Lessons Learned from the Irvine Integrated Freeway Ramp Metering/Arterial Adaptive Signal Control Field Operational Test

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by

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ABSTRACT

A systematic evaluation of the performance and effectiveness of a Field Operational Test (FOT) of an integrated corridor-level adaptive control system was attempted from fall 1994 through spring 1999 in the City of Irvine, California. The FOT was conducted by a consortium consisting of the California Department of Transportation (Caltrans), the City of Irvine, and two private sector consultants, National Engineering Technologies Corporation (NET), and Farradyne Systems, Inc., a division of Parsons Brinkerhoff (PB/FSI), with the City of Irvine as the lead agency. The FOT was cost-share funded by the Federal Highway Administration as part of the Intelligent Vehicle Highway System Field Operational Test Program. The FOT involves an integrated Advanced Transportation Management System (ATMS) which extends the capabilities of existing traffic management systems in the City of Irvine and in Caltrans District 12 (D12). The evaluation originally entailed both a technical performance assessment and a comprehensive institutional analysis.

This report of the Irvine Field Operation Test presented here does not constitute a technical evaluation due to the failure of any of the planned technologies to be successfully implemented in the field. Due to the extended time frame associated with the project and the significant range of technical and institutional issues associated with the development and eventual failure of the FOT, a summary of project development, institutional barriers, and lessons learn is provided.

KEY WORDS

ITS, ATMS, adaptive signal control, ramp metering, integrated corridor, field operational test (FOT)
INTRODUCTION

Achieving Field Operational Test (FOT) objectives typically requires identifying, evaluating, and resolving a wide variety of institutional barriers to successful project completion. Federal and California policy are firmly supportive of the rapid deployment of new technologies associated with Advanced Transportation Management Systems (ATMS), but actual deployment involves integrating diverse technologies from a variety of competing vendors. Since local operators have little experience with ATMS technologies, they must learn to deal with technical and institutional implementation issues. The limitations institutional issues pose should not reduce or confound system effectiveness. Unfortunately, the scope of potential institutional issues is quite wide. The question of interest is, "How can the institutional limitations on programming, implementing, and operating ATMS technologies be prevented from reducing or confounding such technologies' effectiveness?"

This paper examines the technologies, circumstances, events, and results associated with the Federal Highway Administration's (FHWA) City of Irvine Advanced Traffic Control System IVHS Field Operational Test, Integrated Freeway Ramp Meter/Arterial Adaptive Signal Control. This Irvine Field Operational Test (FOT) evaluation is a part of the FHWA program to evaluate Intelligent Transportation System (ITS) concepts and technologies that have the potential for improving mobility, safety, and transportation productivity, as well as reducing congestion and emissions on national highways [1].

Background

The FOT was cost-share funded by the FHWA in cooperation with the California Department of Transportation (Caltrans), the City of Irvine (COI, Irvine, or the City), National Engineering Technology Corporation (NET), and Farradyne Systems Incorporated, a division of Parsons Brinkerhoff (PB/FSI). NET is referred to hereafter as the "freeway consultant," and PB/FSI is referred to as the "arterial consultant." A map of the study area in the City of Irvine is shown in Figure 1.

Caltrans' involvement in the FOT spanned three separate entities. Caltrans Headquarters administered the contract and passed the federal funding to COI. Caltrans District 12 (D12) in Orange County served as the agency responsible for freeway infrastructure and management. The Caltrans Traffic
Operations Section (TOS) developed the specification for the Model 2070 Advanced Traffic Controllers (ATCs) used in the arterial element of the project.

![Map of FOT deployment and study area.](image)

FIGURE 1. Map of FOT deployment and study area.

