Development and Expansion of Santa Clara County's Traffic Operations System

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ABSTRACT

This paper describes some unique technical and administrative solutions, that have been adopted within Silicon Valley, to accommodate video transmission from over 500 CCTV cameras, high quality and redundant data transmission between the TOC and field equipment, and sharing of data between numerous responsible agencies.

The County of Santa Clara has embarked upon a five-year, $23 million program to upgrade the Traffic Operations System (TOS) along the County-operated expressways, extending 55 miles and including 131 signalized intersections. The goals of the project are to improve the flow of all modes of traffic on the expressways, and to improve the response to incidents and accidents.

The County first constructed a Traffic Operations Center (TOC) and, in association with the Silicon Valley Smart Corridor project, installed fiber optic cable to a small number of intersections and CCTV cameras. This proved the concept, and provided lessons to be incorporated into the county-wide deployment.

The current project is expanding the fiber optic communications network to cover all County expressways, install additional surveillance and monitoring equipment, and upgrade the TOC operating software. The key elements of the project are:

- Fiber optic network
- Detector loops
- Fixed video cameras
- Pan-tilt-zoom (PTZ) cameras
- Video detection
- System connections
- Video transmission equipment
- Data transmission equipment
- Communication hub enclosures
- New controller cabinets
- Dynamic message signs (DMSs)
- Highway advisory radio (HAR) transmitters
- Traffic signal cross-coordination

The communications system provides very high efficiency through the use of concepts typically used in the cable TV industry; and a high level of reliability, through use of several sheathed rings to limit the impacts of line damage or equipment failure. Inter-agency cooperative agreements will provide for a high level of cooperation and joint use of facilities by local jurisdictions.

1 INTRODUCTION

Santa Clara County covers 13 Cities that form the bulk of what is commonly referred to as Silicon Valley. Within the county, the Interstate and State highways are controlled and operated

by the California Department of Transportation (Caltrans); the County operates a system of limited access expressways, that generally have at-grade intersections; and the Cities operate signals on the City-owned streets. There is a high level of inter-agency cooperation at an operational level, and most of those agencies are developing the technology to actively integrate the traffic signal and CCTV systems.

The County's expressways are high-capacity, limited access roads that accommodate the bulk of intra-regional travel. They connect the major activity areas to the State facilities and provide a high-level arterial road network. Almost all the intersections on these expressways are controlled by traffic signals, and some form or signal coordination is provided wherever the signals are sufficiently closely spaced.

Since 1996, the County of Santa Clara has been developing a state-of-the-art traffic operations system (TOS) that is playing an integral role in providing efficient traffic operations throughout Silicon Valley. The concept design for the TOS was prepared by DKS Associates (1997) and is closely related to the development of the Silicon Valley Smart Corridor (SVSC).

That study provided recommendations for installation of hardware and development of software in the following categories:

- Communications network;
- Traffic Operations Center (TOC);
- Traffic signal coordination;
- CCTV cameras;
- Automated traffic flow monitoring;
- Traveler advisory systems, such as highway advisory radio (HAR), variable messages signs (VMS), cable television (CATV) and internet.

Since the concept design was prepared, several stages of the plan have been implemented. A new traffic operations center (TOC) has been constructed, Naztec's Streetwise traffic signal system has been installed, the initial fiber optic cable has been installed and several CCTV cameras have been installed. The key elements of the system have been proven in concept and their integration has been shown to be feasible and practical within the Silicon Valley environment.

At the same time, several phases of SVSC have also been implemented, and communications has been established between Santa Clara County's TOC, and the TOCs of the cities of San Jose, Milpitas, Campbell and Santa Clara.

In 1999, the County retained DKS Associates as the General Design Consultant (GDC) to update the concept design and prepare a detailed master design and master specification for the project.

This involved a complete review of the proposed project elements in the light of the experience of the previous three years and the changes in technology that had occurred during that period. This paper describes the revision of the concept design, the rationale for the modifications that were introduced as a result, and the directions for further development as the system is being implemented.

