SMALL-CITY TRAFFIC MANAGEMENT USING UNMANNED AERIAL VEHICLES (UAVs)

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ABSTRACT

Dedicated Traffic Management Centres (TMCs) are only operational in three of the largest metropolitan areas in South Africa (in Gauteng, eThekwini and Cape Town). Smaller cities and towns do not have TMCs to assist with traffic management due to the prohibitive cost of these facilities. This research considers the benefits that a small city environment could gain from live traffic management, specifically considering the town of Stellenbosch in the Western Cape as a case study. Stellenbosch experiences heavy congestion during the morning and afternoon peak periods due to significant trip attractions.

A framework for the implementation of UAVs to monitor traffic as part of TMC activities was determined for Stellenbosch. A case study includes determination of flight parameters; flight height and speed, as well as the path a could UAV follows to monitor traffic in a 4 km radius around its point of deployment. A framework for the implementation of UAVs to incident response is also created, indicating how UAVs could be used to aid emergency response personnel to better understand and respond to an incident scene. The cost benefit of using UAVs compared to traditional CCTV monitoring for traffic management was evaluated. Additionally, the benefits and limitations of such a system are identified according to findings from the case study. It was determined that using UAVs could provide substantial benefits for traffic monitoring in small city environments.

1. INTRODUCTION

1.1 Background

Traffic management plays an integral role in ensuring efficient traffic flows through the road network. This management is often done from a central locale such as Traffic Management Centres (TMCs). A dedicated TMC enables regulation of traffic flow as well as assists to provide a timeous response to accidents or road incidents, which in turn eases the flow of traffic by reducing congestion. These management centres house various systems and processes working together to gather, sort and analyse traffic data, and require skilled practitioners to operate effectively since one process cannot work properly without the other.

Due to rapid urbanisation, an increase in population and the increase in travel demand, Intelligent Transportation Systems (ITS) are being sought out to provide innovative ways to manage and monitor traffic in cities. Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, are beginning to be used by TMCs in the hopes of improving traffic management efficiency and incident response techniques. Using UAVs to manage traffic as opposed to conventional closed-circuit television (CCTV) cameras can create a traffic management platform that is cost-effective and easy to maintain.

1.2 Research Motivation

This study aims to investigate the possibility of using UAVs to observe traffic as input to TMC practices, specifically for small city environments, in order to provide traffic management that is efficient and cost-effective. Two purposes of using UAVs for TMC operations will be considered in this study: traffic monitoring (replacing traditionally used CCTV) and to aid the incident response procedure of emergency response units. Characteristics of how UAVs could be used for these purposes will be determined. Advantages and disadvantages related to the use of UAVs in traffic monitoring and incident response will be considered. The cost effectiveness of using UAVs instead of traditional CCTV will also be discussed.

The university town of Stellenbosch, situated in the Western Cape of South Africa, is selected as the test area for this research since it is a relatively small town (with less than 300,000 people) with high traffic congestion (Western Cape Government, 2019). The town of Stellenbosch does not have a dedicated TMC to assist with traffic management practices. Traffic is controlled via traffic signals, stop control and roundabouts and CCTV footage along certain roads is monitored by Stellenbosch’s Division of Safety and Security, however is not used for traffic observation. There is a large inflow of vehicles to Stellenbosch during the morning peak hour (and out of Stellenbosch again in the afternoon) due to strong trip attractions in the town including Stellenbosch University, business and tourism, while residential availability in Stellenbosch is limited. This makes Stellenbosch a suitable test area for the implementation of UAVs in traffic management. Further, Stellenbosch has experienced a 20% population growth between 2011 and 2018 as well as an increase in the number of traffic offences, such as Driving Under the Influence of substances (DUI) cases that increased from 99 to 189 between 2016 and 2018 (Western Cape Government, 2019).

2. RESEARCH DESIGN

2.1 Methodology

The operational strategy for using UAVs to support TMC functions including traffic monitoring and incident response will be detailed in this study. It is proposed that UAVs could replace traditionally used CCTV for these functions in a small city environment. The cost benefit of supplementing UAVs for CCTV will be estimated and the various benefits and limitations of this substitution will be considered in light of the case study conducted in Stellenbosch.

The study detailed in this paper formed part of a larger research project, carried out by the main author as part of his MEng degree programme at Stellenbosch University to investigate the correct model for a TMC in a small city environment.