The Irvine FOT was to have introduced several new technologies in the project area to create an integrated freeway / arterial corridor that adapted to real-time traffic conditions [2]. The freeway components were designed by Caltrans District 12's freeway consultant. These included a new centrally-controlled, system-wide, traffic-responsive ramp metering system, designated the System-Wide Adaptive Ramp Metering (SWARM) system, and the Caltrans District 12 Transportation Management Center's (TMC) Operator Decision Support System (ODSS). SWARM and ODSS were components of the D12 Advanced Traffic Management System (ATMS) created by the freeway consultant. The D12 ATMS would
oversee the freeway by providing incident detection, surveillance, ramp metering, and CMS control, while ODSS was supposed to provide real-time decision support for incident response. The ATMS/SWARM replaces and supercedes many of the functions of the previously proposed ODSS, which itself replaced the originally proposed [3] Freeway Real-time Expert System Demonstration (FRED), an expert system developed by the University of California at Irvine [4,5,6]. Functional features (only) of ATMS/SWARM were described by freeway consultant in [7].

The FOT's arterial components were provided from three sources, the arterial consultant, Caltrans TOS, and the City of Los Angeles Department of Transportation (LADOT). Caltrans TOS specified the Model 2070 ATC on which the arterial consultant's real-time adaptive signal control software package, Optimized Policies for Adaptive Control (OPAC), was expected to run. At the time the FOT was proposed, the 2070 ATC was still under development, and lacked final specifications and firmware for traffic signal control. Approximately two years following the start of the test, LADOT was retained by COI to provide the missing signal control firmware. Finally, the arterial consultant also provided the central control component of the proposed arterial system, the Management Information System for Traffic (MIST), which was to provide network-wide supervisory control of the local OPAC-based arterial signal controls as well as an operator interface and changeable message sign (CMS) control. MIST's control decisions were to be subordinate to control actions on the corridor freeways initiated by the D12 ATMS, to which MIST was to be linked. The key hardware components of the integrated project are illustrated in Figure 2. Physically ATMS/SWARM was implemented on a local network of HP UNIX workstations in the Caltrans District 12 TMC. MIST was intended to operate on a similar network of HP 9000 Workstations in the Irvine Traffic Research and Center (ITRAC). Corridor control system logic is summarized in Figure 3. Communications between the two supervisory systems were a critical component of the proposed FOT, and was to have been accomplished via one or more data links, but was never fully specified. This link represents the backbone of the integrated system. The hardware mechanization of this data link was not completed, and the exact information to be transmitted between the D12 TMC and the ITRAC remained undetermined. Working components of the data link, which have been demonstrated, included several telephone modem connections, the existing and possibly expanded Caltrans Wide Area Network (WAN), and an existing fiber optic high speed data connection.
FIGURE 2. Main components of Irvine integrated ramp meter/arterial adaptive signal control system.

Outcomes

It is the consensus of the evaluators that no integrated control or control functions were implemented as part of this FOT, and that no operational systems were implemented. SWARM was tested offline extensively in the D12 TMC, but was never implemented due to operational and functional problems, and (as reported by D12 personnel) lack of an operator’s manual for the system. Actual ramp meter control under SWARM/ATMS was not implemented. The City of Irvine installed 2070 controllers at 28 intersections per contract requirements. The arterial consultant provided and installed OPAC at one intersection, and operated it off-line. Its potential to communicate with MIST was demonstrated, but since communications with ITRACT were not operational, and MIST was not yet installed, it is unclear what control function was demonstrated. The arterial consultant ultimately delivered MIST to the City of Irvine, and a demonstration of its user interface only was conducted in February 1999, running on a workstation in
Resolution was dropped by making MIST subordinate to the SWARM system.

FIGURE 3: Summary of the Irvine POT controller control system logic. Conflict monitoring and

Caltrans District ATMS

preway incident information

Look-up Table

Arterial Response Plan (ARP) Module

Candidate Arterial Response Plan

ITRAC (or CD 12 Remote)

Plan

Resolution

yes

Correct

Decision

no

Trade-off

Arterial Traffic Information

Arterial Response Plan

Irvine Arterial Signal Network

Message Signs

OPAC/2070

Note: No Conflict Monitoring at this time.
the ITRAC. No Caltrans HQ, D12, or City of Irvine personnel attended the demonstration. Since data communications were not functional, no features of the system that depended upon communications with either OPAC at an intersection or with the D12 TMC could be demonstrated.

