IMPLEMENTATION OF UAVS AND FCD IN ADAPTING TO THE 'NEW NORMAL' IN THE TRANSPORTATION INDUSTRY: A TRAFFIC MANAGEMENT CASE STUDY

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ABSTRACT

The Transportation industry has grown over the last few decades with the improvement of current transport technologies as well as through the implementation of innovative transport practices. This growth is happening worldwide at a country-specific pace. Now, with travel restrictions due to the COVID-19 pandemic disrupting the transport sector, the Transportation industry is forced to adapt to changes in conventional travel behaviour and practices. Whether it be changes to current aspects of a transport system or reimagining entire processes, adaptation is required. This paper assesses both of these possibilities through a case study relating to traffic management processes in the study area of Stellenbosch. Changes to current traffic management processes relating to road traffic management and incident response with the use of Unmanned Aerial Vehicles (UAVs) and Floating Car Data (FCD) are assessed in this paper. Furthermore, a reimagination of the entire traffic management process is explored theoretically, which incorporates innovative transport technologies and systems. The goal of this paper is to development a framework for efficient transportation management that is relevant for a country with a developing transport infrastructure.

1. INTRODUCTION

1.1 Background

Having been disrupted due to the COVID-19 pandemic, governments around the world aim to regain some form of normality in the transportation industry. Not only has there been direct impacts on transportation such as reduced public transport ridership and increased private vehicle usage, but also certain indirect impacts such as unprecedented drops in vehicle sales and changes in the manner of which people travel. Not all these impacts, however, are negative. The pandemic has helped bring into realisation the fact that, in some professions, people can perform tasks at home partially or entirely, without the need to travel to a dedicated office space. The pandemic has shown world governments that people can adapt to change and that transportation industries need to follow suite in order to maintain the provision of effective transport solutions that are needed by society. These transport solutions should be determined at a country-specific level to aid the needs of different people based on their desired trip destination.

In a diverse country such as South Africa with cities and townships that houses people with varying needs, finding one solution that fulfils everyone's needs can be difficult. The difficulty of this task is amplified since the current transport infrastructure is already being put under strain by the number of people it is required to serve. This strain filters through to all sectors of transportation management and requires attention in order to be relieved.

1.2 Research Motivation

Traffic management plays an integral role in ensuring efficient traffic flows through the road network. This management is often done from a central locale known as Traffic Management Centres (TMCs) by managing traffic-related incidents and accidents through different management processes. These processes enable 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. For systems to adapt to change, utilities within these systems are sometimes required to adapt as well. This notion is the basis of this article, which assesses how Unmanned Aerial Vehicles (UAVs) and Floating Car Data (FCD) obtained from vehicular data probes can aid transport management processes. Furthermore, using UAVs have an added benefit mobility of providing surveying in 'dark spots' of CCTV cameras, which aids in the monitoring of NMT activities and NMT-related incidents.

2. RESEARCH DESIGN

2.1 Methodology

The operational strategy for using UAVs and FCD to support traffic management and incident response processes will be detailed in this study. This report assesses ways in which UAVs and FCD can be implemented to traffic management processes to aid adaptation to change. Both components are assessed individually, followed by a Cost-Benefit Analysis highlighting the costs associated with these components. Finally, a theoretical long-term goal of achieving cloud-based traffic management is explored.

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. The full study details the design of two Test Models (TM 1 and TM 2) where TM 1 is the implementation of conventional TMC practices for Stellenbosch, and TM 2 is a reduced-hardware version of TM 1 with UAVs and FCD replacing some hardware components in TM 1.

2.2 Study Area

The road network of Stellenbosch assessed in this study is indicated in Figure 1 and consists of the following roads:

- 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, passing northbound through Stellenbosch to the R101 (red).
- The R304 from the R101 to Stellenbosch at the intersection with the R310 (purple).
- Annandale Road from the R310 to the R44 (blue).