2.2 Study Area

The road network of Stellenbosch assessed in this study is indicated in Figure 1:

- The R310 from Annandale Road to Stellenbosch (highlighted in yellow).
- The R310 from Stellenbosch to the R45 east of Stellenbosch (grey).
- The R44 from Annandale Road, through Stellenbosch to the R101 (red).
- The R304 from the R101 to Stellenbosch at the intersection with the R310 (purple).
- Annandale Road from R310 to R44 (blue).

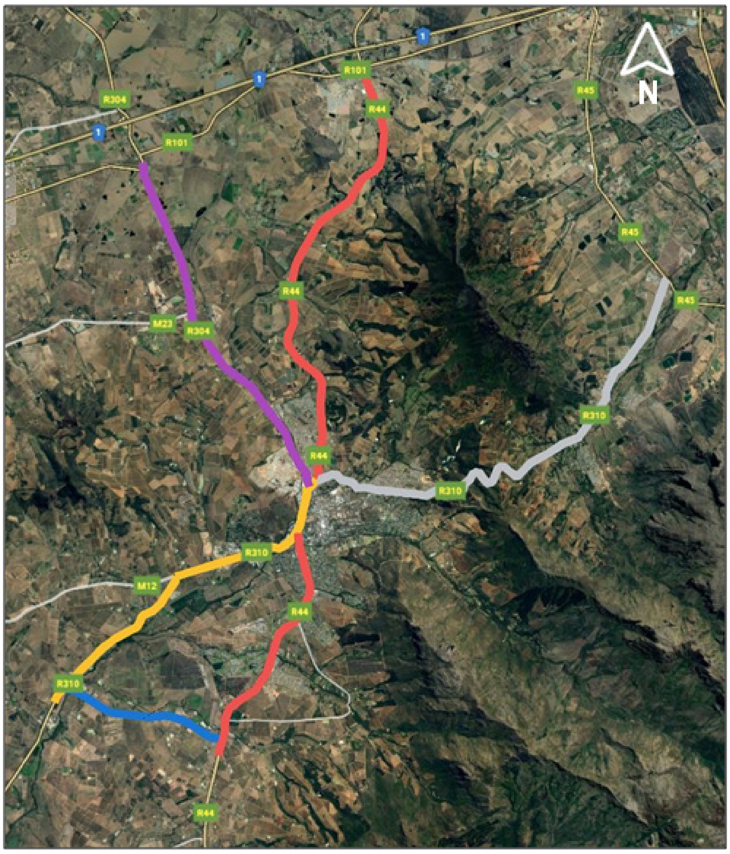

Figure 1: Study area for research (Google Earth, 2020)

2.3 UAV Used in Study

The UAV used in this study is the commercially available *DJI Inspire 2*, shown in Figure 2. Among various specifications related to this UAV, the most important for this study are:

- Videos can be recorded at up to 6K resolution (6000 pixels of horizontal resolution) at 4.44 Gbps and the camera can pan, tilt and zoom. The camera can tilt up to 90° in either direction and the camera's field-of-view (FoV) is 55° either side vertical.
- UAV has a maximum speed of 94 km/h, accelerating from 0 to 80 km/h in 5 sec.
- UAV has two batteries allowing for a maximum flight time of 27 minutes.
- DJI Inspire 2 has obstacle avoidance technology.
- Footage is stored on a Micro-SD Card and is transferred to a Cloud service for storage and data analysis.
- The UAV has a controllable range of 7 km from the controller (DJI, 2020).

Figure 2: DJI Inspire 2 (Prindle, 2018)

2.4 Assumptions

In order for this study to be completed, certain assumptions are required to allow a theoretical procedure of analysis to be followed.

These assumptions are:

- Obstructions and interferences that may affect the controllable range of the UAV were not determined and it is assumed that the controllable range is true for any location in the study area.
- Effects of changing video quality and other UAV options on the battery life of UAV was not considered and 27 minutes is used as the maximum operating time for the UAVs based on the maximum flight time provided by the batteries of the UAV.
- All UAVs used in study can fly to the height required and are kept within commercial height regulations as constructed by The South African Civil Aviation Authority (SACAA).

3. UAVs FOR TRAFFIC MONITORING

3.1 UAV Operating Times

Due to the limited battery life associated with UAVs, the study area cannot be monitored for the whole day. It was therefore decided that the morning and afternoon peak 2-hour periods will be assessed (06h00 – 08h00 and 16h00 – 18h00). The maximum battery life of the DJI Inspire 2 is 27 minutes. Due to this, the morning and afternoon peak 2-hour periods are monitored by four UAVs that each fly for 25 minutes. These operating times are indicated in Table 1.

