San Diego Field Operational Test of Smart Call Boxes
Technical Aspects

JAMES H. BANKS AND PATRICK A. POWELL

Smart call boxes are devices similar to those used as emergency call boxes in California. The basic call box consists of a microprocessor, a cellular transceiver, and a solar power source. The smart call box system also includes data-collection devices, call-box maintenance computers, and data recording systems at a central location. The goal of the smart call box field operational test (FOT) was to demonstrate that smart call boxes are feasible and cost-effective means of processing and transmitting data for tasks such as traffic census, incident detection, hazardous weather reporting, changeable message sign control, and video surveillance. The objective of the FOT evaluation was to determine the cost-effectiveness of smart call boxes, but because of schedule slippage the evaluation focused on only functional adequacy and capital costs. The concept for the smart call box system was found to be feasible but not necessarily optimal for the tasks involved. System integration was a major problem. Also, the number of external devices that can be attached to a single call box while maintaining the economic advantages of the system is restricted by wiring costs and limitations of the solar power supply. Test system performance was mixed. One subtest was canceled before the installation of equipment, functional systems were produced for only three of the four remaining subtests, and reliable operation was observed in only one case. In most cases, system costs will be dominated by the expense of installing wiring. Consequently, smart call boxes will be cost-effective compared with hardwire systems at many sites but may not be cost-effective compared with alternative wireless systems.

The Intermodal Surface Transportation Efficiency Act of 1991 authorized the Secretary of Transportation to carry out operational tests related to intelligent vehicle and highway systems. In 1992, the FHWA responded by soliciting proposals for a series of field operational tests (FOTs). These FOTs were intended to serve as a transition between research and development activities and full-scale deployment of Intelligent Transportation Systems (ITS). One of the first tests completed under the 1992 program was the San Diego smart call box FOT.

Smart call boxes are devices similar to those used as emergency call boxes in California. The basic call box consists of a microprocessor, a cellular telephone transceiver, and a solar power source. The smart call box system also includes field data-collection devices such as traffic counters, weather sensors, or video compression devices; call-box maintenance computers; and some type of data handling system at a central location, such as a transportation management center (TMC). Figure 1 is a block diagram illustrating the architecture of a generic smart call box system.

The purpose of the smart call box FOT was to determine whether smart call boxes are a feasible and cost-effective means of performing specified data processing and transmission tasks. The FOT was divided into five subtests, each focusing on a particular task. These were as follows:

- Traffic census,
- Incident detection,
- Hazardous weather detection and reporting,
- Changeable message sign (CMS) control, and
- Closed-circuit television (CCTV) surveillance.

The main emphasis of the FOT was on developing and evaluating the field portions of the overall smart call box system rather than the data recording and display systems required to complement them. Consequently, the FOT focused on the problems of combining data collection devices with call boxes and included data recording and display features only to the extent needed to demonstrate that data could be transmitted to a central location.

This paper summarizes the major technical results of the FOT evaluation. Overall results are documented in the evaluation reports (*1,2*); another paper in this Record reports on some of the more important institutional lessons learned.

PARTICIPANTS

The smart call box FOT was funded by FHWA and the state of California. It was carried out by a consortium (the FOT partners) of District 11 of the California Department of Transportation (Caltrans), the Border Division of the California Highway Patrol (CHP), and the San Diego Service Authority for Freeway Emergencies (SAFE). The San Diego SAFE is the local agency responsible for providing emergency call boxes in San Diego County.

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., which acted thereafter as the project manager under subcontract to Titan. On January 1, 1996, RMSL changed its name to TeleTran Tek Services (T-Cubed).

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

Technical supervision of the FOT was the responsibility of a regional coordination team (RCT) consisting of voting representatives of the partners and nonvoting representatives of the project manager and the evaluator. In addition, nonvoting representatives of FHWA, the Caltrans Office of New Technology, and PATH sometimes attended RCT meetings.

