Red Light Running Monitoring Made Affordable

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ABSTRACT

With the continuous advancement in technology, more applications for it in the transportation field are arising on a daily basis. A widely used technology in the transportation field is the camera/video technology. Traffic surveillance is one task the camera/video technology is increasingly being used for worldwide. Of the many applications of the camera/video technology in traffic surveillance, its use to monitor red light running behavior at signalized intersections is on the rise. Red light violators contribute significantly to the occurrence of right-angle accidents at signalized intersections between vehicles losing the right of way and those gaining it. To better understand red light running behavior at signalized intersections, it is necessary to study drivers' behavior at the onset of the yellow and red signal indications. One method of observing drivers' behavior in response to the yellow and red signal indications is video surveillance. One of the objectives of this research was to develop and deploy a video surveillance system that can be used to monitor drivers' behavior in response to the yellow and red signal indications at signalized intersections. To achieve the objectives of this research, an extensive review of the literature was conducted to identify and evaluate surveillance systems and camera technologies used by other researchers. Three systems were identified, however, the cost associated with any of the three was beyond the budget for this research. Therefore, an "over the shelf" video surveillance system was developed that captured the same type of data captured by the other three systems at one third of the cost. It is recommended that research efforts be geared towards the development of economically feasible surveillance and monitoring systems. Such efforts would enable the smaller communities to deploy Intelligent Transportation System technologies to their transportation networks.

INTRODUCTION

A significant proportion of accidents that occur at signalized intersections are generated during the yellow clearance interval. When presented with the yellow signal indication, drivers approaching a signalized intersection must decide whether to stop or clear the intersection. Incorrect decisions, coupled with inadequate clearance intervals, often give rise to either rear-end collisions between vehicles approaching the intersection, or right-angle accidents between vehicles losing the right-of-way and those gaining it. Red light runners, (i.e., vehicles entering the intersection on yellow and clearing it on red, or vehicles entering the intersection on red and clearing it on red, depending on local statutes), contribute significantly to the occurrence of right-angle accidents.

To better understand red light running behavior at signalized intersections, it is necessary to study drivers' behavior at the onset of the yellow signal indication. One method of observing drivers' behavior in response to the yellow signal indication is video surveillance. This paper presents the development and deployment of an "over the shelf" video surveillance system that can be used to monitor drivers' behavior in response to the yellow and red signal indications. The video system was developed for as part of a comprehensive study that was conducted to determine the effect of media advertising and police enforcement on red light running behavior.

OVERVIEW

One effective way of monitoring drivers' red light running behavior at signalized intersections is through the use of red-light-cameras. Used in countries worldwide, red light cameras automatically photograph the rear license plates of vehicles that run red lights. The camera system is connected to the traffic signal and to sensors buried in the roadway. The camera is triggered to photograph vehicles passing over the sensors after the light has been red for a predetermined time interval, so only unequivocal violations are recorded. The purpose of such cameras is to detect deliberate red light runners - those who pose a threat to pedestrians and traffic in intersections, not drivers who inadvertently enter intersections when the light is yellow.

Typically, two photographs are taken of vehicles in intersections as shown in Figure 1. The data recorded by the camera are: (1) time of day (2) time elapsed since the light turned red, and (3) speed of the violating vehicle. An electronic flash produces a clear image of the vehicle in virtually all light and weather conditions. The average cost of a red light camera system is approximately $50,000 [1].

Due to the high cost of such systems, several researchers have turned to developing their own video systems to monitor red light running behavior at signalized intersections. In the Netherlands, Horst [2] conducted a study to monitor drivers' behavior at the onset of the yellow signal indication. He utilized video equipment to study, in detail, the behavior of drivers who are in a 100-meter decision zone in front of the stop-line, at the beginning of the yellow phase. At each study location, two video cameras were used, one directed on the approach lane and the other on the area near the stop-line and the traffic signal heads in order to record and identify changes in the signal indications. The video files were then used to extract variables such as type of vehicle, vehicles' distance to stop line at the onset of the yellow signal indication, vehicles' travel time to the stop line at the onset of the yellow signal indication, the driver's decision to stop or go, and the occurrence of any red light running activity.

