15,725	$17,565

Tables 6 and 7 make it clear that telephone access distances are the dominant factor in life-cycle cost comparisons between smart call box and hardwire systems. Consequently, such comparisons are highly site-specific. To give a rough idea of the telephone access distances that might be encountered in case of full-scale deployment, Table 8 presents the maximum, minimum, and median telephone access distances involved in each subtest. These figures show that there was a wide range of telephone access distances; consequently, it is difficult to predict what typical telephone access distances might be.

Discussion

In the early stages of the FOT, the major technical problems were expected to involve power supply and the sequencing of transmissions. These certainly proved to be major problems, and the vendors were not able to overcome all the difficulties they encountered. For instance, neither vendor was able to design a system that could provide remote control for a PTZ camera, and neither designed a system that could perform more than two data-collection functions without an external power supply. Where these issues were concerned, however, the test systems tended to function as intended. For example, there were no known instances of a system failure due to an inadequate internal power supply, although there were failures due to disruption of external power at sites that required it. Instead, most of the unexpected problems experienced in the FOT were related to system integration.

Table 8. Telephone Access Distances for FOT Subtests.

Subtest	Telephone Access Distance, Ft. Maximum	Minimum	Median
Traffic Census	8,500	115	800
Incident Detection	7,100	115	1,850
Weather Reporting	8,500	1,600	4,500
CCTV Surveillance	3,250	300	1,100

The major technical surprise of the FOT was the difficulty of system integration. System integration problems began with the Subphase 0 preliminary communications test and continued throughout the FOT. They seem to have been primarily related to two features:

1. Data collection software supplied by vendors of intelligent external devices (weather sensors, traffic counters, and video compression units) assumed a direct or telephone-modem-based connection to the intelligent device. The call box could be integrated into the system by either modifying the software to communicate with the sensors via a call box, or by having the call box emulate a modem and pass through data without processing or conversion.

2. Vendor software was not adapted to wireless communication. Even when configured as a pass-through system, the wireless communication link characteristics, such as high error rate and variable delays, continued to cause problems.

In light of the experiences of the FOT, it appears that system integration problems are likely to recur any time any component of a smart call box system is changed or upgraded, possibly affecting all of the attached devices.

Most system architectures developed by the FOT made little use of the call box microprocessor card. In addition, most systems relied on external central computers to provide data reduction and logging capabilities. In light of these facts and the system integration problems, there may have been a fundamental flaw in the smart call box concept. The original concept of *smart* call box systems was to take advantage of the unused computing power of the call box processor card. But in the systems that were actually developed, the call box processor card contributes little or nothing to the data processing capabilities of the system and adds substantial integration problems.

An alternative would have been to use intelligent single-purpose sensors and connect them to the data processing facilities using cellular modems as the communications link. Like the call box, the sensors and cellular modems of these systems can be powered by solar units where appropriate. Also, if necessary, they can be housed in existing call box cabinets, since these have already been crash tested and approved for installation in the roadway clear zone. Such systems are likely to be cheaper to produce than smart call boxes, as simple cellular modems are cheap compared with existing call boxes, and the system packaging could be done in a much simpler and less costly manner. Consequently, it is likely that several individual systems employing cellular modems could be produced for less than a single smart call box system duplicating their functions.

One way to change this situation would be to have a standard protocol for intelligent sensors or similar devices to communicate with call boxes. The call box sensor communication could be well defined and the processing power of the call box could then possibly be used to analyze data reported by sensors. Since each different type of sensor would report data in the same format and manner, it would be possible to develop software that would run on the call box and perform many of the management functions performed by the central processing and logging system. In addition to the sensor-to-call-box-protocols, a central-data-processing-to-call-box system would also need to be developed. This would allow users that have specialized processing requirements to either access the data stored on the call box or to directly access their devices.