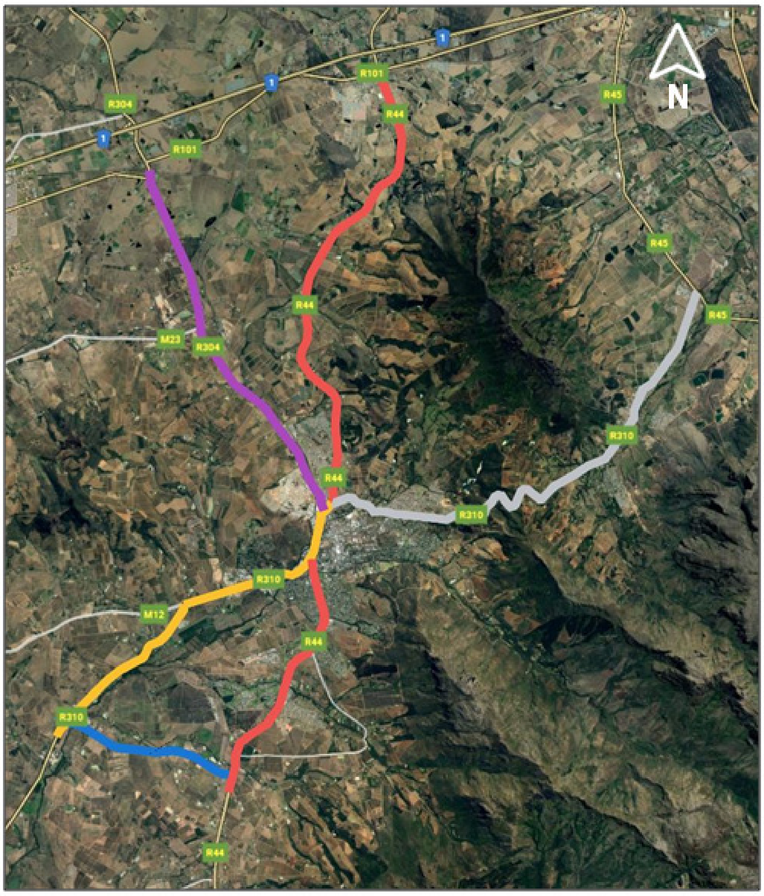


Figure 1: Study area for research (Google, 2022)

2.3 Assumptions

The assumptions made for this study to be completed are:

- Inclusion of UAVs:
  - The UAV is assumed to be controllable to the maximum range from the controller for any location in the study area and has a maximum battery life of 27 minutes.
  - All UAVs used in the study can fly to the height required and are kept within commercial height regulations as constructed by The South African Civil Aviation Authority (SACAA).
    - In order for this analysis to continue, it is assumed that all licensing requirements (operating and pilot licenses) are availability and that UAVs can fly in all zones as a study to determine no-fly zones would be extensively detailed and was not done for this study).

- Inclusion of FCD:
  - It is assumed that 5% of vehicles on roadways of the study area are probes that transmit location data for analyses, based off the assumption that 5% of vehicles are data probes on a national level (Houbraken, et al., 2017).
    - This assumption was kept for South Africa, although the number of vehicle probes may differ due to various aspects of the country.
  - Delay calculations are not required and only need to be discussed.

3. CHANGES DUE TO IMPLEMENTING UAVs AND FCD

With implementing UAVs and FCD in sectors of traffic management in Stellenbosch, there are changes in the number of hardware components and personnel. These changes are summarised in Table 1. Note that Table 1 only shows the components that have changed. More information is provided in the chapters that follow.

Table 1: Changes in hardware and staff when implementing UAVs and FCD

Component of traffic management	**TM 1 (Conventional TMC)**	**TM 2 (Implementing UAVs and FCD)**	**Comment**
Quantity of components			
Arterial CCTV Cameras	25	7	72% Hardware reduction
Urban CCTV Cameras	36	5	86% Hardware reduction
Arterial Vehicle Detection Sensors (VDSs)	28	7	75% Hardware reduction
Urban VDSs	9	0	None required as UAVs aimed to provide coverage of urban areas
UAVs	0	5	
Number of Staff			
Urban CCTV operators	6	3	50% reduction (Arterial operators kept the same as these staff members manage VMSs as well)
UAV Pilot	0	1	SACAA RPAS qualified pilot
FCD Package	0	1	Based on estimate at the time of study for annual TomTom FCD package

From Table 1:

- There are a number of components and staffing that are reduced when implementing UAVs and FCD, and an assumption is that the UAVs and FCD introduced will be able to maintain and increase the level of functionality of traffic management practices with conventional hardware and staffing. A detailed functionality assessment is presented in the full thesis.
- The full thesis has detailed descriptions of component placements and quantities for both Test Models set up. Table 1 is therefore a snippet of this information, showing the amount of hardware and personnel being replaced with UAVs and FCD.

The procedure in which UAVs and FCD are implemented to traffic management is presented in Chapters 4 and 5.

4. INCLUSION OF UAVs TO TRAFFIC MANAGEMENT

There is no doubt that technology plays a key role in improvements of various systems. As systems innovate and adapt to change to avoid becoming obsolete, the implementation of modern technological devices becomes a core practice. The same notion can be followed when considering the transportation industry. In order to adapt to change, newer technologies need to be brought in to assist (and possibly even replace) older components in order to keep surfing the century's disruptive wave.

Using UAVs in traffic monitoring processes not only allows for an improvement to current practices, but also provides a pioneering outlook on traffic monitoring that can be used to adapt to change. UAVs are used for such purposes in aspects of traffic management in this study: Traffic Monitoring and Incident Response.

4.1 UAVs Used for Traffic Monitoring

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 drone used for this study is the DJI Inspire 2. This is a survey drone owned by the Department of Civil Engineering at Stellenbosch University. Key features of the DJI Inspire 2 include: HD video recording up to 6K resolution, a 7 km maximum operational range from the controller, and built-in obstacle avoidance technology (DJI, 2020). The DJI Inspire 2 is shown in Figure 2.

