Surface Transportation Surveillance from Unmanned Aerial Vehicles

Benjamin Coifman, [a,b]
coifman.1@osu.edu

Mark McCord,[a]
mccord.2@osu.edu

Rabi G. Mishalani,[a]
mishalani.1@osu.edu

Keith Redmill [b]
redmill.1@osu.edu

a: Department of Civil and Environmental Engineering and Geodetic Science, The Ohio State University, Columbus, OH, 43210

b: Department of Electrical Engineering, The Ohio State University, Columbus, OH, 43210

ABSTRACT

Unmanned Aerial Vehicles (UAVs) promise a low cost means to achieve a "bird's eye view" and a rapid response for a wide array of transportation operations and planning applications, including incident response, coordination among a network of traffic signals, traveler information, emergency vehicle guidance, and measurement of typical roadway usage. However, many obstacles to operational use exist, including ambiguous and sometimes prohibitively restrictive Federal Aviation Administration (FAA) guidelines and liability concerns. This paper expands on these benefits and barriers to deployment and discusses preliminary results of a field experiment in which a UAV was used to monitor freeway conditions, track vehicle movements in an intersection, observe conditions on a network of roadways, and monitor parking lot utilization. This extended field experiment provides a strong indication that the application of the UAV technology to surface transportation surveillance seems viable and potentially valuable. In addition, the experiment clearly points to the need for continued experimentation and refinement to develop and document the potential benefits and familiarize the operations community with this emerging technology.

INTRODUCTION

As congestion continues to grow on roadway networks it becomes increasingly important to collect precise and timely information about the traffic state for improved control and response. The need for faster assessment and response to incidents is just one example of this need. Faster response can lead to reduced traveler delay, as well as improved health status of injury victims through faster medical attention. At any given instant, the biggest value comes from monitoring only a small portion of the network. Unfortunately, the specific portion that would provide this largest value is constantly changing and often is not known a priori. For example, the points where queuing will form as a result of an incident depend on where the unpredictable incidents occur. Conventional traffic surveillance uses a set of detectors (including cameras) deployed at fixed locations, requiring a high density of detectors to ensure the ability to respond rapidly under changing conditions throughout the network. When information is needed from beyond the range of these fixed detectors a person may be deployed to assess conditions. For example, a highway patrol officer may be directed to the scene of an incident to prescribe remedial measures. Often this first responder would have to travel through prevailing queues before reaching his or her destination.

Technological advances in electronics and communication have recently enabled an alternative to an inflexible fixed network of sensors or labor-intensive and potentially slow deployment of personnel. Unmanned Aerial Vehicles (UAVs) capable of carrying a video camera, geo-positioning sensors and communications hardware to relay data to the ground are becoming available on the commercial market. Examples include the MLB-BAT [1] and GeoData Systems-Airborne Data Acquisition System (ADAS) [2]. These aircraft have capabilities ranging from conventional model aircraft control to sophisticated autonomous flight. Various models have different payload and data collection capabilities. Most transmit video data to the ground in real-time, and some are capable of storing higher quality video or images on-board.

While the various companies have developed the technology and demonstrated the capability of such aircraft, researchers at the National Consortium for Remote Sensing in Transportation-Flows (NCRST-F) have recognized the potential of UAVs to provide a low cost means to achieve a "bird's eye view" and a rapid response for a wide array of transportation operations and planning applications. The focus is on how these technologies can be used for surface transportation applications, identifying benefits and determining barriers to deployment, as discussed in the following sections. The paper also mentions applications NCRST-F researchers have been developing that could possibly benefit from UAV-based traffic surveillance.

BENEFITS OF UAVS

While most traditional traffic monitoring is spatially myopic, only capturing conditions at discrete locations, airborne vehicles have the ability to cover a large area and focus resources on the current problems. They can travel at higher speeds than ground vehicles. Moreover, they are not restricted to traveling on the road network, so they can potentially fly directly to their destination, unencumbered by a circuitous road network or congestion on the ground.