**FOT Evaluation**

In this FOT, there is no system to evaluate, and little in the way of individual components. Consequently, it is impossible to assess the ultimate deliverables of this FOT in terms of technical capacity. The assessment of institutional issues is the central evaluation task. Data required for evaluating institutional issues are substantively qualitative and inevitably somewhat subjective. It is important to gather information from multiple sources to minimize bias in interpreting data.

The first source was direct observation of participants over the duration of the project at formal project meetings and in less formal field situations. The Project Manager and members of the evaluation team shared independently-recorded meeting minutes documenting formal meetings. Although approved early, the Irvine FOT evaluation trailed the evaluations of other FOTs due to various delays. Several reports documenting institutional issues associated with these projects provided a second useful data source. See [8] and [9]. The Anaheim FOT evaluation [10, 11] which the same evaluation team completed concurrent with the Irvine FOT evaluation, was one of these sources. Finally, the evaluation team interviewed all key project participants to assess their opinions on the progress of the FOT, and on the relative role of various institutional issues.

Interviews began in January, 1997 and concluded with final interviews and follow-ups in March, 1999. The team interviewed key individuals from all agencies and firms participating in the project including participants from the City of Irvine, PB-Farradyne, Inc. (the arterial consultant), National Engineering Technologies Corporation (the freeway consultant), Caltrans Headquarters, Caltrans District 12, the City of Los Angeles Department of Transportation, and the Federal Highway Administration. The evaluators also interviewed selected FHWA administrators based in Washington, DC to obtain a national view of the project. In some cases, evaluators conducted follow-up interviews for clarification of certain issues.
The interview consisted of four sets of questions, one set for all participants, and another set for each of three groups of participants. These three groups are:

- high-level administrative participants,
- project management (key agency and firm participants), and
- engineers and technicians.

The last portion of each interview addressed the effect of specific problems on the overall performance of the FOT project.

**FOT PARTNERS’ PERSPECTIVES: INTERVIEW RESULTS**

**Project Scheduling**

Table 1 describes each agency’s assessment of its ability to maintain its project schedule. It also summarizes any problems that respondents for other partners may have identified. Overall, many agencies indicated they failed to maintain their project schedules. However, respondents who identified schedule delays most often attributed these delays to *other* participants.

**FOT Technologies**

Respondents associated problems with all of the planned FOT technologies: SWARM, OPAC, MIST, Arterial Response Plan (ARP), and the 2070 ATC.

**SWARM System**

Respondents reported two primary concerns about SWARM. First, Caltrans received neither the training nor documentation needed to understand fully SWARM operations. Second, SWARM did not seem to work when Caltrans ran it. Caltrans tested SWARM functions over a six-week period, but nothing related to SWARM ever appeared to work, and Caltrans never identified what SWARM did internally. Caltrans let SWARM run in the field on a small section of road for two days, but once again there was no indication SWARM was functioning. Caltrans did not find any evidence that SWARM was affecting any ramps. Interviewees also noted that SWARM’s inability to save parameters might render it effectively unusable.
Despite these problems, Caltrans D12 expected to use SWARM if it met current functional requirements and operated twenty-four hours a day. Other Caltrans respondents expected SWARM to reduce delay on the freeway and be completely automatic and robust. The freeway consultant believed the entire ramp metering system should switch to SWARM.