Design and installation of test systems were carried out by two vendor teams under contract with the partners. One of these teams

J. H. Banks, Civil and Environmental Engineering Department, and P. A. Powell, Electrical and Computer Engineering Department, San Diego State University, San Diego, Calif. 92182.

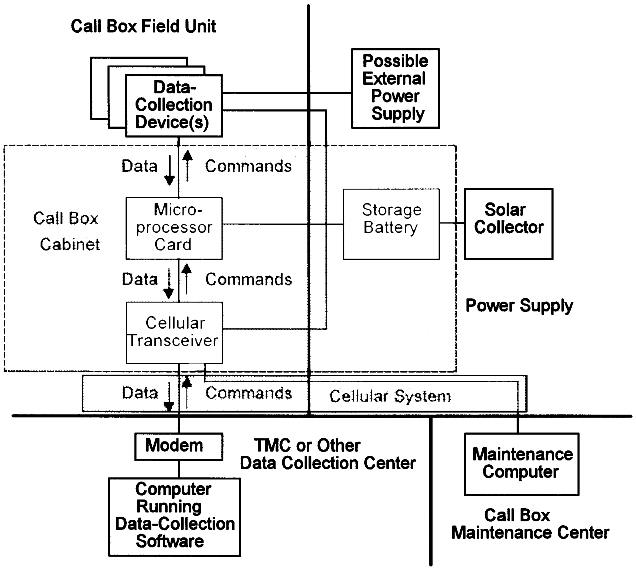

FIGURE 1 Generic smart call box system architecture.

was led by GTE Telecommunications Systems of Irvine, California, and the other by U.S. Commlink (USCL) of San Leandro, California. Input on the management of the FOT by the vendor teams (and, in theory, by any other interested parties) was provided by means of a technical advisory committee.

SUBTESTS

The FOT subtests each involved at least two test systems; as originally planned, each subtest also was to include participation by both vendors. During the conduct of the FOT, its scope changed so that GTE participated in only three subtests and U.S. Commlink in four. The subtests were as follows:

1. Traffic census. This subtest involved testing five system configurations, installed at eight sites, to process and transmit traffic census data. Each vendor provided two system configurations, both using loop-detector counters. One system configuration used external counters (counters installed outside the call-box cabinet) and the other internal counters (counters installed in the call-box cabinet). (In the planning phase, it was thought that internal counter systems could use call-box microprocessors to process sensor information; however, neither vendor attempted this architecture.) In addition to the loop-counter systems, U.S. Commlink provided a system using an infrared detector counter.

2. Incident detection. This subtest involved testing three system configurations, installed at eight sites, to process and transmit incident alarms. The original plan was to use one or more of the incident detection algorithms documented in the literature (3–5), but this was changed to limit the test to detection of congested traffic, as indicated by specified speed thresholds. GTE provided a single system based on internal loop-detector counters. U.S. Commlink provided one system based on an external loop-detector counter and one based on an infrared detector counter.

3. Hazardous weather conditions detection and reporting. This subtest involved testing three system configurations, installed at four sites, to process and transmit hazardous weather alarms. Test systems generated alarms for low-visibility conditions and high winds. GTE provided a low-visibility alarm system based on a Jaycor visibility detector. U.S. Commlink provided a similar system plus a high–wind-speed alarm system based on a Davis weather station. U.S. Commlink originally had proposed to provide a visibility-alarm system based on a Vaisala weather station but later substituted the Jaycor system.

4. Changeable message sign control. As originally planned, this subtest was to have involved the use of smart call boxes to control CMSs. It had been hoped that smart call boxes not only would relay messages to CMSs but also would automatically evaluate various alarm conditions (e.g., low visibility or high wind) and post predetermined warning messages. As the FOT proceeded, however, institutional and technical problems led to changes in the scope of this subtest and, eventually, its cancellation.

