HAROKOPIO UNIVERSITY OF ATHENS

SCHOOL OF ENVIRONMENT, GEOGRAPHY & APPLIED ECONOMICS

Department of Geography

APPLIED GEOGRAPHY & SPATIAL PLANNING: GEOINFORMATICS

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nexus route

Ambulance-Drone Network

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1) Είμαι ο κάτοχος των πνευματικών δικαιωμάτων της πρωτότυπης αυτής εργασίας και από όσο γνωρίζω η εργασία μου δε συκοφαντεί πρόσωπα, ούτε προσβάλει τα πνευματικά δικαιώματα τρίτων.
2) Αποδέχομαι ότι η ΒΚΠ χωρίς να αλλάξει το περιεχόμενο της εργασίας μου,μπορεί να τη διαθέσει σε ηλεκτρονική μορφή μέσα από τη ψηφιακή Βιβλιοθήκη της, να την αντιγράψει σε οποιοδήποτε μέσο ή/και σε οποιοδήποτε μορφότυπο καθώς και να κρατά περισσότερα από ένα αντίγραφα για λόγους συντήρησης και ασφάλειας

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I would also like to thank Anna Roussi for providing me with multiple sources of information about the functionality of the emergency management system. Anna Roussi is head of emergency services of the National Emergency Center.

CONTENTS

ΠΕΡΙΛΗΨΗ

Ο αριθμός των καρδιακών επεισοδίων που συμβαίνουν εκτός νοσοκομείου στην Ελλάδα είναι υψηλός και το ποσοστό επιβίωσης τέτοιου περιστατικού, αρκετά χαμηλό. Η καρδιακή προσβολή (καρδιακό επεισόδιο) είναι η ξαφνική παύση άντλησης αίματος απ’ την καρδιά προς το υπόλοιπο σώμα. Όταν τυχαίνει μια καρδιακή προσβολή, ο ασθενής πρέπει να λάβει τις πρώτες βοήθειες όπως καρδιοαναπνευστική αναζωογόνηση (ΚΑΡΠΑ), και πρέπει να γίνει ηλεκτροσόκ στην καρδιά μέσα σε 4 με 6 λεπτά. Εάν δε δωθεί βοήθεια οι πιθανότητες επιβίωσης είναι ελάχιστες εάν όχι μηδενικές. Σε πολλές Ευρωπαϊκές χώρες πραγματοποιείται συνεχής έρευνα για την αύξηση του ποσοστού επιβίωσης. Τα αποτελέσματα είναι αισιόδοξα. Ειδικότερα στην Ελλάδα υπάρχουν λύσεις για τη μείωση του χρόνου απόκρισης σε περίπτωση καρδιακού επεισοδίου, όπως οι «Σαμαρείτες», ποδηλάτες του ερυθρού σταυρού που κατά τους θερινούς μήνες περιπολούν το τουριστικό κέντρο της Αθήνας, και οι μοτοσυκλετιστές του ΕΚΑΒ στο κέντρο της Αθήνας. Ωστόσο οι λύσεις αυτές δεν έχουν αυξήσει τα ποσοστά επιβίωσης. Μία ακόμα λύση είναι η χρήση αυτόματου εξωτερικού απινιδωτή (ΑΕΑ) σε ΣμηΕΑ (Drone), λύση η οποία δεν έχει εφαρμοστεί ακόμα. Σκοπός της έρευνας είναι ο στρατηρικός σχεδιασμός τοποθέτησης Drone. Αυτό θα πραγματοποιηθεί μέσω χωρικής ανάλυσης ούτως ώστε να βρεθούν οι κρίσιμες περιοχές. Η περιοχή μελέτης είναι ευρύτερη περιοχή της Αθήνας. Η ανάλυση θα γίνει και μέσω θεωρίας με εργαλεία GIS (πολυκριτηριακή ανάλυση), και μέσω επιτόπειας ανάλυσης καταγράφοντας τους χρόνους απόκρισης των ασθενοφόρων. Τα GISεργαλεία στοχεύουν στην εύρεση των χρονοαποστάσεων από τα σημεία εκκίνησης των ασθενοφόρων προς οποιοδήποτε μέρος της περιοχής μελέτης. Η επί τόπου παρατήρηση θα επαληθεύσει τα γενικευμένα αποτελέσματα του GIS. Οι κρίσιμες περιοχές θα είναι εκείνες όπου ο χρόνος απόκρισης του ΕΚΑΒ είναι μακρύς, όπου έχουν καραγραφεί στο εγγύς παρελθόν θάνατοι λόγω καρδιακών επεισοδίων και υπάρχει μεγάλη πυκνότητα του «επικίνδυνου πληθυσμού», 50 και άνω ετών. Το επόμενο βήμα είναι η δημιουργία μιας ενός αλγορίθμου που θα αποφασίζει ποιο Droneθα πηγαίνει στο περιστατικό χρησιμοποιώντας τις συντεταγμένες από την κλήση του τηλεφώνου. Το Droneθα πετάει με αυτόματο πιλότο, αλλά θα έχει και χειριστεί που θα εποπτεύει την πτήση και την ορθή χρήση του ΑΕΑ από τους καλόντες βοήθειας. Στόχος μας είναι η αύξηση του ποσοστού επιβίωσης από 7% σε 80%. Τα Droneμε ΑΕΑ θα είναι επικουρικό μέσο των ασθενοφόρων, τα οποία θα εκκινούν την ίδια στιγμή για τη διακομιδή του ασθσενούς στην πλησιέστερη κλινική για περαιτέρω εξετάσεις.

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ

ΓΠΣ. ΣμηΕΑ, ΑΕΑ, Δίκτυο ΣμηΕΑ, Καρδιαγγειακά νοσήματα

ABSTRACT

The number of out-of-hospital cardiac arrest incidents that occur in Greece every year is high and the surviving rate is extremely low. Cardiac arrest (OHCA) is the sudden stop in effective blood flow due to the failure of the heart to contract effectively. When a cardiac arrest occurs, the patient must take cardiopulmonary resuscitation (CPR) and the heart must be shocked within 4 to 6 minutes. If no help is given, surviving chances are from little to none. In several European countries, there is ongoing research on increasing the surviving rate. The results are very promising. Particularly in Greece, there is a couple of solutions like the cyclists of the Red Cross, and the motorcyclists of the National Emergency Center in the Athens city center. However, the results have yet to show their potential. Another solution –not yet applied- is the carriage of an automatic external defibrillator (AED) inside a drone. This drone should fly above the city of Athens delivering first aid to emergencies up to 10 times sooner than that of an ambulance. The purpose of the thesis is the strategic placement of drones. This will be done by a spatially motivated analysis in order to find the critical areas in a case of emergency. The study area will be the Athens metro area. The analysis will include both a theoretical approach using GIS tools (multi criteria analysis), and an empirical approach by recording time distances of ambulances. The GIS tools, aim to find the time distance of any place of Athens from the ambulances' starting points. The empirical approach should certify our theoretical results, and find any errors. The areas we will mark as "critical" will be places with long-approaching times by an ambulance that have a dense OHCA case history, and high elder population (older than 50 years old). The next step is the creation of an application that decides where the drone should fly at. The cell-phone signal of the emergency call will be located and the application will dispatch the nearest ambulance drone. It will fly via automatic pilot but will have an operator to supervise the flight and a physician to instruct whom calls to help, on how to use the AED. Our aim is the increasing of the survival rate from 8%, to 80%. The ambulance drones will not replace ambulances, but they will be used as subsidiary health service.

KEY-WORDS

GIS, UAV, AED, Drone Network, Cardiovascular Diseases

ABBREVIATIONS

AED – Automated External Defibrillator

AKA – Also Known As

CPR – Cardiopulmonary Resuscitation

CVD – Cardiovascular Disease

EMS – Emergency Medical Services

ETC – Et Cetera

EU – European Union

GIS – Geographical Information System

HSA – Hellenic Statistical Authority

IDW – Inverse Distance Weighed interpolation

MCE – Multi Criteria Evaluation

NEC – National Emergency Center

OHCA – Out of Hospital Cardiac Arrest

SCD – Sudden Cardiac Death

UAV – Unmanned Aerial Vehicle

USA – United States of America

USAF – United States Air Force

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CHAPTER 1:INTRODUCTION

1.1 BACKGROUND

The aim of this thesis is to look at the use of drones (unmanned aerial vehicles – aka UAVs) in healthcare services, and especially in out-of-hospital cardiac arrest emergencies (OHCA). Each year around 35.000 people die due to cardiovascular diseases in Greece (CVD). By average, 343 per 100.000 habitants die due to CVD while in other countries of similar economy and living standards like Italy and Spain this number is limited to 200 deaths per 100.000 habitants (Wilkins et al. 2017). The life expectancy at birth for Greek residents was amongst the highest in the 1970's, but gradually they have slipped to 26th position of the world ranking of life expectancy (HSA, 2014). This observation raises some interesting questions in relation to the falling life expectancy and the difference between Greece and other developed countries.

In order to answer these questions, we need to address the factors that contribute to high death rates. Data from Eurostat have shown that 35% of population fertility is due to CVD. However, at the age group of 65+ year-olds, this number increases to over 50%. Therefore, age is the main risk factor of a CVD-related episode (Wilkins et al. 2017). Dietary risk is one more factor that the European Cardiovascular Disease Statistics have shown along with low physical activity, smoking, alcohol use, high systolic blood pressure and others. However, none of these seems to have a significant role behind the high death rates. More or less every EU country is bound to face the same risk factors for a cardiac episode possibility. Studies have shown that in almost every EU country the survival rate is 7% – 8 % (Van de Voordea et al. 2017). Therefore, even if the CVD possibility is high or low, the survival possibility is the same.

Another factor we should consider is the healthcare services' quality. In the past 8 years, an economic crisis occurred in EU, with some of the economically weakest EU member states facing public funding cuts. From 2009 to date, about €2.5 billion were cut due to governmental funding shortage in Greece (Eurostat report, 2016). The Eurostat's report of death causes has showed that deaths in Greece due to CVD have not changed that much before and after 2009. Therefore, we can safely assume that these funding cuts have not yet affected the CVD patients.

In conclusion, risk factors play their role on how many people are likely to face an OHCA due to CVD, but none of the above tells us why all countries have a similar surviving rate of about 8%. The reason behind this is time. Even with advanced health services, even if the living standards are high, the method we choose to manage OHCA incidents is poor. When a cardiac episode occurs, the survival rate is 74% if a person is shocked within 3 minutes of the arrest (Valenzuela et. al. 2000). Each minute passes, there is a 10% loss of surviving possibility and in the end, after a 10-minute passing, the patient faces brain damage and inevitably finds his demise. What we need to do is not an enhancement of healthcare funding, nor is it a better living standard. What we need to change, is the response time. Survival is highly dependent on time to treatment (cardiopulmonary resuscitation (CPR) and defibrillation) (Ringh, 2014).