Efforts are currently underway to develop a National Transportation Communications for ITS Protocol (NTCIP) that will address some of these issues. The purpose of the NTCIP is to be a standard for transmitting data and messages between electronic devices used in ITS. NTCIP is to be a common standard which can be used by all vendors and will provide a common language (messages) and a common syntax (protocols). Of necessity, it is a family of protocols. NTCIP will resolve system integration problems by allowing different manufacturers' components and systems within a common communications infrastructure. The elements going into the family of protocols are well-known international standards, where they exist. This is important, because using "standards" means that inexpensive hardware and software is already available in the market to implement these protocols. The proposed NTCIP standards are available from the http://fhwatml.com World Wide Web site (*6*). Information available from this source includes the NTCIP protocols and discussions of work in progress.

The recommended NTCIP physical layer standards are EIA/TIA-232-E, commonly called RS-232, and Bell 202 FSK (frequency shift key) Modem. The data link layer standards are Point-to-Multi-Point Protocol (PMPP) and Point-to-Point Protocol (PPP); the basis is High Level Data Link Control (HDLC). The network layer is Internet Protocol (IP), or is null (service not provided). The transport layer is User Datagram Protocol (UDP), Transmission Control Protocol (TCP), or null. The session and presentation layers are null. The application layer is Simple Transportation Management Protocol (STMP) or Simple Network Management Protocol (SNMP) as defined in the Simple Traffic Management Framework (STMF), Telnet and File Transfer Protocol (FTP).

It would be necessary to develop standards for the smart call box higher level interactions (such as data collection and data reporting). The NTCIP Class B or Class C standards (see http://fhwatml.com/ntcip/library) appear to address these, but do not provide a "reference implementation" or guidelines for developers. A further "application level interface" specification is under development.

Adoption of these protocols for smart call boxes would require a standardization and implementation effort in the intelligent sensor, data communications, and computer software areas that is unlikely to take place unless the potential market for smart call boxes is large enough to allow recovery of the development costs. The technical problems involved in developing the necessary software are surprisingly complex. Most sensor software assumes a direct, low delay, low error rate connection from the sensors to a data processing package. Some manufacturers have already developed versions of these software packages that function with cellular modems, and while some packages do not work satisfactorily at all times with different sets of modems, the standardization of modems and introduction of Cellular Digital Protocol Data (CDPD) modems could reduce these problems in the future. Development of additional protocols, enhancements to software, and other changes to accommodate the use of smart call boxes does not appear viable unless either a large number of sensors will be used for these applications or else users are willing to pay a premium price for these facilities. Because no quantitative market research was performed as a part of the FOT, it is difficult to estimate the potential market for smart call box devices or the sensitivity of this market to their prices.

In addition, system reliability must be considered. Data gathered during the FOT indicated that major points of failure in the system were the smart call box software and systems that were used to configure the smart call box. System reliability does not appear to be improved by the addition of the call box, and may actually be decreased due to the problems with management of maintenance modes, setting time-of-day clocks, and other issues that were discovered during testing.

Finally, problems of system maintenance and diagnostics were repeatedly evident throughout the FOT. It is clear that built-in test capability to locate system defects is essential if a system is to be used for either incident detection or on-demand functions such as traffic census or CCTV surveillance. The experience of the FOT was that a high level of expertise was needed to determine what element in the system was failing or not performing at an adequate level, and that it took a long time to solve the problems that developed. While problems of this type are to be expected during prototype development and testing, many of them occurred with equipment that had been used in other areas for substantial amounts of time. It appears that integration of new and different types of sensors will require a substantial investment of time and expertise, not only during the initial stages of deployment, but also during system use.

INSTITUTIONAL CONSIDERATIONS

Evaluation objectives related to institutional issues encountered in the Smart Call FOT included:

2.1 To determine whether any institutional issues encountered in the Field Operational Test have a potential for affecting the performance of similar systems if widely deployed.

2.2 To determine the perceptions of participants in the Field Operational Test regarding the administration of the Field Operational Test, any other significant institutional issues encountered, and the effect of institutional issues on similar systems if widely deployed.