5. CCTV surveillance. This subtest involved use of smart call boxes to control video cameras and to transmit video signals. As planned, it was to have involved both fixed-field-of-view (FFOV) and remotely controlled pan-tilt-zoom (PTZ) units. Both vendors were to have participated, and each was to have supplied both types of system. In addition, this subtest was intended to complement other subtests, with the FFOV systems used to verify CMS messages and visibility conditions and the PTZ systems used to verify traffic conditions at incident detection sites. Neither vendor could solve the communications problems involved in use of smart call boxes to provide remote PTZ control; consequently, this objective was abandoned during the design phase. GTE could not install equipment by the deadline set by the RCT and was dropped from this subtest. U.S. Commlink installed two systems. One of these was a monochrome FFOV system intended to verify CMS messages and visibility conditions. The other was an FFOV color system that incorporated a PTZ camera (that is, the camera had PTZ capability but could not be controlled remotely). These test systems were installed at three sites.

Figure 2 is a map of locations of the various test sites in the San Diego area. Table 1 is a summary of systems installed at each site.

EVALUATION

As planned, evaluation of the FOT was to involve determination of the cost-effectiveness of the test systems when compared with one another (where more than one was proposed for a particular task) and with existing hardwire telephone data communications systems used by Caltrans. Effectiveness was understood to include both functional adequacy and reliability. Adequacy was measured by a two-step process in which system designs were compared to a set of performance standards adopted by the RCT, then actual system performance was compared with expected performance. Reliability was measured as system availability, with 90 percent availability the standard in most cases.

Costs included capital costs, telephone charges, and maintenance costs. Capital costs for full-scale deployed systems were estimated by having Caltrans determine how bids for smart call boxes would be structured and then asking vendors to estimate prices for items they were supplying, assuming large-scale deployment. For items not supplied by the vendors, standard Caltrans cost estimates were used. Telephone charge estimates were based on rates paid by the San Diego SAFE for its voice call box system and by Caltrans for hardwire telephone service. Maintenance costs were estimated by

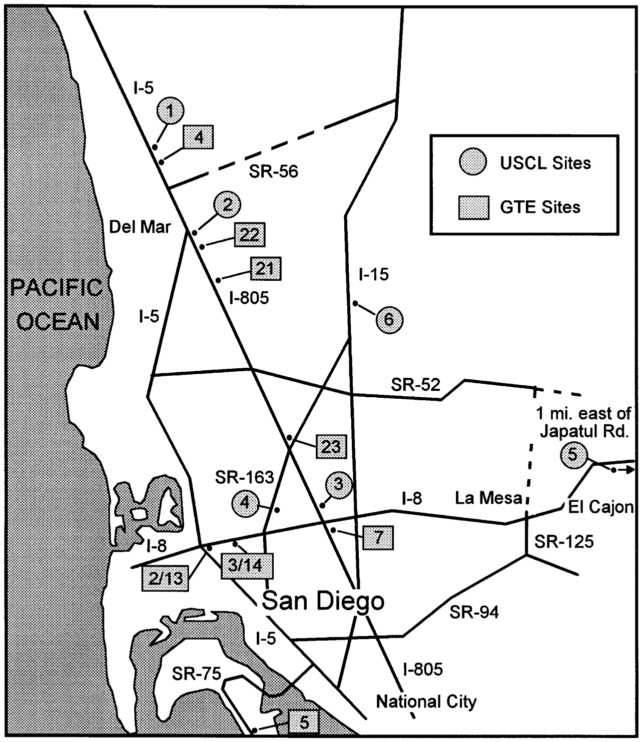

FIGURE 2 Map of FOT field test sites (USCL = U.S. Commlink).