Figure 2: DJI Inspire 2 (Prindle, 2018)

Certain factors affected the choice of drone. Firstly, DJI is one of the most cost-effective and market-dominating drones in the market, controlling 70% of the drone-market worldwide (Hambling, 2015). The video recording resolution is superior when compared to other drones. The camera on the DJI Inspire 2 also has relatively high frame rates, producing a smoother output. In addition to this, there are many apps that can be linked easily to the software of a DJI drone for various reasons, including the creation of 3D models of terrain and measuring volume of materials. This software is good for surveyors, architects, and engineers and has room for improvement for future uses. Finally, the DJI Inspire 2 was used as this was the best drone of all drones available at the time of the study, based on the aforementioned specifications.

The maximum battery life of the drone used in this study 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. In total, 4 UAVs will fly for 25-minute periods between 06h20 – 08h00 in the AM and 16h20 – 18h00 in the PM

4.1.1 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. Furthermore, the static Field-of-View (FoV) angle of the camera on the UAV was chosen as $\Theta = 50°$. This means that the FoV to either side of the UAV is 50°, providing a total FoV of 100°. Using a Pythagorean relationship, the maximum distance the UAV can see clearly is 143 m from its centerline.

4.1.2 UAV Flight Path

The area of highest traffic congestion around central Stellenbosch was found to fall within a 4 km radius. It is proposed that the UAVs used in the traffic management 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 3. The total flight distance for each UAV is 18.43 km. To provide acceptable image quality, the simple relationship of speed = d/t was used. With known parameters, the speed each UAV flies was determined to be 45 km/h.

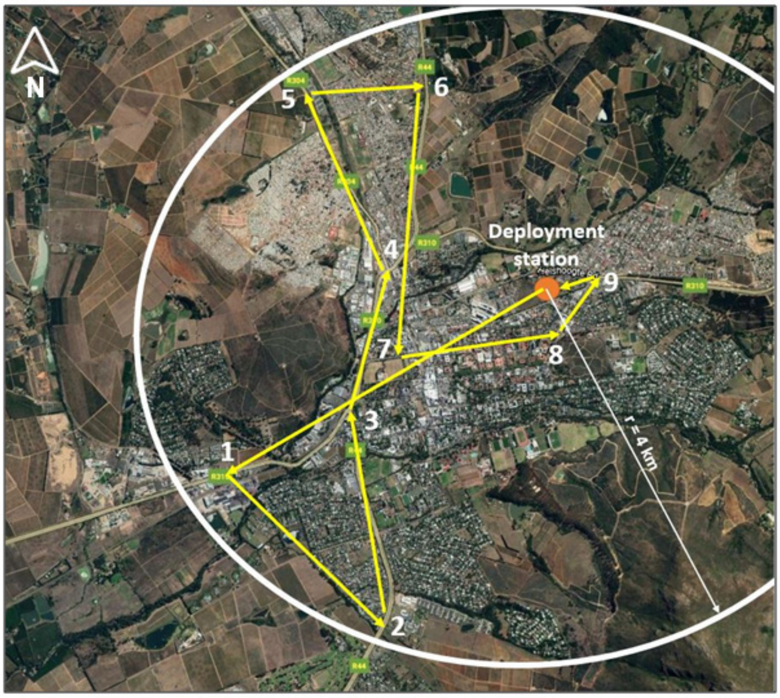


Figure 3: UAV Flight Path

4.2 UAVs Used to Aid Incident Response Procedures

Apart from being used to aid traffic monitoring procedures, UAVs can also be used to assist emergency units' responses to incidents. For this study, each incident responded to with the aid of a UAV is called a UAV Incident Unit (UAVIU). The UAVIU consists of the UAV and accompanying payloads (camera and LIDAR to aid mapping of incident scene), a transport vehicle, ground control station (a laptop for navigational control and to analyse imagery obtained), and two-way data communication infrastructure to allow the UAVIU to transmit data in real-time to the operators at the relevant Base of Operations (BOO). Tt 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. 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 4 is a simple illustration which indicates the procedure followed for incidents occurring beyond the 7 km range.