2 SYSTEM OVERVIEW

The key elements of the proposed system are:

- Communications network – fiber optic cable, connecting all intersections and locations of other field devices to the TOC;
- Traffic Operations Center – rooms within the traffic engineering complex containing several work stations, video wall displays and CCTV controls, providing access and control to all signal controllers and cameras, and access to video images from neighboring agencies' TOCs;
- Traffic signal coordination – through the new Naztec Streetwise system, with central control and management equipment at the TOC and field masters controlling the coordination of local intersections;
- CCTV cameras – fixed CCTV cameras on every approach at every intersection on the expressways and pan-tilt-zoom (PTZ) cameras at other strategic locations;
- Automated traffic flow monitoring – volume and occupancy detectors at many locations along the expressways (in addition to the counting capabilities of the local intersection controllers) to provide system control and monitoring data;
- Traveler advisory systems, such as highway advisory radio (HAR), variable messages signs (VMS), cable television (CATV) and internet. While provision is made in the design for all these elements, the rate at which they will be introduced will be in keeping with the development of county-wide policies and practices.

3 CURRENT SYSTEM STATUS

Since the initial study was completed, the County has installed its TOC, and fiber optic cable has been installed along Montague Expressway and San Tomas Expressway, and short sections of Lawrence and Central Expressways. The fiber is connected to the County's TOC via Old Oakland Road, and to the City of San Jose TMC and the City of Santa Clara City Hall.

Communication has been established between the County's TOC and traffic signal field masters along Montague and San Tomas, fixed cameras have been installed at several intersections along those two expressways, and one pan-tilt-zoom (PTZ) camera has been installed at the interchange between Central Expressway and Lawrence Expressway. A Data Exchange Network (DEN) has also been installed and connected to several jurisdictions.

All the new communications are via fiber optic cable, although the pre-existing dial-up lines at the TOC and the field masters have been maintained as a back-up.

Several further stages of the Smart Corridor project have been funded and have recently commenced.

4 FIBER OPTIC NETWORK

The primary lesson learned over the previous three years has been the vulnerability of the fiber optic cable to damage due to construction activities outside the control of the County. The cable has been cut during construction of a new bridge, construction of a new light rail line, boring for

installation of another fiber optic cable by a communications company, and during road widening. As a result of this, a substantial review was undertaken of the proposed fiber optic cable network, and the design was modified to provide significant redundancy. This is expected to significantly reduce the risk of communications between the TOC and field devices being disrupted.

The original design assumed a basic star arrangement, with one communications path between the TOC and each of the field devices. This was consistent with current design practices for traffic systems. During the review, consideration was given to several means of providing alternative communication on occasions when the primary cable is not functional. The alternatives considered included:

- Complete redundant arrangement, providing fiber optic communication to each field device by two alternative routes, with manual intervention to switch from one communications route to another in the event of a fault;
- An arrangement similar to the first option, but with automatic detection of faults and switching from one communications route to another, making it self-healing;
- High bandwidth telecom line (e.g., DSL or T1), either permanently connected or installed but not activated;
- Dial-up telephone line connection.

Following consideration of the cost, expected time to repair, and likely impact of disruption of communications to various field devices, a two-level distribution architecture was adopted, providing redundancy between the TOC and several hubs, and single lines between those hubs and the field devices. At the lower level, individual intersections will be connected via a "star" network directly to a hub. This will provide point-to-point connection from each intersection to the nearest hub, for all cameras. Signal controllers will continue to communicate with field masters using the existing twisted pair copper wire. At the top level, the hubs and master controllers will be connected to the TOC by means of one or more fiber optic cable rings. Since most of the distance between any given intersection and the TOC will be via the ring, this will result in higher overall reliability, and containment of the impacts of cuts and smaller outages when they do occur, without the cost of duplicating the connections to every field device.

The overall concept of the ring and stub operation is to provide each hub with connections to:

- Two fibers in each direction to the TOC, for transmission of the CCTV signals;
- One fiber, on a drop and repeat basis for PTZ data; and
- One fiber, on a drop and repeat basis for traffic signal data.

To implement the two-level architecture, hubs will to be provided at key locations, with connections to the TOC in two directions, and to the field masters and intersections in one direction. In selecting hub locations, consideration was given to:

- The maximum distance to the intersections to be served by the hub;
- The number of controlled or monitored intersections to be served by the hub; and
- The feasibility of construction of a small equipment enclosure at the location.

Hubs will be installed at five locations, provide a reasonably uniform distribution of the number of signalized intersections and cameras to each hub, and similar maximum distance from hub to

intersection, as described in Table 1. The South County location will not be connected to the TOC via fiber optic cable, because of its remoteness and the smaller number of cameras and intersection controllers. A final decision on the communications medium will be made in 2003.