Institutional issues were identified by reviewing documents related to the FOT and interviewing FOT participants. These issues were analyzed by preparing summaries that described and discussed each issue, listed the organizational participants that raised it, and identified ways to avoid problems associated with the issue and/or actions that need to be taken with regard to it. The details of this process are documented in the Subtest Reports (*1*).

Issues Related to Deployment

For purposes of analysis, institutional issues were divided into those pertaining to the FOT itself and those likely to be encountered in the deployment of smart call box systems. Some, but not all, of the issues encountered in the FOT itself are likely to be encountered in deployment. Of the institutional issues likely to affect deployment, the most important have to do with the viability of the smart call box systems and the appropriateness of the designs produced by the FOT. These include:

The Compatibility of System Designs with Transportation System Management Needs

This issue is whether the FOT system designs were based on input from the right people, and whether under-representation of certain groups in the process of developing the system specifications may limit acceptance of the resulting systems. FOT system designs were mostly worked out between the RCT, the Project Manager, and the vendors, with some input from local Caltrans operational personnel and representatives of the sponsoring agencies. Input from operational personnel was incorporated by means of performance standards that were developed by the Evaluator and approved by the RCT. These were not adopted until just before the deadline for submission of proposals by the vendors and had only a minor impact on basic system designs. A more important source of guidance to the vendors was the project RFP, which was developed by the Project Manager, and which contained rather loose descriptions of the desired technical features of the test systems. It might have been better to have involved a wider group in the development of specifications, and to have had better communication among those who were involved. In particular, it would have been better to have involved operational personnel, vendors, and representatives of the sponsoring agencies prior to the development of the RFP. Also, it might have been useful to have sought input from operational personal from outside the San Diego area.

Procurement Concepts for Deployment

Procurement of smart call box systems is apt to differ considerably depending on geographical location. In California, there are already extensive voice call box systems, and an institutional system to provide these. This system features county-level funding agencies and a highly privatized system for managing the system and installing and maintaining the call boxes. In the context of the California system, introduction of smart call boxes raises a number of issues related to their ownership and funding, since the agencies providing the voice call boxes are not normally expected to be users of smart call box data. Elsewhere, rather different institutional arrangements are likely to result, such as direct ownership and operation by state departments of transportation or similar agencies.

Market Size and Profitability

This is the crucial issue from the point of view of potential vendors of smart call box systems. Lack of quantitative market research was an important omission in the Smart Call Box FOT. As indicated above in the discussion of the technical results of the FOT, a fairly large market may be required in order for potential vendors to recover future development costs, especially in view of the system integration problems encountered in the FOT. It is not clear that a market of this magnitude exists, especially since it appears that a close substitute exists that may avoid some of the technical difficulties experienced in the FOT.

Structure and Business Practices of the Electronics Industry

Several of the private-sector organizations participating in the FOT experienced organizational instability or cash flow problems during the course of the FOT, and in some cases these appear to have had a negative impact on performance. These problems appear to stem largely from an industry structure that features many small, highly specialized units that are owned by much larger companies that tend to trade them around and, sometimes, to neglect them. Similar situations are likely to arise in the deployment of smart call box systems. Potential problems can be minimized by careful investigation of the qualification of prospective vendors, with particular attention to their resources and the commitment of the parent firm (if any) to the project.

Standards

Many of the technical problems encountered in the FOT were related to system integration. These might have been less severe had there been standard communications protocols for intelligent sensors and similar devices to communicate to smart call boxes. The NTCIP standards currently under development will address some of the system integration problems encountered in the FOT, but it will still be necessary to develop standards for the smart call box higher level interactions. This issue is closely related to that of the size of the potential market for smart call boxes. Development and adoption of standard communications protocols for smart call boxes is unlikely to take place unless the potential market is large enough to allow vendors to recover the development cost.

A number of other issues related to deployment are discussed in the subtest report on Institutional Issues (*1*).

