

VIDEO-BASED AUTOMATIC INCIDENT DETECTION ON SAN-MATEO BRIDGE IN THE SAN FRANCISCO BAY AREA

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ABSTRACT

The use of CCTV cameras has been in continuous expansion for the past 30 years in the transportation industry. As the use of CCTV cameras in the field of traffic and roadway monitoring continuously expands, systems are beginning to meet with limitations.

In the San Francisco Bay Area, Traffic Operators at the Caltrans Traffic Management Center deal with several hundred cameras and monitor hundreds of miles of highways and expressways. This is the reason why Caltrans and MTC have decided to test a video-base incident detection system in order to quickly and efficiently warn Traffic Operators of incidents occurring on the roads.

A video-based incident detection system was deployed on 8 existing PTZ cameras monitoring the San Mateo-Hayward Bridge in the San Francisco Bay. The self-learning system image processing algorithm analyses movement and automatically warns Traffic Operators of any vehicle stopped within the field of view of a given camera.

The test showed that the system proved to be efficient in detecting accidents or incidents on traffic lanes and also in detecting vehicles pulled-over on the shoulder. The system showed little sensitivity to traffic conditions, night/day, weather conditions and disturbances such as vibrations of the cameras

KEYWORDS

Video Detection, Incident Detection, Incident Management, Accident

TRAFFIC MONITORING

The use of CCTV cameras has been in continuous expansion for the past 30 years in the transportation industry. As expansion of CCTV camera use in the field of traffic and roadway monitoring continues, CCTV systems are beginning to meet with limitations.

In the San Francisco Bay area, Traffic Operators at the Caltrans Traffic Management Center deal with several hundred cameras and monitor hundreds of miles of highways and expressways.

Behavior studies clearly show that the ability of a Traffic Operator to focus traffic monitoring decreases with the time spent in front of screens and with the number of monitors. The

studies show that an operator is very unlikely to focus on more than 10 to 15 screens efficiently.

This is the reason why most of the traffic information provided by CCTV cameras is under-used or not used at all. Traffic operators are not aware of traffic information in real-time.

Increasingly, CCTV cameras in transportation are only used to assess incidents or accidents eventually reported by other means than video surveillance (cell phones, police, highway patrols...).

Considering that traffic monitoring is crucial for mobility, safety and security issues, it is extremely unlikely that we see the number of CCTV camera decrease in the next few years.

It is also doubtful that we can afford to forever increase the number of Traffic Operators in front of CCTV screens monitoring traffic.

This is the reason why Caltrans and MTC have decided to test a video-base incident detection system in order to warn Traffic Operators of incidents occurring on the roads.

The San Mateo-Hayward Bridge was chosen for several reasons:

- Bridges are critical infrastructures for which traffic safety often meets security
- The San Mateo-Hayward Bridge is one of seven bridges providing a vital traffic link across San Francisco Bay
- Testing on the San Mateo-Hayward Bridge provides “real-world” traffic conditions in which to evaluate the video detection system.

SAN-MATEO BRIDGE

Completed in 1967, the San Mateo-Hayward Bridge carries OVER 80,000 vehicles a day. It is located on Highway 92 between San Mateo and Alameda Counties.

The original San Mateo-Hayward Bridge was the longest bridge in the world when it was completed in 1929. A vertical lift was added to allow ships to pass through. By the late 1950's traffic congestion on the Bridge had become a serious problem and in 1957 traffic was halted six times a day while the lift span was in operation. Construction of a new span was completed in 1967 providing an award-winning smooth causeway design and arching elevated span.

However, traffic congestions continued to build over the years. Between 1980 and 1993 the average daily traffic on the San Mateo/Hayward Bridge increased from 42,000 to 72,000, a 70 percent increase. Plans for a parallel trestle bridge were developed at that time and in 2002 the new bridge span was opened to traffic. It is estimated that by 2010 the Bridge will carry 95,000 vehicles.



Figure 1 – San Mateo Bridge

VIDEO-BASED AUTOMATIC INCIDENT DETECTION

Video Detection systems have successfully been deployed over the world for Automatic Incident Detection in tunnels, advanced intersection controls or traffic data collection [1].

However, conventional Video Detection systems require a setup and calibration that must always match the roadway for which it has been defined. This is the reason why these systems require fixed cameras.

However, the Caltrans traffic cameras are Pan-Tilt-Zoom (PTZ) cameras at 90%.