There is little that can be done with a UAV that cannot be achieved with a manned aircraft. However, there are many functions that can be carried out at lower cost, faster, and more safely. In general both the fixed cost (e.g., the aircraft) and hourly costs (e.g., fuel and maintenance) are much lower with a UAV than with a manned aircraft. With these lower costs, it is conceivable that the aircraft may already be aloft collecting data of a more "routine nature" before being assigned to an emergency task. The time of response is especially important when considering a victim's mortality and morbidity after a severe injury accident. Additionally, even small savings in response time can save many hours of traveler delay in the queue behind a major incident. UAVs could also potentially fly in conditions that would be too dangerous for a manned aircraft, such as might arise when monitoring evacuation conditions. The autonomous craft could offer greater stability in these situations, since the instrumented flight controls do not have to account for passenger comfort, and losing the aircraft would not endanger human crews. Of course such emergency landings would also have to avoid harming people and property on the ground but the relatively smaller size of UAVs in itself reduces such risks. Many commercial UAVs presently use automatic parachute deployment when control is lost. Such a system has to be carefully engineered to ensure safety in emergency situation. In addition, smaller UAVs can fly much closer to the ground than manned aircraft, which results in their ability to fly "under the weather" and, therefore, operate in conditions where manned aircraft cannot. Indeed, in our field experiments discussed below, we were able to collect data on a day where the cloud ceiling was sufficiently low that the manned aircraft were operating under instrument flight rules. Traditional surveillance aircraft would not have been able to view the ground while data was being collected.

As a result of these factors, UAVs promise a new cost-benefit relationship for collecting aerial data. The first practical use of UAVs will likely be that of implementing existing applications for lower cost. Several of these applications are outlined below. Once aloft for such tasks, they will enable new applications that are presently unimagined.

Many cities already have manned aircraft monitoring roadway traffic conditions during peak periods. UAVs could easily substitute for these manned aircraft to provide traveler information. But perhaps the most important role that UAVs could fill is providing a rapid response to incidents. As previously mentioned, time of response is important in victim survivability and eventual health state. Flying the aircraft directly to an incident and transmitting images back to the operators will allow more rapid assessment of the situation, which in turn would lead to better allocation of emergency response resources. In the rural setting, the lower density of emergency facilities increases the importance of a rapid and accurate assessment. An emergency vehicle's travel distance (and thus time) is usually much larger than in an urban setting, and once that vehicle has been committed it is generally a longer time before it becomes available for other calls. In the urban setting, after being used to assess an accident scene, a UAV could fly one intersection ahead of emergency responders and provide an advance view ensuring that cross traffic has stopped in response to their sirens and reduce or eliminate the need for an ambulance to slow down when entering an intersection on a red signal. The earlier assessment could also speed traveler diversion and incident clearance time. In addition to reducing traveler delay, reducing the queue would also reduce the likelihood of secondary accidents. The overhead perspective may allow better and more rapid documentation of information needed for accident reconstruction so that lanes could be opened that much more quickly after an accident. Finally, the UAV could be used to monitor conditions on (non-instrumented) alternate routes.

A UAV requires an operator on duty for any time sensitive application, whether the aircraft is airborne or sitting on the ground. These personnel resources will likely dominate the operating costs. Since the personnel would be on duty to be ready for emergency calls, the UAV could eventually be airborne most of the time. Being airborne would potentially offer a faster response time by eliminating the need to launch the vehicle after an event occurs. More importantly, with the vehicle patrolling aloft while waiting for a call, it can be used for traffic applications that are not of an emergency nature, such as data collection or congestion monitoring. As of now, power limitations and lack of experience with operations would limit flight time, but these limitations could likely be overcome if widespread deployment is targeted.

In addition to emergency-based applications, UAV-based surveillance may also be valuable for traffic management and monitoring applications. One example is using these aircraft to collect network usage data, e.g., average annual daily travel (AADT) on links. We have already demonstrated the feasibility of estimating AADT from aerial imagery [3]. In this methodology, measured density (vehicles per mile of roadway) is converted to a short-term flow via the fundamental equation of traffic flow theory (flow = density ∏ speed) with the assumption that imaged vehicles were traveling at the posted speed limit. Conversion factors from ground detectors were then used to expand these short-term flows to AADT. Manually identifying vehicles in 14 different images, each one including a ground based detector station on a highway segment, the approach successfully estimated AADT within 31 percent of the corresponding ground counts for all 14 images, and within 15 percent for 12 of the images. This approach could supplement and enhance the existing traffic monitoring programs.