**TABLE 1 Summary of Project Scheduling Problems**

<table>
<thead>
<tr>
<th>AGENCY</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>FHWA</td>
<td>The FHWA fully maintained its schedules and deadlines.</td>
</tr>
<tr>
<td>Caltrans Headquarters</td>
<td>Caltrans headquarters maintained its schedule. However, respondents said Caltrans HQ could have facilitated earlier development of the MOU with the City of Irvine.</td>
</tr>
<tr>
<td>City of Irvine</td>
<td>All City representatives indicated that the City did a fair job of maintaining its deadlines; however, it encountered some infrastructure problems due to new construction. Concerns from the other partners focused on slow decision-making, infrastructure problems related to new construction, and poor management.</td>
</tr>
<tr>
<td>Caltrans District 12</td>
<td>District 12 did not seem to encounter any delays; however, it did not provide a consistent presence early in the project. District 12 did not provide any technical review or leadership throughout the project.</td>
</tr>
<tr>
<td>NET (freeway consultant)</td>
<td>Although NET experienced technical problems with SWARM implementation, and its schedule slipped a little, NET finished SWARM before the end of the project.</td>
</tr>
<tr>
<td>PB/FSI (arterial consultant)</td>
<td>The arterial consultant did not realize the scope of work required to convert MIST from OS/2 to UNIX. Slow development of the 2070 specifications and firmware added to the delays, as did slow decision-making by project management.</td>
</tr>
<tr>
<td>LADOT</td>
<td>LADOT placed higher priority on this project than on others. City of Irvine respondents felt LADOT response time was quick and LADOT responded to all City needs. The arterial consultant respondents felt LADOT had a tremendous impact on its ability to finish tasks in a timely manner because the consultant was effectively beta testing Traffic Signal Control Program (TSCP) for LADOT.</td>
</tr>
</tbody>
</table>

**OPAC**

The arterial consultant stressed multiple concerns about implementing the OPAC technology, while other participants questioned its validity as an effective algorithm. The arterial consultant worried that:
• City staff must understand and set-up OPAC parameters, because the arterial consultant was not contracted to do this work.

• OPAC might have difficulty coordinating closely-spaced intersections.

• An oversaturated arterial might overwhelm OPAC.

The quality of data from the stopline detectors determines OPAC performance. The arterial consultant expressed further concerns that the FOT constituted a substandard OPAC implementation.

OPAC/MIST operations would have burdened the City's staff. Establishing timing pages seemed quite time-intensive, and even the arterial consultant's technical team did not fully understand the process. Acceptable OPAC performance thresholds varied among City staff, who suggested OPAC should reduce delays and stops by 10 to 25 percent relative to the City's existing Multisonics system. City respondents indicated they anticipate scrapping the OPAC system and returning to the existing Multisonics system.

*MIST*

The MIST system also elicited different opinions. The arterial consultant respondents stressed that the City of Irvine would need to invest adequate staff time to learn the new system and complete its implementation. The primary technical concern related to using too many devices on one communications channel. The agencies, in contrast, questioned MIST's overall functionality rather than specific correctable details.

*ARP Module*

Since the FOT never tested the ARP module, its functionality remains unknown. Administrators and consultants stated simply that ARP might be routinely ignored. While the team’s opinions on ARP performance requirements differed greatly, a significant portion of them simply wanted to see it function.

*2070 ATC*

Respondents expressed a variety of technical concerns regarding the 2070 Advanced Traffic Controllers. The consultants worried about 2070 stability and functionality, specifically that the CPU might not optimize OPAC completely. One participant from the City of Irvine worried about keeping up with frequent maintenance problems. Two other agency respondents were preoccupied with firmware
functionality. They were concerned that the firmware might not work properly, or it might not work with an updated 2070 specification, especially with respect to the device drivers. The arterial consultant respondents observed hardware flaws such as electrical shocks and fires, and blown modem cards. In their view, the 2070s were poorly manufactured: During an environmental test, one third of the power supplies died.

Integration

Over three quarters of the respondents believe this FOT was overly ambitious, including integration of too many untested new technologies, particularly the 2070 ATCs and SWARM. A majority of the interviewees wanted to prove the technologies separately in smaller pieces before bringing them all together. Ideally, separate field operational tests would evaluate the 2070 controllers, the MIST conversion and OPAC, and the SWARM system.

More than a quarter of the participants recommended scrapping MIST and OPAC altogether and replacing them with different technologies. MIST’s inability to provide real-time management (actual performance is every 30 seconds) and OPAC/MIST’s lack of quality control make them unattractive for future implementations. Further, neither system was Y2K compliant.