Issues Related to Conduct of the FOT

In addition, several issues related to the conduct of the FOT were identified. Although not likely to affect the deployment of smart call boxes, these issues may be encountered in future FOTs. The most important of these were:

Appropriateness of the Overall Organization of the FOT

The basic organization of the FOT featured a private consulting firm acting under contract as Project Manager and an arm-length relationship with the vendors. This organizational scheme resulted in a number of problems: 1) There was considerable delay due to time consumed in negotiating and processing contracts with the vendors. 2) The technical performance of the vendors was negatively affected by the RCT's decision to split the project between them. Each vendor submitted a proposal which addressed all subtests and proposed use of all available funds. Throughout the proposal review process, the RCT discussed the possibility of partially funding both proposals. It finally decided to fund both vendors for all subtests, but for reduced numbers of units in each test. This decision reduced the funding received by each vendor to roughly half that originally expected without a comparable reduction in the engineering effort required. 3) The necessity of retaining a Project Manager after the FOT was funded created an awkward situation. Employees of the firm that became the eventual project manager actually wrote the FOT proposal. Since the Project Manager was not an integral part of the FOT partnership, however, the public sector partners later had to go through a formal selection process. Although the firm that wrote the proposal clearly had an advantage due to its familiarity with the project, some members of the San Diego SAFE board of directors felt it might constitute a conflict of interest to award the contract to the firm that had proposed the project (even though the proposal was not *to* the SAFE board, but actually *on behalf of* the public-sector partners, including SAFE). A more appropriate basic organizational model might have been to include the vendors and Project Manager in the original proposal as partners.

Contracting Procedures of the Sponsoring Agencies

Considerable delay was also experienced due to the extremely cumbersome contracting procedures of the State of California and the fact that the separate FOT and Evaluation contracts were not processed simultaneously.

CONCLUSIONS

This report has presented an overview of the evaluation of the Smart Call Box Field Operational Test. Major conclusions are as follows:

1. For the most part, the performance standards adopted for the FOT provided a reasonable basis for design and evaluation of the test systems; however, in some cases they were probably too restrictive and in other cases turned out to be unrealistic. Also, several important issues were overlooked. The performance standards would probably have provided a better basis for evaluation had a wider range of people been involved in their development. In particular, participation by representatives of the vendors, the sponsoring agencies, and operational personnel from outside Caltrans District 11 would have been useful. Also, their effectiveness as an evaluation tool would have been enhanced by better communication with the vendors during system development, so that unrealistic or inadequate standards could have been identified and revised.

2. The major technical lesson learned from the FOT was the difficulty of system integration for smart call box systems. This difficulty appears to be related to incompatibilities between the smart call box concept and existing communication system designs for traffic counters, weather sensors, and similar devices.

3. Standard communications protocols for traffic counters, weather sensors, and compressed video systems that accommodate the requirements of wireless communications systems are highly desirable. Given the tendency for equipment to evolve, such standards may be the only way to ensure that new and different smart call box systems will not need to be invented every time a new model of counter or sensor is introduced. It may be questionable, however, whether the market for smart call box systems is large enough to support development of such a protocol. Any such protocol would form a part of the NTCIP standards currently under development. In order to produce standards specifically adapted to smart call boxes, the current NTCIP effort would need to be extended to include standards for smart call box higher level interactions, such as data logging and alarm reporting.

4. Most system architectures developed by the FOT made little use of the call box microprocessor card. This may indicate a fundamental flaw in the smart call box system design concept, since one major feature of the original concept was to take advantage of the unused computing power of the call box microprocessor. In the systems actually developed, these contributed little or nothing to the data processing

capabilities of the system and created substantial integration problems. In retrospect, it would have been interesting to compare the performance of smart call boxes with single-purpose wireless data communication systems without the call box microprocessor.