The features provided by PTZ cameras allow flexible video surveillance of road networks. Not only the Operator can choose the direction of traffic to monitor, but it also allows the focus on specific zones of interest. They provide road operators with so much information that their use has rapidly expanded to unexpected levels.

This is the reason why Caltrans/MTC decided to test a new generation of video detection systems.

ACTIVE VIDEO SURVEILLANCE SYSTEM

Concept

The system being tested by Caltrans/MTC is called VisioPaD and is manufactured by Citilog. It is an active video surveillance system, which aims at assisting Traffic Operators to identify and quickly respond to road incidents.

The system uses algorithms capable of learning traffic patterns and for that reason does not require any set-up or calibration. Thus this system is usable on any field of view as opposed to a pre-determined field of view as for conventional video detection systems.

The image processing algorithm analyses movement within the frame and automatically spots any stopped trajectory in the image.



Figure 2 – Detection of a bus stopped at night on the San Mateo Bridge

The system warns Traffic Operators of any vehicle stopped within the field of view of a given camera. It also differentiates fluid and congested traffic and has different detection times for each condition (typically 20 seconds in fluid and over 40 seconds in congestion).

The operator is warned by an audible alarm and can check the location of the alarm on the graphical user interface of the system.

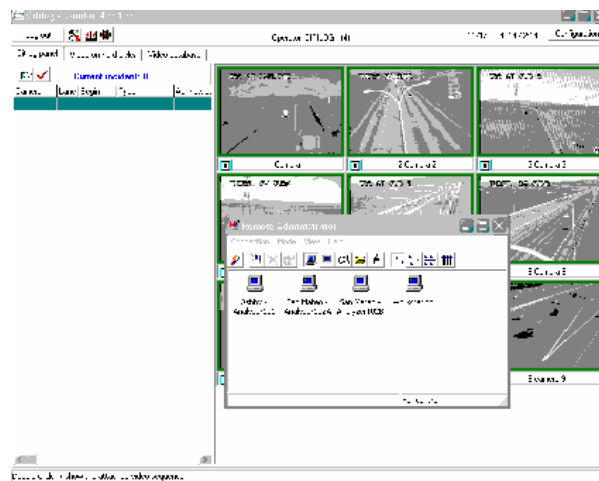


Figure 3 – Graphical user interface of the Active Video Surveillance system

When an incident is detected and an alarm is produced, the system automatically records a digital video clip encompassing the time before and after the incident. This allows Traffic Operators to review incidents in real time and verify the causes and the severity of the incidents.

These video clips are stored in a database and thus can be used offline to perform a more thorough analysis of the incidents occurring on the roadway.

In our case, these video clips were used to assess the performance of the system.

Operation on PTZ cameras

Since the system uses a self-learning algorithm, it is capable to operate on PTZ cameras without using preset positions.

Any movement of the camera by the Traffic Operators -zoom, pan, or tilt- is automatically detected by the system. A self-learning process performed on the new camera field of view follows this. It takes 60 seconds for the system to be fully operational after any camera movement.

System architecture

The basic system consists in: a set of **video detection units** (analyzers) receiving video signals from the cameras and running the image processing algorithm, a video detection supervisor concentrating the data from all analyzers and workstations displaying alarms to Traffic Operators