TABLE 1 Site Configurations

Site	Subtest			
	Traf. Cen.	**Incid. Det.**	**Weather**	**CCTV**
USCL-1	Ext. Counter	--	Jaycor	B/W
USCL-2	Ext. Counter	Ext. Counter	--	Color
USCL-3	Ext. Counter	--	--	--
USCL-4	Ext. Counter	--	--	B/W
USCL-5	Int. Counter	--	Davis	--
USCL-6	Infrared	Infrared	--	--
GTE-2, GTE-13	Ext. Counter	Int. Counter	--	--
GTE-3, GTE-14	Int. Counter	Int. Counter	--	--
GTE-4	--	--	Jaycor	--
GTE-5	--	--	Jaycor	--
GTE-7	--	Int. Counter	--	--
GTE-21	--	Int. Counter	--	--
GTE-22	--	Int. Counter	--	--
GTE-23	--	Int. Counter	--	--

determining the frequency of types of maintenance actions encountered in normal call box system operation and assigning estimated costs to these.

Several evaluation objectives of the FOT were compromised because of schedule slippage, leaving inadequate time for gathering data. These delays were caused by both institutional and technical difficulties. As a result of this schedule slippage, initial design flaws were not worked out of many of the systems. In most cases, systems were in normal operation for too short a time for reliability to be evaluated or maintenance costs to be estimated. Consequently, evaluation of cost-effectiveness focused on functional adequacy and capital costs.

SYSTEM CONCEPT

In concept, smart call boxes are multipurpose data processing and transmission systems using independent solar power supplies and wireless communications. The smart call box FOT was motivated by a belief that such devices can fill an important niche in the overall ITS architecture. At the time the FOT was proposed, the draft ITS architecture identified a roadside terminal that would be connected via bi-directional communications links to both TMCs and vehicles. It was thought that smart call boxes could serve this function.

Where well-developed voice call box systems already exist, as in California, smart call boxes were seen as a way to achieve greater use of existing infrastructure, because modification of existing call boxes was predicted to be cheaper than deploying special-purpose data terminals. In addition, smart call box technology would avoid the need for both electrical and telephone wiring. Caltrans estimates the cost of installation for wiring to be about $35/m for trenching, conduit, and wiring and $300/m for jacking cables under the traveled way. Consequently, elimination of wiring can result in significant installation cost advantages at many sites. Finally, existing call boxes have been crash tested and approved for installation in the roadway clear recovery zone. If modifications do not significantly alter the weight distribution, the use of smart call boxes avoids the tedious and expensive process of crash testing that might be required for some alternative device.

Key features of the smart call box concept are

- Multiple functions, including voice transmission and possibly several types of data transmission,
- Independent solar power supply,
- Significant use of call box microprocessors for data processing,
- Use of call box transceivers for data transmission, and
- Continuous accessibility from some central location such as a TMC.

Key design issues resulting from these requirements include the following:

- System architecture. Which data processing tasks are to be performed by which components is a major issue. An assumed advantage of smart call boxes is use of surplus computing capacity in call-box microprocessors. However, existing counters and weather sensors already have considerable data processing capability. The issues here are whether call-box microprocessors have significant additional capacity and, if so, whether it is needed.
- System integration. Smart call box systems contain several components that were not designed to work together. For instance, in a smart call box system, traffic counters or weather sensors that were designed to communicate directly by hard wire with data-collection software must instead communicate through a cellular transceiver. System integration is a major design challenge, involving numerous software, hardware, and system compatibility problems.

- Power supply. A critical feature of all designs for smart call box systems 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 run multiple data-collection devices. Potential solutions are to design components and system operation to minimize power consumption; to increase solar power supplies; or to compromise the objective of independent power supply by designing systems that require external power.
- Physical connectivity. If smart call boxes are to serve as multipurpose devices, the various components must connect to one another. This requires that call box microprocessor cards be designed to accommodate multiple ports and that connections be designed so that all necessary wiring can be accommodated in the confined space provided by call-box cabinets.
- Sequencing of transmissions. In multipurpose smart call box systems, there may be 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.
- Integration with the TMC. The final design issue relates to integration of data from smart call boxes into data systems and operational routines of TMCs. The complete system must be integrated all the way from field data-collection devices to the ultimate user. This involves consideration of how data are to be displayed and used so that they can be provided in a useful form.