Table 1 Recommended hub locations

ID	Hub Location	Intersections with Signals				Distance to farthest intersection	Likely number of cameras
		County Expwy	Other County	Non-County[1]	State		
1	Central/ Lawrence	34	2	35	6	7.5 mi.	136
2	Central/ San Tomas	35	0	57	4	7.5 mi.	170
3	Page Mill/ Foothill	25	8	14	5	8 mi.	100
4	Almaden/ Capitol	37	2	33	1	9.25 mi.	148
5	South County[2]	0	10[3]	0	0	4.5 mi.	16
	Totals	**131**	**22**	**139**	**16**		**570**

A fiber connection will also be provided to another County property remote from the TOC, to provide an offsite location for system and data backups for emergency response purposes.

Fiber connections will also be provided to the various pump stations along depressed sections of expressway and underpasses. This will permit monitoring of the pumps and validation of the proper operation of the pumps. In addition, the number of fibers provided and the equipment configuration will permit the future provision of an ethernet connection at each local controller cabinet, to enable a laptop computer and/or the local controller to be connected to the TOC.

The routes along which fiber will be laid are illustrated in Figure 1. The locations of hubs are also illustrated in that figure. In addition, where the main ring and stubs intersect, patch panels will be provided to allow the communications routes to be manually switched in the event of a cable break.

[1] Number of non-county signals may vary as projects proceed
[2] South County may not require a hub, but is included for completeness
[3] Includes signals not yet operational