5. Of the smart call box systems tested, functional adequacy was demonstrated for loop-based traffic census systems, weather alarm systems, and monochrome fixed-field-of-vision CCTV systems intended to verify the condition of changeable message signs or other fixed objects. The performance of the color CCTV system intended for incident verification was marginal. Functional adequacy was not demonstrated for the incident detection systems; the deficiencies of these systems may be comparatively minor, however, and might be corrected by further testing prior to deployment. The CMS Control subtest was canceled (in part) because it was discovered that the CMSs used in California are incompatible with smart call box systems.

6. With the exception of the GTE weather alarm systems, reliability was not demonstrated for any of the test systems. In several cases, this conclusion is due to a lack of time to adequately establish system reliability rather than observed unreliable performance. In these cases, no real conclusions can be drawn concerning system reliability. Test systems in this category include the U. S. Commlink weather alarm systems and the color CCTV system . In other cases, there were numerous problems, some of which may have been due to initial design flaws. Test systems in this category include the traffic census systems and the monochrome CCTV system. None of the incident detection systems ever functioned correctly, so that no conclusion can be drawn concerning their reliability. With the exception of the GTE weather alarm systems, further testing needs to be conducted prior to deployment to establish system reliability.

7. Based on the test system designs developed as part of this FOT, it appears that smart call box solar power systems can support no more than two data-related functions at one site. This conclusion is based on the performance of U. S. Commlink Site 5, which was equipped with an augmented solar power supply and an external storage battery (that is, the battery was located in an underground vault rather than in the call box cabinet). It is not known whether further improvement of solar power supplies is feasible, since this was not attempted as part of the FOT. Systems involving more than two data-related functions require an external A/C power supply, which will add very significantly to the cost at most sites. In terms of their potential utility, logical system packages that meet the constraint of no more than two functions include traffic census-incident detection, weather alarm with sensor-data download capabilities, and monochrome CCTV for verifying the condition of fixed objects such as CMSs.

8. Smart call box systems are cost-effective compared with hardwire telephone systems at most sites, provided their functional adequacy and can be demonstrated and their maintenance costs prove to be reasonable. It is much less likely that smart call box systems will be cost-effective when compared with single-purpose systems consisting

of a cellular modem and a traffic counter, weather sensor, video compressor, or similar device.

9. At individual sites, the cost-effectiveness of smart call box systems as compared with hardwire systems will usually depend on access distances to the conventional telephone system.

10. The potential market for smart call box systems may be fairly limited. Prior to further development of smart call box systems, prospective vendors need to conduct market research to determine market size and profitability.

11. A number of institutional issues need to be resolved prior to full-scale deployment of smart call box systems. Agencies considering deployment should prepare detailed deployment plans to resolve such issues as ownership, financing, and provision of maintenance services. Such planning should also include careful investigation of the qualifications of prospective vendors. Details of such plans will depend heavily on local conditions. In particular, typical deployment plans are likely to differ significantly between California, where there is a well-developed institutional system for providing voice call boxes, and other states.

12. Major institutional problems in the conduct of the FOT itself included inadequate involvement of the sponsoring agencies and potential users of smart call box systems in the development of system designs, an organizational structure that resulted in a lengthy vendor-selection process, and cumbersome contracting procedures on the part of the sponsoring agencies. These last two problems led to major delays that had a negative outcome on the FOT. A more appropriate basic structure might have been to have included the vendors and the Project Manager as partners in the original proposal.

In addition to these major conclusions related to the overall results of the FOT, a number of specific conclusions may be drawn concerning the technical issues involved. These include the following.

1. The functionality of the infrared-detector-based system used in the traffic census and incident detection subtests was inadequate. The limitation of this system to a single lane per counter and its 24-hour rotating memory feature are major deficiencies. Also, the counts were not accurate on a consistent basis; at best, these detector systems require careful adjustment in order to function correctly. Even if it had functioned adequately, infrared detection technology is expensive, and would rarely be cost-effective when compared to loop-detector-based systems.

2. Among loop-based traffic census and incident-detection systems, those not requiring external power will normally be more cost-effective than those that do, provided reliability and maintenance costs prove to be similar.