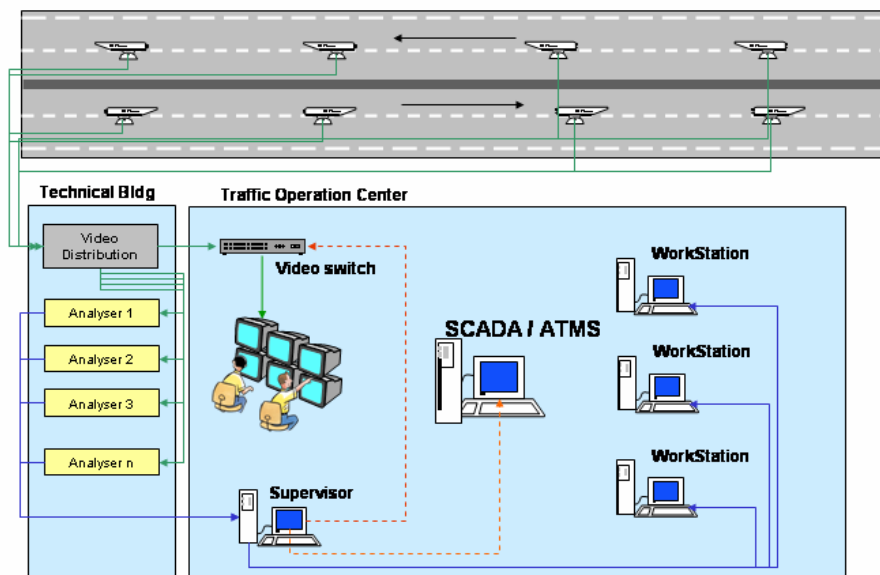


Figure 4 – Architecture of the Video Detection system

In our case, the analyzers were located in a technical building at the San Mateo Bridge. The Supervisor and Workstation were located in the Traffic Operation Center of Caltrans District 4 in Oakland, CA. The analyzers and the Supervisor were connected via an ISDN line.

Optionally the system could be connected to a traffic management system (ATMS / SCADA).

It could also trigger a video switch to automatically display the real time image of the camera on alarm on a dedicated surveillance monitor.

SYSTEM TEST

The system was tested in real conditions. That means that at all time, Traffic Operators used the PTZ cameras on the San Mateo Bridge as if there was no system connected to it. Traffic Operators were free to change the field of view of the cameras, adjust the camera parameters (change the iris setup for better night vision for example).

The system was not manually adjusted for these changes. From day 1 of the test, none of the parameters of the system was changed.

RESULTS

Using the incident video clips in the database, all incidents detected by the systems were reviewed and analyzed.

Incident categories

The incidents were categorized as follows:

- Stopped vehicles in fluid traffic: these are isolated stopped vehicles not part of congestion. Most of these incidents will be vehicles stopped on the shoulder.
- Stopped vehicles in congested traffic: these are stopped vehicles that are part of congestion. These incidents are caused by stopped traffic or stop & go traffic.
- Unwanted alarms: these alarms are due to various factors. They can be caused by shadows, streetlights, camera movement, and camera vibrations, boats stopped within the field of view of the camera, rain or by a poor quality of video signal.

172 incidents were not taken into account in this analysis. These incidents were triggered by stopped vehicles at the tollgate of the San Mateo Bridge. Traffic Operators were free to move the cameras and left the camera number 8 monitoring the tollgate at times.

Although they were valid detections, we believe that pointing the system to a tollgate does not make sense as far as traffic monitoring is concerned. Knowing that vehicles stop at the toll is not valuable information to Traffic Operators.

Results

	Periods		
	4/28/2004 9/23/2004	9/24/2004 10/15/2004	10/15/2004 02/22/2005
Stopped vehicles in fluid traffic	150	73	137
Stopped vehicles in congested traffic	63	2	29
Unwanted alarms	72	56	255
Number of days	148	31	128
Number of cameras	8	8	8
Unwanted alarms per camera and per day	0.06	0.23	0.25
1 unwanted alarms per camera every ... days	16.44	4.43	4.02

Table 1 – Detail of incident signaled by the system

The system on the San Mateo Bridge has a relatively low average number of stopped vehicles per camera and per day (as compared to other bridges or highways).

Although the frequency of unwanted alarms is very low (1 unwanted alarms per camera every 4 days), a number of them are due to the very large field of view including sky, water and other non-relevant items and to the poor quality of video signals. Thus, they could have been avoided.

The system had a very low number of detections related to traffic congestion.

The system handles vibrations of the cameras well. These vibrations can be particularly bad on the bridge, especially when the camera is zoomed-in. The system is able to detect stopped vehicles when the camera undergoes moderate vibrations.

The system will also rarely trigger an alarm when a camera is moved and has proved to deal efficiently with PTZ camera movements.

These results can in part be explained by the characteristics of the cameras and the traffic pattern on the bridge:

- Long fields of view between ½ mile and 1 mile (see Appendix)
- Relatively low traffic and few congestions at rush hours
- Old cameras with a mediocre quality picture (blooming, smearing, change of iris turning the picture almost white or almost dark)
- Cameras operated daily by operators (Pan, Tilt, Zoom, change of Iris...)
- Moderate traffic volume on the bridge with moderate occurrence of stopped vehicles (except camera 8 when not looking at the toll: the hard shoulder just before the entrance of the bridge had a rather high occurrence of stopped vehicles)

Interesting findings

The system's ability to track vehicles enables it to detect vehicles hardly visible to the human eye. In the example below, a vehicle is detected in the upper right corner of the picture. Only part of the vehicle is visible but the trajectory has been followed by the algorithm, which enables the system to reliably detect it.