Vendors participating in the FOT were not necessarily required to design systems resolving all these issues or possessing all the characteristics implied by the system concept. For example, although it had been hoped that vendors would produce multipurpose systems, the FOT was structured as a series of single-function subtests, which meant that this was not required. Vendors had near-complete freedom to determine the system architecture. Independent power supplies were not required, in part because it was not clear that they would be feasible for all proposed systems. Finally, integration of test systems with TMC operations was deliberately excluded because it was perceived to be beyond the FOT's resources.

The designed and tested systems met the criteria of the smart call box concept only to a limited extent. U.S. Commlink's approach emphasized multipurpose systems and continuous accessibility. Provision of these features required redesign of the call-box microprocessor and power system to reduce power consumption and include multiport capability. The resulting microprocessor provided four ports for data collection devices and continuous availability to receive incoming calls. Solar power supplies were not adequate to take full advantage of these capabilities, however. Only one U.S. Commlink test site (USCL-5) was designed to function without AC power. At this site, both traffic census and wind-speed alarm capabilities were provided with an augmented solar power supply (tripled solar-panel capacity and an 85 A-hr storage battery rather than the normal 20 A-hr battery), but system access still could not be provided on a 24-hr/day basis because of solar-power supply limitations.

GTE, on the other hand, did not attempt to provide either multipurpose systems or continuous accessibility. GTE traffic census and incident detection systems provided for downloading of data during predetermined time windows, and GTE weather alarm systems did not provide for downloading of data. GTE never deployed field equipment for either of the subtests (CMS control and CCTV surveillance) that required call boxes to be continuously accessible.

Neither vendor made much use of call-box microprocessors for data processing. U.S. Commlink's loop detector–based incident detection system did use a call-box microprocessor to download and process current speed from a traffic counter to determine whether alarm thresholds had been crossed. Otherwise, key data processing functions were carried out by intelligent external data-collection devices such as weather sensors and traffic counters. The motivation for this approach appears to have been both the limited capabilities of the call box microprocessors and the well-developed data processing capabilities of existing counters and sensors.

EVALUATION RESULTS

Test system effectiveness was evaluated for functional adequacy and reliability. Functional adequacy, in turn, was evaluated on the basis of the extent to which system designs met performance standards and the extent to which system performance met expectations. Results are summarized in Table 2.

System Designs

In Table 2, evaluation of system designs is based on the extent to which they meet specific requirements contained in the performance standards and Request for Participation issued to prospective vendors. These requirements focus on details of system designs for the individual subtests rather than major design issues and primarily were intended to ensure that test systems meet the needs of prospective users.

For the most part, test-system designs did meet these performance standards. One exception was the infrared-sensor system used in the traffic census and incident detection subtests. The memory and timekeeping system of this counter were inconsistent with the performance standards and appear to be inadequate for normal traffic census use. In addition, the incident-detection algorithm supplied for this unit did not include all required alarm conditions. Finally, this system is limited to one lane per counter, so that with U.S. Commlink's current call-box design no more than four lanes can be counted from a single call box. The performance standards required that traffic census systems be able to count up to 12 lanes.

Other cases in which vendor teams were unable to meet stated design criteria were the CMS control subtest and the CCTV surveillance subtest. In the case of the CCTV surveillance subtest, neither vendor could solve the communications problems involved in the use of a smart call box to provide remote control for a PTZ camera.

In the case of the CMS control subtest, the design criteria changed significantly after adoption of the performance standards because of the concerns of Caltrans operational personnel. Considerable time and energy were expended to find an acceptable way for the TMC to preempt control of CMSs during testing, should this be necessary. Although draft guidelines for use of CMSs in the FOT had been proposed before the cancellation of the subtest, this issue was never settled.