1.2 CARDIOVASCULAR DISEASE (CVD)

Generally, sudden cardiac death (SCD) refers to an unexpected death from a CVD in a person regardless of a pre-existing heart disease (Field, 2009). “Cardiovascular diseases” is a sum of heart related diseases, but in order to specify the issue, we will refer to them as cardiac arrest. Cardiac arrest is the sudden stoppage of blood flow due to failure of the heart to contract effectively (Schenone et al, 2016). Some of the symptoms are loss of consciousness, abnormal breathing or even no breathing at all, chest pain and nausea (just before the episode). If not treated within 4 to 6 minutes brain damage or death occurs (Adams, 2012). Coronary artery disease, heart failure, low potassium or even intensive exercise can result hears attack (Schenone et al, 2016). Prevention includes regular physical activity, lack of smoking and body mass maintenance (Field, 2009). Nevertheless, if a cardiac arrest occurs the treatment must be immediate with cardiopulmonary resuscitation (CPR) and/or defibrillation (Adams, 2012). Defibrillation is our topic, and it is used in order to restore heart rhythm and eventually save the CVD patient. Prevention is not entirely on one’s hand, even though we all should take precautions for future heart attacks. In Western Europe, healthy life is a living standard and many of the young generation follows it by dietetic programs, and sporting activity. Although there is one exception: The adult Greeks may have come to a record-breaking healthy life and physical/sporting activity (HSA, 2014), young boys in Greece suffer overweighting more than ever. Greece is on top of charts regarding child-obesity. If children grow and remain obese, at the age of 50, they will increase the possibility of cardiac arrest. Either we talk about the present or the future, public healthcare needs to make the next step and advance on a topic that humanity has never used before; drones.

1.3 UAVs & DRONES

Drones have entered our everyday life for good. Their use varies from photogrammetry, mapping, gaming, racing, cinematography or even carriage of light objects. Although drones refer to all types of driverless ground or aerial vehicles, on this thesis we will refer to the unmanned aerial vehicles (UAVs) only, as drones.

The oldest known use of an unmanned aerial “vehicle” dates back to the mid-way of the 1800’s. In 1849, the Austrian military deployed balloons that carried explosives and attacked the then enemy Italian city of Venice. The plan didn’t go as planned, as the wind rerouted the balloons with a result of bombing Austrian territory instead (Baker, 2012). Since then, humans used UAV’s and drones quite rarely for science and later military purposes. The most common use of a UAV was weather forecast. After the first successful flight of the Wright brothers in 1903, humans evolved quickly the flying machines. Drones were slowly developed. At the beginning of 20th century, there was a scientific challenge amongst inventors: “Men flying with heavier-than-air machines”, so no one really cared about UAV’s back then (Smithsonian Institution, 2012). After the First World War, the progress was massive, and militaries from Axis and Allied forces developed several UAV systems. Radio controlled vehicles were designed during the WW2 (first designed by Nikola Tesla in 1898), but in many cases they remained as prototypes as they were never been used (Dillow, 2014).

In the words of the United States Air Force General George S. Brown of the Air Force Systems Command, in 1972, "*The only reason we need (UAVs) is that we don't want to needlessly expend the man in the cockpit*". From that statement, he went to say:"*we let the drone do the high-risk flying ... the loss rate is high, but we are willing to risk more of them ...* ***they save lives!***”

From then on, drones have evolved to a merchandize level, where companies making drones for various uses, from racing, to science and from military to cinematography. Until the end of the 20th century, drones were just for modalism and classified military projects. In 2000, companies started to produce many types of drones, for all kinds of customers, but it was until 2010 that massive production started. In 2013 amazon announced the “Amazon – Prime air", a drone that could fly and deliver faster and more efficiently products to customers. This has inspired many other researchers on doing something different about the public regarding of drones.

1.4 CURRENT REASEACH

In 2013, researchers thought about using drones to carry medicine or AEDs. Public services and health emergency systems via drones started to surface in the academic world, with the so-called ambulance drone. The ambulance-drone concept is a new idea with a handful of researchers studying the prospects of such service-enhancement. Low surviving percentage of OHCA incidents is a problem of the Western world, and the solution lies upon UAV's. Apart from projects about ambulance-drones, it is worth noting other projects that serve the public and/or enhance current emergency management system. First, the Red Cross research group in Switzerland made a drone carrying explosives, in order to create artificial avalanches faster, with more accuracy and with no risk (Scott J & Scott C, 2015). Side note: Artificial avalanches is a security measure in order to prevent them from happening during skiing events (Falser, 2010).

Drones carrying a thermal sensor of SAR satellite search for people trapped in avalanches (Modroo&Olhoeft, 2004). In US California, a team of rescuers is using drones as remote sensing tools, to monitor possible shark raids. These projects are stunning and worth the academic attention, although they focus on occasions that happen in certain areas. On the other hand, the ambulance-drones can be used anywhere, anytime, for a bigger population. These projects started by companies such as Google and Amazon, in order to use drones to transfer medical kits in remote areas of the sub-Saharan Africa. In Europe, the main problem that needs solving is the "OHCA emergencies". The fast response time of a drone carrying a defibrillator, has drawn the attention of researchers in the Netherlands, Sweden, Germany and Norway.

1.4.1 THE NETHERLANDS

In 2014, a research group of the TU Delft University started a survey about the use of the "Ambulance-Drones". The goal is to minimize death rates of OHCA episodes, from 8% to 80% (Van de Voordea et al, 2017). The vision started with the creation of a foldable drone, capable of saving lives including a built-in AED (Momont, 2014). The past 2 years this group is seeking solutions for the next step: the creation of a network. For the moment, they have achieved testing flights above the city. As the creator of the ambulance-drone says:

"The results showed clear added value by the speed of deployment, accuracy and automated flight in the field of emergency response (EMS). The goal was thus defined to create a high speed response network that worked in a decentralized way to provide faster response times."(Momont, 2014 drones for good - http://www.alecmomont.com/projects/dronesforgood).

1.4.2 SWEDEN

Sweden is not the first EU country to introduce a medical-drone system, but is the first to operate one. A project about the strategic placement of drones operates already. As JosefinLenartsson says, the strategic placement of a medical-drone network must address the following questions: Where are the hotspots of OHCA cases, which are difficult to access? In how many cases a Drone can reach the OHCA case faster than the emergency management system (EMS) (Lenartsson, 2015).

The tools that were used in that thesis of the KTH Royal Institute of Technology in Stockholm, were mainly geographic information systems (GIS). Although using spatial statistics can be also a useful tool as the research group of Pulver used for the Salt Lake region in the US (Pulver et al, 2016). The community has seemed to be open on using drones for medical reasons, although restrictions and policies are the reason for being a step back. The Centre for Resuscitation Science at Karolinska Institute in Stockholm, made one of the first flying tests of a drone delivering an AED.

Their drone is a 5.7kg UAV carrying a non-built-in AED. It is capable of flying up to 70km/h with a range of 15km straight distance (Claesson et al, 2017). The drone itself has a weight of 5kg, although the AED weighs 760gr. It carries a global positioning system (GPS), a camera and a built-in microphone. The big propellers allow the drone to travel very fast.

The three-day test flights showed that the drone's defibrillator could be operational within 3 seconds after its arrival compared the 3-minute delivery time of the current Swedish emergency service team. These are averages, because the emergency service team may reach a patient instantly if he is outside, but the high buildings slow the delivering time. In addition,

the flight tests showed that the drone is capable of reaching a patient in just 5 minutes compared to the 22-minute time-distance of the current emergency management system (Claesson et al, 2017). It is worth noting that the 5-minute delivery time is the surviving threshold. Since then, each minute passing decreases the surviving rate by 10% (van de Voordea et al, 2017).

Figure I: Ambulance drones of Royal Institute of Technology (left), and the TU Delft (right) (Sources: Claesson et al, 2017 and van de Voordea et al, 2017)

1.4.3 NORWAY

In Norway, there is an ongoing research about medical drones. The Norwegian University of Science and Technology made a stakeholder analysis about this issue. They found that the drones must beat the response time of that of the ambulances by a significant margin. In Oslo alone the average response time is 10’. In addition, the drone must be small to enter inside houses (because the 80% of cardiac arrest emergencies is out of hospital), and above all it must be equipped with a camera and a microphone for bystander-base communication (Rootwelt, 2016). This analysis does not give any results about locating drone bases or even give information about the drone’s requirements, but gives a clear picture of how and why such a network should operate. Currently it is limited through flight-restrictions’ laws.

1.4.4 GERMANY

In Germany, DHL Parcel has created the Parcelcopter drone generation-row (Scott J & Scott C, 2015). The first two generations were to test the capabilities of their drones, and after the stunning results of delivering blood supplies & medicine amongst cities, in 2016, DHL’s

Parcelcopter has delivered 130 parcels of urgent needs. The response time was just 8 minutes, compared to the 30-minute road trip in winter (Scott J & Scott C, 2015).

1.4.5 REST OF THE WORLD

There are also some other projects from research groups and companies that operate around the world using drones in medical services, delivering medicine & vaccines, defibrillators and blood samples (Scott J & Scott C, 2015). For instance, in the USA many hospitals used medical drones to deliver blood supplies.They used them because only 23% of 108,985donated blood units wereactually distributed to hospitals' blood banks. Only 1.3%of these units delivered to the disaster site within 4 days (Cornelius et al, 2015).

In Virginia, Nevada, a drone company named Flirtey, uses UAVs to provide with medications (Scott J & Scott C, 2015). A research group in USA made the first attempt to create a drone **network**, instead of a single ambulance-drone in Salt Lake City, Utah. Their study focused only on the potential reduction of the "wheels rolling time", by using a medical-drone (AED-Drone) to respond to OHCA patients. Their goal was to improve survival rate (Pulver et al, 2016).