3. Where the choice is between use of a stand-alone device with a dedicated cellular phone (whether a smart call box or some other design) and a multipurpose smart call box (that is, one providing both voice and data transmission) the decision may depend on the distance from the data collection devices to the call box. Where an installation is planned for smart call box use from the start, data collection devices such as loop detectors can be installed in close proximity to the call box (or vice versa), but for installations where both call boxes and data collection equipment are already installed and cannot be moved, the distances between the call box and the data collection equipment may be prohibitive.

4. In their current state of development, smart call boxes are probably not capable of handling complicated incident detection algorithms (*7-9*) that involve combining data from multiple locations. It is not clear that the accuracy of algorithms of this sort is great enough to warrant further development to adapt smart call box systems to them. A possible alternative, which would get around some of the limitations of the speed alarm approach used in the FOT, would be to develop an expert system in which TMC software interprets speed alarms in terms of time of day, location, and possibly data downloaded from nearby locations.

5. In the case of the low-visibility warning system, there may be need for more than isolated warning devices. Rather, what may be required is a carefully designed network of alarm stations which can provide advance warning of the approach of fog.

6. In the selection of weather sensors, there may be a tradeoff between cost and accuracy. This issue was not confronted directly in the FOT because a planned test by U. S. Commlink of a system incorporating a Vaisala weather station was canceled. As originally planned, the U. S. Commlink portion of the subtest would have compared systems incorporating a low-cost weather station (the Davis) with one involving a more expensive but more accurate unit (the Vaisala). Careful consideration needs to be given to the level of accuracy required for traffic-related weather alarms before systems involving high-end weather stations are developed.

7. Real-time video transmissions and PTZ control are both beyond the current capabilities of smart call boxes.

RECOMMENDATIONS

The following recommendations are based on *technical lessons* learned in the course of this FOT and apply to the future development of smart call box and related technologies.

1. No further effort should be expended on the development of smart call box systems for the control of CMSs, as the two technologies appear to be incompatible.

2. Further development of smart call box CCTV systems for general traffic surveillance should be undertaken only if it appears that remote PTZ capability can be achieved and that it is possible to significantly improve the refresh rates achieved in this FOT.

3. Prior to deployment, all systems produced by this FOT should be subjected to additional testing. Specific objectives should be to 1) better establish the reliability and maintenance costs of all systems, 2) correct problems with congestion detection algorithms and verify their accuracy, and 3) develop and test response strategies and sensor networks involving multiple locations for low-visibility detection systems.

4. Development of the following system enhancements should be pursued: 1) modification of the GTE traffic census systems to provide continuous availability to download data, 2) combination of traffic census and low-speed detection capabilities in a single system, 3) development of multiple alarm levels and all-clear indications for all weather alarm systems, 4) modification of the GTE visibility alarm systems to provide for sensor verification capability and the ability to download sensor data, 5) development of software to record and display weather and congestion alarms at the TMC, and 6) development of a monochrome CCTV system and successful congestion detection systems that do not require external power.

The following recommendations are based on *lessons learned in the conduct of this FOT* and are intended to apply to future tests of similar technology. In particular, they relate to tests that involve some element of technology development, as opposed to those that merely demonstrate the applicability of an existing technology in a real-world setting.

1. Where possible, tests should focus on solving problems as they are perceived by potential users of the technology being developed, and not on the exploitation of a particular type of technology. In this case, this would have implied a focus on developing wireless data collection systems rather than on exploiting existing call box technology.

2. Market research, resulting in quantitative estimates of potential market size, should be included as a formal part of any test that involves development of new technologies or systems.

3. All participants essential to the conduct of the test should be included in the partnership responsible for it and all should be identified in, and contribute to, the initial proposal. This should include the evaluator, any project manager, and any vendors or similar firms essential to the test. It should not be necessary for participants to negotiate contracts among themselves after the test is underway. Inclusion of the evaluator at the initial proposal stage is needed to ensure that the test design provides adequately for evaluation. Independence of the evaluation may still be assured by having the evaluator report directly to FHWA.