A second example is examining the feasibility of using UAVs to estimate Origin-Destination (OD) flows for traffic control, travel guidance, and off-line planning applications. A study was conducted whereby a network consisting of three adjacent intersections was observed using video cameras located on a tall building, emulating an ideal airborne platform [4]. The video images were processed to obtain the necessary data to carry out dynamic OD flow estimation. Four scenarios reflecting the availability of different types of surveillance data were defined, ranging from a loop detector based surveillance system to one where link travel times and intersection turning movements could be observed, as would be typical of what would be expected from an air-borne based surveillance system. We found that measuring turning movements and travel times, two traffic characteristics that are difficult to obtain with conventional point detectors, improved the accuracy of OD estimates.

Both of these applications require automatic vehicle detection or vehicle tracking for operational implementation. Other NCRST-F research efforts have shown that airborne video can be used to simultaneously track vehicles and stabilize the image using only properties of the imagery. That is, the method does not need to know anything about the location and altitude of the platform [5]. The tracked vehicle information can then be used to derive travel time estimates along urban streets [6].

The UAVs could also be used to conduct congestion surveys, such as those presently conducted by Skycomp [7] with manned aircraft. Similarly, they could provide traffic counts, queue measurements, or sign inventories without sending personnel out to the field. The airborne vantage point would facilitate other studies as well. For example, the spatial perspective offered from the air would be better than presently available ground-based views for observing lane change maneuvers in a weaving section.

BARRIERS TO DEPLOYMENT

There exists many obstacles that could derail the practical deployment of UAVs for traffic monitoring. There is an "alphabet soup" of federal agencies that have jurisdiction over some portion of UAV operation. The Federal Aviation Administration (FAA) has a very specific definition of UAVs and extensive restrictions on their operation. As a result of these restrictions, most of the commercial UAVs available today do not meet the FAA definition of a UAV. Instead, the commercial UAVs fall under the vague guidelines for model aircraft. Although this fact has enabled UAV development, many prohibitively restrictive regulations remain on where and how the craft can be flown. For example, model aircraft cannot be flown within several miles of large and medium sized airports. To be effective, UAVs must be able to fly in harmony among manned aircraft, both within this restricted airspace and when the manned craft fly outside of their legal airspace. The Ohio Department of Transportation (ODOT) has proposed reserving the airspace above state highway right-of-way's and below a pre-specified ceiling for use by UAVs. Regardless of the airspace, an active collision avoidance system may prove to be a significant problem, since the hardware for non-transponder detection is fairly heavy. These technological problems can be overcome, but they will require further development.

The Federal Communications Commission (FCC) also plays a significant role in enabling or impeding UAV technology through control of the broadcast licenses necessary for radio connections, both the low bandwidth control channels and high bandwidth video channels. To ensure safe operation, a UAV must have a redundant and secure control channel. Of course it is inevitable that radio interference will disrupt even a secure channel, so the vehicle must have a fail-safe mode when communications are disrupted.

Other policy issues must be addressed before widespread use or deployment of UAVs can be realistically anticipated. Liability concerns are probably the most prominent. They must be established before a catastrophic accident occurs, so that proper insurance coverage can be arranged.

Then there are barriers that UAVs share with other technologies. There is the risk that a UAV could be used as a weapon, as is the case of any vehicle. Similarly, some of the new applications that are presently unimagined but will be enabled by UAVs are potentially undesirable.

> "Once the eyes in the sky are up there what is to stop state and local governments, or even the federal government, from broadening the scope of what these drones will be permitted to monitor. [*sic*]" [8]

Although this quote may seem far-fetched, left unchecked, UAVs could eventually be used to infringe on personal freedoms and civil liberties. Such changes usually occur between generations and are inherent to many Intelligent Transportation Systems (ITS), e.g., the slow evolution of close circuit television (CCTV) from simple monitoring applications to traffic enforcement over a period of 30 years. Rather than slowly evolving towards an undesirable state, there is a need to be proactive and develop clear policy up front to address concerns for the future and make sure technology does not wander beyond our control. Similar issues have already arisen in the context of radio frequency tags and [9] provides a good overview.

FIELD EXPERIMENTS

To further explore the benefits of UAV applications to transportation surveillance and understand the barriers to reaping these benefits, it is critical to conduct field experiments with UAVs. Field experiments would also allow UAV operators to compile a track record of safe operations and practitioners to join in shaping the evolution of the technology for useful applications. As a first step in this direction, on July 22, 2003 a set of experiments were conducted on the campus of The Ohio State University in Columbus using the BAT III technology [1] carrying a payload of two video cameras. Four distinct experiments were conducted.