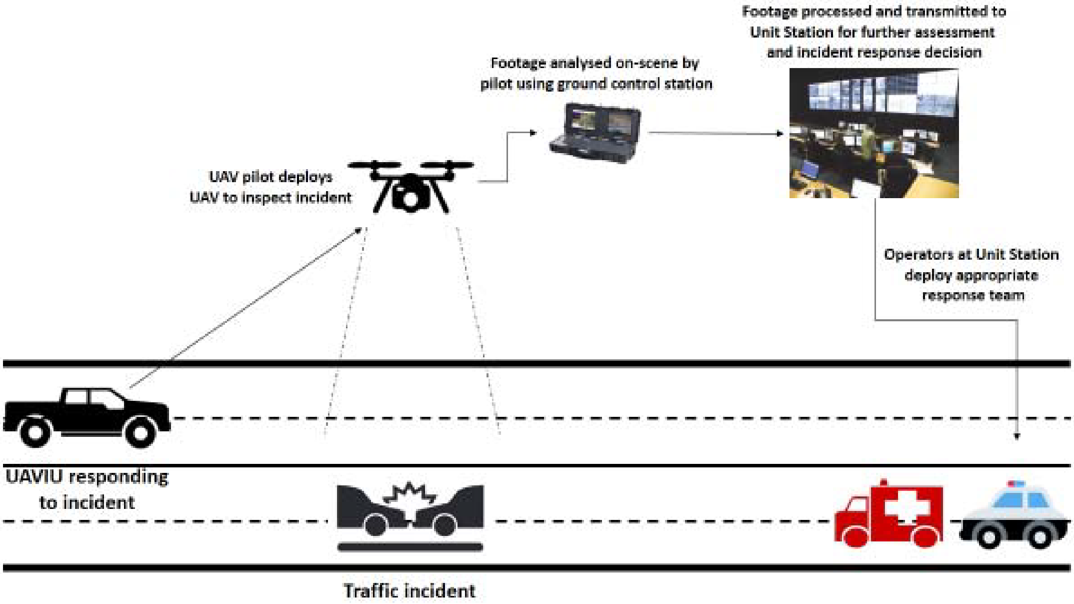


Figure 4: Incident response procedures for UAVs. References for images used in this Figure: (Alpha Unmanned Systems, 2020) and (Hi-tech Security Solutions, 2013)

4.3 Limitations Associated with UAV Traffic Management

There are limitations associated with using UAVs in traffic management, such as:

- A lack of presence in government policies may cause the implementation of UAVs in traffic management to be delayed.
    - Special authorisation is required to operate a UAV close to airports, highways and telecommunication buildings.
    - There are also issues regarding privacy due to UAVs being able to observe people's personal spaces during monitoring.

- The limited battery life associated with UAVs reduce the flight time available and the flight path and times are constrained to this.
    - 24-hour traffic monitoring is not possible with the limited battery life. Thus, only the morning and afternoon peak periods were assessed in this study. A mixed model would be ideal with CCTV cameras on main portions of roadways.
    - The UAV is limited to its controllable range, thus operating over central Stellenbosch. More UAVs and UAV pilots would be required to monitor traffic of the larger road network.

5. IMPLEMENTATION OF AN FCD SYSTEM TO TRAFFIC MANAGEMENT PROCESSES

The use of FCD in traffic management processes has increased exponentially over the past few years due to Big-Data sources being more readily available. This increased FCD usage has allowed its application to be grown from conventionally only showing delays in travel speeds, to predicting optimal routes and congestion times for major and minor roadways. FCD can also be used to optimise responses of emergency vehicles, which is discussed in this chapter.

5.1 FCD Incident Detection System (IDS)

For the purpose of this study, only vehicular probes is used for data collection. For this study, probe data is obtained from a third-party provider (for example, TomTom®).

The FCD IDS uses location data provided by a third-party supplier to detect incidents.

Data is requested for a specific and the dataset provided consists of:

- The date and time period associated with the dataset.
- The data source (in this case, vehicle probes).
- The route length covered.
- Sample size of vehicles on the roadway for the given time period.
- Average travel times and speed, with which percentile travel times and speed can be determined.

The IDS for this study uses the speed, location and time information obtained by probes to determine if an incident has occurred or where traffic is becoming congested. The IDS has three velocity parameters; a lower velocity limit, V_{lower}, upper velocity limit, V_{upper}, and an average velocity placeholder, $V_{average}$. V_{upper} is the free-flow speed that vehicles travel (the speed limit of the road), $V_{average}$ is the average speed that a vehicle travels based on congestion levels at a given time, and V_{lower} is the lowest speed a vehicle can travel at maximum congestion level. These velocities are updated in real-time based on the data received from data probes. When the speed on a road in the study area drops below V_{lower} for a period of time T longer than the average peak congestion time T_{APCT}, this indicates that an incident has occurred on the particular roadway (T_{APCT} is unique to each roadway for a specific time of day and this is determined from trip generation processes not discussed in this study). This action prompts the VMS to inform drivers to expect delays or to alter their route if they are affected. This action also notifies traffic management staff who can confirm the incident by sending a UAV to inspect the incident scene, as described in Section 5.3 (since the result of congestion may be a faulty traffic signal). Once the speed of vehicles on the roadway increasing to a value above V_{lower}, this indicates that the incident, congestion or accident has been resolved and normal traffic operations are continuing. Locations where drivers break the speed limit V_{upper} can also be identified with the FCD so that measures can be put in place on that particular roadway to prevent reckless driving (since driver identities are not obtained from data probes). This process is illustrated in Figure 5.

