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Drones for Traffic Flow Analysis of Urban Roundabouts

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Abstract The reliability of traffic measurement data becomes an essential prerequisite for road traffic studies, in order to respond effectively to the major challenges caused by the significant growth in vehicle volumes on the road network. Today several techniques are used to obtain these count data, but they have disadvantages such as the limited range of action, sometimes requiring the coupling of several sensors, insufficient processing time, or degradation of the equipment, which requires high maintenance costs for local authorities. Drone technology is quickly accepted as a very dynamic and reliable technique for the collection of detailed and accurate traffic data. The current paper investigates, through a real-life case study in an urban roundabout, the potential offered by drones for traffic measurements in order to overcome certain difficulties encountered by conventional sensors. The counting data from the drones provides ease of processing and a comprehensive view of the operation of the study area. The results from drone videos show relative errors mostly less than 10% and low absolute errors.

Keywords Traffic flow, Drones, Roundabouts, Comparative analysis

1. Introduction

1.1. Traffic Monitoring Techniques

The efficient monitoring and control of continuously increasing traffic flows, occasionally concluding into congestion problems, is a critical challenge that traffic operators must face worldwide. Roundabouts provide an alternative traffic management solution considering capacity and safety issues at urban intersections, where a high volume of conflict points arise. A roundabout (also called a traffic circle, road circle, rotary, rotunda or island) is a type of circular intersection or junction in which road traffic is permitted to flow in one direction around a central island, and priority is typically given to traffic already in the junction, hence ensuring a smooth and safe flow of traffic [1].

Traffic control in roundabouts has been traditionally performed by using manual counters and observers, induction loops, stationary video recorders etc.

Traffic count techniques can be categorized into two types. The intrusive such as pneumatic road tubes, piezoelectric sensors and magnetic loops and non-intrusive, such as which are based on remote observations such as manual counts, passive and active infra-red, ultrasonic and passive acoustic and video image detection. The main drawbacks of these techniques include issues like limited lane coverage, sensitivity to meteorological conditions, inefficiencies due to low speed flows and high maintenance costs. Generally, the main drawbacks of the conventional methods is the limited 'point' data they provide, which cannot be used to estimate complex traffic flows as well as the lack of capability to capture the increasing number of hidden points i.e. objects of interest hidden either partially or completely behind other objects e.g. trees, trucks etc. The increase of cameras/sensors as a solution seems to be most of the times unrealistic due to the high cost involved. On the other hand, recent IoT based technologies for traffic management like smartphones and GPS provide big and difficult controllable data [5].

No single detection technology can be considered the most suitable for all applications: each one may have good performance or some limits, depending on various factors and a successful application of a detection system largely depends on proper matching between the established requirements and the technology selection [2] [3] [4].

1.2. Potential Applications of UAVs Technology

Recently, Unmanned Aerial Vehicles (UAVs) or drones have been proposed for traffic monitoring, management, and control purposes as an alternative in order to overcome the above-mentioned limitations and shortcomings of current practices.

UAVs may be used in several applications in traffic management, including weather and pavement conditions monitoring. UAVs also support emergency vehicle guidance, incident responses, measuring the usage of roadway, monitoring the utilization of parking lots, estimating origin and destination, traveller information,

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tracking vehicle movements at an intersection, and coordinating among a traffic signal network [6]. UAVs have several advantages over manned vehicles in terms of cost, safety, and time [7]. Based on Karan et al. [8], state Departments of Transportation (DOTs) in the United States have considered the integration of UAV technology for different applications including monitoring the environmental conditions of roadsides, tracking construction projects on highways, traffic safety and management applications, and structure inventory performance for road maintenance. Based on Barfuss, et al. [9] UAV could be used to define different construction zones based on time intervals, aiming at safer transportation throughout the construction projects. In the past few years, UAVs have been introduced in several transportation management applications, mostly being used to observe, analyze and evaluate the traffic flow as well as safety conditions.

The use of UAVs could enhance effectiveness of traffic operators [10] by enriching databases for better predictions about congestion phenomena, improving range and speed of intervention at difficult approachable scenes and eventually avoiding accidents, increasing to near real time data collecting and monitoring frequency, providing the ability to cover large areas with a single drone, which is not achievable with a single inductive or pneumatic sensor.

However, being a recent technology, the traffic management applications have not yet fully developed. Also, several restrictions issues and limits have to be considered in each case of real application. Internal and external factors that can influence the planned activities should be identified and analyzed when merging of drone technology and road traffic management.