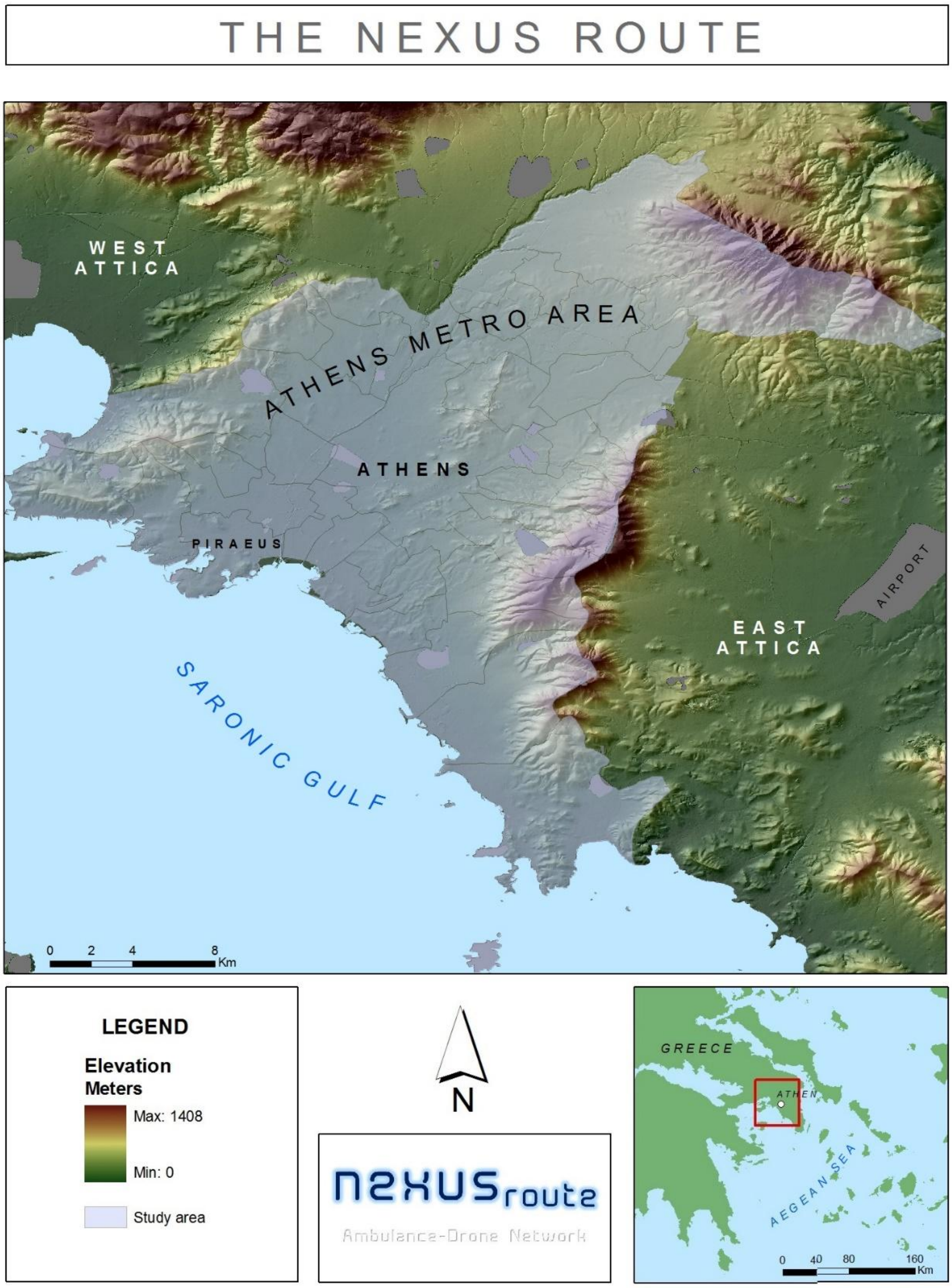
Auto-piloted drones by Matternet, use GPS to navigate across ground stations in order to deliver medication in remote locations in Haiti (French, 2015), New Guinea and Dominican Republic (Choi-Fitzpatrick et al, 2016). The drones automatically generate a route based on the terrain, weather conditions and population density, delivering items via a parachute (Raptopoulos 2013).

Worth noting is that the first fully functional medical-drone projects started in Africa for two main reasons. First, only a third of the Africans live closer than 2km of main roads (Scott J & Scott C, 2015). In addition, the lack of policy for drone usage in almost the entire continent, helped companies to flourish this technology. Some of them are the UPS & Zipline companies, which use drones to deliver blood and vaccines towards 20 clinics in remote sections of Rwanda (Khazan, 2016). This has led to the reduction of infant deaths due to malaria, down to half. Drones prove to be vital.

1.5 STUDY AREA

The study area is the metropolitan area of Athens, the most populated city of Greece with

3.06 million inhabitants (HSA, 2011). Athens metro area is a region of 40 municipalities, which spreads on 460km^2. The city center (municipality of Athens) and other municipalities are quite dense populated areas. In addition, each year around 17.5 million tourists visit the capital of Greece (Eurostat database, 2009). Athens has many geographical features such as rivers and hills. It was built amongst three mountains and has many spatial planning issues.



The lack of driveways on tight roads make the accessibility difficult and thus, slowing the response-time.

Map I: The study area.

1.6 CURRENT EMERGENCY MEDICAL SERVICES

Currently the National Emergency Center (NEC) of Greece, operates a network of 620 ambulances across the country, 85 of which operating in Athens. On average, the NEC transfers 850 patients each day inside the study area on average (Roussi, 2012). The 85 ambulances operating in Athens divide into two groups with 55 to 60 ambulances operate in daytime and 30 in nighttime. According to international standards, the emergency management system (EMS) must have one ambulance per 30,000 people in country level. Although, in Greece there is one ambulance per 150,000 people (Perdikogiannis, 2006).

Additionally, the NEC operates six motorcycles and four small vehicles in Athens (2 Smarts and 2 Citroen Jumpers).The motorcycles operate inside the city center, with a medical crew of 2 people. Additionally, the motorcycles carry medical equipment such as: band aids, infrared clinical thermometer, a semi-automatic AED, oxygen masks, acid attack burns insulin injections and others. The small vehicles operate 24/7 with the same equipment, although there is a qualified physician alongside the 2-man medical crew. Unfortunately, these do not carry AED

AUTOMATED EXTERNAL DEFIBRILATOR (AED)

The automated external defibrillator is a portable electronic device that automatically diagnoses the cardiac arrhythmias of ventricular fibrillation of a patient (Kerber et al, 1997). The need of such a tool is essential because it can be used in OHCA cases instantly saving lives. In 2017, there are very few AEDs located in public places. Almost all of them are donations from civilians, or talking heads of several associations, mainly from sports. In particular, the Greek government has instructed that all public places must have an AED. The "public places" are identified as sport venues, subway stations, schools, prisons, shopping malls, tourist areas, airports and ports. Although, it was the year 2007 that the Greek government voted for the locating of AED in public areas, ten years later the only AEDs in airports.

1.7 DRONE COST

The cost of a drone varies upon the needs of the user. Dependent variables are the size of the drone, its carriage ability, and the battery capacity. The creation of such network is bound to the projects' principle: "lowest cost". We need a drone capable of carrying an AED, which has a camera, GPS sensor, and high top speed. In order to operate flights even if the weather is bad, we need a reasonably big drone. We communicated with many drone companies from Greece, Cyprus and the United States. The cost of a custom made drone is €2,000 to €5,500 depending on the company. Although, it is also possible to use a commercial drone with some special modifications upon it, and would cost around €2,000. The specifications of the commercial drone would be the same. The price is significantly low, because such drones have a lot of demand.On the other hand, custom-made drones need more time to design and extra production time to create, therefore, the price raises.

1.8 THE NEED OF THE NEXUS ROUTE

Why do we need a Drone-Network? The answer lies upon three factors. The emergency-health-service employees' factor, the economic factor and of course, the patient's factor. Therefore, the answer is the following:

EMPLOYEES' FACTOR

Time is a source of anxiety and fear (Lovibond&Lovibond, 1995). In a survey conducted by Anna Roussi on NEC personnel in 2012, showed that 42 out of 67 employees (67.6%) is feeling anxiety due to OHCA emergencies. Two facts worth noting; first, it is by far the main cause of the natural illnesses that affect employees, with the next illness (stroke) affecting 15% of the employees. Secondly, only car accidents surpass the OHCA anxiety levels with the 74% of the employees being affected. In the same survey 91% said that there should be a stress-relief program. Stress-relief program is a procedure that the employees pass through from a qualified psychologist in order to avoid entwining work's stressful experiences with their every-day lives (Roussi, 2014).

ECONOMIC FACTOR

One of the most problematic situations in the emergency health-services is the "unfinished transfer". Unfinished transfers aredeployments of ambulances:

- Which did not find the destination point (wrong address).
- Whom transfer was cancelled.
- In which the patient denied the transfer itself.
- Although the emergency call was fake.

The total calls which were labeled as unfinished transfer were 76.919 in 2012 alone (NEC annual report, 2013). Unfinished transfersare loss of fuel. The average transfer-distance an ambulance makes is 7km (Roussi, 2012). Using data from a survey conducted by Haidari in 2016, the cost of a 7km transfer costs about €1. We accounted fuel consumption of 7 kilometers per liter of gasoline, and a price of €1,50 per liter. Therefore, the unfinished transfers create a loss of €77,000 annually (Haidari et al, 2016).

On the other hand, we do not know how many of these fake calls were about OHCA. Although, it is safe to say that a drone could monitor the emergency site before the ambulance was even deployed due to the drone's ultra-fast response time. The use of medical UAVs is a logistic cost-saving method (Haidari et al, 2016); single deployment costs about €0.06.

PATIENTS' FACTOR

Patients need medical treatment instantly in almost every occasion. Particularly in OHCA emergencies, when the patient is possible to survive an episode within a 5-minute treatment. With that in mind, if there is a medical-drone network, it could assist the current EMS reach patients fast enough to survive cardiac arrest. An ambulance arrives as well at the emergency site, to transport the patient to a hospital for further examination.

1.9 HOW CAN WE DO THIS?

We propose the Nexus Route as a method of saving human lives. The ultra-fast response times of the drone, can increase the survival rate of cardiac arrest victims from 7% currently in Greece (Eurostat, 2014) to at least 80%. We believe that we can cover the demand of the emergency management system for an entire city with drones located strategically. These drones shall carry a detachable automated external defibrillator, that can be used easy by anyone, trained or not.

Today people call the emergency number of 166 in Greece to call for an ambulance transfer. The communications center has immediate contact with the ambulance drivers via radio, in order to minimize the response time 24/7 (Roussi, 2012). We propose an enhancement of the communications center. With this enhancement we will be able to verify the location of the emergency via the phone's call signal. When the communications' operator verifies a cardiac arrest emergency, she/he will import the coordinates to the system, and the nearest drone will dispatch immediately. This will be done via our application.

The application will locate the emergency through the telephone's signal, and when ready, the drone deploys. With an autopilot program and a medical crew at base they will monitor the flight and the emergency through a live streaming camera. The crew will be a qualified drone operator, as well as a qualified cardiologist. They will give instructions to caller, on how to use the drone's AED properly while the ambulance reaches the emergency site to transfer the patient for further examination.