In another study, Bonneson [3] also utilized video surveillance to monitor drivers behavior at the onset of the yellow signal indication. The camera was mounted on a 30 foot mast and was located approximately 200 feet upstream of the intersection. Periodic changes in the signal indication were recorded by placing a tapeswitch sensor strip over of the LED display for the yellow light inside the controller cabinet. Thus, every time the signal indication turned to yellow, the time of the event was detected and recorded by the tapeswitch sensor that was connected to a data collector. It should be mentioned, however, that the system required continuous monitoring to ensure that the tapeswitch sensor was functioning properly. Those changes were later synchronized with video times and superimposed on the video recordings. The data extraction from the video tapes proceeded on a cycle-by-cycle basis. While the tapes were reviewed, and if vehicles were present on the approach every time the light turned yellow as recorded by the tapeswitch, the vehicle's distance from the stop-line, travel time to the stop-line at the onset of the yellow signal indication, and the driver's behavior to stop or go were measured.

Due to the high cost of red light running camera systems, the high cost of using two cameras per study location, the extensive supervision requirements of Bonneson's system, and the limited budget of this study, it was necessary to develop a less expensive system, yet one that would yield the same data as the other systems. As a result, a video surveillance system was developed to monitor the intersection areas of six signalized intersections. The equipment was specifically designed to measure the elapsed time after the onset of the yellow and red light signal indications at which vehicles entered the intersection, and the average speeds at which those same vehicles traversed the intersection area using "off the shelf" components. A description of the deployed system is presented in the following section.

EQUIPMENT INSTALLATION

The system was deployed at one intersection corner of each site. The video cameras were mounted on the street light/traffic signal poles and the view of the traffic lanes was an "overhead view" as defined by Bonneson and Fitts [4], and as illustrated in Figure 2. The camera's field of view was almost perpendicular to the travel direction and traffic moved horizontally (from left to right or from right to left) on the screen display. Figure 3 represents photographs of the implemented video recording system.

One problem of filming downwards from light poles is that, at some locations, the signal heads cannot be included in the field of view, thus changes in the signal indications cannot be recorded. As mentioned earlier, to overcome this difficulty, Horst and Wilmink [1] used two cameras, one focused on the intersection and one directly on one set of signal heads. In this research, however, a simpler approach was employed. This required that the cameras be mounted on the light pole at the same intersection corner where the signal control cabinet is located.

To register the periodic changes in the signal phases on the video film, the recording unit was located in the signal control cabinet and connected to the camera by siamese cable that was extended inside the light/signal pole combination and through an underground conduit into the control cabinet. The controller cabinets were supplemented with 300 watts light bulbs to ensure system operation during cold temperatures. Both the camera and the recording unit were driven by the AC supply to the control cabinet. In addition, a DC driven logic board was installed inside the recording unit and was connected to the controller's yellow and red outputs for the phase (direction of travel) under consideration . Hence, every time the signal indication turned yellow or red for the monitored phase, the respective outputs became active and an audible signal was emitted and recorded into the video recorder via the sound input port. To differentiate the different types of light changes, a different pitch was used for each type of signal termination (green to yellow, and yellow to red). Also, a time/date generator was connected to the recording unit which registered the time and date at the bottom of the screen display. Figure 4 represents a schematic of the video system deployed for this study.

Two technicians with the City of Lincoln's Department of Public Works were required to install the system at each of the study sites. One person held the camera and was elevated in a boom truck to an elevation of 25 to 30 feet above the ground. The other person, while viewing the resulting field of view on a 9 inch monitor connected to the camera, directed the aiming of the camera by the person in the lift to achieve the desired view. The camera was enclosed in a weather-proof housing and bracketed to the light/signal pole combination by a pole mount. The cable, which was already extended inside the light pole and into the control cabinet, was then connected to the camera on the light pole and to the recording unit in the control cabinet. To activate the system, a member of the research team was required to open the control cabinet, turn the system ON, insert a blank video tape, and press the record button on the recording unit. At the end of a 2-hour study period, a member of the research team would open the control cabinet, stop the recording, retrieve the video tape, prepare the system for the next study period, and shut the system OFF.

DATA COLLECTION

At each of the six study sites, data were collected until the minimum required sample size was obtained. Each day, the morning peak period, the off-peak period, and the afternoon peak period were recorded. Morning data were collected between 7:00 am and 9:00, off-peak data were collected between 11:00 am and 1:00 p.m., and afternoon peak data were collected between 4:00 p.m. and 6:00 p.m.. Recording was conducted for three intersections at a time, and before each recording period, members of the research team would activate the recording systems, and deactivated them at the end of each period. All recording periods were 2-hours long, and a member of the research team checked on the systems every hour. Data were collected on weekdays under dry pavement conditions only, while the University of Nebraska was in session.