The delay indicated in Figure 5 is a function of the following factors:

a. Delay in Data Transmission (A)
When a data packet is sent to the server, this does not occur instantly. There is a slight delay involved with the transmission of GPS data. This delay is usually 20 seconds and is dependent on the specifications of the server system being used and is influenced by connectivity type, hardware and software (Houbraken, et al., 2017).

b. Sampling Delay (B)
Another delay when receiving data is due to the number of vehicles that are data probes on the road. FCD usually works with 5% penetration, meaning that 5% of the vehicle population on the road are probes for transmitting location data, affecting the frequency of received data. This is based on the research conducted by Houbraken et al (2017).

c. <u>Data Filtering Delay (C)</u>

Similar to the delay associated with data transmission, there is a delay related to the central server's procedure for filtering data that is incomplete or erroneous.

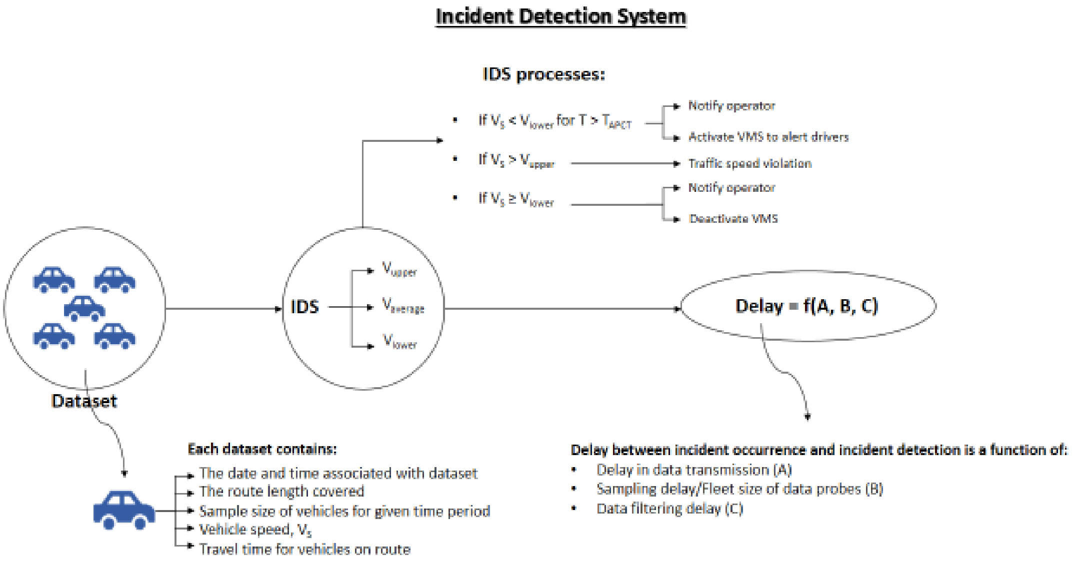


Figure 5: IDS

5.2 FCD Incident Response Analysis

As part of this study, a travel time analysis assessing the location of the proposed Unit Station which houses incident response vehicles was conducted. The Unit Station (US 1) is located in Central Stellenbosch at the Cluver Road/Helshoogte Road intersection as current fire and rescue vehicles are housed here. FCD is used to analyse how effectively units deployed from this location can respond to an incident occurring within that portion of the Cape Winelands Municipality.

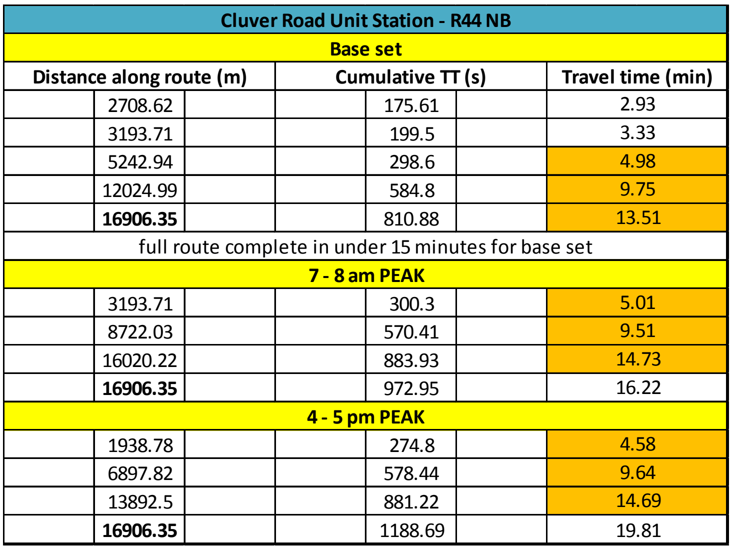
For Stellenbosch, historic FCD obtained from TomTom® was used to determine the times where traffic speeds are the lowest. The peak periods, using FCD, was found to be:

- AM Peak: 07h00 – 08h00.
- PM Peak: 16h00 – 17h00.
- Off-peak: 23h00 – 05h00.