With the Nexus Route we aim to achieve the following:

- Enhancement of the current emergency management system (EMS).
- Decrease the response time 10 times at minimum.
- Increase the surviving rate of cardiac arrest victims to 80%.
- Decrease the logistic costs.
- Keep the current personnel number.

The creation and the operation of the Nexus Route will benefit both parties, NEC and patients. We will not replace ambulances with medical drones. The Nexus Route will coexist with the current EMS assisting it. We aim to optimize public health services and save people that will not survive a cardiac episode otherwise.

CHAPTER 2. DATA

2.1 OHCA CASES

The data used in this research came from the National Emergency Center (ΕθνικόΚέντροΆμεσηςΒοήθειας - EKAB), representing the region of Attica where the Athens metro area is located. The data include information about the causes of death and cover a period from 2012 to 2016. The data also includeinformation about the date and place of each emergency took place. In addition, in every case the NEC has recorded the possible cause that led to cardiac arrest. However, this particular information is classified, as being personal data and thus, not available for this study since the goal of the study is to minimize the response-time, and not explain the reasons behind cardiac arrest deaths (OHCA) The acquired data were sufficient. The most important information was the spatial dimension of the data, i.e. the OHCA cases' coordinates, verified via the emergency call signal.

For this study we first excluded all death causes not labeled as "cardiac arrest". In addition, we excluded cardiac arrest that occurred inside hospitals. Worth noting is that there were some particular OHCA cases that were labeled as "crew witnessed". These cases are also excluded as the EMS was already there when the OHCA occurred and so, the time response was nigh to zero. Later, we distributed these cases in GIS environment as a layer with x, y coordinates.

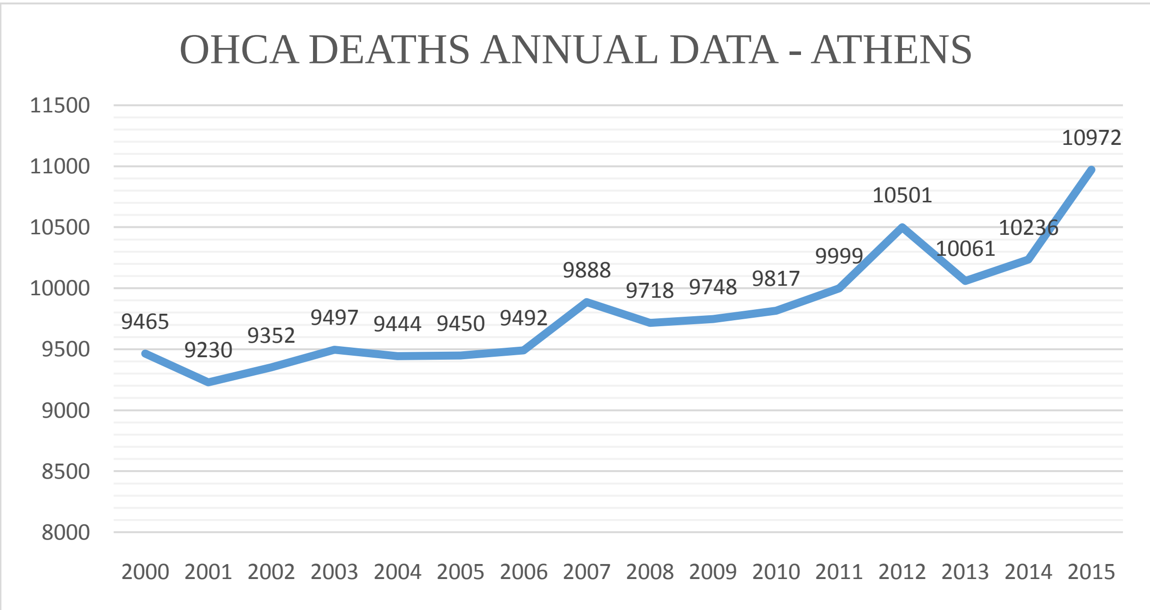


Figure II: OHCA Deaths per year for the Athens metro area. Data source: Eurostat.

2.2 SPATIAL & DEMOGRAPHIC DATA

The Hellenic Statistical Authority (HSA), and Eurostat were the sources of every demographic data, such as data about the population and the population density in municipality level. Wealsouseddatafromthe National Cartography Authority (NCA), for the use of a Digital Elevation Model of Attica.

Sector	Population (in thousands)	Sector	Population (in thousands)
Central Sector	***1,029.2***	***North Sector***	***591.9***
Athens	664	Aghia Paraskevi	59.7
Byronas	61.3	Amaroussion	72.3
Galatsi	59.3	Vrilissia	30.7
Dafni-Hymettus	33.6	Heraclion (Athens)	49.6
Zografou	71	Kephisia	71.2
Ilioupolis	78.1	Lykovrysi - Pefki	31.1
Kaissariani	26.4	Metamorfosi	29.8
Nea Filadelphia	35.5	Nea Ionia	67.1
West Sector	***487***	Papagou - Holargos	44.5
Aghia Varvara	26.5	Penteli	34.9
Aghii Anargyroi	62.5	Filothei	26.9
Egaleo	69.9	Halandrion	74.1
Ilion	84.7	***Piraeus Sector***	***445.9***
Peristeri	137.9	Piraeus	163.6
Pertroupolis	58.7	Keratsini	77
Haidari	46.8	Korydallos	63.4
South Sector	***605.6***	Nikea	116
Aghios Demitrios	72.9	Perama	25.3
Alimos	41.7	***Total***	***3,089***
Glyfada	87.3		
Argyroupolis	51.2		
Kallithea	100.6		
Moschato - Taurus	114.9		
Nea Smyrni	73		
Paleo Phaleron	64		

Table I: Demographic data of Athens, population. Source: HSA.

The table above shows the population of each municipality included in the study area. As in many capitals in the world, the population is mostly accumulated in the city center, as 35% of the population of Athens metro area, is located in 20% of the total area. The NEC covers all 3 million inhabitants by 85 ambulances each day.

Sector	2014	2015	2016
Central Sector	242,027	244,380	246,653
West Sector	178,002	179,859	181,519
North Sector	395,311	394,287	392,355
South Sector	215,309	217,488	219,439
Piraeus Sector	205,276	205,081	206,387
Total	1,235,925	1,241,095	1,246,353

Table II: Demographic data of Athens, population older than 50 years old. Source: Eurostat.

The demographic data provide information about the population structure, vital to our analysis. It is clear that the population age group of "older than 50 years old" is constantly increasing due to demographic ageing (Eurostat – Demographic Ageing Report, 2017). This phenomenon increases the possibility of more cardiac arrest emergencies and thus, the demand as well. With no health-service enhancement, the survival rates are likely to drop.

Section	All Deaths	OHCA	Population
Central Sector	11,196	3,679	1,023,312
West Sector	4,682	1,538	490,214
North Sector	5,519	1,814	595,085
South Sector	5,369	1,764	528,003
Piraeus Sector	5,194	1,706	451,554
Total	*31,960*	*10,501*	*3,089,068*

Table III: Demographic data of Athens, per sector, 2012. Sources: HSA, NEC.

Section	All Deaths	OHCA	Population
Central Sector	10,726	3,524	1,021,716
West Sector	4,486	1,474	489,387
North Sector	5,288	1,737	544,257
South Sector	5,144	1,690	528,176
Piraeus Sector	4,976	1,636	450,726
Total	*30,620*	*10,061*	*3,084,262*

Table IV: Demographic data of Athens, per sector, 2013. Sources: HSA, NEC.

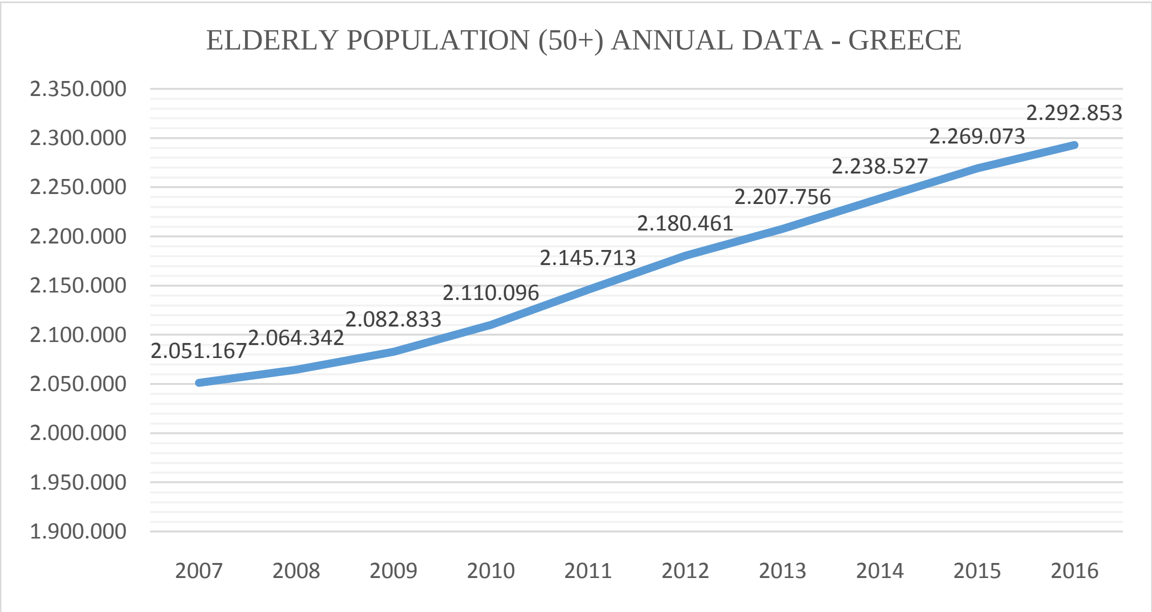
Sector	All Deaths	OHCA	Population
Central Sector	10,913	3,587	1,020,096
West Sector	4,562	1,499	488,558
North Sector	5,376	1,768	593,429
South Sector	5,233	1,720	527,348
Piraeus Sector	5,092	1,663	449,898
Total	*31,154*	*10,236*	*3,079,329*

Table V: Demographic data of Athens, per sector, 2014. Sources: HSA, NEC.

Sector	All Deaths	OHCA	Population
Central Sector	11,700	3,844	1,018,640
West Sector	4,895	1,607	487,730
North Sector	5,757	1,895	592,400
South Sector	5,634	1,843	526,520
Piraeus Sector	5,408	1,783	449,070
Total	*33,394*	*10,972*	*3,074,160*

Table VI: Demographic data of Athens, per sector, 2015. Sources: HSA, NEC.

These are the data provided by the NEC, reformed and presented with all needed information. These data show a constant increase on cardiac arrest deaths, as the critical population (50+ year-olds) increases.