Table 1: UAV Operating times

UAV number	AM operating time	PM operating time
1	06h20 – 06h45	16h20 – 16h45
2	06h45 – 07h10	16h45 – 17h10
3	07h10 – 07h35	17h10 – 17h35
4	07h35 – 08h00	17h35 – 18h00

3.2 UAV Flight Parameters

For this study, a specified flight path, height above the ground and travel speed were pre-determined. The height that a UAV can fly depends on the UAV camera's image quality. The DJI Inspire 2 has a good camera relative to other UAVs, allowing a flight height of 120 metres. Figure 3 shows the quality of an image taken with a DJI Inspire 2 at a height of 400 feet (≈ 122 metres). Each UAV would fly the same path throughout the study area and a UAV pilot operates the UAV.

Figure 3: DJI Inspire 2 image quality at 122 metres (Dronegenuity, 2018)

The angle, Θ, which determines the camera's Field-of-View (FoV) is static, was chosen as Θ = 50°. This means that the FoV of the footage is cut-off at 50° to the left and 50° to the right, therefore providing a total FoV of 100° (the maximum possible angle is 110°). Following this, the UAV's FoV is determined using a Pythagorean relationship to be 143 metres either side of its centre point above the ground, therefore resulting in a full FoV of 286 m. Figure 4 is a basic illustration to aid the determination of the FoV.

$$Total\ FoV = 2 \times (120 * \tan(50°)) = 286\ metres$$

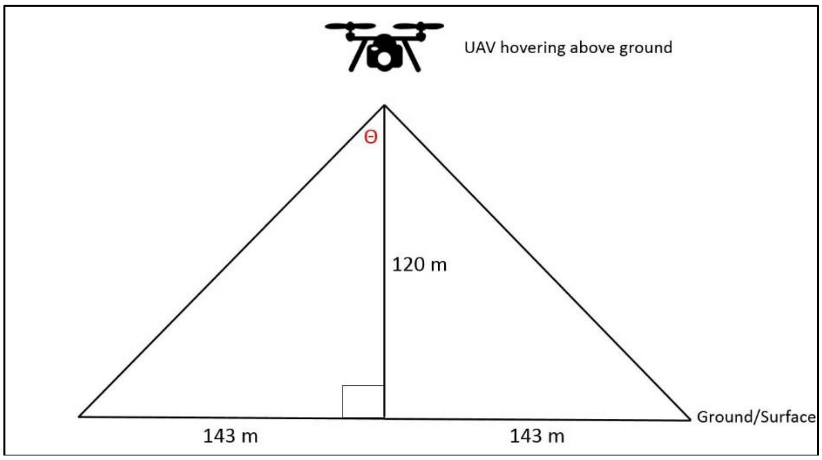

Figure 4: FoV determination for study area

3.3 UAV Flight Path

The path that the UAVs would fly for the morning and afternoon peak periods is indicated in Figure 5. A 4 km radius around the UAV deployment location was chosen as the coverage area for traffic monitoring since this is where the highest congestion occurs in Central Stellenbosch. It is proposed that the UAVs used in the TMC operations would be stored and deployed from the Stellenbosch Fire and Rescue Unit Stellenbosch (corner of Helshoogte Road and Cluver Street) to avoid the cost of constructing a location solely for UAV deployment. The points at which the UAVs change direction are labelled 1 to 9 in Figure 5. The total flight distance for each UAV is 18.43 km.