Project Management

Interview respondents were sharply divided along jurisdictional lines over project management. The City of Irvine and the freeway consultant, the two partners responsible for project management and system coordination, feel the project management and schedule were extremely useful. All other parties think the project lacked overall management and reported that the schedule served no purpose because most participants did not use it, refer to it, or adhere to it.

Administrative concerns focused on leadership and decision-making. Respondents felt that since the City was in charge, it did not have to answer to anyone, and felt no need to consult with any other partners in making decisions. The City demonstrated very little administrative follow-through and required considerable time to complete decision-making tasks, especially regarding the ARP, the 2070 software and hardware, and CMS hardware. One quarter of the participants noticed that the project stalled repeatedly
while waiting for technical decisions on technology selection. According to respondents, the City's poor project administration hindered the entire project.

Participants suggested several significant changes to the FOT process to address administrative issues, including:

- Require software developers to put up a bond, as construction contractors do.
- Require an initial systems requirements document designed to fit existing budgets. The document should cover functions and features of the technologies involved.
- Remove the cost-sharing requirement when an FOT is really a research and development project.

Clearly define decision-making authority by empowering either the group, an independent party, or FHWA to make binding decisions needed to move the project ahead. A representative of FHWA suggested changing the FOT contracting process to design-build or design-build-operate projects to avoid some of the problems on this and other FOTs.

**Operational Issues**

Respondents almost unanimously believed the partners failed to plan adequately for the operations, maintenance, and training needs of the new system. Half of the respondents emphasized that both the freeway consultant and Caltrans District 12 forgot to include SWARM system training in the FOT. This seemed to be the most critical omission during the planning phase. Three of ten respondents noted that the 2070 controllers required more maintenance than the existing controllers.

The City did not plan adequately for the transition to a new system; in that it seemed unprepared to care for the system or to add intersections after the FOT was complete. However, the City blamed these difficulties on the software configuration and inadequate training. The City admitted that it did not understand MIST or OPAC operations. The arterial consultant provided training, but the City staff were unable to attend on a consistent basis. The arterial consultant recommended follow-up training after an initial burn-in period. The burn-in period never occurred, so no additional training was needed.

All of the partners except the City of Irvine felt the FOT was an important step in developing a City-wide, state-of-the-art traffic control system, and in expanding city-wide 2070 use and MIST coverage. In financial terms, the FOT helped the City, which wanted to replace its existing traffic control system, by
providing new 2070 controllers, five CMSs, additional speed, occupancy, and headway (SOH) loop

detectors, and other hardware. City respondents believe Irvine benefited operationally because it worked
with District 12 and obtained a more responsive system with more tools.

THE EVALUATORS’ PERSPECTIVE: WHAT REALLY HAPPENED?

The evaluation team believes the following circumstances imposed binding constraints on the FOT’s
success.

Caltrans’ Role in Technology Choice

Originally, the arterial consultant wanted to use OPAC on arterials to accommodate freeway dumps,
although they ultimately recommended OPAC for modeling vehicle queues on freeway ramps. If the
arterial consultant successfully modified the algorithm, OPAC would have set ramp metering rates based
on the ramp queues. Caltrans did not like this approach; and, during the proposal process, Caltrans
changed certain objectives and partners. For example, Caltrans tried to eliminate OPAC completely, and
use an NTCIP installation and its own ramp metering. Caltrans unilaterally selected the freeway consultant
to replace the University of California at Irvine on the project because of the consultant’s existing statewide
relationship with Caltrans.

Developing Firmware for 2070 ATCs

The City wanted to use 2070s as opposed to ATCs for a variety of reasons. First, it did not want to place
both ATC and Multisonics controllers in one cabinet. There was no room. Second, Caltrans was
committed to providing support for 2070s in the future. During this key decision-making stage, the City
consulted with Caltrans HQ and LADOT, but excluded the other FOT partners, specifically the arterial
consultant. In hindsight, one member of the arterial consultant firm believes that the consultant should
have demanded using ATCs with specific firmware with which the consultant was familiar.