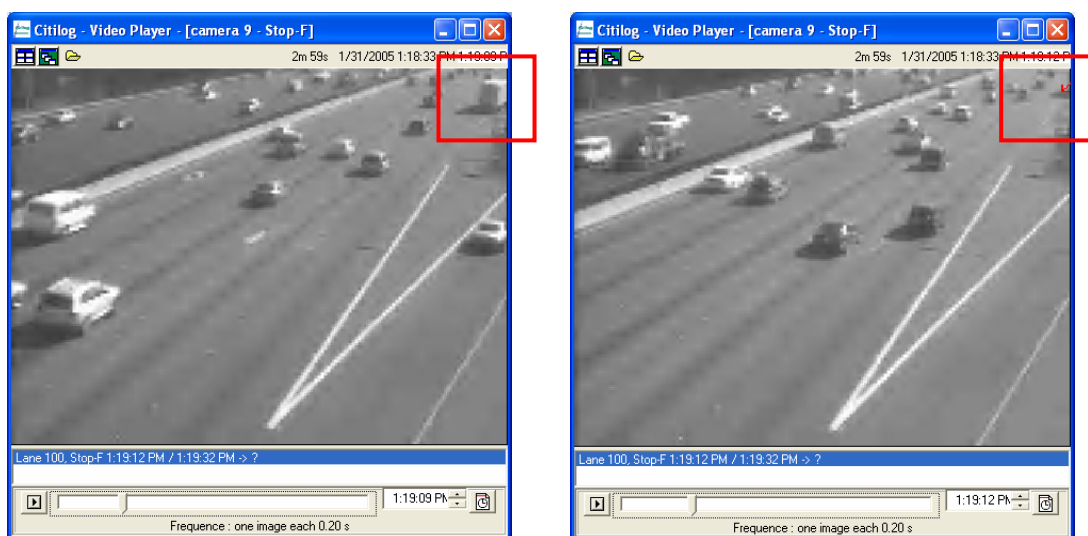


Figure 5 – Ability of the system to track vehicles

In the examples below, vehicles are detected at night, although the bridge is not lighted. The system's algorithm tracks vehicle's headlights and backlights. This enables the system to reliably detect at night and at great distances.

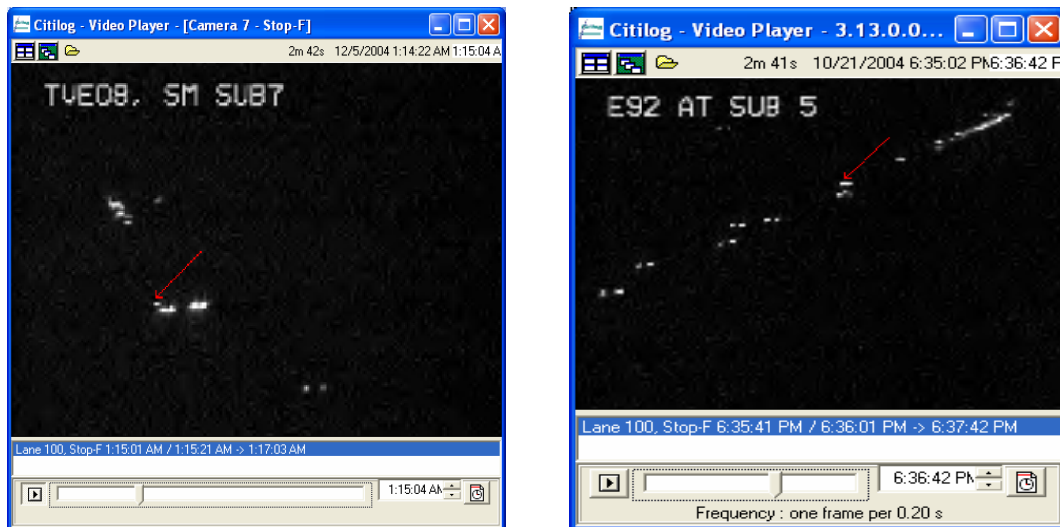


Figure 6 – Ability of the system to detect at night and at great distances

LESSONS LEARNED

How to improve performances of the system on the San Mateo Bridge

Although the system's performance was good, it could be improved by addressing the following issues.