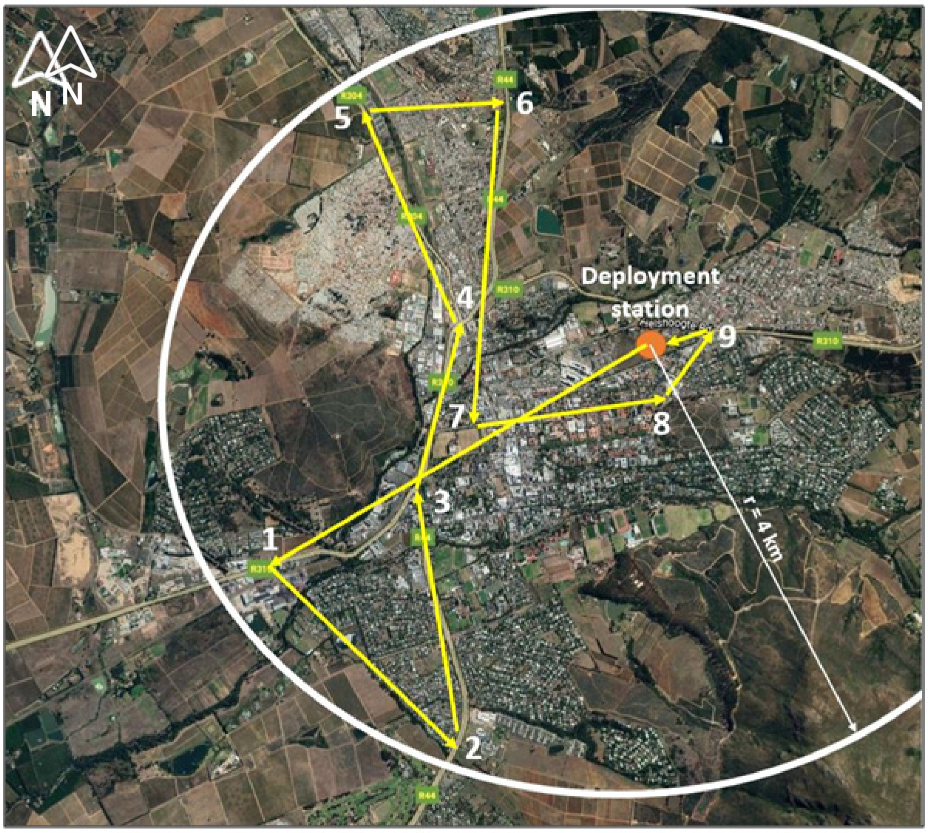

Figure 5: UAV path

The speed at which the UAVs should fly can be determined from the available flight time and flight distance. With a 25 minute (0.4167 hours) flight period for a total distance of 18.43 km, the speed of the UAVs would need to be set at 45 km/h.

$$UAV\ speed = \frac{distance}{time} = \frac{18.43}{0.4167} = 44.2\frac{km}{h}, use\ 45\frac{km}{h}$$

This is a reasonable speed which would allow the UAV operator adequate time to identify any incidents related to traffic flow. This speed also gives the UAVs more time to process images, providing clear visuals of the traffic conditions for traffic monitoring. At this speed, and using the four UAVs, the full study area would be covered once every 25 minutes during the peak traffic periods.

4. UAVs AIDING INCIDENT RESPONSE

4.1 Incident Monitoring

UAVs could be used in cohesion with TMC practices to aid the incident management process. UAV aid is suggested to be used for the following reasons:

1. UAVs sent to inspect incident sites to justify the accuracy of incident reports.
2. UAVs used to improve on-scene management by providing information from an overhead view.
3. UAVs used to improve the safety of on-site responders by providing information regarding hazardous environments (such as an chemical spill or civil unrest) and by providing enhanced imagery to the responder to aid in the preparation of incident clearance.

4.2 UAV Incident Unit

One UAV Incident Unit (UAVIU) is used in this study per incident. The UAVIU consists of:

- A UAV and digital imaging payload. This UAV is not one of the four UAVs used in traffic monitoring (additional UAV should be secured). The imaging payload is the 6K camera attached to the UAV.
- Sensor payloads – sensor payloads such as infrared and Light Detection and Ranging (LIDAR) are required to aid the UAV pilot to map an incident scene. This software is available with the DJI Inspire 2.
- UAV Response Unit (UAVRU) – a vehicle to transport the UAV and pilot to an incident site if the incident occurs more than 7 km from the Unit Station (>max controllable distance from controller).
- UAV ground control station – a laptop for navigational control and to analyse data obtained from processed images.
- Two-way communication – equipment that allows the UAVIU crew on site to communicate with traffic management operators at the Base of Operations (BOO) to transfer information relating to the severity of the incident and which incident response crew needs to be sent out. The UAVIU uses the conventional radio used by paramedics.
- Data communication infrastructure – equipment that allows the UAVIU to transmit data in real-time to the operators at the BOO. In this study, it is assumed that the footage observed by the UAV pilot at the incident scene is transmitted in real-time through display mirroring software associated with the laptop.

4.3 Incident Response Process

Since the DJI Inspire 2 has a maximum controllability range of 7 km from the remote, two scenarios are created for UAVIU response. For incidents that occur within the UAV's 7 km controllability range where UAVs are stored, the UAVs are deployed from the BOO. For incidents that occur outside this range, the UAVIU is deployed to the scene. Figure 6 indicates the procedure followed for incidents occurring beyond the 7 km range.