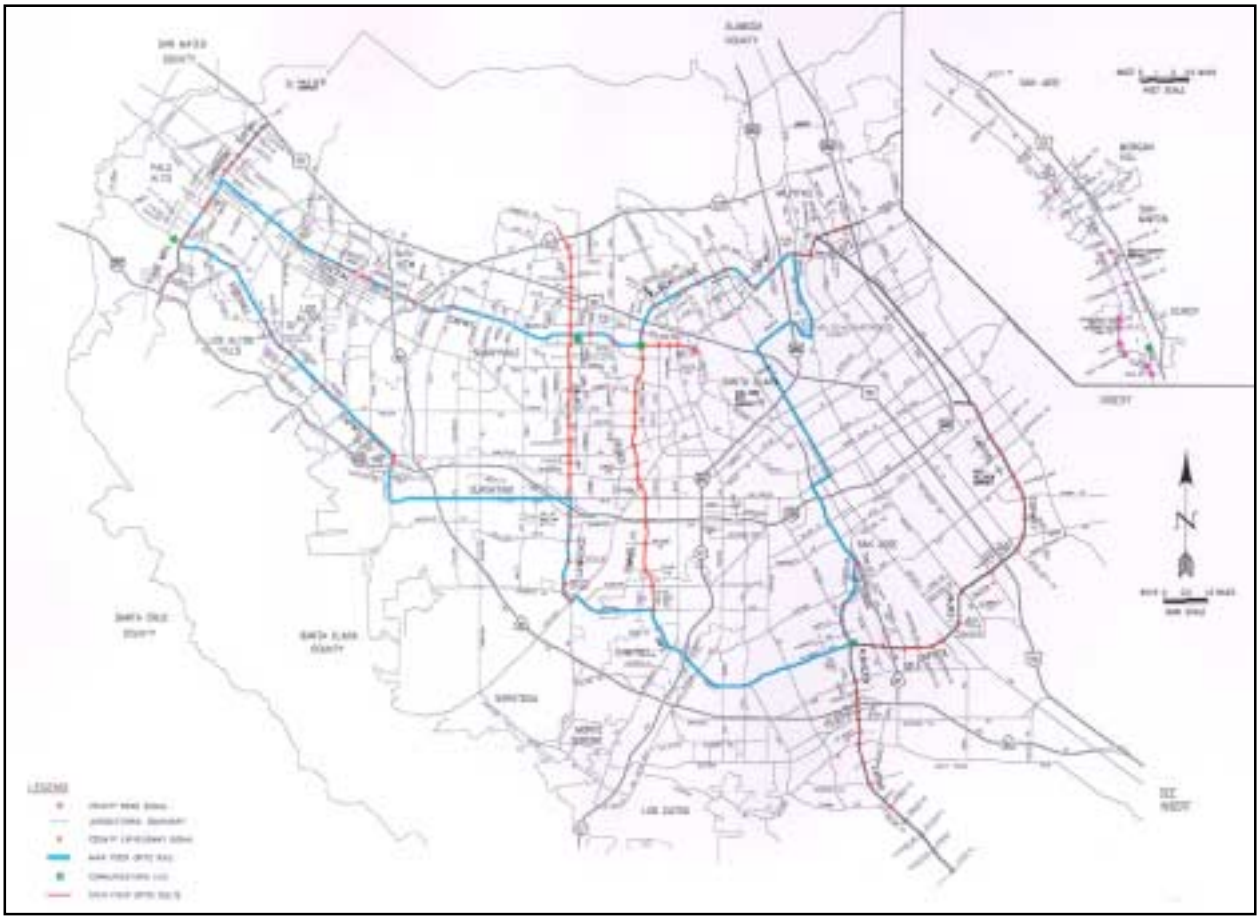

Figure 1 Recommended fiber ring and stub routes

5 VIDEO AND TRANSMISSION EQUIPMENT

There are many ways of approaching a video-monitoring project of this magnitude.

- The video for each camera at each intersection may be transported directly to the TOC.
- Multiplex video signals at each intersection or at each hub for transport directly to the TOC.
- Utilize baseband video to directly modulate optical lasers in a video transceiver.
- Modulate baseband video onto an FM subcarrier then transport over optical lasers;
- Digitally encode video at full resolution for transport on a digital medium.
- Digitally encode and compress baseband video for transport on a digital medium. This includes packetized digital video transmitted via the Internet Protocol (IP)
- Each video feed may be transported over a separate fiber or they may be multiplexed on a single fiber.
- If hubs are used, a first level of switching with a matrix switch may be deployed. This assumes that not all video feeds will be required simultaneously.

- Hubs may be co-located with master controllers or separately. They may be of virtually any size, with the tradeoffs including amount of fiber required, cost and overall reliability.
- If hubs are used, any of several transport formats may be used between there and the TOC, not necessarily the same as the format used between individual cameras and hubs.
- At the TOC, modulated video may be retained in modulated form, converted to baseband video, digitally compressed or utilized in some other format for distribution within the monitoring room. The same or a different format may be used for remote locations, such as at other agencies.

The number of permutations is very large.

5.1 Analog/Digital transmission

A key decision affecting many of the other decisions about options available for the video transmission and switching, is the form in which to transmit the video signal. As part of the evaluation process, the study team members examined the image quality obtained from existing traffic observation systems that use analog and digital transmission, comparing color, refresh rate and ease of use of PTZ controls. Discussions were held with staff and observations made at the San Diego Caltrans/CHP TMC; City of Stockton Traffic Operations Center; several vendors of CCTV and digital communications equipment; City of San Jose and the County's own traffic operations staff. It was concluded that, in order to meet the County's requirements, it is necessary to transmit the video signals in analog form. The analog-based systems investigated consistently had high picture quality, while the digital systems had variable quality. In summary:

- The analog systems maintained full motion video in either color or black and white, which was comfortable to watch, and would be suitable for use with a video detection unit at the TOC;
- The digital systems observed had variable frame rates, resulting in jerky pictures, which makes it difficult for operators to distinguish between stopped traffic and moving but congested traffic;
- To provide full motion (30 frames per second) with adequate resolution for traffic management requires high bandwidth;
- The digital systems require relatively expensive digital encoding and decoding equipment for each video signal;
- Analog systems had no appreciable signal delay, enabling accurate PTZ control. With the digital systems, if bandwidth becomes constrained, the frame rates become variable, resulting in poor control of PTZ cameras, because of the inherent latency and sometimes variable delay in the system, which makes the task of the operator more difficult and time consuming, especially during emergencies when camera pre-sets may not be applicable; and
- Color analog video was of constant quality, while the digital systems had relatively poor and variable color rendition, which makes the image less distinguishable and harder to watch for extended periods. The quality of the color and smoothness of picture motion is dependent on the amount of movement on the screen and the number and complexity of pictures being compressed onto one line.

Consideration was given to the number of simultaneous images required by the operations staff, both for normal signal timing and fine-tuning, and for incident management. Consideration was given to optimizing the communications infrastructure by one or more of the following techniques:

- Limiting the number of simultaneous images required to be transmitted from a hub for display at the TOC;
- Limiting accessibility to cameras by outside agencies when images are being displayed at the TOC;
- Transmitting images from an intersection in time slices (video tours) rather than all available simultaneously.