One of the highest influencing factors on UAVs applications is the regulatory restrictions. The rules on drones must provide the basic principles to ensure safety, security, privacy and the protection of personal data. On 22 December 2017, EU ambassadors (Permanent Representatives Committee) endorsed the deal concluded with the European Parliament on 29 November 2017 on revised common safety rules for civil aviation and a new remit for EASA. The reform includes the first-ever EU-wide rules for civil drones. It allows RPAs of all sizes to fly safely in European airspace and will bring legal certainty for this rapidly expanding industry. The purpose of the new rules is to create the right conditions so that the EU has the capacity to handle the expected 50% increase in air traffic over the next 20 years, of which a lot is expected to come from the increasing use of drones [11]. The regulatory revisions could be translated as a great opportunity of drones' technology adaptation in traffic management.

This paper presents a framework to evaluate the performance of a roundabout based on determining traffic volume via OD matrices for each leg, providing also valuable insights in the traffic control performance between manual observation, traffic monitoring masts and drones. The experimental data to analyze traffic flow conditions was obtained over an urban compact roundabout situated in the city of the of Villepinte (France). The paper is structured as follows: firstly, the existing literature is discussed concisely. The proposed framework for the roundabout flow analysis is then presented. In the next section, a case study in France is presented to investigate the applicability of the proposed framework and compare the extracted traffic flow measurements. Lastly, a conclusion discussing results, limitations and potential future work is presented.

Table 1. SWOT Analysis

Internal Factors	
Strengths	Weaknesses
-The drone applications are a value-added service in the field of transport. - Recent research and experiments can serve as supportive tools for professional applications. - The different drones' applications may respond to different transportation management needs simultaneously. - The drone capability of broad view monitoring may save time and provide flexibility in traffic management cases.	- Low drone's technology adaptation in France. - Drones applications strongly conditioned by regulatory issues. - Battery life is still the least mature technology of those associated with drone system. - Tolerance of drones to face weather conditions weather is still out of focus. - Little knowledge of drones and their specifications by traffic managers. - Uncertainty about the profitability of the sector.
External Factors	
Opportunities	Threats
- Existence of poorly addressed needs that may have significant growth potential. - Wired drone technology broadly adapted. - Competitive advantage for private companies	- High direct and indirect competition. - Acceptability issues due to constraints imposed by restrictions related to airspace limit the operational territories range and disrupt their progress. - The regulations are still strict, despite the progress since the 2012 advanced regulations.

2. Related Work

Several studies have been carried out to apply drones' technology in traffic monitoring and various types of drones are used or tested to measure traffic data. Toth et al. [12] studies the quality of traffic data obtained by operating a drone helicopter, and aerial images, without adequate vehicle position sampling due to camera limitations. Puri et al. collects data in real time to monitor traffic, assess and analyze patterns, resulting to measurements statistical error due to drone instability and the limitation of data collection only when drone is in movement [13]. Heinz et al. establishes a high -level awareness of traffic conditions in Urban areas, in which traffic behavior of tracked vehicles is examined in real time [14]. Based on Ro et al. [15], one of the potentials of drones is the enhancement of traffic monitoring. Traditional techniques and traffic monitoring systems are used only for observing simple traffic counts at specific locations, while comprehensive traffic operations are excluded in rural areas, mainly due to cost effectiveness. On the other hand, UAVs appears to be a cost-effective solution that covers rural traffic monitoring requirements. Coifman et al. investigated the application of UAV in traffic flow monitoring on roadways. They developed and implemented several applications for urban areas, by extracting and using data sets collected by UAV, including annual average daily traffic, service level, original destination flows on small networks, intersection operations, and the utilization of parking lots [16]. Zhang and Elaksher introduced research on using a UAV-based digital imaging system to collect efficient surface condition data over rural roads in United States. A technique based on a three-dimensional (3D) surface model was used to measure distress over a road distress area. The evaluation of the case study concluded on reliable and accurate results, proposing a UAV-based digital imaging system of high acceptance rate [17].

Kanistras et al. [18] adopt the same approach by synthesizing bibliography of on-board unmanned aerial vehicle applications for traffic management. Zheng et al. develop a UAV system specifically for monitoring driving behaviors to prevent accidents. Based on a diagram, the authors propose a methodology for real-time tracking of vehicles using processing image, and vehicle risk modeling using analysis statistical. However, the main objective of this work is the evaluation of the behavior of drivers and the development of a risk analysis model [19].