1) Freeway conditions: The UAV flew over a freeway for the purpose of observing flows, speeds, densities, off-ramp weaving, and vehicle trajectories. Figure 1 shows four sample video frames captured during this experiment.

2) Intersection movements: The UAV circled an intersection for the purpose of observing flows, turning movements, and queue lengths. Figure 2 shows two sample video frames captured during this experiment.

3) Network paths: The UAV traversed an urban street network consisting of seven intersections for the purpose of observing path flows, speeds, densities, queue lengths, and vehicle trajectories. Figure 3 shows two sample video frames captured during this experiment.

4) Parking lot monitoring: The UAV made a tour of surface parking lots for the purpose of assessing their utilization. Figure 4 shows a sample video frame captured during this experiment.

Each of these experiments can relate to real-time transportation management and off-line transportation planning applications. The choice of experiments resulted from discussions among transportation researchers, the UAV operator, and several regional operating agencies. The UAV was flying at an altitude of 500 ft and an air speed of 30 mph while transmitting the video images collected by its on-board camera to the ground station in real-time. What follows are qualitatively encouraging conclusions and observations:

1) The Federal Aviation Administration official and the representatives of the helicopter unit of the Columbus Police Department, after ground- and air-based inspections, approved the operation of the UAV in an area close to the Columbus international airport, and the regional Don Scott airport, as well as several police and hospital heliports. They attended the first flight from preflight planning, through take-off, to landing, and left apparently satisfied.

2) The UAV followed its pre-programmed flight plan covering the locations of interest accurately.

3) Flows, speeds, densities, weaving, intersection turning movements, queues, and parking utilization were observed directly from the video images. Most of these variables are readily evident in Figures 1 through 4. Although it is not clear from these figures, speeds can be computed from a sequence of images.

4) One of our flights occurred on an overcast day, and the FAA ordered other aircraft to operate under Instrument Flight Rules (IFR). Because the UAV normally operates below the controlled airspace, we were able to fly. Moreover, any other manned aircraft would have needed to fly above the low cloud ceiling and not have been able to image the ground. As a result of this experiment, it is evident that flying low may be advantageous in providing aerial surveillance when manned aircraft would be unable to do so.

What follows are issues that require further investigation or refinements:

1) Identifying distinguishing characteristics in individual vehicles did not seem possible given the resolution and, therefore, observing vehicle trajectories when a vehicle leaves the field of view and reappears would not have been possible with the data collected. This challenge may be overcome by improving the resolution of the on-board camera.

2) Beyond a distance of 1 mile there was some radio interference corrupting the images transmitted to the ground over sporadic periods of up to a few seconds in duration. This problem was thought to be due to the urban nature of the environment. Such interference can be addressed by utilizing a dedicated communication channel.

3) The turning radius of the fixed wing UAV is such that changing directions at waypoints can take some time and space until the vehicle regains its course. When traversing roadway links of lengths less than 400 ft, large portions of the links went unobserved. This can be addressed by utilizing a clover-leaf type flight plans when sharp turns are required to maintain a good view of an urban street network or further development of the UAV.

Clearly, the above discussion is preliminary and qualitative in nature as the collected data has yet to be quantitatively analyzed. Such analyses are expected to be valuable for reaching firmer conclusions regarding specific potential benefits and barriers. Nevertheless, the conducted field experiments provide good indications that the application of the UAV technology to surface transportation surveillance seems viable and potentially valuable. In addition, these experiments clearly point to the need for continued experimentation and refinement in order to achieve further advancements in this area.

SUMMARY

Airborne cameras offer many benefits over ground-based detectors. They offer mobility to cover a large area and potentially greater speed than surface vehicles. The bird's eye view could enable new measures and new surface transportation studies. UAVs promise to be the lowest cost aircraft to operate. As a result of their characteristics, UAVs have changed the cost/benefit relationship for airborne data collection. A UAV has a rapid launch compared to manned aircraft, where the pilots must get to the vehicle and potentially taxi before takeoff. UAVs are both fast and highly maneuverable compared to ground vehicles, with the speed coming not only from velocity but also the simple fact that a UAV can travel in almost a straight line and avoid congestion on the road network. While the lower cost of operation compares favorably to conventional aircraft.