DATA REDUCTION

As mentioned before, video equipment was used to measure the elapsed time after the onset of the yellow signal indication at which vehicles entered the intersection, and the average speeds at which those same vehicles traversed the intersection area. A detailed description of the data extraction process follows.

While viewing the tape, the observer paused the picture as soon as the beep representing the onset of the yellow light was heard. The observer then advanced the tape on a frame-by-frame basis, while counting how many frames had elapsed, until the front tires of a vehicle entering the intersection (if any) crossed the stop line (first reference line). The observer, then, paused the picture for a second time and recorded the total number of elapsed frames. Then, the observer continued to advance the tape, still counting how many frames had elapsed, until the front tires of the vehicle crossed the outer crosswalk line at the end of the intersection (second reference line). The picture was then paused for a third time and the cumulative total of elapsed frames was recorded. In addition to the numbers of elapsed frames, the observer recorded the time of day the entry occurred to the nearest minute. The stop line and the far outer crosswalk line were marked on the pavement and were represented on the video display by thin strips of paper.

At a rate of 30 frames per second for commercial VCR's, the number of elapsed frames, from the moment the picture was paused the first time until the picture was paused for the second time, represented that vehicle's entry time after the onset of the yellow signal indication. The number of elapsed frames between the second and third pauses, represented the vehicles travel time across the intersection area. Considering the fact that the picture was paused as soon as the observer heard the beep, it was necessary to adjust the recorded entry time and travel time. The purpose of the adjustment was to account for observer's perception reaction time, and for the time elapsed from the moment the "Pause" button was pushed until the picture actually paused. This was accomplished by pausing the picture at a point towards the end of the green phase for the traffic direction under consideration. The observer then advanced the tape on a frame-by-frame basis, while watching the signal indication on the screen. Once the signal indication turned yellow, the observer counted and recorded the number of frames it took for the front tires of an entering vehicle (if any) to cross the stop line (first reference line). The tape was then rewound, and the observer measured the entry time for the same vehicle using the same procedure that was described earlier (using the beep as a signal to pause the picture). The difference between the number of frames measured using both procedures represented the observer's perception reaction time. The process was repeated until an adequate sample size (450 measurements) was obtained to determine perception reaction time with the desired level of precision of 0.1 second.

The speeds of these entering vehicles was calculated by using the vehicles' adjusted travel times across the predetermined distance whose boundaries were marked on the intersection pavement. Assuming the vehicles maintained a constant speed to traverse the intersection area, it was possible to determine the location of the vehicle at the onset of the yellow signal indication, upstream of the intersection stop line. Other variables that were estimated from the three aforementioned variables were: (1) the average number of yellow entries per cycle, (2) the average number of red violations per cycle, (3) the number of entering vehicles upstream of their upper dilemma zone boundary as a proportion of all entering vehicles, and (4) the number of entering vehicles downstream of their lower dilemma zone boundary as a proportion of all entering vehicles.

Using the methodology outlined above, and with an adequate sample size, event times were measured to the nearest 0.1 second. A more detailed description of the sample size requirements to achieve this desired level of precision is presented in the following section.

SAMPLE SIZE REQUIREMENTS

The precision in estimating population means for the study sites is dependent on the number of observations, the variance in the population, and the variance of the measurement process. The relationship among these variables is

$$N = (t_{\mu/2}\ S_p/e)^2 \qquad (1)$$

where

N = sample size needed for a 1-a level of confidence,

$t_{a/2}$ = test statistic corresponding to a/2 (two-tail test) for normal distribution,
S_p = pooled standard deviation, and
e = permissible error (or precision) of the estimate of the true population mean.

The pooled standard deviation combines the variance in the population and the variance in the measurement process as

$$S_p = (S^2 + S^2_m)^{1/2} \tag{2}$$

where S is the population standard deviation and S_m is the standard deviation of the measurement process. This section identifies the sources of variability in the measurement of traffic events by using the methodology described in the previous section. The equations used to develop these sources are then used to estimate the adjustment needed to remove this variability in the recorded data and to estimate the standard deviation of the measurement process for sample size estimation. A detailed description of those sources of variability is reported elsewhere [4].