Errors may occur in detection and tracking of vehicles by drones due to various reasons such as partial occlusions, shadows, nearby objects or false detections. Studies conducted on the method of tracking objects in videos from drones also believe that the errors made during processing are due to the inability of detection of objects whose size varies considerably during their passage or which move too fast [20]. Another study notes that the perspective projection during the formation of the image on the camera sensor results in a loss of information relating to the depth in the image because an image is a 2-dimensional representation of a scene in 3 dimensions, therefore the same object, observed from a camera point of view, can have a very different appearance in the image. Processing software algorithms must therefore be robust in the face of these many situations [21]. On the other hand, some limitations regarding current drone technology have been observed. These include the limited operating time of mini drones. Time of operation of these drones depends on internal and external factors. Internal factors include size, payload, battery type, etc. while external factors include weather, wind and weather conditions directives from the regulatory authorities, ordering the discontinuation of a drone flight for security reasons related to the occupation of airspace [22].

3. The Framework

The proposed framework consists of 5 steps, all intrinsically dependent and also defined based on each specific study scope and objectives.

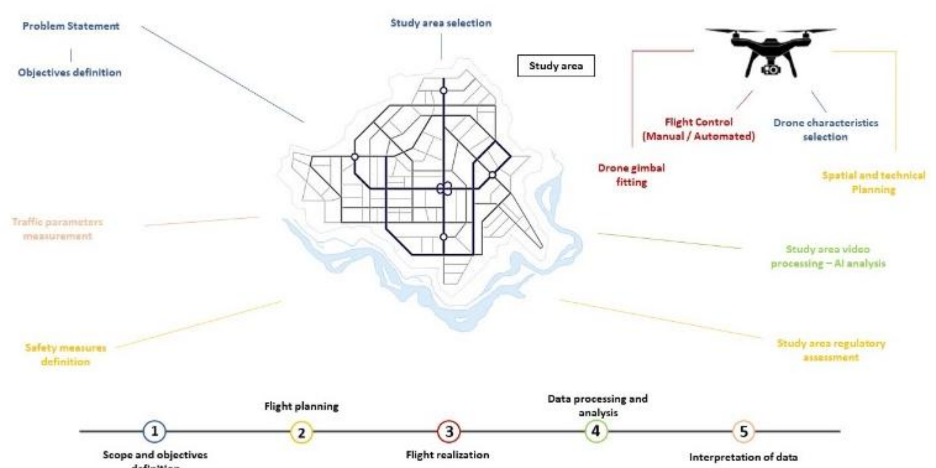

Figure 1. Framework scheme

Step 1: Scope and objectives definition

A clear problem statement with well-defined project objectives must be defined during this step. Also, the constituent elements of the study must be selected, concerning the selection of the study area and the characteristics of the drones to be used. The drone selection should ensure the fulfillment of several requirements like for example, knowing the position relative to the route, having the ability to fly in the face of winds up to 20km / h, having a robust intrinsic safety device, visualizing a road scene, distinguish between the different categories of vehicles and guaranteeing the safety of users and other stakeholders. At the end of this step, the expected measurements and specific traffic parameters to be extracted should be adequately defined.

Step 2: Flight planning

Flight planning step is responsible for defining and preparing the ideal conditions for the realization of the drone flight. The drone view area must be assessed from a regulatory perspective. It is mandatory to check that the area is not near a prohibited area (No fly zone), while in the opposite case of additional authorizations from the responsible Air Navigation department are required. It is also necessary to know the environment type (urban, peri-urban or rural) in which the drone will operate in order to define the exact safety measures to be implemented. In addition to spatial planning, temporal planning must also be defined by selecting the optimal situation considering weather conditions and the intensity of natural light. Finally, technical planning is also necessary in order to guarantee optimal data acquisition quality. Technology advancements allow the clarification of the drone crossing points coordinates before the flight, concluding in data accuracy compared to a manual setup.

Step 3: Flight realization

The flight, depending on user preferences and expertise, is controlled manually via the radio controller or automatically via the autopilot function. During this step, drone stability must be ensured for capturing sharp images. Drones are fitted with gimbals to allow the camera to have an independent and rotational movement on a single axis. Also, the framing of the captured image should adequately cover the study area while keeping altitude within authorized limits.

Step 4: Data processing and analysis

The processing of aerial videos is a relatively recent technology, more complex than analyzing traffic from counting masts videos. Automated traffic data analysis is an emerging method that involves filters and advanced image processing techniques to detect and track vehicles flows in the studied areas.