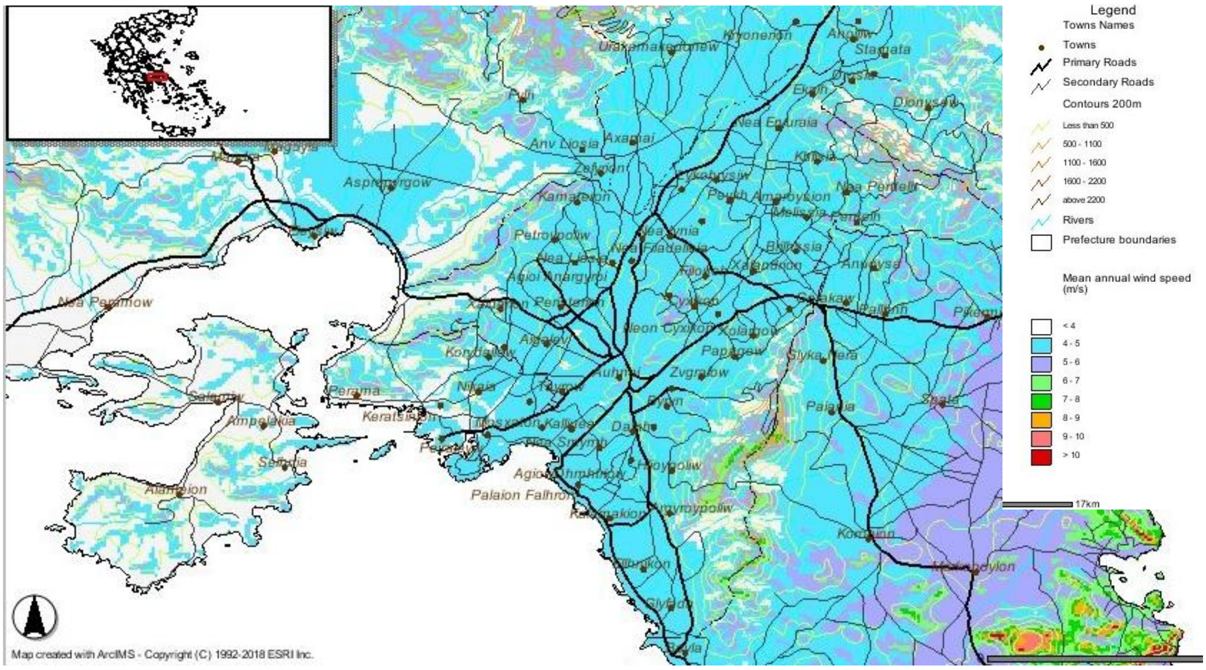
FigureIII: Elderly population (older than 50 years old) by year. Source: Eurostat

Even though deaths caused by cardiovascular disease are increasing as time passes (Graph I), their percentage from the total deaths in Greece remains relatively stable. We can explain this by seeing the percentage of the critical age for CVD, which is growing the last decades due to population ageing. Graph II shows the 65+ year-olds, an age group, which is always growing.

2.3 PARAMETERS AFFECTING THE DRONES

2.3.1 WEATHER

The Center of Renewable Energy Sources (CRES) offers data of wind maps and temperatures for Greece. As the map of cres.gr shows below, the mean annual wind speed of the city is 4 to 6 m/s. Drones fly through air resistance, so there is a wind-speed limit that drones can fly. The most popular drone company named DJI gives maximum wind-speed feedback for users. Additionally we have obtained wind-speed data for Attica to study the functionality of a



drone network relative to wind speeds.

Figure IV: Map of mean annual wind speed for Attica. Source: CRES

Drones fly through air resistance. The propellers turn so fast that they create turbulence underneath the drone, a force which makes it hover. If the forces that apply on the drone are greater than the drone's weigh, it cannot fly safely. The wind can even make the drone crash. In these situations, the wind speeds are high. Therefore, weather data are important to see the possibility of drone use throughout the year. The study area seems to have very low wind speeds on average, which is promising for constant and safe drone flights.

Knots	Beaufort	m/s	km/h	mph	Effect on land
1	0	0 – 0.2	1	1	Calm. Smoke rises vertically
1 to 3	1	0.3 – 1.5	1 – 5	1 – 3	Wind motion visible in smoke
4 to 6	2	1.6 – 3.3	6 – 11	4 – 7	Wind felt on exposed skin. Leaves rustle
7 to 10	3	3.4 – 5.4	12 – 19	8 – 12	Leaves and smaller twigs in constant motion
11 to 15	4	5.5 – 7.9	20 – 28	13 – 17	Dust and loose paper raised. Small branches begin to move

16 to 21	5	8 – 10.7	29 – 38	18 – 24	Branches of a moderate size move. Small trees begin to sway
22 to 27	6	10.8 – 13.8	39 – 49	25 – 30	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult. Empty plastic garbage cans tip over
28 to 33	7	13.9 – 17.1	50 – 61	31 – 38	Whole trees in motion. Effort needed to walk against the wind. Swaying of skyscrapers may be felt, especially by people on upper floors
34 to 40	8	17.2 – 20.7	62 – 74	39 – 46	Twigs broken from trees. Cars veer on road
41 to 47	9	20.8 – 24.4	75 – 88	47 – 54	Larger branches break off trees, and some small trees blow over. Construction/ temporary signs and barricades blow over. Damage to circus tents and canopies
48 to 55	10	24.5 – 28.4	89 – 102	55 – 63	Trees are broken off or uprooted, saplings bent and deformed, poorly attached asphalt shingles and shingles in poor condition peel off roofs
56 to 63	11	28.5 – 32.6	103 – 117	64 – 73	Widespread vegetation damage. More damage to most roofing surfaces, asphalt tiles that have curled up and/or fractured due to age may break away completely
64 to 71	12	Over 32.7	Over 118	Over 74	Considerable and widespread damage to vegetation, a few windows broken, structural damage to mobile homes &poorly constructed sheds and barns. Debris may be hurled about

Table VII: Wind speed categories. Source: windfinder.com

The table above aims to show the comparison of different wind speed units to those who are not familiar with wind speeds, divided in a beaufort scale. The drones are bound to wind speeds on whether they would fly or not. The following table shows the maximum speeds of some of the most popular commercial drones, with different sizes. We show the maximum wind speeds the drone company gives, and the users' maximum wind speeds they used their drones.

Drones can fly normally even if they exceed the given wind speed limits. Each drone company gives a theoretical maximum safe speed for drone use, normally at 5 or 6 beaufort. Nevertheless, users tend to use them at even higher speeds. A questionnaire was given to 30 drone users, in order to answer the following:

- Which is the maximum wind speed the drone company gives?

- How often do you exceed those limits?
- How much do you exceed those limits?
- Which is your maximum safe wind speed you operate a drone?

All the participants answered that they exceed the wind speeds which the company gave quite often. Ten out of thirty said that they operated the drone in strong winds in order to find their true limits. All thirty participants reported that do not mind about wind, unless they can't operate it. The answers of maximum wind speeds while operating a drone, are shown at the table below.

Drone	Max speed (DJI)	Beaufort	Max speed (users)	Beaufort
Phantom 4 pro	**22 (mph) / 35 (km/h)**	**≤5**	**28 (mph) / 45 (km/h)**	**≤6**
Mavic Pro	**22 (mph) / 35 (km/h)**	**≤5**	**30 (mph) / 48 (km/h)**	**≤6**
Inspire 2	**25 (mph) / 40 (km/h)**	**≤6**	**32 (mph) / 50 (km/h)**	**≤7**
Matrice 200	**25 (mph) / 40 (km/h)**	**≤6**	**37 (mph) / 60 (km/h)**	**≤7**

Table VIII: Drone maximum speeds from DJI and users feedback

The drones above are the 4 most popular amongst drone users. Sorting them from smallest to biggest, the data show that bigger drones can resist more wind speeds. Given that over 7 beaufort even the bigger commercial drones are difficult to handle, we can make a scale of safety for the dronesof our network and put a maximum wind speed limit. Once the Nexus Route is operational, the wind must be less than 7 beaufort, and more specifically under 36mph in order to operate a drone without risking crash-landing.

The next step is to ensure that the wind speeds are less than 7 beaufort at most of the days of the year. For that matter, we obtained data from CRES. As Figure III shows, the average wind speed is 4 beaufort, which is safely under the maximum of 7 beaufort. We show below the three most "windy" months of 2017, in order to check the number of days that the wind speed exceeds our limit. January, February and August were the months of 2017 with the highest average wind speeds.

JANUARY DAILY MAXIMUM WIND SPEEDS

Jan1st	Jan2nd	Jan3rd	Jan4th	Jan5th	Jan6th	Jan7th	Jan8th	Jan9th	Jan10th
7	5	4	4	5	7	11	8	5	12
Jan11th	Jan12th	Jan13th	Jan14th	Jan15th	Jan16th	Jan17th	Jan18th	Jan19th	Jan20th
14	16	13	9	10	6	10	11	16	19
Jan21th	Jan22th	Jan23th	Jan24th	Jan25th	Jan26th	Jan27th	Jan28th	Jan29th	Jan30th
21	24	20	19	21	15	12	14	16	11
Jan31th									
9									
FEBRUARY DAILY MAXIMUM WIND SPEEDS									
Feb1st	Feb2nd	Feb3rd	Feb4th	Feb5th	Feb6th	Feb7th	Feb8th	Feb9th	Feb10th
9	7	9	5	6	8	10	9	11	14
Feb11th	Feb12th	Feb13th	Feb14th	Feb15th	Feb16th	Feb17th	Feb18th	Feb19th	Feb20th
17	24	25	21	24	18	20	18	12	15
Feb21th	Feb22th	Feb23th	Feb24th	Feb25th	Feb26th	Feb27th	Feb28th		
19	21	18	14	18	25	27	22		
AUGUST DAILY MAXIMUM WIND SPEEDS									
Aug1st	Aug2nd	Aug3rd	Aug4th	Aug5th	Aug6th	Aug7th	Aug8th	Aug9th	Aug10th
5	5	6	5	7	4	5	8	6	7
Aug11th	Aug12th	Aug13th	Aug14th	Aug15th	Aug16th	Aug17th	Aug18th	Aug19th	Aug20th
5	4	4	6	8	12	16	24	26	21
Aug21th	Aug22th	Aug23th	Aug24th	Aug25th	Aug26th	Aug27th	Aug28th	Aug29th	30-31
24	29	28	30	32	**36**	28	21	22	No data

Table IX: Wind speeds over Athens (in miles per hour). Daily data provided by CRES.