A more important problem of this subtest had to do with system architecture. During the design phase, it was discovered that the CMS used in California employed an external controller to switch the individual lights in the sign matrix. It had been intended to replace this controller with a smart call box, but the amount of

TABLE 2 Summary of Test System Evaluations

System	Functional Adequacy: Design	Functional Adequacy: 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	

wiring required far exceeded the physical connectivity limits of call boxes. This meant that the only possible function of the call box was as a communications link. An obvious alternative was to use a cellular modem with the existing controller. Since Caltrans already had this capability, there was no reason to continue the subtest.

In other cases, stated performance standards were met, but the standards themselves may have been inadequate. In the hazardous weather reporting subtest, the standards were to spell out the exact alarm conditions required. Decisions about required alarm conditions were postponed, however, and the vendors decided which would be used. In all cases, systems were designed to respond to only a single level of visibility or wind speed. The usefulness of these systems could be increased by adding more alarm levels.

Also, the design standards failed to state that some type of all-clear signal was desired. U.S. Commlink systems repeat alarms every 20 minutes if the alarm condition persists and allow for downloading of data from the weather sensors to determine exact conditions. The GTE visibility-alarm system provided neither of these capabilities and hence allowed no way for determining whether an alarm condition had cleared.

Finally, both alarm-system subtests (hazardous weather reporting and incident detection) suffered from the decision to exclude issues related to integration of data into TMC operations. In the other subtests, the interfaces to the TMC either already existed (as in the case of data collection software used for traffic census) or were obvious. In the case of the alarms, however, the systems produced by the FOT are of little practical use in the absence of an acceptable way to record and display alarms.

System Performance

The performance of the test systems was evaluated for functional adequacy and reliability. 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 because of a lack of comparable data. The infrared detector–based system did not function adequately because the detector failed to produce consistently accurate volume counts or speeds. All the traffic census systems had significant reliability problems, involving extensive down time at all but one test site. These problems included system integration problems, component failures, and AC power supply interruptions at two U.S. Commlink sites that required it. Although some of these problems were the result of initial design flaws and other circumstances peculiar to the FOT, the reliability of the traffic census systems was not demonstrated.

The hazardous-weather alarm systems functioned satisfactorily to the extent that they sent alarms at times that appeared reasonable. A possible exception is the U.S. Commlink low-visibility system, which was installed after the fog season and never sent a "real" alarm. The GTE visibility alarm systems appeared to function reliably once initial design flaws were corrected. The Davis weather system did not function when initially installed but did function reliably after it was reinstalled in April 1996; however, since this system was in operation for no more than 2 months before termination of data collection, it is difficult to draw definite conclusions about its reliability.

The incident detection systems did not function adequately. The GTE system sent only one alarm in 3 months. This failure apparently was one of system integration, since GTE reported that the counter produced the alarm signals at the call box after it was installed in the field. U.S. Commlink incident-detection systems sent numerous alarms, but the time patterns of the alarms appear unreasonable. The loop-detector–based system sent alarms that sometimes appeared to be valid but that also appeared to understate the degree of congestion at the site. By using the CCTV installation at this site, it eventually was possible to confirm that alarms were not always sent when traffic was congested. The time patterns of alarms from the infrared-detector system clearly were unreasonable.

The CCTV systems functioned adequately, except that the usefulness of the color system (intended for incident verification) is limited by its lack of PTZ capability and by its slow refresh rate. This system functioned reliably for about 6 weeks; however, the monochrome system failed after about 3 or 4 weeks for undetermined reasons.

Costs

Costs for smart call box systems include capital costs, telephone charges, and maintenance costs. Capital costs for smart call box systems and hardwire telephone systems performing similar functions were estimated on the basis of standard Caltrans cost estimates and prices supplied by the vendors. Estimated capital costs varied a great deal from site to site. Cost comparisons between smart call boxes and hardwire systems usually were dominated by the costs of providing access to telephone and external power systems. Smart call box systems tend to have a significant advantage at most sites because of the high cost of providing access to hardwire telephone systems. For the sites used in the FOT, this usually was the case even where the smart call box system required AC power, because access distances for the telephone system were greater than those for the power system.