Step 5: Interpretation of data

This step aims at measuring traffic parameters and understanding traffic behavior and patterns. Results are compared and analyzed with the use of existing theoretical traffic models. In our study we focus on the measurement of traffic data in the context of time-delayed applications in which the data are aggregated into hourly or daily sequences for statistical analysis.

4. Case Study

The main aim of this paper is, by using off the self-equipment, to demonstrate the potential applications of UAVs for traffic analysis and management, particularly in the scenario of urban roundabout flow analysis. In this section, a detailed case study is presented in order to validate the practicality of the UAV-based traffic data collection, processing and analytical framework. The data collected via UAV flights is used for analyzing traffic volume and capacity by generating origin-destination (OD) matrices. During the field test, two different image resolution transmission schemes are performed for comparison and differences identification. The following present a description of the whole experiment and the analytical process based on the proposed framework steps.

Scope and objectives definition: The scope of this study is to investigate the applicability of the proposed framework and compare the extracted traffic flow measurements by drones with those acquired by the conventional monitoring masts. During the first step a roundabout that is difficult to be handled using camera sensors or other types of sensors is identified, while also verifying that the drone can perform the overflight operation remaining in the vision area of the operator. The necessary conditions for the smooth running of the experiment are identified:

- The roundabout diameter should be between 70 m and 150 m in order to represent a relatively complex situation to measure flows by using traditional sensors.
- The experiment duration sis set to be a two hours' time slot.
- To time period is decided for optimal weather and visual conditions, while at the same time reflecting heavy traffic conditions (peak hours).

Figure 2. C1 roundabout - Villepinte (Géoportail)

Table 2. Île-de-France region roundabouts

N° Carrefour	Département	Commune	Code postal	Type carrefour	Diamètre	Nb branches	Coordonnées maps
1	Seine et Marne	Villeneuve-le-Comte	77174	Giratoire	60 m	4	48.818747, 2.818397
2	Seine et Marne	Villeneuve-le-Comte	77174	Giratoire	59 m	5	48.823417, 2.834842
3	Seine et Marne	Villeneuve-le-Comte	77174	Giratoire	60 m	4	48.815114, 2.841933
4	Seine et Marne	Courtevoult	77580	Giratoire	28 m	5	48.856570, 2.858932
5	Seine et Marne	Châtres	77610	Giratoire	25 m	5	48.728420, 2.814440
6	Seine et Marne	Châtres	77610	Giratoire	27 m	4	48.727171, 2.813437
7	Essone	Lisses	91090	Giratoire	65 m	4	48.589424, 2.430483
8	Essone	Avrainville	91630	Giratoire	56 m	4	48.565514, 2.261806
9	Val d'Oise	Luzarches	95270	Giratoire	40 m	5	49.111637, 2.393613
10	Val d'Oise	Taverny	95150	Giratoire	100 m	4	49.028107, 2.203852
11	Seine-Saint-Denis	Villepinte	93420	Giratoire	100 m	6	48.963977, 2.553743
12	Seine-Saint-Denis	Villepinte	93420	Giratoire	110 m	4	48.961625, 2.555179
13	Seine-Saint-Denis	Villepinte	93420	Giratoire	100 m	4	48.945484, 2.567840
14	Seine et Marne	Fontainebleau	77300	Giratoire	80 m	6	48.408550, 2.686516
15	Seine et Marne	Fontainebleau	77300	Giratoire	80 m	6	48.396954, 2.692186

The roundabouts of the different departments of the Île-de-France region are identified as depicted in Table 2.

The department of Seine-Saint-Denis presented a reactivity from an administrative point of view e as well as an openness to this type of innovative experiments. The three roundabouts of this department have been considered, and crossroads 1 and 2, located in the town of Villepinte and Carrefour 3 in Tremblay-en-France, have been pre-selected based on the relevance to the study criteria.

Flight planning: C1 roundabout which is located in the town of Villepinte (Figure 2) has been finally selected based on the prerequisite to carry out the study in an area with complex regulatory procedures. This roundabout connects the A104 motorway and D40 road. This crossroad has the particularity of being located near the Villepinte prison.