Banners
SAFE FLIGHTS – 0 to 15 meters per second
SAFE FLIGHTS (with GPS mode) – 16 to 21 meters per second
SAFE FLIGHTS WITH CAUTION – 22 to 26 meters per second
FLIGHTS WITH CAUTION – 27 to 34 meters per second
NO FLY DAY– over 35 meters per second

Table X: Banners of fly conditions.

Table IX shows the daily maximum speeds provided by the Centre of Renewable Energy Sources of the three most windy months of the year by average. There was only one day in those three months that we could not have flown a drone. Nevertheless, there are some particular days throughout the year with wind speeds over 36mph. However, the three windiest months of 2017 had only one day that a drone would not be able to fly.

The 77.17% of the days are labeled with a “Safe flight” banner, the 10.86% are labeled with a “Safe flight with caution” banner, the 6.52% are labeled as “Flight with caution”, and the 1.08% as “No fly day”. It is safe to say that there are only a few days with a “No fly day” banner. Two days of the database had nothing but average speed. In particular there were 6 more days throughout the year with extreme winds inside the city which represents the 1.91% of the days of 2017.

2.3.2NOISE LEVELS

The rapidly emerging sector of UAV industry created concerns about the proper use of a drone. Although there has been quite limited research about the public acceptance (Clothier et al, 2015), there have been surveys in Australia about the public perception; acceptance concerns and misuse. Responders did not consider the drone technology to be unsafe, but are viewed as being on equal levels of risk as the manned aviation (Wackett, 2013). Furthermore, drone terminology had little to no effect on public perception, likely due to lack of knowledge. The point is that the public is not concerned about drone technology if this is presented as beneficial for the public (Clothieret al, 2015). Our goal is to minimize any possible risks (accidents etc.). Wackett(2013) has pointed out that the society has yet to form an opinion about drones. They need to learn more on drones and while the public knowledge increases, the overall opinion about drones is likely to change. Clothier makes a step further on that, saying that industry communication and media coverage will likely influence the public opinion by adopting their position, which can be difficult to change, once established. Therefore, we have the responsibility to present drones beneficial to the public.

As psychologist Richard Wiseman says: “taste is subjective” on his book Quirkology: How we discover the big things in small things (BasicBooks, ISBN-13: 978-0465010233, 2007), on the other hand, there are some objective elements we have to address and study. One of these elements is the sound, the noise. Public acceptance helps drone industry flourish (Wackett, 2013), although if the public is annoyed by its noise, acceptance can easily become denial. The following section analyzes the sound a drone makes in perspective of an urban environment.

Environmental sound	Decibels
Weakest sound heard	0 dB
Whisper Quiet Library at 2 meters	30 dB
Normal conversation at 1 meter	60 – 65 dB
Telephone dial tone	80 dB
City Traffic (inside car)	85 dB
Level at which sustained exposure may result in hearing loss	90 – 95 dB
Hand Drill	98 dB
Snowmobile, Motorcycle	100 dB
Pain begins	125 dB
Even short term exposure can cause permanent damage	140 dB
Jet engine at 30 meters	140 dB
Gauge Shotgun Blas	165 dB
Death of hearing tissue	180 dB
Loudest sound possible	194 dB

Table XI: Decibel levels.

Decibels (dB) is a logarithmic used to express the ratio of one value of a physical property to another, and may be used to express a change in value (e.g., +1 dB or -1 dB) or an absolute value (Davis & Davis, 1997).The decibel is commonly used in acoustics as a unit of sound pressure level. The reference pressure for sound in air is set at the typical threshold of perception of an average human and there are common comparisons used to illustrate different levels of sound pressure (Peters, 2013). DJI forums and the drones' manuals state the decibels a drone reaches. The following drones are amongst the most popular. Note that an ambulance drone should be at the size of Inspire 2 (48cm wide, 47cm long and 32 cm high), in order to carry an AED.

- Mavic Air ~73.4dB (at one-meter distance)
- Mavic Pro ~75.8dB(at one-meter distance)
- Phantom 4 Pro ~76.9dB (at one-meter distance)
- Inspire 2 ~79.8dB (at one-meter distance)

The size of said drones goes from smallest to biggest. Not much of a surprise that the biggest drone is the loudest one. Its propellers are bigger than the others and the power to lift a heavier drone is greater. The noise range between these drones is 6.4dB. From 0 to 3 decibels, the difference at the human ear is nigh unnoticeable, and from 4 to 6 noticeable but not too much louder (Davis & Davis, 1997). Therefore, their sound difference is not much. Comparing these drones to urban environment sounds, like a telephone dial tone (80dB) is louder than the Inspire 2, or city traffic which is just over 85dB.

What we extract from this information is that a drone could not be annoying inside the city, especially when traffic sounds or inside-home sounds occur. In addition, a flight at 70km/h is equal to 19.4m/s. At that speed, the drone would be visually detectible from pedestrians for three to four seconds. Including traffic, the buzzing sound of the drone could be even unnoticeable while flying. Tests made in the US and the Netherlands showed that people are more distracted from ground noise (traffic) than the aerial noise of a drone passing by (van der Voordea et al, 2017 & Caffrey et al, 2002).

2.3.3 FLIGHT POLICY

Since January 1st2017, the Greek Civil Aviation Authority operates an amendment at the Greek Council for proper use of UAV flights (Official Journal of the Greek Government, 2016). This amendment was conducted following an instruction from the European Council, featuring safe and proper use for drones (Official Journal of European Union, 2008). The flying rules are:

- Maximum permitted flight: 132 meters (400ft).
- Flights are permitted further than 8km from airports.
- Flights are permitted further than 30m from buildings, vehicles & civilians.
- Drones must have insurance contracts.
- Each drone must have a visible unique code number.
- The operator must carry a UAV flying license.
- New drones must be enlisted on the fleet list, and non-operative drones must be erased from said list.
- Flying permits have a duration of 12 months. Although, they can be renewed after their 12-month period.
- Flights are forbidden above no fly zones (military sites, schools, prisons).

Although, if the Nexus Route will be considered as a state entity, these rules would be scrapped via application to the Civil Aviation Authority. Nevertheless, flights over 132 meters (400ft) are forbidden, as well as flights closer than 30 meters (100ft) from buildings vehicles or civilians whatsoever. For that matter, ambulance-drones' flights should be 30 meters above the highest building of their operation area.

CHAPTER 3. METHODS

3.1 METHOD A: FIELD RESEARCH

Field research is our qualitative method and focuses on gathering data from the EMS response times. More specifically, we recorded ambulance deployments in various periods of the day and recorded the response time. We also had the opportunity to gather data from a day which there was a strike, and the main/central roads of the city were closed.

Response time is the time-period beginning from the emergency call until the moment that an AED is used (Generally "until the moment that the crew reaches the patient"). This time divides into three sections. The first section is the time that the crew needs to prepare and deploy (preparation time). The second one is the "wheels-time" and refers to the time that the ambulance needs, in order to reach the emergency. The third is the time that the crew needs to reach the patient with the defibrillator (reach time).The corresponding equation to calculate the total response time follows.

$$Response\ time = preparation\ time + wheels\ time + reach\ time$$

The preparation and reach times are the sum of the "dead time", the period that is pretty much the same from case to case. From 27 cases of ambulance deploys, we learned that the crew must be ready in 30 seconds and they reach the patient within 35 to 40 seconds. The time-period that varies at most is the "wheels-time". It is recorded in kilometers per minute (km/min). The reason behind that metric unit is that we need not the average speed of an ambulance, but the distance it can cover in one minute. In 27 cases, 17 at daylight (rush hours), 8 at nighttime (between 10pm and 4am), and 2 at a special day (workers' strike) where the major roads of Athens were closed.

Additionally, we interviewed some of the ambulance drivers. The type was "open interview", and asked questions concerning:

- The validity of our records – *Question 1: How close were the recorded timings to a normal day?*
- The amount of influence from traffic jam and/or strikes – *Question 2: How much does the traffic and strikes affect the EMS?*
- Situations that happen often during a day but we did not record – *Question 3: Have you experienced any special cases that affected the response times (not recorded from us)?*

3.2 METHOD B: GIS

GIS stands for Geographical Information Systems. It is our quantitative method where we automate the response time calculation. Field research showed us that timing varies amongst scenarios like traffic jam, empty roads or even closed major roads depending mainly on which period of the day we refer to. The analysis will be carried out with the help of GIS software. We used the data of the field research, and like a statistical analysis, we use the sample of the OHCA cases, applying these results in whole of the Athens metro area by averages, using weights (more on that later). Generally, “GIS tools” is the best analysis method when variables include a spatial reference. In the case of Aaron Pulver et al (2016), the analysis was made in GIS environment using parameters which include spatial reference. JossefinLenartsson (2015) used as well GIS tools, resulting a strategic locate of ambulance drones, by finding risk areas (areas where it is more possible for a cardiac arrest to occur). This method is more sufficient than others, because it relies on space, providing spatial justice. Space is a fundamental dimension of human societies. Spatial (or social, speaking of society) justice is embedded in it. Therefore we need to understand the parameters that create inequalities through space, and focus on reducing them (Harvey, 1992).

DATA PREPARATION

The raw data used in our analysis were the following: a digital elevation model of Attica, road infrastructure of Greece, a table for the OHCA cases between 2012 and 2016 and a “municipalities’ regions” shapefile. We pre-processed these raw data in order to use them with the best way possible.

PROJECTION

Projection is the first step a GIS expert does, in order to analyze data properly. Especially here, where we need a metric system (m/min) we need to project all data the same. We used the World Geodetic System WGS84. WGS84 is an Earth-centered and Earth-fixed reference system and geodetic datum (European Organization for the Safety of Air Navigation, 2007). It is based on a consistent set of constants and model parameters that describes the Earth’s size. It is compatible with the international terrestrial reference system (ITRS), and the global positioning system (GPS) which is an advantage in GIS analysis, making the analysis available with all countries (Malys et al, 2015).

MASKING

Masking is the tool that reforms the analysis's outputs. We need to create a region of interest (study area), so the analysis is applied correctly minimizing (or even vanishing) any possible errors. The mask of our analysis was the border of Athens metro area, which includes 40 municipalities. This helps us find all analysis's outputs inside the study area.

JOIN & MERGE

The data of the OHCA cases were classified by year and sorted by occurrence time with x, y coordinates. We imported that file in GIS software using the x, y coordinates, in order to give it spatial reference. Then we created a point layer of the OHCA cases for each year. The next step was to merge all that data to a single layer in order to analyze a large sample since our analysis did not consider temporality. We used the merge & masking tools on the digital elevation model of Attica as well. We excluded all regions outside said boundaries and used it as a base map.