At the time of the proposal, the partners realized that no 2070 firmware existed, but the City of
Irvine volunteered to obtain it. Three entities were developing 2070 firmware at the time, including
LADOT. Selecting the firmware provider required a great deal of time. According to City respondents,
everyone knew that the LADOT controller software worked and had been used during the 1994 FOT research and development phase. However, there was no prototype available to allow development of device drivers. The City selected LADOT because its price was low, they had worked together in the past, and the City did not have to pay a license fee. The arterial consultant remained staunchly opposed to the LADOT firmware throughout the FOT because respondents felt public agency software represented a high risk and was not sufficiently available. Ultimately, the development of firmware required diverted FOT funds because it was not part of the budget.

Problems with use of the 2070 ATCs began during Caltrans' tests. This prevented the City of Irvine from establishing a final prototype until early 1996, not 1994 as was assumed in the FOT proposal. Caltrans HQ handled the 2070 hardware development, but continually changed its specifications. The first prototype from Caltrans HQ was provided over a year late, in the middle of 1995. As a result, the arterial consultant's software coding efforts became extremely difficult. Device drivers posed a problem for both the arterial consultant and for LADOT. LADOT involvement began in 1994 when it developed software on its own for what eventually turned out to be the wrong hardware prototype. The need to reach agreement on data exchange between the traffic signal control program (TSCP) and OPAC slowed implementation of OPAC. As a result, LADOT changed its firmware to try accommodating OPAC's needs. Instead the change constrained optimum operations.

The City sometimes had difficulty readying all of its infrastructure for the arterial consultant. The Changeable Message Sign (CMS) firmware also created significant problems. Changes and bugs at different points during the project might cost the arterial consultant as much as an entire month of delays.

**Converting MIST to UNIX**

At the proposal stage, one of the partners insisted on a UNIX platform for MIST. The arterial consultant spent considerable time implementing the platform change to a UNIX system and 2070 controllers. Developing the server, timing pages, and TSCP was associated with these tasks. This change in platform and controllers sharply constrained the further development of the OPAC algorithm. In the end, the only area of OPAC research associated with this project was addition of cumulative delays and stops to the algorithm.
Testing the SWARM System

SWARM lacked necessary documentation, and its failure management and malfunction scheme needed redesign. SWARM and all pertinent reports were tied to the conclusion of the freeway consultant's ATMS project, which hindered the development of these additional systems. The freeway consultant was responsive to many requests, but refused all requests that "required a major redesign," or documentation. The freeway consultant last responded to Caltrans District 12 during late summer 1998. Major problems with the algorithm included the consultant requirement that SWARM be implemented one ramp at a time (as opposed to freeway section by section), and lack of permanent memory to store the setup parameters at each ramp meter. Turning SWARM off thus required that all ramp parameters be re-entered, a process for which no documentation existed. Caltrans respondents do not believe the freeway consultant anticipated the extensive testing that District 12 performed on SWARM.

The freeway consultant did little follow-up work on the D12 SWARM system. As a result, District 12 had to wait for completion of ATMS2, the District 7 (Los Angeles) SWARM system, before it could begin retesting the ATMS and SWARM. District 7 would perform most of the testing of ATMS2, with District 12 stressing the importance of a future evaluation of SWARM prior to statewide deployment.

CONCLUSIONS AND LESSONS LEARNED

Significant lessons were learned during the course of the Irvine FOT. Two of these lessons are particularly prominent:

- It is important to incorporate detailed technical specifications in contract documents, and
- there is a strong need for complete technical review and an appropriate level of technical understanding on the part of the contracting agency.