Flight realization: The drone flight was performed on Friday October 18, 2019 between 4 p.m. and 6 p.m., in cooperation with a drone service provider. The operation was carried out in compliance with the safety instructions imposed by the Directorate General of Civil Aviation (DGCA) and the Navigation Service Air - Paris region (NSA-PR). The test was carried out by operating two drones with 20 minutes autonomy to cover the desired time slot. However, the flight was forced by a Bourget airport request to stop for 10 minutes to allow the safe passage of a plane flying at low altitude. An image extracted from the drone control screen during the flight is shown in Figure 3.

Figure 3. Study area image by drone

Drone technical specifications and experiment conditions are summarized in Table 3.

Table 3. Experimentation conditions

DRONE	Model	DJI Mavic Pro
	Autonomy	~ 20 mins
	dimensions	83 mm (H) x 83 mm (W) x 198 mm (W)
	Weight	743 g
CAMERA	mega pixels	1920x1080 (HD)
	video resolution	25 frames / sec
	fps	25 frames / sec
CONDITIONS OF TEST	number of drones	2
	Operating radius	30 m
	Number of flights/numbers of battery	5
	Altitude	95 m (relative to roundabout) 100m (from the take-off point)
CONDIITONS WEATHER	rainfall	0%
	wind	20km / h

With the aim to compare the measurement by drone system to those by standard methods, 2 counting masts equipped with cameras were placed at strategic points of the studied area (Figure 4) which allow to visualize all the branches of the roundabout. The 1st point is at the entrance to the roundabout via the RD40 North, and the 2nd at the entrance to the roundabout via the RD40 South.

Figure 4. Images from cameras on counting masts: i) 1-RD40 South

Data processing and analysis: At this step, the videos were processed using Wintics image processing software. Wintics automatic video processing software produces multimodal traffic statistics and the Origin / Destination matrices. This multiplatform software is ideal for real time directional measuring studies. The strengths of the software are:

- Advanced algorithmic innovations to transform videos indicators and statistics.
- Automatic and rapid processing in real time.
- A greater than 97% precision rate.
- Interoperability with various camera types providing AVI, MPG, MP4, MKV videos.

Figure 5 shows a frame from a video processed by Wintics software.

Manual vehicle counting was conducted using the videos in order to measure the precision of the image processing software. These measurements were made by following vehicles from their entry to their exit from the roundabout and by carrying out a systematic check at various points to minimize possible errors. Also, the data from the counting masts were processed in order to measure deviations in flows recorded between the two processes.

Figure 5. Image processed by Wintics software

Interpretation of data: The reliability of vehicle counting data is essential prerequisite for road traffic studies, not only for carrying out a diagnosis of current traffic conditions but also for the calibration of static or dynamic models allowing predictive analysis in the short or long term. Road traffic flow is measured by counting the number of vehicles over a period. The common PCU (private car unit) is used s unit metric, and in order to take into account the different types of vehicles, the specific unit is defined as follows:

- A light vehicle or a van = 1 PCU
- A heavyweight of 3.5 tons and more = 2 PCU ~ 3 PCU
- A two-wheeled vehicle = 1/3 PCU ~ 1/2 PCU

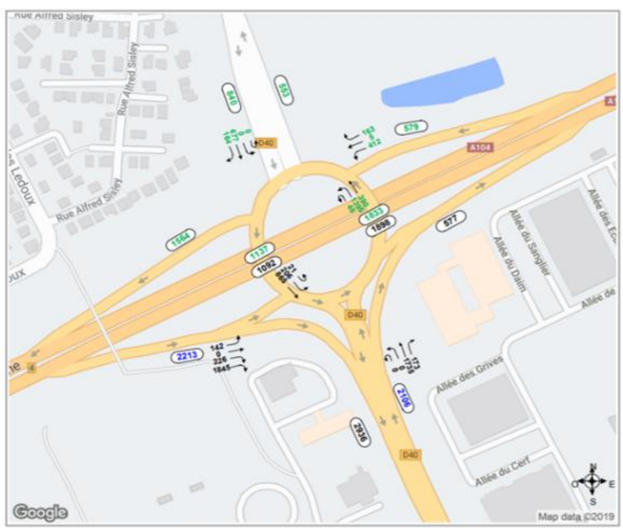

Figure 6. PCU measurements between 4:40 p.m. and 5:48 p.m.- metering masts equipped with cameras

The PCU results over the entire schedule range extracted by both methods, metering masts equipped with cameras and drones, are depicted in Figures 6 and Figure 7.

The PCU results of the different measurements carried out over 15 minutes. in order to allow us to compare with the measurements made manually. The results are presented on an Origin / Destination matrix giving the incoming and outgoing flows on each branch of the crossroads (details of the results in appendices 1 and 2).