DATA PROCESSING: BUFFER

Buffer is a GIS tool, which creates zones around the shape of the layer as a raster file. It creates various forms of buffs, relevant to the metric unit we choose. We used this feature on two occasions. First, road infrastructure is a single line shapefile, which does not have a solid existence. Buffer keeps the shape of the roads' lines transforming it to a solid vector file. We transformed it later to a raster file. Roads are quite often 10 meters wide by average, so we made a buffer zone of 5 meters. We used this buffer zone in place of the raw-road-infrastructure line shapefile, masked within the study area. We also used buffer zones at drone-points. Drone-points are the optimal places where we locate medical drones. These buffers are circles around the points of various radiuses, for various flight scenarios (more on that later). Additionally we used Thiessen polygons to delimit areas that are outside the circles of the buffer zones, in order to include the whole study area in the Nexus Route.

EUCLIDEAN DISTANCE & IDW

Euclidean distance is another GIS tool relative to buffer. It finds the distance from a certain startpoint across space. Our starting points were the EMS stations. We used the average response time in meters per minute, and masked the cost-distance function within the road infrastructure buffer zone. Then we reclassified the output in three groups: faster, equal and slower than medical drone's response-time.

Inverse distance weighted interpolation is the acronym of IDW. This is the way to evaluate our projected time distances with the help of the 27 recorded response times. As these points sparse across the capital of Greece, we find the errors that occur from the automated cost distance. It finds how much difference there is between the projected results and the recorded ones.

OHCA DENSITY

OHCA density represents the regions on the map of Athens with the most OHCA cases accumulated in clusters. It doesn’t matter if these places are tourist sites or shopping malls or just neighborhoods. What matters most is the best possible population coverage with medical drone stations. Point density is a tool that counts the points within a specific region (Lennartson, 2015). The output is a raster file representing the density of OHCA cases as a value. With the help of the digital elevation model of the study area, the output cell size was set to just 5 meters.

POPULATION DENSITY

Population density is the number of people living in a square kilometer. This is an assisting layer, which adds another consideration on our analysis. The OHCA-cases record has a span of 5 years. We did a layer overlay of OHCA and population density and found that there are dense populated areas in Athens where there are no OHCA recorded. We must consider the possibility of other OHCA cases, which may happen in the future. The targeted population is over 50 year-olds, as this is the borderline critical age for a cardiac arrest occurrence.

MCE

MCE stands for multi-criteria evaluation. It is a way to find the optimum places by ranking all layers (criteria) with weights. Weights are numbers, which represent the importance of each criterion, and they add up to 1. In order to plan a strategic placement for the Nexus Route, we need more than one criterion. We need to know the areas that the EMS is responding critically slow to an OHCA emergency for sure, but we need to find the places where OHCA occurred the past 5 years. For instance, if an ambulance is too far away and its response time is over 20 minutes that means that an OHCA patient will be deceased. Nevertheless, if such place has no record of OHCA cases the past 5 years, then this place is less critical than others are. So we need response times, as well as we need OHCA density and of course, population density. We consider population density as a criterion for the special cases. For example, it is possible that a populated area has ever recorded an OHCA the past 5 years by luck, or either because of low elder-population percentage. Therefore, we need to address the possibility of an OHCA case where we do not have a record of it yet. Bibliography has multiple ways to find the layers' optimal weights, although the norm follows the "researcher's judgement". With that in mind, we need to weight two scenarios of MCE with different numbers to judge the best evaluation.

The first scenario will follow the 50-30-20 principle. Response time: 50%, OHCA density: 30%, Population density: 20%. Response time is the number one criterion, although not the only one. In the first scenario, we almost equalize the weights of population and OHCA case density. The two of them are equal to the response time weight. As Tzeng (2005) showed, the response time is the number one criterion on working on MCE. The subject of the analysis may not be always the fundamental criterion (Carver 2007). If its outcome is bound to an independent parameter, the independent holds the highest weight (here is the response time).

The second scenario will follow the 60-30-10 principle. Response time: 60%, OHCA density: 30%, Population density: 10%. As above, response time plays a significant role on whether a patient will survive a cardiac arrest episode, but we reduced the importance of the population density. The reason behind this decision is the following. We may experience in the future an OHCA case in now-uncharted territories. Although, a five-year record is a bold one and gives a clear picture of where people suffer cardiac arrest episodes. OHCA case density is equally significant in both scenarios. The different scenario will show any weakness on our MCE. This approach allows slight changes of the weights and generates results that can easily be analyzed statistically to provide insights into multi-criteria model recommendations (Butler et al, 2007).

The reclassification will have scores from one to five. One (1) will be the least dangerous place, and five (5) will be the most dangerous place. We will first reclassify the response time with scores from 1 to 5. From time distances less than 4 minutes the class will have a "1" score. From 4 to 6 minutes response time the class will have a "3" score. The response times over 6 minutes are the most dangerous and therefore we will classify them with a "5" score. OHCA density will be reclassified in 5 classes of natural breaks. The most sparse OHCA-case areas will have a "1" score, and the most dense OHCA-cases areas a "5" score. The "over 50 years old" population density will be reclassified in 5 classes as well. Most sparse areas will have a "1" score and the most dense ones a "5" score.

Then we will make a raster calculation, and find the most dangerous areas that a deadly OHCA can occur. The equation is the following.

Scenatio 1

$$F(x) = Response\_time * 0.5 + OHCA\_density * 0.3 + Population\_density * 0.2$$

Scenario 2

$$F(x) = Response\_time * 0.6 + OHCA\_density * 0.3 + Population\_density * 0.1$$

<SIDE NOTE>

$$Population\ density = Pop\_over50 * 0.75 + Total\_population * 0.25$$

Class	Response time	OHCA density	Population (total)	Pop. Dens. (over 50)
1	Less than 4’	Under 43 d/km^2	Less than 41,700	Under 1840 p/km^2
2	-	44 - 53 d/km^2	41,800 – 67,000	1841 - 2090 p/km^2
3	4’ – 6’	54 - 72 d/km^2	67,100 – 106,900	2091 - 2669 p/km^2
4	-	73 - 104 d/km^2	107,000 – 163,600	2670 - 3969 p/km^2
5	Over 6’	Over 105 d/km^2	Over 163,100	Over 2970 p/km^2

Table XII: MCE weights pre criterion

3.3 CRITICAL AREAS & DECISION MAKING

Critical areas are those with the highest score after the multi-criteria evaluation. These areas will be the core for locating medical drones. Depending on where these areas are, we will locate other additional medical drones, to cover the maximum number of the population. At this section of the analysis, we decided to manually place of the drones. The Nexus Route is a network with the optimal planning, and that is why we need to ascertain on how this can be done. By creating multiple scenarios, we can find the advantages and disadvantages of such planning. The best scenario is the one that minimizes the disadvantages and have the most advantages. We prioritize the spatial thinking as we decide visual for the optimal solution.

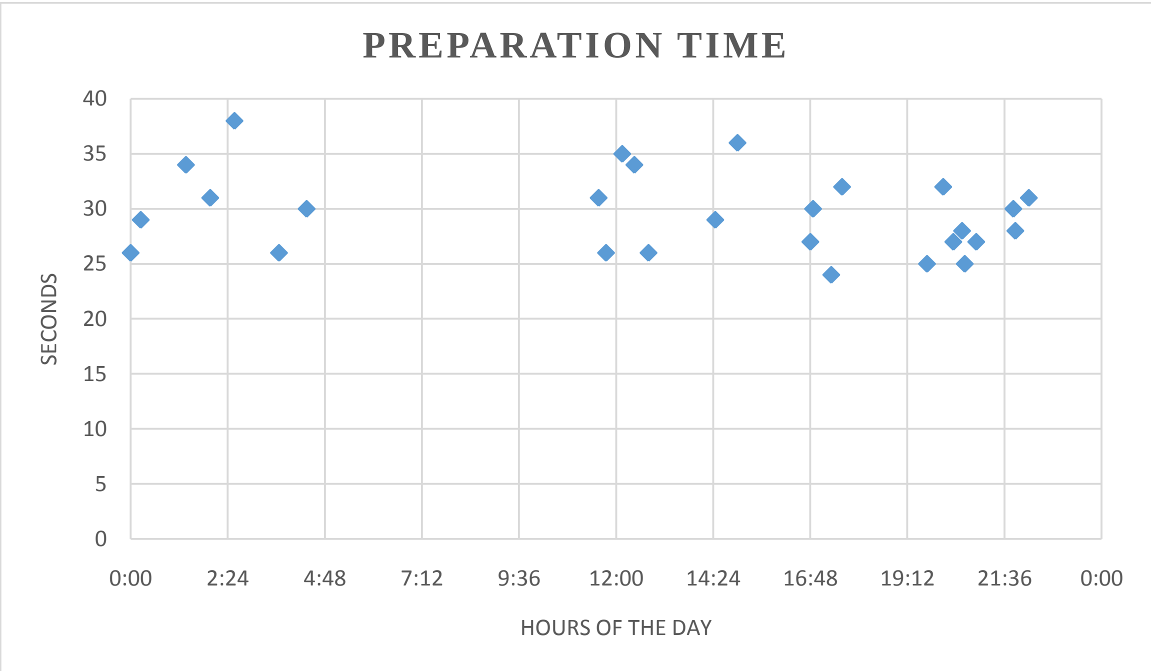
There are some other techniques for planning a medical drone-network, like the mathematical approach (Boutilier et al, 2018). This research applied a model using 53,702 OHCA cases that occurred in eight regions of Toronto, Canada, between 2006 and 2014. Their results showed that 81 drones could have covered the whole area. They used a solely quantitative model lacking spatial reference, although, it is an accepted scientific approach as the simulations showed an 80% chance of survival.

It is sure that the methods we use vary, especially when they are compatible with the data provided. In the case of another study from Norway, Jo Røislien explored optimal air ambulance base locations using advanced mathematical modelling. They used high resolution population data, with a digital elevation model of Norwaywith 1km×1km cells. The advances mathematical modeling resulted optimal helicopter base locations using the maximal covering location model, exploring the number of bases needed to cover various fractions of the population (Røislien et al, 2016). These methods apply in high population data analysis, sacrificing the spatial reference. In our modeling we focus on spatial analysis in order to provide spatial equality, and spatial justice amongst patients. Spatial is special, and combining high spatial resolution with high population data analysis we can provide a strategic placement of ambulance drones which will assist the current emergency management system.

CHAPTER 4. RESULTS

4.1 RESPONSE TIME

We used the recorded data to create scatter plots for the ambulances' timings, which includes all 27 occasions. The average "preparation-time" was 30 seconds, with a very close range. Ambulances deployed at "rush hour" (07:30-09:30, 13:30-15:00, and 16:00-17:30) were significantly slower than that of the nighttime deploys. One of the two special occasions was not affected by traffic alterations (closed roads), as the crew clarified, they were soon to the emergency by luck. The other occasion with closed major roads resulted traffic-jam on the remaining roads. This resulted a tragically delay in response time, with the patient dead after 20 minutes of delay. Only 12 of the 27 emergencies recorded were OHCA. The rest were other types of emergency, as we needed to record response time not specifically for OHCA.