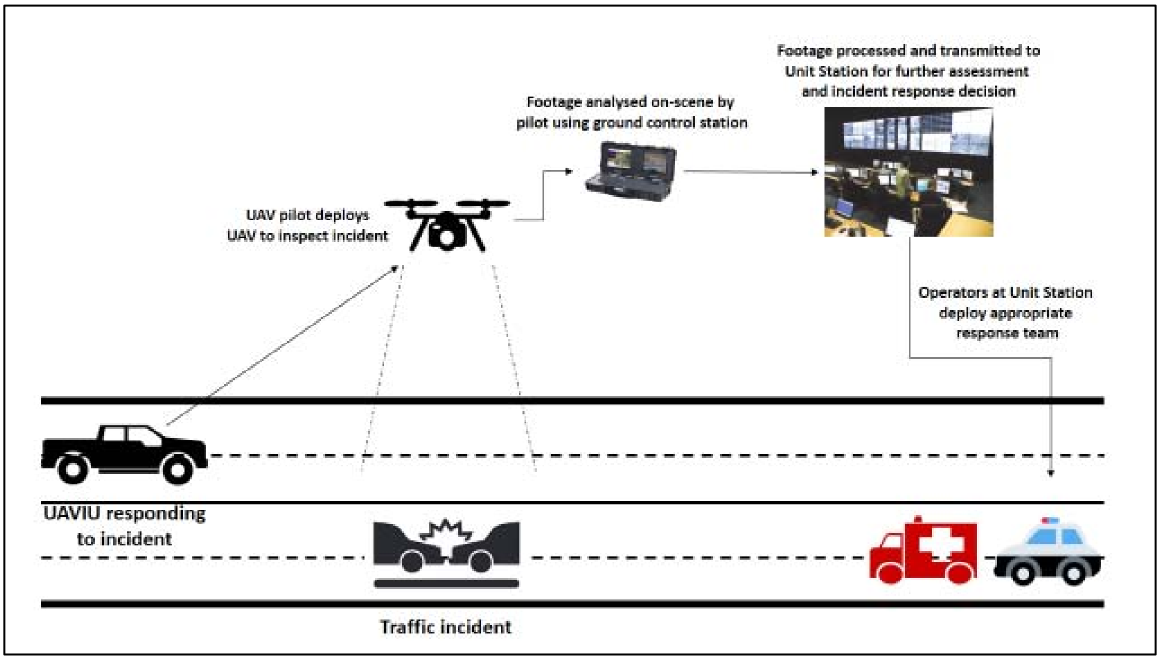

Figure 6: Incident response procedure for UAVs. Images used in Figure from Alpha Unmanned Systems (2020) and Hi-Tech Security Solutions (2013)

The steps related to Figure 6 are as follows:

1. Notification that an incident has occurred is received by operators at the BOO.
2. The UAVIU is deployed to the incident scene for inspection for incidents further than 7 km away from the BOO where UAVs are stored. For incidents within a 7 km range of the base, the UAV is deployed from the BOO directly.
3. The UAVIU pilot launches the UAV.
4. The UAV is flown to assess the incident scene and transmits this data in real-time high-definition video format to the on-scene ground station.
5. The ground station transmits this data to the BOO for assessment.
6. Depending on the situation, the UAV pilot may give camera control (allowing camera to pan, tilt and zoom) to personnel at the BOO to aid assessment. The UAV is always fully controlled by the pilot.
7. Depending on the severity of the incident scene and the time it takes to assess, the UAV can be returned to the pilot for a battery change.
8. Once the relevant decisions are made by the operators at the base, the UAVIU departs from the incident scene.

The time it takes for the UAV to be deployed from the BOO or UAVIU to arrive at the incident scene will affect the arrival time of response units to the scene, potentially having a big impact on incident clearance and medical response. It was therefore decided that for serious reported incidents further from the BOO than 7 km, that a life support paramedic should be deployed and accompanied by the UAVIU. For incidents occurring within the 7 km radius of the BOO, the UAV would be flown at its maximum speed of 94 km/h. This would mean that from detection, the UAV would be on scene and an incident could be observed and verified within 4.5 minutes.

5. BENEFITS AND LIMITATIONS

5.1 Traffic Monitoring Benefits

Freeway Management Systems, an ITS application implemented along freeways, often have CCTV cameras placed to allow continuous video coverage of the entire freeway network, requiring a CCTV camera to be placed approximately every 1 to 1.5 km. The cost of this infrastructure is offset by benefit of the system afforded to the high number of vehicles that use these Class 1 roads. In a small city environment, often without Class 1 roads (as is the case for Stellenbosch), such continuous coverage would not be economically viable. A major benefit of UAVs in traffic management is that UAVs are not fixed to a location as CCTV cameras are, allowing for mobile coverage of a study area with only one camera.