The first source of variability in the measurement process is frame error. The video image is composed of a series of still frames. Therefore, in advancing the tape on a frame-by-frame basis, the measurement of event time is limited to an error range of one frame. At the rate of 30 frames per second for commercial VCR's, this error range amounts to ±0.017 second. The error from this type of process follows a uniform distribution with a standard deviation of

$$s_F = 0.0096\ n \tag{3}$$

where s_F is the standard deviation of measurement associated with frame error (sec), and n is the number of frames in error range (1 frame).

The second source of variability stems from the width of the pavement reference line. A wider reference line can increase the variability in the estimate of crossing time. The error range for this source is equal to the vehicle travel time across the reference line. The variance of this process can be written as;

$$s_W = 0.30\ W_d/V \tag{4}$$

where,
s_W = standard deviation of the measurement error associated with reference line width (sec),
W_d = width of reference line (m), and
V = mean vehicle speed

The variance of the event time measurement process is represented by the summation of the previously described component variances. The basis for this formulation stems from the additive nature of component variances of error sources. However, the variance of an entry time adjusted for perception reaction time (that involves the same sources of variability) is twice of that of an unadjusted entry time. As a result, the combined variance of the two components is;

$$s^2_s = 2(s^2_F + s^2_W) \qquad (5)$$

The sources of variability in travel time measurements are similar to those for event time measurement, except for the fact that two event times are measured and differenced to determine travel times. As a result, the variance of the error in travel time measurement can be computed as:

$$s^2_{Ft} = 2s^2_F \qquad (6)$$

where,

s^2_{Ft} = variance of travel time measurement error associated with frame error (seconds^2), and

s_F = standard deviation of measurement associated with frame error (Equation 3) (seconds)

The variability associated with reference line width can be derived from Equation 4. As there are two measurements made for each travel time, the total measurement variance can be computed as the sum of the variance for each event time measurement. Thus, the variance of the error that is due to reference line width can be computed as:

$$s^2_{Wt} = (0.3/V)^2\ (W^2_{d2} + W^2_{d1}) \qquad (7)$$

The total variance of travel time that is due to measurement with videotape systems can be computed as:

$$s^2_{tt} = s^2_{Ft} + s^2_{Wt} \qquad (8)$$

The error in the measurement of travel time results in an error in the estimate of speed. The following equation can be derived for estimating the variability of the speed measurement error:

$$s_V = (D/tt^2)\ s_{tt} \qquad (9)$$

where s_V is the standard deviation of speed measurement error (meters per second).
Computing the error variances presented above, and using Equation 1, the necessary sample sizes for the desired levels of precision (0.1 second) are calculated.

SAMPLE RESULTS

As mentioned in the previous section, the precision in estimating population means for the measured variables (i.e. the elapsed time after the onset of the yellow and red light signal indications at which vehicles entered the intersection, and the average speeds at which those same vehicles traversed the intersection area) depends on the sizes of the collected samples. Table 1 summarizes the minimum sample sizes, and the associated error variances, required for each of the six Lincoln sites to at least ensure a 0.1 second level of precision for entry time after the onset of the yellow/red signal indications and a 2 mph level of precision for the speed calculation. These levels of precision were deemed suitable for the purposes of this study.

It should be mentioned, however, that higher levels of precision (as specified by any user) can be obtained using the same methodology with larger sample sizes.

DISCUSSION

Comparing the video surveillance system developed for the purposes of this study to the systems used in other studies, it can be said that the system at hand has several advantages over the others. In comparison to the red-light-camera technology, even though the data extraction from video surveillance system is significantly more time consuming, it provides data on drivers' response to both the yellow and signal indications, whereas the red-light-camera technology only provides data regarding red light runners. In addition, at a cost of $3,000 per system unit, the video surveillance system is significantly cheaper than the red-light-camera technology.

Both the system used for this study and that used by Horst [2] yield the same type of data, however, the system at hand requires half the number of camera units that would be needed by Horst's system. Also, the field of view covered by the system at hand (i.e., the entire intersection area) allows for the video files to be utilized for several studies that would otherwise require field observation, such as turning movement counts and delay studies.

Finally, in comparison to the system developed by Bonneson [3], the video surveillance system at hand requires less supervision and installation time. Thus, allowing more intersections to be studied in a given time frame.

RECOMMENDATIONS

With the continuous advancements in technology and the increased need for Intelligent Transportation Systems, it is recommended that governments allocate more funds towards researching the deployment of such systems. It is also recommended that research efforts be geared towards the development of economically feasible systems. Such efforts would enable the smaller communities to deploy ITS technologies to their transportation networks.