Figure 7. PCU measurements between 4:40 p.m. and 5:48 p.m.- drones

The overall load of the crossroads according to each measure, the latter being the sum of all incoming flows on the crossroads is presented in Table 4.

Table 4. Counting results on the roundabout

Measurement Results (PCUs)		RD 40 North	A104 Est	RD 40 South	A104 West	Total per Branch	Total
Drones	RD 40 North	0	9	95	40	144	761
	A104 Est	39	0	81	9	129	
	RD 40 South	73	0	0	322	395	
	A104 West	16	2	61	0	79	
Masts	RD 40 North	0	43	84	40	167	797
	A104 Est	44	0	98	1	143	
	RD 40 South	80	0	0	318	398	
	A104 West	36	0	53	0	89	
Manually	RD 40 North	0	54	92	33	176	789
	A104 Est	38	0	85	8	131	
	RD 40 South	70	0	0	320	390	
	A104 West	29	2	61	0	92	

The measurement results by counting masts are calculated by considering the roundabout as two crossroads with 4 branches (use of two masts) independent of each other. Consequently, the incoming and outgoing flows on either side of the crossroads according to each video are not aligned, which increases the uncertainty on the number of vehicles present on the roundabout. Results from drones showed that due to the drone position, it was possible to monitor the movements on all the branches of the crossroads simultaneously, allowing to extract knowledge of the vehicles distribution with high precision. The differences of measurements using the two methods are relatively small, noting however that the errors produced by drone are less than those by counting masts, with an exception regarding movements on RD40 North → A104 East and A104 West → RD40 North where significant deviations are observed. The root of such deviations was the signal loss caused by bushes along the roundabout.

In order to quantify the calculation errors on each movement, a formula was defined to calculate the absolute error on the measurement flows for each directional movement compared to manual measurements, applied for both drone and mast method. The equation used to calculate the absolute error on each branch is:

$$yAE(pcu) = | y_i - x_i | \tag{1}$$

with yi the flows measured manually and xi the flows measured automatically (by drones or masts). In parallel, the relative errors made in the automatic measurements compared to manual ones were quantified, according to the following formula:

$$EAR\ (\%) = | y_i - x_i | / y_i \tag{2}$$

Relative errors are represented by using colors based on the defined intervals as shown in Figure 8 (EAR calculations presented in appendix 3):

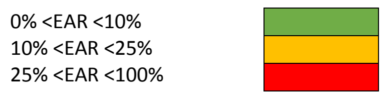

Figure 8. EAR representation

The table below depicts the relative errors values.

Table 5. Relative errors

		Absolute error / Relative absolute error			
		RD 40 North	A104 East	RD 40 South	A104 West
Measurements by drone images (PCU)	RD 40 North	0	45	3	7
	A104 East	1	0	4	1
	RD 40 South	3	0	0	2
	A104 West	13	0	0	0
Measurements by masts (PCU)	RD 40 North	0	11	8	7
	A104 East	6	0	13	7
	RD 40 South	10	0	0	2
	A104 West	7	2	8	0

The results from the drone videos show relative errors predominantly less than 10% and overall errors overall low. The movements A104 East → A104 West and RD40 North → A104 West are infrequent, and the relative error is therefore not sufficiently representative of the difference. Results from videos of counting masts show relative errors overall between 10% and 25%. Movements A104 East → A104 West and A104 West → A104 East have relative errors greater than 25% due to the angle of view of these videos which did not allow a clear view of these branches, and these streams were therefore deducted from the other movements on the crossroads.

Another formula used in traffic modelling to compare two sets of traffic volumes is GEH (Geoffrey E. Havers). Rather, it is an empirical formula that has proven useful for a variety of traffic analysis purposes [23,24,25]. The formula for the "GEH Statistic" [26] is:

$$GEH=\sqrt{\frac{2(M-C)^2}{(M+C)}} \quad (3)$$

where M is the hourly traffic volume from the drone or mast count (new count) and C is the real-world (manual) hourly traffic count (or the old count).

Using the GEH Statistic avoids some pitfalls that occur when using simple percentages to compare two sets of volumes, because the GEH statistic is non-linear, a single acceptance threshold based on GEH can be used over a fairly wide range of traffic volumes. A GEH of less than 5.0 is considered a good match between the modelled and observed hourly volumes. According to DMRB, 85% of the volumes in a traffic model should have a GEH less than 5.0. GEHs in the range of 5.0 to 10.0 may warrant investigation. If the GEH is greater than 10.0, there is a high probability that there is a problem with the data.