Following discussions with operations staff, it was concluded that, within the operations room, it is unlikely that the operators will wish to view any more than six images simultaneously. However, other operators within the building (and, in the future, at other agencies) may wish to view, process or record other images at the same time, and they should not be limited by what is displayed in the operations room.

It was therefore decided that all images at a hub need to be available for selection at the TOC.

5.2 Signal Processing At Hubs

The baseband video signal will be transmitted from the intersections to the hubs, where they will be combined onto two fibers to be transmitted to the TOC. The baseband signal will be modulated using normal cable television channel frequencies extending from 55.25 MHz (channel 2) through 547.25 MHz (channel 78), giving a total of 77 channels per fiber, with all frequencies per EIA-543 "Standard" channel plan. Where more signals are required than can be accommodated by the plan, a second set of modulators will be used, duplicating as many channels as required, as illustrated in Figure 2. This will use standard pieces of equipment in common use in the cable TV industry.

5.3 Video Links Between Hubs And TOC

The proposed configuration between each hub and the TOC is a “sheath ring”, meaning that one dedicated fiber for each set of modulators extends from each hub to the TOC clockwise around the ring and another dedicated fiber runs counter-clockwise around the ring.

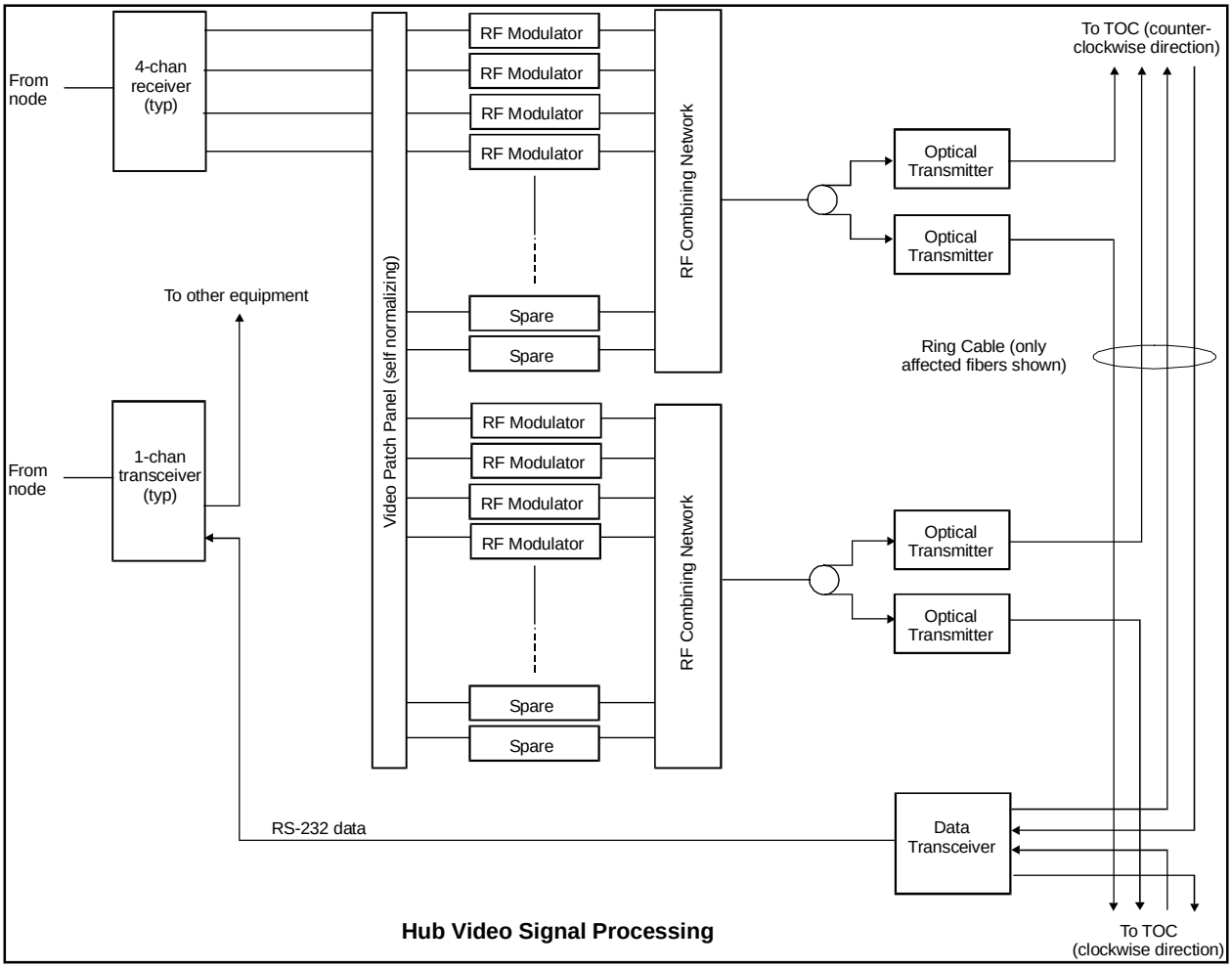

Figure 2 Hub signal processing

5.4 Transmission Summary

5.4.1 Primary Recommendation

The overall arrangement of these various elements is illustrated in Figure 3. This shows the locations and types of the main components of the system, and includes the RF modulators and combiners at the hubs. From the point of view of the fiber requirements:

- Two fibers will "drop and repeat" from data transceiver to data transceiver around the ring in a configuration and will carry both signal information and PTZ control information in a RS-232 format. Should it be desired to separate the signal information from the PTZ control signals, two additional fibers will be required.
- In each portion of the ring, one fiber will be dedicated to video transmission for each set of modulators for each hub. Since each of the four proposed hubs on the ring will potentially originate more than 77 video feeds, two fibers will be required from each hub to the TOC each way around the ring.