Greater attention to these two elements would have significantly increased the likelihood of identifying and preventing the problems that lead to the FOT's major delays; and, ultimately, to the failures in delivery and implementation encountered in the Irvine FOT. For example, the Caltrans 2070 controller was specified as the platform for OPAC under the 1994 [3] (final) proposal revision. The proposal did not specifically address the issue of whether the 2070 would replace the existing Multisonics controllers, or would be installed in addition to the existing controllers. The proposal also did not specify what entity
would be responsible for the signal actuation software that would be required for the ultimate configuration, which would consist of either the Multisonics controller and the 2070, or the combined functions operation of just the 2070. These ambiguities subsequently led to contractual disputes between the arterial consultant and the City of Irvine, and were ultimately the source of the most significant project delays.

The arterial consultant clearly expended a great deal of effort on the FOT, and reported ultimately losing a considerable amount of money. The freeway consultant met contract deliverables by providing over thirty status reports and specification documents, many duplicative and irrelevant to the successful execution of the project. The problems that might realistically have been avoided include the following:

- Dependency of the 2070 controller, which had not yet been fully specified or delivered, could have been avoided. Depending on a controller that was still in development complicated the software porting tasks required of arterial consultant, and was cited by this consultant as the primary reason for delays. An independent entity (LADOT) was brought in to supply custom signal control software that could communicate with OPAC and MIST.

- The need for signal control (actuation) software, which facilitated the joint implementation of the intersection control and OPAC modules on the 2070 controller could have been avoided if these functions had remained split between the Multisonics and 2070 controllers. The arterial consultant had assumed this split configuration.

- The integration deliverables to be performed provided by the freeway consultant were largely decoupled from, and independent of, the arterial consultant’s work. Integration must occur concurrent with other implementation activities. If the involved parties had considered complete integration important to the project’s completion, the freeway consultant’s continued involvement should have continued after their contract expired in 1997 through a new contract agreement, in anticipation that the arterial consultant’s deliverables might be delayed well beyond that time.

- The contractor should establish the nature of the documentation required rather than the vendors. This would have helped to avoid the problems associated with freeway consultant’s choice to provide large quantities of mostly irrelevant status reports and specifications for systems that would
never be implemented, while declining to provide an operator's manual for the SWARM system software.

- A schedule of formal design reviews, tied to contract milestone payments, should be incorporated in partner contracts. This is typical in similar contracts administered by the DOD or DOT.

- Success of large technical projects such as the Irvine FOT is usually facilitated by assigning the program manager full responsibility and authority. The Irvine FOT was characterized by a desire for consensus that translated into nebulous project authority and a circular review structure. This ultimately led to loss of coordination, project direction, and morale.

- It is essential that technical leadership have direct access to the actual software development personnel in any project involving the development of large integrated software packages with multiple developers and responsible entities. In the Irvine FOT, attempts to achieve coordination only through high-level management contacts led to miscommunications, unrealistic lead-time requirements for simple changes, and extensive development delays.

- Coordinating systems information and dissemination to all parties required the contribution of a systems engineer. A systems engineer might have been able to address some of the arterial consultant's problems with LADOT, which had to supply the device driver for consultant's systems driver. LADOT made as many as twenty revisions to the TSCP. This imposed 300-400 hours of delay and undocumented costs to the arterial consultant.

- Provision for independent technical evaluation and review should be incorporated into the original program proposal and all participating partners' contracts. The inclusion of evaluators early in the process, and a clearer standing of the evaluation team within the context of the project, would have led to more productive use of evaluation resources. Evaluators might be consulted with regard to the specifications, workplan and deliverables in the partners contracts prior to their approval. In the Irvine FOT, the evaluators were not permitted to see the partners' contracts until after the project was terminated, over five years after the fact.

- The actual FOT deliverables and timetable were never fixed, evaluation man-hours were wasted meeting ad hoc requests from the FOT partners to repeatedly update evaluation workplans for systems that were ultimately never deployed. The evaluation team complied with these requests in
an unsuccessful effort to encourage reciprocal responsiveness from the FOT partners. The objective of the evaluation should have been allowed to focus on assuring technical and institutional performance, rather than assessing the consistency of the FOT with nation-wide ITS objectives.

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