Following this, the distance that emergency vehicles can travel along each of the main arterials including surrounding urban areas was determined by manipulating the FCD obtained from TomTom®. This is indicated in Table 2 for one arterial in the study area. The same procedure was applied to all arterials. Furthermore, an additional Unit Station (US 2) is proposed at the Molteno Road/R310 (Adam Tas Road) intersection in case of simultaneous incidents as well as to respond to incidents closer to it. The locations of US 1 and US 2 are indicated in Figure 6.

This distance was plotted for 5, 10 and 15 minutes as incidents occurring in urban areas should be responded to within 15 minutes (Stein, et al., 2015). Maps were produced for each peak period. Figure 6 indicates these travel times. To avoid repetition, only the map for the off-peak period is shown.

Table 2: 5-, 10- and 15-Minute Travel Times from US 1 to the R44 (NB)/R101 intersection



Cluver Road Unit Station - R44 NB		
Base set		
Distance along route (m)	**Cumulative TT (s)**	**Travel time (min)**
2708.62	175.61	2.93
3193.71	199.5	3.33
5242.94	298.6	4.98
12024.99	584.8	9.75
16906.35	810.88	13.51
full route complete in under 15 minutes for base set		
7 - 8 am PEAK		
3193.71	300.3	5.01
8722.03	570.41	9.51
16020.22	883.93	14.73
16906.35	972.95	16.22
4 - 5 pm PEAK		
1938.78	274.8	4.58
6897.82	578.44	9.64
13892.5	881.22	14.69
16906.35	1188.69	19.81

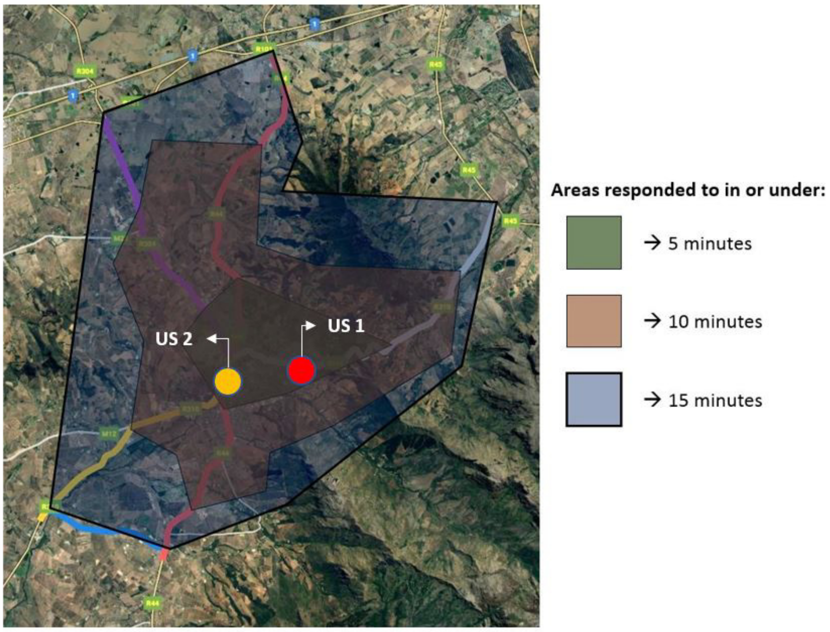


Figure 6: Travel Time Response map for Off-peak Period

From Figure 6:

- For the base period, any location within the study area can be responded to in under 15 minutes. This is due to the low traffic at these hours (23h00 to 05h00).
- Overall, the PM peak experiences the worst traffic and response times to the end points of all the arterials, except the R310 NB, are the highest. Analysing both the AM and PM peak travel time maps with the FCD indicates a large portion of time is spent between the R310 (Adam Tas Road) – R44 and R310 (Adam Tas Road)/R304 intersections. This is due to the bottlenecks formed at the Adam Tas Road/Merriman Avenue and Adam Tas Road / R310 intersections when university students and staff, school students and other workers are all exiting Stellenbosch.
- In total, 52.40 km of arterial roadway is covered in the morning peak hour and 45.60 km in the afternoon peak hour. In contrast, 14.1 km and 24.3 km of roadway are not covered in at least 15 minutes during the morning and afternoon peak hours respectively.

The applicability of the Unit Station's location can be determined when analysing the response time for emergency vehicles from the Unit Station to high accident zone areas. Historic accident information for Stellenbosch for the years 2014 – 2016 was provided by Professor Marion Sinclair from Stellenbosch University and assessed. In total, 7094 road-related incidents occurred over the three-year period, ranging from non-injury accidents to fatal accidents. The four roads with the highest number of accidents (or in the vicinity of the road) are: Adam Tas Road (to Vredenburg intersection SB, 1.5 km north of Helshoogte Road / Adam Tas Road intersection NB), Bird Street, Merriman Avenue and the R44. An acceptable response time to the furthest point on these roads from the Unit Station would mean that the location of the Unit Station is appropriate. Table 3 indicates the response time to the furthest point on these roads from the Unit Station for the base, morning-and-afternoon peak periods. The number of accidents and the percentage of total accidents on these roads are also provided in Table 3.