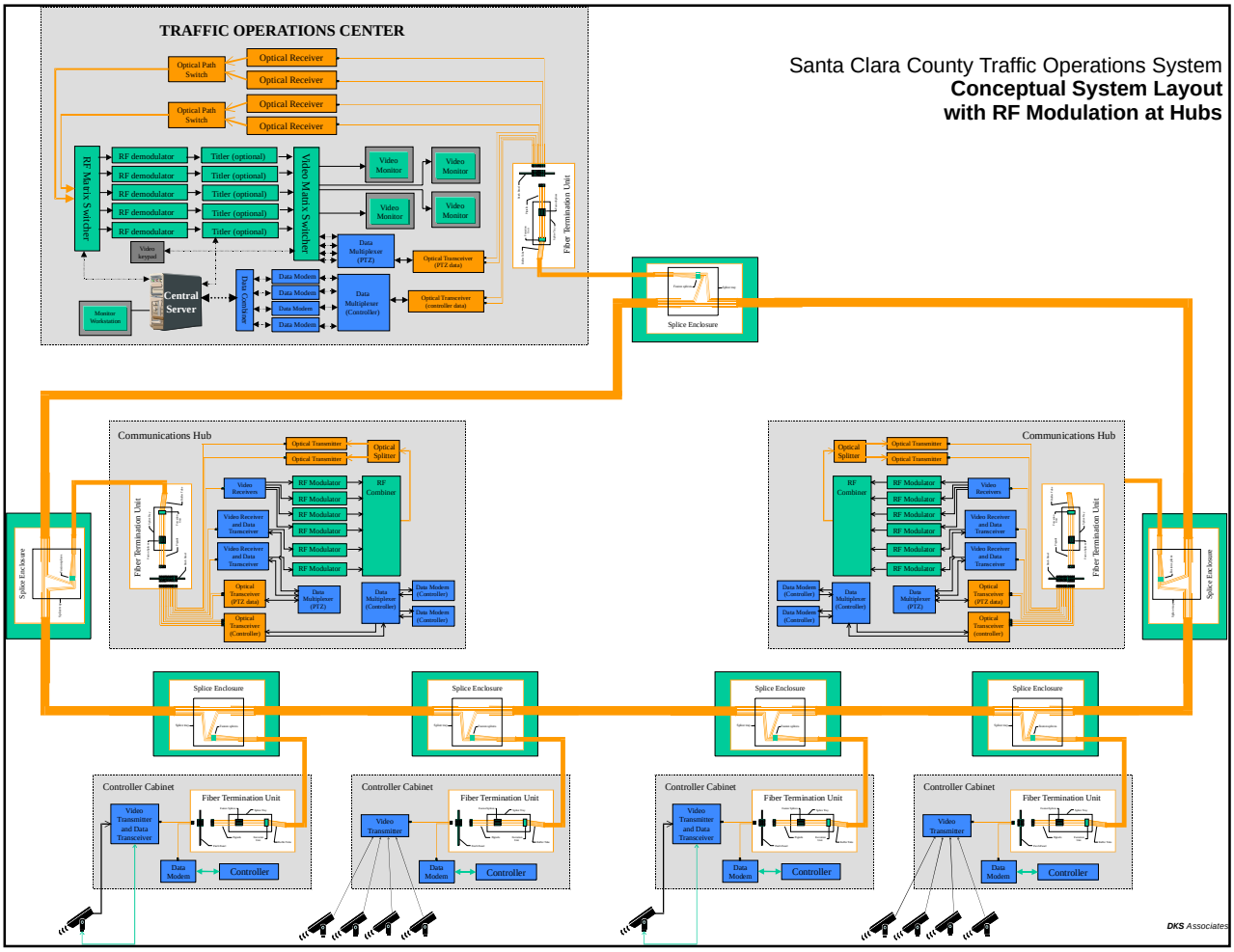

Figure 3 Conceptual system layout, with RF modulation at hubs

5.4.2 Alternative Trunk Transmission

Consideration was given to multiplexing the video signals, rather than encoding on different RF carriers. While this would also provide an elegant technical solution, it was discarded on the basis of the cost evaluation.

6 CCTV CAMERAS

There are several key objectives for the use of CCTV cameras:

- Provide vision so that incidents and congestion may be monitored and managed as efficiently as possible by the operations staff in the TOC;
- Allow operations staff in the TOC to more efficiently set up and fine tune signal timings (both local controller settings and coordinated timing plans);

- Provide a means for maintenance staff to respond quickly to fault and accident reports by visually confirming problems and dispatching the appropriate equipment and personnel;
- Provide a test bed for video detection in the Santa Clara environment, and a basis for future widespread use of video detection as a supplement to or replacement for loop detectors once their performance becomes acceptable; and
- Make images available to other agencies (such as neighboring Cities, Caltrans and VTA) to help them manage traffic on their own facilities.

To fully meet these objectives, it is necessary to provide coverage of the entire length of each expressway. The expressways have relatively few significant horizontal or vertical curves, and the fixed cameras will give adequate coverage of most of the sections of interest.

A meeting with County operations staff identified key locations that have a high priority need for images to be available at the TOC using the following criteria:

- Locations of recurring congestion;
- Locations that become critical during incidents on freeways;
- Sections that are remote from the proposed fixed cameras at intersections or the vision will be obstructed by structures or curves.

The master design now assumes that fixed cameras will be installed covering every approach at each signal on the expressways, plus PTZ cameras will be installed at an additional 20 to 26 locations.

7 TRAFFIC OPERATIONS CENTER

Additional elements of the project of relevance to the TOC include:

- Additional hardware to accommodate the expansion of the fiber optic cable network and the heavy increase in the video load;
- Additional hardware to facilitate access to new CCTV cameras by other agencies;
- Upgraded software in the StreetWise system to accommodate improvements in data collection and traffic operation;
- A controller cabinet equipped for video detection units be tested with CCTV camera images from the video switcher;
- Provision of a wireless video feed to laptops to be used in the field by technicians and traffic engineers;
- Additional workstations with video in the Traffic Engineering Section;
- Provision of a video feed to a CATV station;
- Provision of video capture equipment and a video/internet server for public access to camera views.

Proposed upgrades to the County's Naztec StreetWise traffic signal management system include:

- Support for up to 64 detector inputs;

- Additional phases and rings;
- Left turn and pedestrian overlaps;
- Unequal double cycling;
- Enhanced traffic responsive pattern selection algorithm;
- Dynamic split optimization and phase duration prediction;
- Improved offset transitioning;
- Multiple timing values;
- Database integrity check;
- Performance monitoring including cause of phase termination;
- Adaptive and non-cycle based coordination;
- Improved reporting, particularly including parameter data, customizable reports and a timing sheet report of basic timing and parameters;
- Parameter change tracking;
- High speed communications with field masters and/or controllers, possibly using ethernet.

8 CONCLUSIONS

The County's traffic operations system has a number of elements that are not typically found in an installation of this nature. There is a high number of cameras, which create a heavy communications load. This is being accommodated using an innovative technique that is well proven in the cable TV industry, but new to the ITS community. A level of redundancy is being built into the fiber optic cable deployment that will substantially enhance the reliability of the system, while not increasing the installation and equipment costs substantially.

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