The field of view

The San Mateo PTZ cameras are used daily by Traffic Operators who leave them with different field of views.

Sometimes, field of views would not focus on the roadways.

This lowers the detection rate (vehicles are smaller) and raises the unwanted calls frequency (more "unwanted" elements in the picture: shadows, clouds, trees, boats...).

With more experience of the system, Traffic Operators understand that they can improve its efficiency by placing the cameras in an adequate position. The use of preset positions can be helpful.

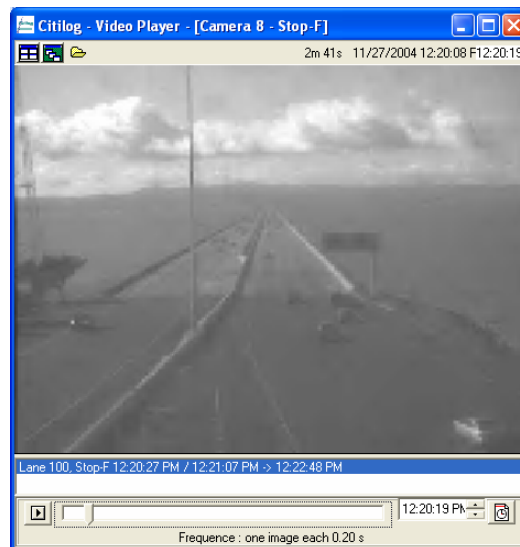


Figure 7 – Camera not focused on roadway

The quality of video signals

The San Mateo PTZ cameras are old and the video signals are not as clean as they could ideally be. The cameras are also very sensitive to blooming and smearing.

However, the system has dealt rather well with those issues.

The issue that has hurt the most was that operators would manually change the iris from daytime to nighttime thus causing the picture to go very white or dark.

This could be fixed by explaining the issue to Traffic Operators who could weigh the benefits of having the Video Detection system work with nominal performances.

Keys to a successful deployment of an Active video surveillance system

Carefully choose site for deployment

An Active Video Surveillance system makes sense where a stopped vehicle will be the exception and not the rule.

This excludes: signaled intersections, parking lots or tollgates. Knowing that vehicles stop at these locations is not valuable information to Traffic Operators.

Some locations will have a high occurrence of stopped vehicles and are interesting to monitor because those incidents may require assistance or generate secondary accidents.

Other locations like the San Mateo Bridge will have a low occurrence of stopped vehicles. However, they are key infrastructures and any stop can have bad consequences in terms of traffic, in terms of safety (secondary accidents) or even in terms of security.

Cameras

Although the system will operate on rather degraded video signals, it will have nominal performances when video signals are of good quality.

With rare exceptions, this does not necessarily mean replacing the cameras but changing the settings so as to optimize the pictures for the detection algorithm.

Generally speaking an optimized setting for the Active Video Surveillance system is also the best setting for visual monitoring by Traffic Operators.

Involve Traffic Operators

Deploying an Active Video Surveillance system on an existing CCTV system will change the way Traffic Operators operate the PTZ cameras. If they are involved, they will be motivated to make the deployment successful.

Ensure that the Active Video Surveillance is operable, maintainable and sustainable

The system should be simple to operate and not require any specific knowledge to be installed, setup and maintained. This is particularly true if the number of cameras monitored by the system is high. Traffic Operators should be able to concentrate on dealing with the incident once reported by the Active Video Surveillance and not dealing with the system itself. Also important is a low frequency of unwanted alarms.

CONCLUSION

The Video Detection system has been efficiently deployed and tested on 8 of the PTZ cameras monitoring the San Mateo Bridge. The results are summarized as follows:

- The system proves to be efficient in detecting accidents or incidents on traffic lanes, but also vehicles pulled-over on the shoulder.
- The low frequency of unwanted alarms is key to an efficient deployment of the system.
- The system is relatively insensitive to traffic conditions. It shows the same efficiency to detect isolated stopped vehicles in fluid, stop and go or congested traffic.
- The system is insensitive to time of day and weather conditions. In several cases the system has detected stopped vehicles at night at great distances. It is not significantly affected by adverse weather conditions such as rain, clouds or shadows.