UAVs could potentially be justified on the basis of primary, emergency-related applications, e.g., incident response and verification. Once in possession of the aircraft for these low frequency emergency-related applications, marginal cost of operations would be low, and the aircraft could prove cost-effective for non-emergency traffic surveillance applications, such as measuring network usage or quantifying turning movement at intersections. This paper has described several of these applications, as well as barriers to the use of UAVs for traffic data collection. To further understand the potential applications and barriers, four experiments were conducted. The set of experiments have led to encouraging conclusions and identification of issues requiring further attention.

ACKNOWLEDGMENTS

This study was funded through a grant to NCRST-F from US Department of Transportation. The authors acknowledge the help of the many agencies – including the Federal Aviation Administration and the Columbus Police Department – and their staff that enabled the UAV experiment. We particularly appreciate the efforts of Steve Morris from MLB to provide the aircraft and operator for the field experiment.

REFERENCES

[1] http://spyplanes.com, accessed on July 11, 2003.

[2] http://www.geodatasystems.com, accessed on July 11, 2003.

[3] McCord, M., Yang, Y., Jiang, Z., Coifman, B., Goel, P., (in press). Estimating AADT from Satellite Imagery and Air Photos: Empirical Results, Transportation Research Record [draft available in the *Proc. of the 82nd Transportation Research Board Annual Meeting*, 2003].

[4] Mishalani, R., Coifman, B., Gopalakrishnan, D., (2002). Evaluating Real-Time Origin-Destination Flow Estimation Using Remote Sensing Based Surveillance Data, *Proc. of the 6th International Applications of Advanced Technologies in Transportation Engineering*, ASCE, Cambridge, MA, pp 640-647.

[5] Shastry, A., and Schowengerdt, R., (2002). Airborne Video Geo-registration for Visualization and Parameter Estimation of Traffic Flows, *Proceedings of the Pecora 15 and Land Satellite Information IV Conference*, Denver, CO.

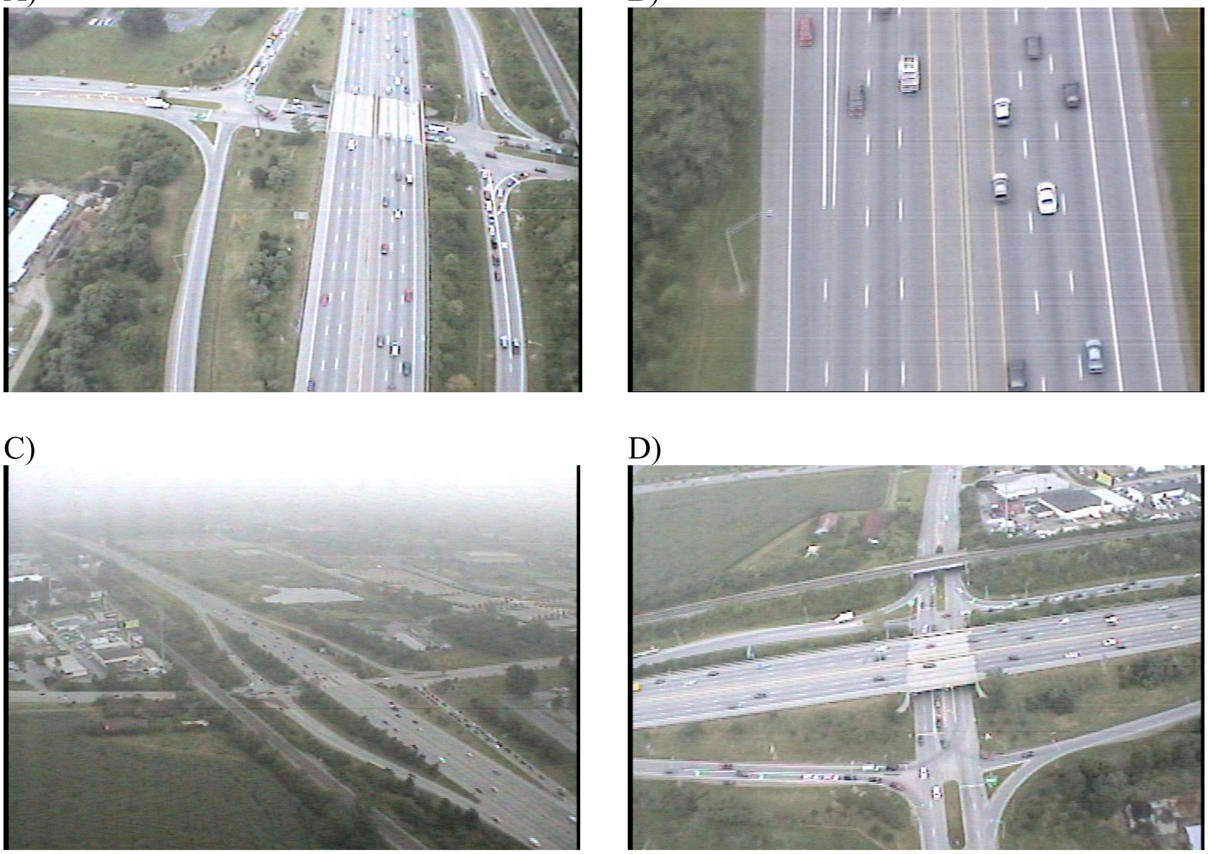
[6] Hickman, M., (2002). Robust Passenger Itinerary Planning Using Transit AVL Data, *Proc. of the IEEE Intelligent Transportation Systems Conference*, Singapore, September, pp. 840-845.