4. FHWA should decrease its emphasis on formal evaluation plans and data-management plans. These are less important than having a clear idea from the very beginning of what is to be demonstrated and how. The FOT proposal should discuss evaluation objectives and include enough information on evaluation methodology to demonstrate the feasibility of the evaluation objectives.

5. Where development of new technologies or systems is involved, definition of performance standards and specifications should take place early in the process of planning for the test. All test participants (including potential users, vendors, and sponsoring agencies) should be involved in this process. In some cases, it will be desirable to also include potential users from other geographical areas.

6. Contracting procedures used for funding tests should be kept as simple as possible. If separate contracts are to be issued for the test and its evaluation, they should be processed simultaneously.

7. Where systems are intended to serve multiple purposes, and it is necessary to stage the development of the system, each stage or development phase should be organized as a separate test. This is to avoid situations in which schedule slippage in early phases compromises system development and evaluation for later ones. In general, it is best to concentrate on doing one thing at a time. Also, it is wise to start with simple solutions and add enhancements later.

8. In general, evaluation of system functionality and system reliability should be conducted as separate tests. No attempt should be made to evaluate reliability until a system has demonstrated functionality. In assessing reliability and potential maintenance costs, it is also important to make sure that maintenance practices simulate as closely as possible those expected to apply to deployed systems.

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APPENDIX A

VENDOR TEAMS

Team 1

Prime Contractor: GTE Telecommunications Systems, Inc.

Subcontractors:

Jaycor Corporation
TRW Avionics & Surveillance Group
Icon Networks
Gyyr Inc.

Team 2

Prime Contractor: U. S. Commlink

Subcontractors:

Ball Engineering Systems
CCS Planning and Engineering, Inc.
Coastal Environmental Systems
Cohu, Inc.
Davis Instruments
FPL and Associates, Inc.
Icon Networks
Jaycor Corporation
Lawrence Livermore National Laboratories
Gyyr Inc.
Peek Traffic, Inc.
Schwartz Electro-Optics, Inc.
Vaisala, Inc.

APPENDIX B

PERFORMANCE STANDARDS

TRAFFIC CENSUS SUBTEST

Counters: System must either interface with existing counters (Sarasota (now Peek) VT-1900) or must provide comparable capabilities. These include the following:

> *Count modes:* Volume count, headway, axle classification, independent speed and length, correlated speed and length, statistical speed and length.
>
> *Memory:* Must store up to 40 days worth of hourly counts from up to 12 detectors. Current counters have 25k characters (4-bit nibbles) with option to extent to 57k. Must have capability of resetting memory from data collection point.
>
> *Channels:* At least 12 channels (detectors).
>
> *Time bases for counts:* 1 minute, 2 minutes, 5 minutes, 6 minutes, 10 minutes, 15 minutes, 30 minutes, 1 hour, 2 hours, 3 hours, 6 hours, 12 hours, 24 hours.

Transmission system:

> *Availability:* Must provide 2 hour windows on four consecutive days (normally first and last days of month) during which transceiver is in receive mode. All data transmissions to be initiated from data collection point. Must have capability to reset time of day of window from the data collection point. For purposes of test, windows may need to be provided more frequently.
>
> *Data record description:* 9 character ASCII records. (Note, if other than existing counters are used, 11 character records may be desirable.)
>
> *Maximum individual transmission:* 6000 records.
>
> *Receive mode capabilities:* Must be able to handle set up and interrogation commands. Commands for existing counters consist of up to 9 ASCII characters. Set up consists of up to 12 interactive steps. Existing counters provide for 18 interrogation commands and associated responses.

Remarks: It is desirable that counters, detectors, etc., be identical with existing in order to simplify job of Caltrans field crews. Use of equipment which results in increased training requirements is discouraged.