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Hamed Benouar is the Executive Director of the Center for commercialization of ITS Technologies at the University of California in Berkeley.

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Michael Lee is an engineer at Caltrans D4 in Oakland, CA.

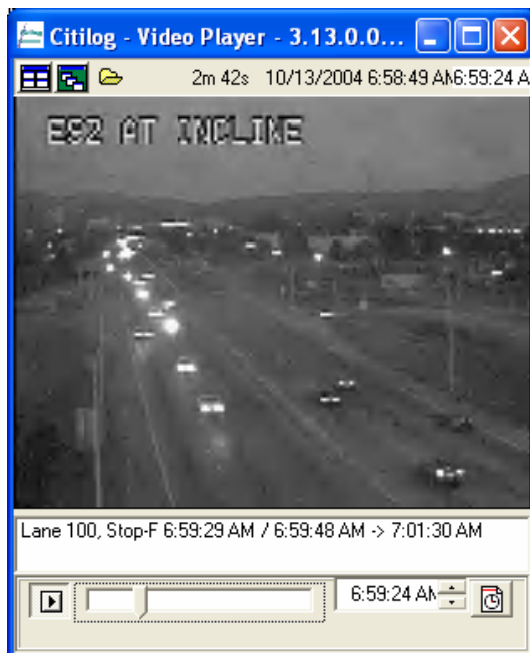
John Cox is President of TANN Corporation in Diamond Bar, CA and project manager for the INCIDENT DETECTION CAMERA NETWORK (IDCN) under which this project was conducted.

REFERENCES

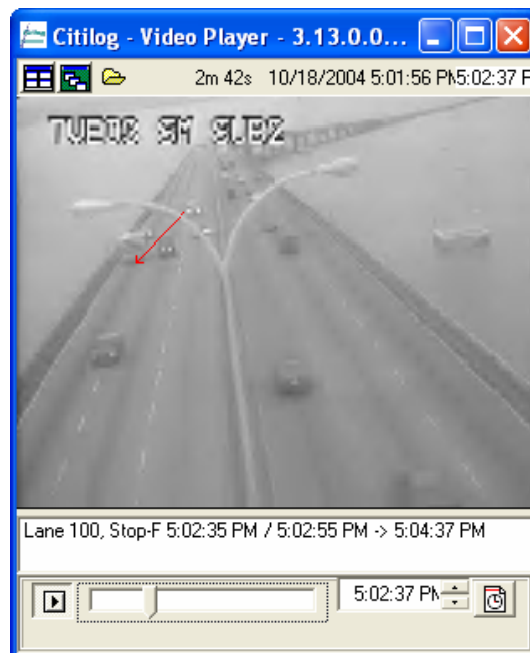
- [1] E. Toffin, G. Pernot, Video Detection in road tunnels (2002), Traffic Technology International Apr/May, pp 77-80
- [2] E. Toffin, G. Pernot, S. Bouzar, Active Video surveillance (2002), Traffic Technology International Oct/Nov, pp 28-30

APPENDIX

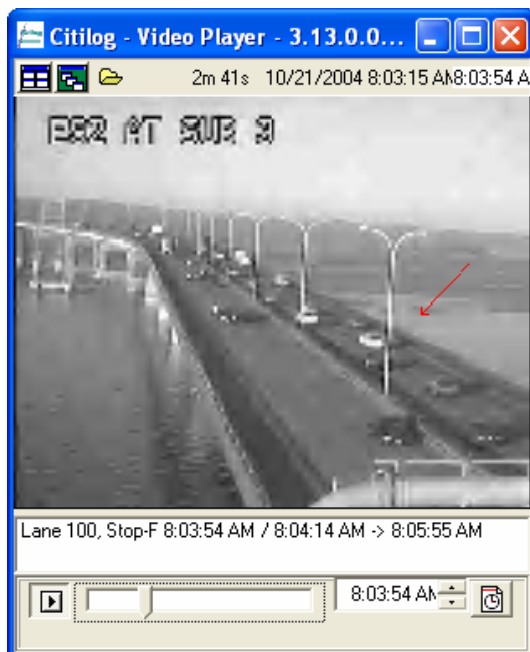
Views of the 8 cameras of the San Mateo Bridge used in this project.



Camera 1



Camera 2



Camera 3



Camera 4



Camera 5



Camera 6



Camera 7



Camera 8