For the Stellenbosch study, at least 15 CCTV cameras would be required to provide coverage on the route, which is equivalent to that of one roaming UAV, as defined in Figure 5. These CCTV cameras would only provide coverage of the arterial road network, however, while the UAV would also provide coverage of adjacent collector and local roads.

The installation of a single, 2 megapixel CCTV camera (including infrastructure such as the mass concrete base, a 13 metre galvanised steel pole, camera mounting bracket, electronic components and fibre splicing components) costs R200,370 (cost estimate provided by SANRAL). One CCTV operator would also need to be employed to monitor all 13 cameras as once (so continuous coverage is also not possible as the operator must pan through the various cameras). In contrast, one UAV costs R156,660 (PC Link Shop, 2020), with one UAV pilot, who would also be viewing the footage. A capital cost saving of R2.22 million is therefore possible (cost of 15 CCTV cameras minus cost of 5 UAVs). In addition to this, annual maintenance cost is also reduced significantly by limiting infrastructure, and no downtime of systems is necessary as UAVs can be substituted out when another is undergoing maintenance.

5.2 Incident Management Benefits

The aerial view of a UAV allows for better understanding of traffic and incident conditions. Additionally, UAVs are not fixed to a location as CCTV cameras are, allowing for more optimal camera placement and footage of specific congestion triggers and incident scenes. UAVs provide an opportunity to monitor traffic at incidents without the limitation of roadside infrastructure placement. Using UAVs for incident response allows emergency response units to view an incident from a different angle or to view the severity of an incident to better understand which response vehicles should be deployed to the incident scene.

5.3 Limitations

One limitation of using UAVs to monitor traffic and observe incidents is that continuous observation of the road network is not possible. Traffic monitoring is only monitored in morning and afternoon peaks according to the strategy developed in this case study. Additionally, every location is only observed every 25 minutes as the UAV passes over. This also has a negative impact on incident management, because there is no video coverage of the incident taking place, which is often available with continuous CCTV coverage (depending on the view of the camera when the incident occurs).

To compensate for this reduced observation field, another alternative traffic monitoring tool, namely Floating Car Data (FCD) can be used to augment The TMCs functionality. FCD can be obtained from a third-party provider (for example, TomTom, HERE or Inrix), providing real time average speed data along the road network. If speeds drop below average speeds on a particular link on the route during different periods of the day, then traffic management staff can be notified of a possible incident or unexpected congestion, prompting inspection by a UAV. Locations where drivers break the speed limit can also be identified with FCD.

Another significant limitation related to using UAVs in traffic management is the lack of presence of government policies which may cause delays in UAV implementation. In addition to this, flight regulations for UAVs introduced by the South African Civil Aviation Authority (SACAA) have many restrictions relating to special flight permissions such as flying close to buildings and airports and flying over roadways. Secondly, limitations are introduced relating to the flight time of a UAV due to its battery life as well as the distance the UAV can operate from the remote. Finally, due to the limited battery life, traffic monitoring is not possible for a 24-hour period. A larger UAV network would then have to be implemented, which could become expensive considering the cost of UAV licenses.

6. CONCLUSION

This paper has detailed the implementation strategy for a UAV system that can be used for traffic monitoring and incident response using five UAV units. A UAV flight path was determined for traffic monitoring during the morning and afternoon peak 2-hour period. This included the determination of the UAV flight parameters, which are flight height and speed. It was found that a UAV would be able to travel at a controllable speed of 45 km/h and cover a 4 km radius around its deployment location in 25 minutes, covering all major arterials and collector roads in Stellenbosch. This would require an equivalent of 15 CCTV cameras to provide continuous coverage, and therefore the UAV option allows a significant capital cost saving (R2.22 million). Following this, a procedure for implementing UAVs to assist with traffic incident response was developed. A framework for how UAVs are used by incident response personnel was created which is affected by the controllability range of the UAV from its remote.

An analysis of the benefits and limitations relating to using UAVs in traffic monitoring and incident response found that, for Stellenbosch, UAV coverage would be considerably cheaper to maintain and implement than multiple CCTV cameras. The limitation of implementation of UAVs for traffic management can be solved somewhat by using FCD for real-time monitoring of traffic speeds. Where speeds decrease suddenly and unexpectedly, an incident may have occurred, prompting closer inspection with a UAV.

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