The equation 3 based on the values of Table 3 produces the GEH results (Table 6).

It can be observed that most of the GEH values based on the drone's measurement are less than 5.0 and less than the corresponding values based on the mast's measurements. The RD40 North → A104 West route, where GEH is greater than 5.0, is infrequent and requires further investigation. No value is greater than 10.0, which provides sufficient evidence for the accuracy of the measurements. Also, for both drones and masts, more than the 85% of the GEH values are less than 5.0.

Table 6. GEH results

GEH		RD 40 North	A104 Est	RD 40 South	A104 West
Drones	RD 40 North	0	8,02	0,31	1,16
	A104 Est	0,16	0	0,44	0,34
	RD 40 South	0,35	0	0	0,11
	A104 West	2,74	0	0	0
Masts	RD 40 North	0,00	1,58	0,85	1,16
	A104 Est	0,94	0	1,36	3,30
	RD 40 South	1,15	0	0	0,11
	A104 West	1,23	2	1,06	0

5. Discussion of Results

The traffic data at the roundabout which was acquired by the drone allow estimation of various traffic parameters. In this study, we estimated the flows. The estimated values and the manually counted values were then used to assess measurement error. Overall, the traffic parameters estimated from the data acquired by the drone do not show major errors, and although the processing of the videos was carried out with success there are still some limitations.

In order to identify the differences but also the common points between measurement by drone and measurement by counting masts, a list of indicators has been established which serves as basis for comparison presented in Table 7.

Table 7. Comparative analysis

	Masts fitted with cameras	Drone equipped with camera
Measures available	LV, PL, 2R speed Spatial distribution of vehicles (partially)	LV, PL, 2R speed Spatial distribution of vehicles
Precision	Debits: 10% - 25%	Debits: 0% - 10%
Autonomy	4 days	~ 20 minutes
Sensitivity to terms weather	Medium sensitivity. Rain causes occultations.	Strong sensitivity. The drone cannot fly under rain or high-speed winds.
Sensitivity to natural light	Strong sensitivity. Minimal light is necessary to make a good data processing.	Strong sensitivity. A minimum of light is necessary to achieve good treatment of data.
Resolution of the image	Very low resolution. These devices do not allow direct reading of vehicle plates in compliance to the requirements of the CNIL	1920 x 1080 High Definition. These devices CNIL thanks to the shooting distance which is relatively large compared to the distance of shooting by counting masts.
Grip height view	7 meters	50 - 150 meters (depending on regulations)
Size of the area study	~ 50 m (for data collection reliable)	Quite large study area, complicated to deal with multiple masts.
Risk on the security of road users	No risk.	Medium risk. The risk of falling for low-weight drones remain relatively low and easily controllable by remote pilots.
Reactivity intervention	1 working day (to have the agreement of department concerned).	5 working days (in order to have the authorizations required to fly the drone).
Staff mobilized	Investigator who installs and removes the masts of counting	Telepilot present throughout the duration of the measured

Some common points between the two methods that reside in the types of measurements performed and the sensitivity to conditions weather and light are noted. The technical limits of drones, i.e. time limited battery, weather constraints and safety concerns and privacy are among the main obstacles to the effectiveness of this technology. Although advanced technology can be used to increase the life of the battery, this would however increase exponentially its acquisition cost. Therefore, it can be concluded that the different method combination turns to be the most effective solution i.e. installing counting masts fitted with cameras on the exits from the crossroads measure the totals of incoming and outgoing flows, while drone operation support the estimation of the flow distribution on all branches.

6. Conclusions

The experimentation test set up as part of this study took place above a roundabout with a diameter of 100 m and six branches at the level of the town of Villepinte in the department of Seine-Saint-Denis. The videos from this measurement were processed using image processing software, the recorded data were compared with the results of the measurements carried out by counting masts fitted with cameras and with the results of manual measurements which represented our benchmark for comparison.

At first glance, the results from counting masts fitted with cameras show non-aligned flows because of the large size of the roundabout which forces it to decompose into two crossroads with four branches independent of each other. Consequently, the incoming and outgoing flows on either side of the intersection according to each video have inequalities, which increases the uncertainty on the number of vehicles present on the ring which is estimated on the basis of hypotheses put forward.