For the systems involved in the FOT, the cost of the call box itself was modest when compared to that of other components. At no site did the cost of the call box (listed at $2,400, installed, by both vendors) exceed half the estimated cost of providing the test system under full-scale deployment conditions. Although many of the test sites served multiple functions, this also is true of all single-function systems tested except the Davis weather system and the monochrome CCTV system.

Overall life-cycle costs also depend on telephone charges and maintenance costs. Based on rates charged to the voice call box system in the San Diego area, smart call box systems appear to have a slight advantage over hardwire systems for telephone charges. In neither case, however, are these costs significant when compared with capital costs.

Given the short period of observation, 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 on the basis of various assumptions about interest rates and access distances to the regular telephone system. For the access distances typical of the sites used in the FOT, break-even differences in annual maintenance costs range from about $500 per unit up to several thousand dollars per unit, depending on the type of system.

DISCUSSION OF RESULTS

In considering the technical results of the smart call box FOT, two points appear to be particularly significant:

1. Actual designs deployed met the criteria implied by the system concept only to a limited extent.
2. Test system performance was mixed. Functional systems were produced for three of the five subtests, but there were serious problems with reliability and system integration.

In retrospect it appears that the FOT took the approach it did because of a lack of awareness of the relative costs of different system components and a lack of appreciation for the difficulty of system integration.

Three major elements of the smart call box concept were completely wireless operation (for both communications and power supply), multiple functions, and use of call-box microprocessors for data processing. Of these features, completely wireless operation offers by far the greatest cost advantage under most circumstances. Based on the cost estimates developed by the FOT evaluation, an entire call box unit can be purchased and installed for roughly the same cost as installing 60 m of wiring. Devices such as cellular modems are even cheaper. Because of this, it often will be cost-effective to minimize wiring costs at the expense of providing extra equipment.

This principle runs counter to the emphasis in the FOT on providing multipurpose systems. In the first place, these are apt to be cost-effective only if the data-collection devices are all located within 30 to 60 m of one another; otherwise the cost of the trenching and wiring will be greater than the cost of separate transmission devices. Even where the wiring cost at the site is not prohibitive, the FOT showed that no more than two data-collection devices can be connected to a call box without exceeding solar power supplies, even if they are augmented. If the only alternative is to supply the site with AC power, separate cellular systems will be cheaper where access to the AC power system is more than 30 to 60 m away.

Meanwhile, call-box microprocessors tended to create serious system integration problems and served little or no purpose in most of the test systems. System integration problems, which were the major technical surprise in the FOT, arose because data-collection software supplied by vendors of intelligent data-collection devices (weather sensors, traffic counters, and video compression units) assumed a direct or telephone modem–based connection to the data-collection device. The call box could be integrated into the system either by modifying the software to communicate with the sensors via a call box or by having the call box emulate a modem and pass data through without processing or conversion.

In addition, the existing software was not adapted to wireless communication. Even when configured as a pass-through system, the wireless communication link characteristics of the call box, such as high error rate and variable delays, continued to cause problems. These system integration problems might be overcome through adoption of a standard communications protocol for devices interfacing with smart call boxes, but it is questionable that the potential market for smart call boxes is large enough to support development and use of such a protocol by vendors of intelligent data-collection devices.

The one case in which a call-box microprocessor was used for a key data-processing function was the U.S. Commlink loop detector–based incident-detection system. In this case, the original plan had been to modify the software of a state-of-the-art traffic counter to provide the alarms. U.S. Commlink abandoned this approach only when the counter manufacturer was unable to provide the software modification. The counter actually used in the test was an obsolete model that is likely to be replaced if any further development of this system takes place; consequently, it is likely that even this system eventually must be modified to have the alarms determined by the counter.