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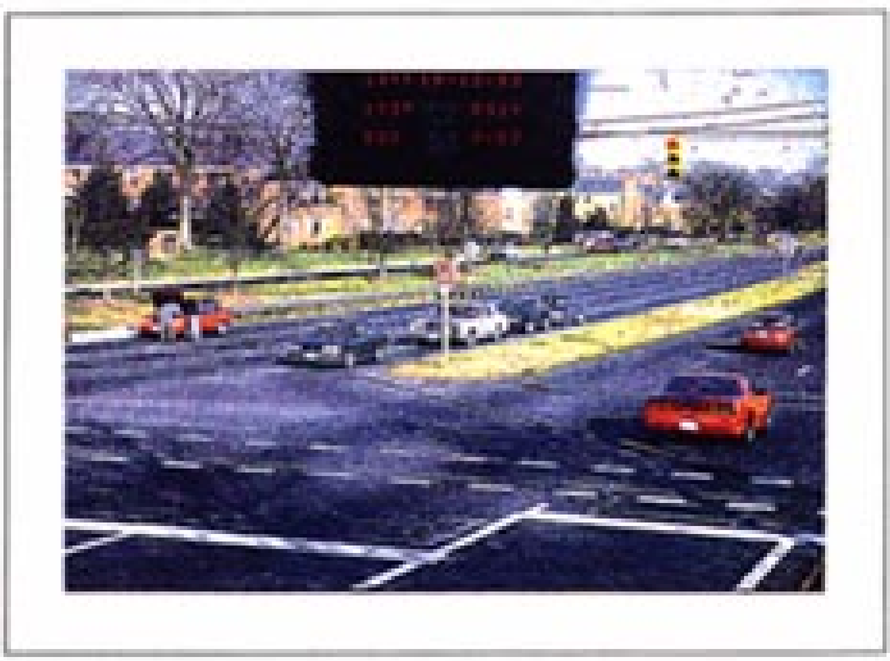
Red light cameras typically take two photographs:

The first photograph records the time, date, and place of the violation. It shows how long the light had been red before the vehicle entered the intersection. This vehicle entered 1.6 sec. after the light turned red.



The second photograph, taken one-half second later, shows the speed at which the vehicle entered the intersection and the length of time the light had been red. It also records the time and place of the violation. This vehicle was traveling at 57 mph – 12 mph faster than the 45 mph limit.

Figure 1. Photographs Taken and Data Recorded by Red-Light-Running Cameras.