Table 3: Response time to accident hotspots on four different roads in Stellenbosch

Road	Number of accidents	% of total (7094) accidents	Base period response time (minutes)	AM Peak response time (minutes)	PM Peak response time (minutes)
Adam Tas Road SB	307	4.32%	9	14.9	17.2
Adam Tas Road NB	79	1.11%	3.6	6.2	9.3
Bird Street	802	11.3%	3.2	8	11.4
Merriman Avenue	428	6.03%	2.5	9.7	7.6
R44	1294	18.24%	11.5	17	20.6
Total	**2910**	**41%**			

From Table 3, it is evident that the only roads that exceed the 15 minute response time limit is Adam Tas Road Southbound for the PM peak and the R44 for the AM and PM peaks. The Unit Station's location is therefore appropriate since response units usually travel at faster speeds than average, reducing response time.

6. COST-BENEFIT ANALYSIS OF USING UAVs AND FCD IN TRAFFIC MANAGEMENT

The benefits of implementing UAVs and FCD to traffic monitoring and incident response processes are:

- UAVs:
  - UAVs provide a better understanding of an accident by obtaining aerial imagery and are not fixed, allowing for better surveillance in accessible areas.
  - Reduced maintenance costs due to UAVs being non-intrusive (no physical hardware needs to be installed on roadways).
  - It was found that one UAV has potential traffic monitoring capacity equivalent to 15 fixed CCTV cameras, which significantly reduces cost of traffic management hardware (R2.2 million reduction).

- FCD:
  - FCD is non-intrusive reducing hardware and maintenance costs.
  - Although only 5% of vehicles are probes on the road network, this provides data with a relatively high accuracy as compared to data provided by road sensors.
  - FCD provides traffic data for the entire study area including all minor urban and rural roads. Vehicle Detection Sensors only provide data for the portion of the roadway they are installed on. FCD can therefore replace VDSs and can provide travel information on all roadways, not just at places where VDSs are located.

Furthermore, a section of the Cost-Benefit Analysis calculated in the full thesis is provided in Table 4 and Table 5.

Table 4: Installation and Maintenance costs for Implementation of Test Model 1

	Test Model 1		
Year	**Installation cost**	**Maintenance cost**	**Discounted to year 0**
End year 0	R24,858,314.85	R0.00	R23,016,958.19
1	*****	R0.00	R0.00
2	*****	R3,728,747.23	R3,196,799.75
3	*****	R0.00	R0.00
4	*****	R3,728,747.23	R2,740,740.53
5	*****	R0.00	R0.00
6	*****	R3,728,747.23	R2,349,743.25
7	*****	R0.00	R0.00
8	*****	R3,728,747.23	R2,014,526.11
9	*****	R0.00	R0.00
10	*****	R3,728,747.23	R1,727,131.43
11	*****	R0.00	R0.00
12	*****	R3,728,747.23	R1,480,736.83
13	*****	R0.00	R0.00
14	*****	R3,728,747.23	R1,269,493.16
15	*****	R0.00	R0.00
16	*****	R3,728,747.23	R1,088,385.77
17	*****	R0.00	R0.00
18	*****	R3,728,747.23	R933,115.37
19	*****	R0.00	R0.00
20	*****	R3,728,747.23	R799,996.03
TOTAL =	*****	R37,287,472.28	R40,617,626.43

Table 5: Installation and Maintenance costs for Implementation of Test Model 2

	Test Model 2		
Year	**Installation cost**	**Maintenance cost**	**Discounted to year 0**
End year 0	R12,523,880.02	R0.00	R11,596,185.20
1	*****	R0.00	R0.00
2	*****	R1,878,582.00	R1,610,581.28
3	*****	R0.00	R0.00
4	*****	R1,878,582.00	R1,380,813.85
5	*****	R0.00	R0.00
6	*****	R1,878,582.00	R1,183,825.32
7	*****	R0.00	R0.00
8	*****	R1,878,582.00	R1,014,939.40
9	*****	R0.00	R0.00
10	*****	R1,878,582.00	R870,146.95
11	*****	R0.00	R0.00
12	*****	R1,878,582.00	R746,010.76
13	*****	R0.00	R0.00
14	*****	R1,878,582.00	R639,583.99
15	*****	R0.00	R0.00
16	*****	R1,878,582.00	R548,340.18
17	*****	R0.00	R0.00
18	*****	R1,878,582.00	R470,113.32
19	*****	R0.00	R0.00
20	*****	R1,878,582.00	R403,046.40
TOTAL =	*****	R18,785,820.03	R20,463,586.66

From Table 4 and Table 5:

- A year-0 based comparison between two different Test Models (TMs) is shown in Tables 3 and 4. In both instances, maintenance was assumed to be 15% of the initial cost.
- Installation costs refers to the cost of hardware (CCTV, VDSs, loop sensors and Environmental Sensing Stations) and associated software packages (FCD software for TM 2). Cost estimates for components were obtained from SANRAL.
- The reduction in the cost of TM 2 is due to the number of hardware components being reduced on roadways of the study area as UAVs and FCD would replace this functionality.
- A further Functionality Assessment of each component type is provided in the full Master's document.
- It is evident that a well-equipped TM 2-type traffic management system would reduce the cost of implementation to half.