The technical comparison between the two counting tools made it possible to identify their commonalities and their differences, which enlightened us on the observable limits in the drone use case and guided us towards the consideration of a hybrid method.

The limits of the drone system identified can be classified into two categories, the limitations related to drone technology and those related to processing technology. The first one category is mainly represented by the autonomy of mini drones limited to one twenty minutes, this is conditioned by internal factors, size, payload, battery type, and external, weather conditions, wind conditions and the regulations on the occupation of airspace which may be binding and lead to flight interruptions. Limits related to video processing concern vehicle detection and tracking errors which occur following partial occlusions, false detections or even because of variable size of certain vehicles in the image and the angle of view which does not allow view all vehicles in the same way. As such, the algorithms of these tools must be sufficiently advanced and robust in dealing with these complex situations.

To conclude, we can say that drone technology is quickly accepted as a very dynamic technology, especially for collecting detailed data and precise traffic information. The maneuverability and flexibility of the system further increase the value of this technology. Advances in technology and regulations will therefore translate through more efficient and safer use, especially for traffic applications road.

However, we are observing areas for further study following this study which will allow the acquisition of more in-depth analyzes of this use case of drones. In one first, research can be done to study other counting methods vehicles on large sections of road such as the Origin Destination, indeed such a device could replace the use of cameras for reading license plates. Secondly, studies around other related needs data collection could be carried out to further broaden the scope of possible applications for civil drones. Finally, a study on the use of technology wired would bring significant advancement in the field of research on drones.

Appendices

VL (Destinations × Origines)

Vidéo	Destination	1	2	3	4
Vidéo 1	1	-	9	-	93
Vidéo 1	2	33	-	14	71
Vidéo 1	3	7	50	-	296
Vidéo 1	4	81	91	465	-
Vidéo 2	1	-	1	4	164
Vidéo 2	2	47	-	5	89
Vidéo 2	3	21	59	-	322
Vidéo 2	4	105	115	571	-
Vidéo 3	1	-	5	2	166
Vidéo 3	2	51	-	18	83
Vidéo 3	3	19	72	-	296
Vidéo 3	4	84	117	535	-
Vidéo 4	1	-	3	-	98
Vidéo 4	2	26	-	4	77
Vidéo 4	3	8	43	-	258
Vidéo 4	4	75	82	394	-
Vidéo 5	1	-	1	1	143
Vidéo 5	2	37	-	16	105
Vidéo 5	3	12	63	-	333
Vidéo 5	4	107	121	591	-

PL (Destinations × Origines)

Vidéo	Destination	1	2	3	4
Vidéo 1	1	-	-	1	1
Vidéo 1	2	3	-	1	2
Vidéo 1	3	1	2	-	9
Vidéo 1	4	-	2	25	-
Vidéo 2	1	-	-	-	2
Vidéo 2	2	6	-	-	2
Vidéo 2	3	1	6	-	15
Vidéo 2	4	-	2	29	-
Vidéo 3	1	-	1	1	7
Vidéo 3	2	5	-	1	-
Vidéo 3	3	1	3	-	17
Vidéo 3	4	1	4	42	-
Vidéo 4	1	-	2	-	2
Vidéo 4	2	2	-	-	-
Vidéo 4	3	-	-	-	9
Vidéo 4	4	3	9	26	-
Vidéo 5	1	-	1	-	2
Vidéo 5	2	6	-	-	1
Vidéo 5	3	2	3	-	8
Vidéo 5	4	-	2	9	-

Total (Destinations × Origines)

Vidéo	Destination	1	2	3	4
Vidéo 1	1	-	9	1	94
Vidéo 1	2	36	-	15	73
Vidéo 1	3	8	52	-	305
Vidéo 1	4	81	93	490	-
Vidéo 2	1	-	1	4	166
Vidéo 2	2	53	-	5	91
Vidéo 2	3	22	65	-	337
Vidéo 2	4	105	117	600	-
Vidéo 3	1	-	6	3	173
Vidéo 3	2	56	-	19	83
Vidéo 3	3	20	75	-	313
Vidéo 3	4	85	121	577	-
Vidéo 4	1	-	5	-	100
Vidéo 4	2	28	-	4	77
Vidéo 4	3	8	43	-	267
Vidéo 4	4	78	91	420	-
Vidéo 5	1	-	2	1	145
Vidéo 5	2	43	-	16	106
Vidéo 5	3	14	66	-	341
Vidéo 5	4	107	123	600	-

Appendix 1. Raw results from drone video processing

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