INCIDENT DETECTION SUBTEST

Algorithm: Algorithm must respond to threshold speeds of 50 MPH and 40 MPH. Speeds may be measured from double loops or from volumes and occupancies. Data smoothing routine to be identified later, but will probably be simple moving average over three to six minutes.

Required alarm conditions: Speed greater than 50 MPH; speed less than 50 MPH and greater than 40 MPH; speed less than 40 MPH.

Data to be transmitted: Single character alarm indicating first occurrence of particular threshold level, with location, date, and time stamp. Additional data may be specified later. In addition, system must be capable of transmitting standard system alarms and daily status information.

Data record description: 138-character ASCII string.

Data processing and transmission system: Proposed system must be capable of determining volumes, occupancies, and speeds from inductive loop detectors on a continuous basis, executing algorithm described above continuously, and transmitting alarms when appropriate.

Minimum system availability: 90%

Remarks: The "incident detection" system, as described by Caltrans District 11, is actually a congestion-detection system. No attempt will be made to implement an algorithm which can distinguish recurrent congestion from incident congestion. Also, no local calibration of the algorithm will be required. It is desirable if the system has the capability to add additional thresholds and to change threshold levels, however. Proposed system is intended to provide TMC operators a level of information similar to that from the existing ramp metering system, but on an alarm basis rather than a continuous basis.

HAZARDOUS WEATHER CONDITION DETECTION AND REPORTING SUBTEST

Algorithm: Algorithm must respond to weather indicator thresholds listed below.

Required alarm conditions: To be determined.

Data to be transmitted: Single character alarm indicating first occurrence of particular threshold level, with location, date, and time stamp. In addition, system must be capable of transmitting standard system alarms and daily status information.

Data record description: 138-character ASCII string.

Minimum system availability: 90%

Remarks: The Caltrans District does not require automatic weather alarms at present for operational purposes. The current system involves frequent updates of localized weather condition indicators, which are interpreted by maintenance personnel. The test is intended to develop a weather alarm system for use by the TMC; consequently, the test will involve determination and transmission of alarms.

CHANGEABLE MESSAGE SIGN CONTROL SUBTEST

Minimum allowable message length: 80-character ASCII stream for custom message transmissions from TMC to CMS.

Character sets to be supported: ASCII

Equipment compatibility requirements: Must be compatible with existing CMSs and PCs running "Signview" software.

Transmission confirmation requirements: Message displays must be validated by call box system. With current CMS technology, this means verifying switch condition rather than the actual display.

Data to be transmitted to TMC: Standard system alarms and daily status information. Also, message display validations.

Data record description: For transmissions from TMC to CMS, 80-character ASCII string; must be able to transmit 57-character custom sign display message strings and prompts for canned messages. For transmissions from call box to TMC, 138-character ASCII string.

Minimum system availability: 90%

Maximum per cent failed transmissions: 10%. Delayed transmissions will not be completed

Other: Message security is an issue. Dynamic encryption may be required. Also, must be able to activate from TMC at any time.

Remarks: At present, there is no intention by the Caltrans District to have canned messages automatically prompted by incident detection or weather reporting systems. All messages will be ordered from the TMC by human operators.

CCTV SURVEILLANCE SUBTEST

Field of vision and range: For incident verification, operational system must provide continuous coverage of the roadway, with all lanes and shoulders visible at all points. For CMS verification, must be focused on sign in question

Image quality requirements: For incident detection applications, color highly desirable; must be able to distinguish vehicle location and vehicles type (i. e., truck vs. car). For CMS verification, must be able to read CMS.

Digital data to be transmitted to TMC: Standard system alarms and daily status information.

Data record description: For CCTV to TMC, slow-scan video or better. For call box to TMC, 138-character ASCII string.

Minimum system availability: 90%

Maximum allowable per cent failed transmissions: 10%. Delayed transmissions will not be completed.

Minimum duration of sustained transmission: 5 minutes.

Other: Must be able to activate from TMC at any time.