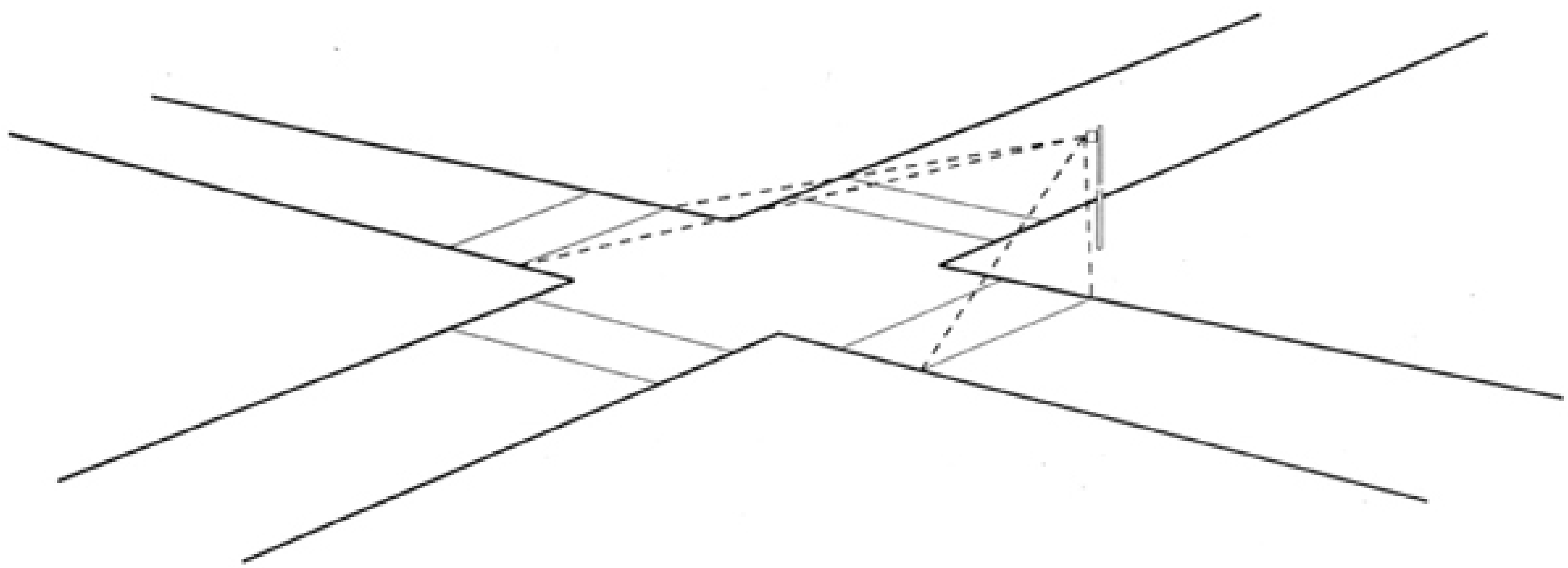


Figure 2. Zone Captured by The Overhead View.

Figure 3. Photographs of The Implemented Video Recording System.

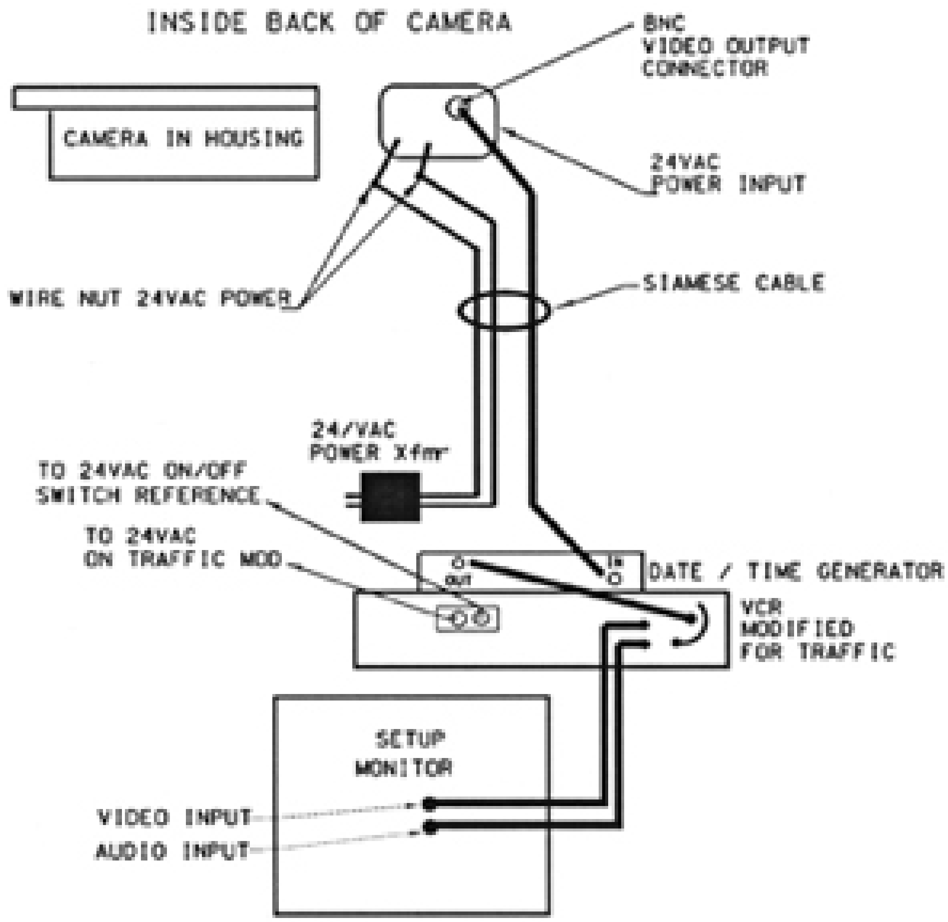


Figure 4. Schematic of The Video System Deployed For The Study

Table 1 Minimum Sample Sizes For The Video Data For The Lincoln Sites

Site	**Error Variance**	**Minimum Sample**
1	0.00032	422
2	0.00038	265
3	0.00029	249
4	0.00032	299
5	0.00028	334
6	0.00029	257

LIST OF TABLES:

LIST OF FIGURES