[7] http://www.skycomp.com, accessed on July 11, 2003.

[8] http://www.libertywatchtower.com, accessed on May 30, 2003.

[9] Warrior, J., McHenry, E., McGee, K., (2003). They Know Where You Are, *Spectrum*, IEEE, Vol 40, No 7, pp 20-25.

A) B)



C) D)

Figure 1, Four views of the SR 315 freeway interchange with Lane Ave extracted from video captured in real-time, remotely from a UAV. (A) Wide angle view looking south while flying along the freeway, (B) telephoto view looking south while flying along the freeway, (C) distant view looking northeast while circling a network of arterial streets, (D), closer view looking west while circling the same network.

A) B)

Figure 2, An example of circling a facility with the UAV, (A) looking west at the intersection of the Kenny Rd and Lane Ave, (B) a second view looking east at the same intersection illustrating the changing perspective when circling a facility. Note that the queue lengths and turning movements are visible in these images.

A) B)

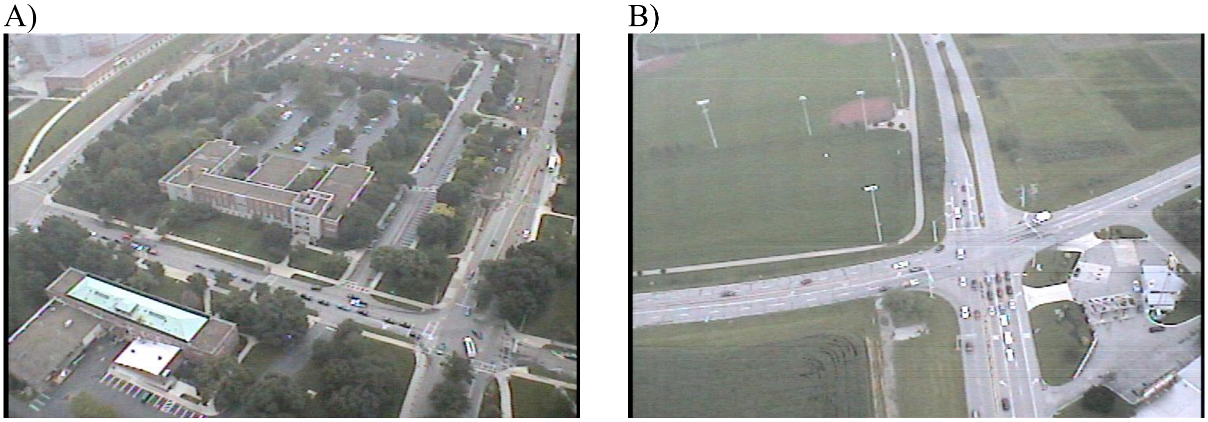


Figure 3, An example of circling a network with the UAV, (A) looking east at the eastern leg of the network, Fife Rd running from Lane Ave on the left to Woody Hays on the right. Note the long queue backed up from Woody Hays, (B) looking west at the northwest intersection of the network, Kenny Rd and Lane Ave.

Figure 4,   A sample view from the UAV showing the utilization of three parking lots.