The problems of hardware and software system integration could be solved by using a set of standards for the following items:

- Physical connection of smart sensors to call boxes. Although the RS232 standard provides a simple device-to-modem interface, it is unacceptable where there are high noise, low power, or electrical isolation requirements. A system using differential transformer coupled signals would be superior technically, and has been recommended by the National Transportation Communications for ITS Protocol standards.

- Standard communications protocols for querying sensors and obtaining information from them. This problem has been encountered in the computer networks field, and has been solved (to an extent) by the Simple Network Management Protocol (SNMP). While the SNMP protocol is far too complex for direct adoption, many of the concepts used in SNMP, such as a management information database, standard formats for queries, and alarm reporting appear directly applicable.
- If data communication is to be carried out over a data channel such as cellular phone, the users must be prepared to deal with high error rates, transmission re-tries, and flow control. This would require the use of far more complex protocols than the current ASCII text-based ones used by most intelligent sensor vendors.

From the point of view of potential users of smart call box systems, the most desirable feature usually will be avoidance of wiring for both external power and telephone communication. Multipurpose devices, and devices involving multiple uses of call-box microprocessors, are less likely to be attractive. This suggests that an attractive alternative system architecture would be a single-purpose data-collection system involving solar power and a cellular modem. In retrospect, it would have been more interesting to compare the smart call box systems developed in the FOT with systems of this type rather than hardwire telephone systems. For usefulness, systems that use a single traffic counter to provide incident detection and traffic census functions, weather-alarm systems that can download data, and monochrome CCTV systems that monitor fixed objects all appear to have potential.

CONCLUSIONS

This paper has described the technical aspects of the smart call box FOT and its evaluation. Major conclusions are as follows:

1. The major technical lesson learned from the FOT is 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 intelligent data-collection devices.
2. 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 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 because, among other reasons, it was discovered that the CMSs used in California are incompatible with smart call box systems.
3. With the exception of the GTE weather-alarm systems, reliability was not demonstrated for any of the test systems. In some cases, the systems may be reliable, but the period of observation was too short to draw positive conclusions. In other cases, there were numerous problems, some of which may have been due to initial design flaws. Further testing to establish the reliability of these systems must be conducted before deployment.
4. 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.
5. At most sites, smart call boxes will be cost-effective compared with hardwire telephone systems, provided their functional adequacy and reliability can be demonstrated and their maintenance costs prove to be reasonable. It is much less likely that smart call boxes will be cost-effective when compared with single-purpose systems consisting of cellular modems and intelligent data-collection devices.

ACKNOWLEDGMENTS

This research was jointly funded by Caltrans and FHWA. The authors thank Brian Blase of San Diego State University, Jim Dodd of T-Cubed, Robert Tam of California PATH, Ross Cather and Richard Sugita of Caltrans District 11, Mike Perkins and Patricia Honeycutt of San Diego SAFE, and Frank Cechini of FHWA.

REFERENCES

1. Banks, J. H., and P. A. Powell. *Smart Call Box Field Operational Test Evaluation Summary Report*. PATH Report D96-33. California PATH Program, Richmond, 1996.
2. Banks, J. H., and P. A. Powell. *Smart Call Box Field Operational Test Evaluation Subtest Reports*. PATH Report D96-52. California PATH Program, Richmond, 1996.
3. Payne, H. J., and S. C. Tignor. Freeway Incident-Detection Algorithms Based on Decision Trees with States. In *Transportation Research Record 682*, TRB, National Research Council, Washington, D.C., 1978, pp. 30–37.
4. Hall, F. L., Y. Shi, and G. Atala. On-Line Testing of the McMaster Incident Detection Algorithm Under Recurrent Congestion. In *Transportation Research Record 1394*, TRB, National Research Council, Washington, D.C., 1993, pp. 1–7.
5. Chassiakos, A. P., and Y. S. Stephanedes. Smoothing Algorithms for Incident Detection. In *Transportation Research Record 1394*, TRB, National Research Council, Washington, D.C., 1993, pp. 8–16.

Publication of this paper sponsored by Committee on Freeway Operations.