Furthermore, Table 6 provides the Present Worth of Costs (PWOC), Benefit/Cost (B/C) Ratio, Internal Rate of Return (IRR) and Net Present Value (NPV) that TM 2 possesses over TM 1 for hardware components. For each evaluation, TM 2 was the cheaper option.

Table 6: PWOC, B/C Ratio, IRR and NPV for TM 2

PWOC (TM 2)	**R20,463,586.66**
B/C Ratio (TM 2)	**1.74**
IRR (TM 2)	**4%**
NPV (TM 2)	**R8,557,854.57**

Another aspect to consider is the operator costs associated with traffic management. As indicated previously in Table 1, there are a significant number of changes that occur when implementing UAVs and FCD. Of these, the main non-hardware related components are the salaries for CCTV operators, UAV pilot and the cost associated with an FCD package. A summary of the full analysis conducted in the thesis for this study is that the annual costs associated with salaries and software for TM 1 and TM 2 are R6.54 million and R7.42 million respectively. Although there are less CCTV operators, TM 2 costs more due to the cost of the FCD package (estimated at R1 million at the time of analysis). The FCD package estimated was for TomTom. An estimated monthly salary of a UAV pilot was set as R20,000 to fly the UAV for two hours in both AM and PM peaks daily. Although TM 2 costs slightly more from a salary and software point of view, the benefits, such as adaptation to future technological trends, can potentially lead to a system that is better equipped to adapt to technological disruptions.

7. THEORETICAL REIMAGINATION OF THE ENTIRE TRAFFIC MANAGEMENT PROCESS

The futuristic idea of having advanced traffic management processes is not a long-term goal anymore. With increasing improvements of components and technology, better and more data is available. Physical TMCs might seize to exist in a few years' time, and UAVs and FCD can be the pioneering factor for traffic monitoring and incident response.

Theoretically, one future option is having a cloud-based TMC which requires no traffic monitoring hardware, other than response units, UAVs and FCD. An optimal combination of UAVs will be needed to provide coverage at all times due to battery constraints. When this is achieved, incident recognition algorithms can be introduced for UAVs, which uses Artificial Intelligence to allow UAVs to autonomously fly a specified path and detect incidents. This can be further improved with UAV-to-UAV communication to calibrate positioning and flight patterns of a UAV network. Incidents picked up by FCD via traffic speed reduction can be instantaneously responded to, reducing delay in response time. The introduction of deep-and-machine learning in software can further develop traffic management processes.

There are endless possibilities and, with technological disruptions occurring rapidly around the world, this idea of a cloud-based TMC would be a pioneering effort to steer the transportation industry in the direction of keeping up with these disruptions.

8. RECOMMENDATIONS FOR FURTHER RESEARCH

It is recommended that pilot studies be conducted to assess the capability of traffic management system using UAVs and FCD due to this thesis being only a theoretical analysis. An optimal combination of UAVs and reduced number of CCTV cameras and other hardware components should be determined that takes into consideration safety aspects associated with CCTV cameras. Blind spots that CCTV cameras do not cover need to be accounted for with UAVs and vice versa. It is also recommended that different types of UAVs with varying specifications be tested so that UAVs can possibly fly at lower speeds, producing visuals with greater quality.

Future research should include the analogy of automated signal changes when emergency vehicles approach. Research into using AI to predict when incidents have/will occur is recommended. This can be done by “training” software to notify operators when normal traffic conditions are altered. The implementation of a cloud-based traffic management system should be assessed, keeping in mind the collaborative environment TMCs provide for stakeholders, law-enforcement and management parties involved in TMC processes. A mixed-model should be set up and tested.

9. CONCLUSION

This paper has detailed the implementation strategy for UAVs and FCD to traffic monitoring and incident response. 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. Furthermore, it was found that FCD has the capability of efficiently aiding Incident Response procedures by optimising emergency unit storage locations and routes of travel. Following this, a cost-benefit analysis of the implementation of UAVs and FCD was presented, indicating that a model with UAVs and FCD replacing certain aspects of conventional traffic management is a more economically viable option. Finally, a discussion regarding the reimagination of the entire Traffic Management process was provided, discussing the bigger role UAVs and FCD play in the Transportation industry.

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