FigureV: Preparation time – 27 cases of ambulance deploy (in seconds)

Preparation is the first of the two periods of "dead time". Even though the preparation records show little loss of time, the drones do not require preparation, as they are stand by to deploy.

Worth noting is the range of the preparation time, as it is little and not bound to the period of the day.

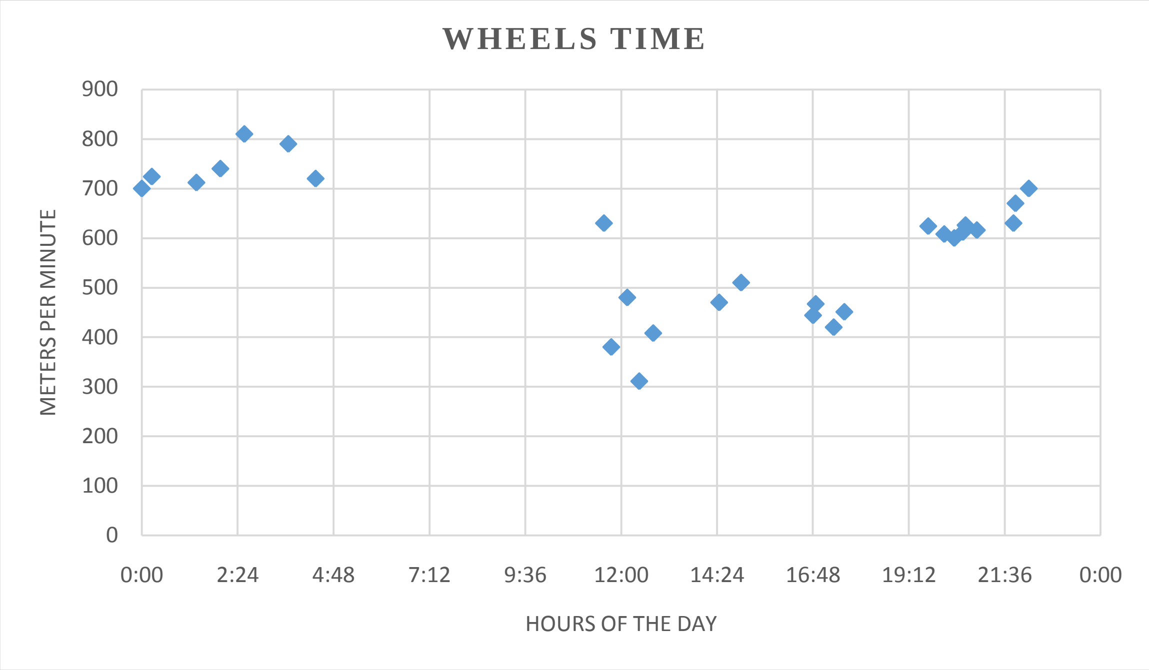


Figure VI: Wheels time – 27 cases of ambulance deploy (in meters per minute)

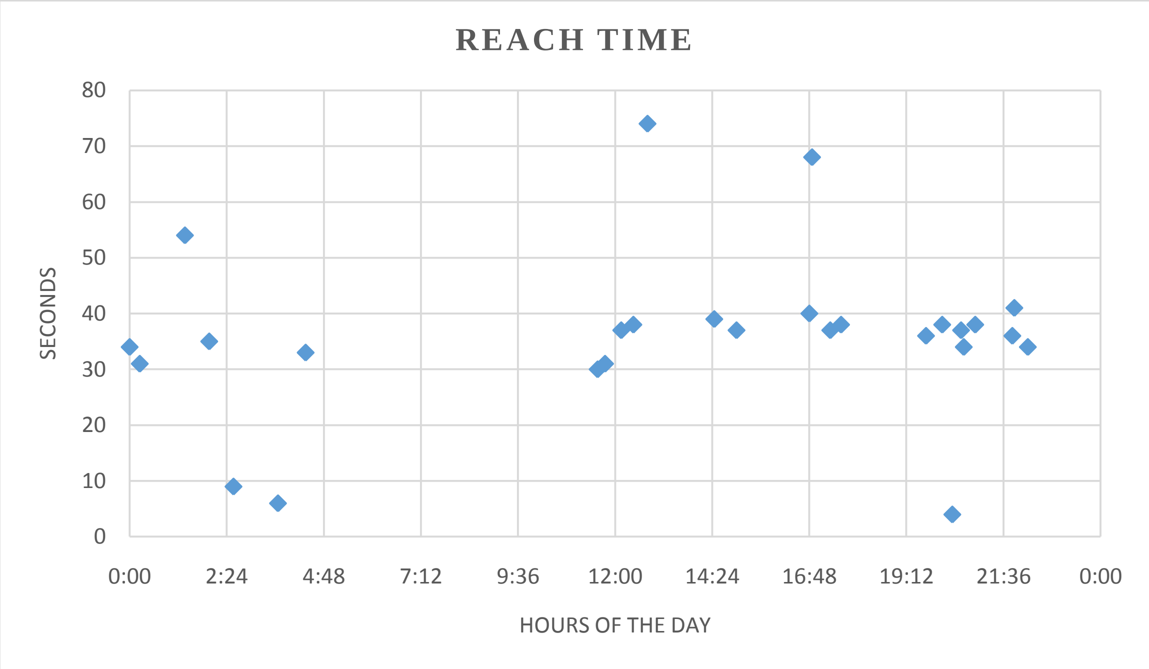


Figure VII: Reach time – 27 cases of ambulance deploy (in seconds)

As we can see, the "preparation time" varies within a range of 12 seconds from minimum to maximum records. The "reach time" is relatively fast and the same for almost all occasions with the exception of six emergencies. The three were too close to the ambulance, so the reaching time was less than 10 seconds. The other three were inside buildings without elevator, or inside buildings, on the highest floors. The "wheels time" is bound to the period of the day. Response times at emergencies with low traffic were significantly faster than emergencies at rush hour. Some ambulance drivers reported that they could see more easily the cars at nighttime because of their lights. Therefore, they did not need to look as sharp as in daytime, resulting higher average speed.

The y-axis shows meters covered per minute. This is the most objective way to compare response times. Time and depends on distance. Therefore, the "meters per minute" unit shows the speed of the ambulance, independently from the distance covered. The following figure shows the difference on the response times of a drone, if it was deployed instead of an ambulance for all 27 occasions. The benefit of straight-line flight is clear.

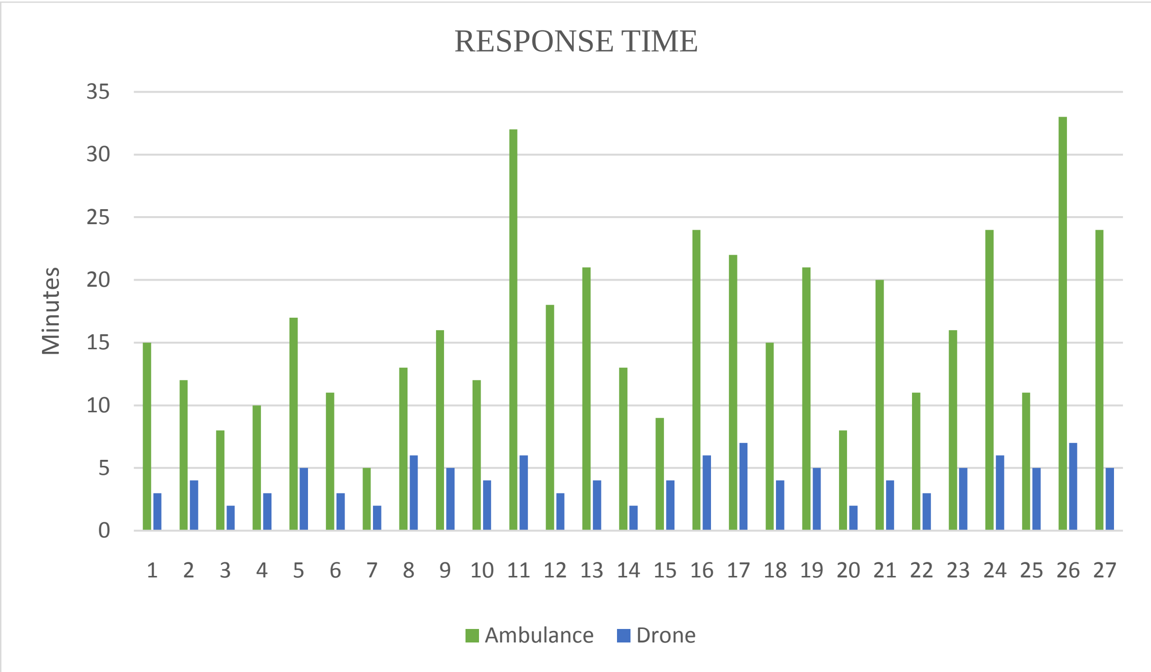


Figure VIII: Ambulance vs Drone – response time

The theoretical starting points of the drone are the same with those of the ambulances. Some factors make the drone faster. First, the road infrastructure. This is a major factor of delay. There were many turns on the ambulances' path, while the drone could have flown in a straight line above the city. On the other hand, many emergencies had a traffic delay. The ambulance drivers reported that the civilians do a good job on keeping the road clear for an ambulance. Nevertheless, even if the other drivers keep the road clear, the ambulance has to slow its pace for a safe passage through the traffic. The third factor is the average speed. The highest average speed an ambulance has reached was 53km/h, while the drone flies constantly at 60km/h on average. There is no occasion where the drone could not have reached the OHCA victim faster.

4.2 EXPERIENCE REPORTS

An open interview was conducted to four ambulance drivers about their experience throughout the years. The goal of this interview was to obtain knowledge we may not find via field research or GIS analysis. We interviewed all four drivers separately but they reported the same:

- Fake calls: The ambulance dispatched to reach a fake emergency, where it could dispatch to another one, real.
- Wrong addresses: Emergency calls sometimes can be difficult, as the caller is in panic. Ambulance reached the wrong address and then they had to drive to the correct one, resulting loss of valuable time.
- Traffic jam: Traffic can be so dense that the ambulance would “stuck”, and stand still until the driver can reach a way out.
- Strikes: Strikes can result accidents or even OHCA incidents, inside the crowd. The closed roads (because of the strike), make things difficult to the EMS and patients bleed for a lot of time (in case of accident), or even die due to delay (in OHCA case).

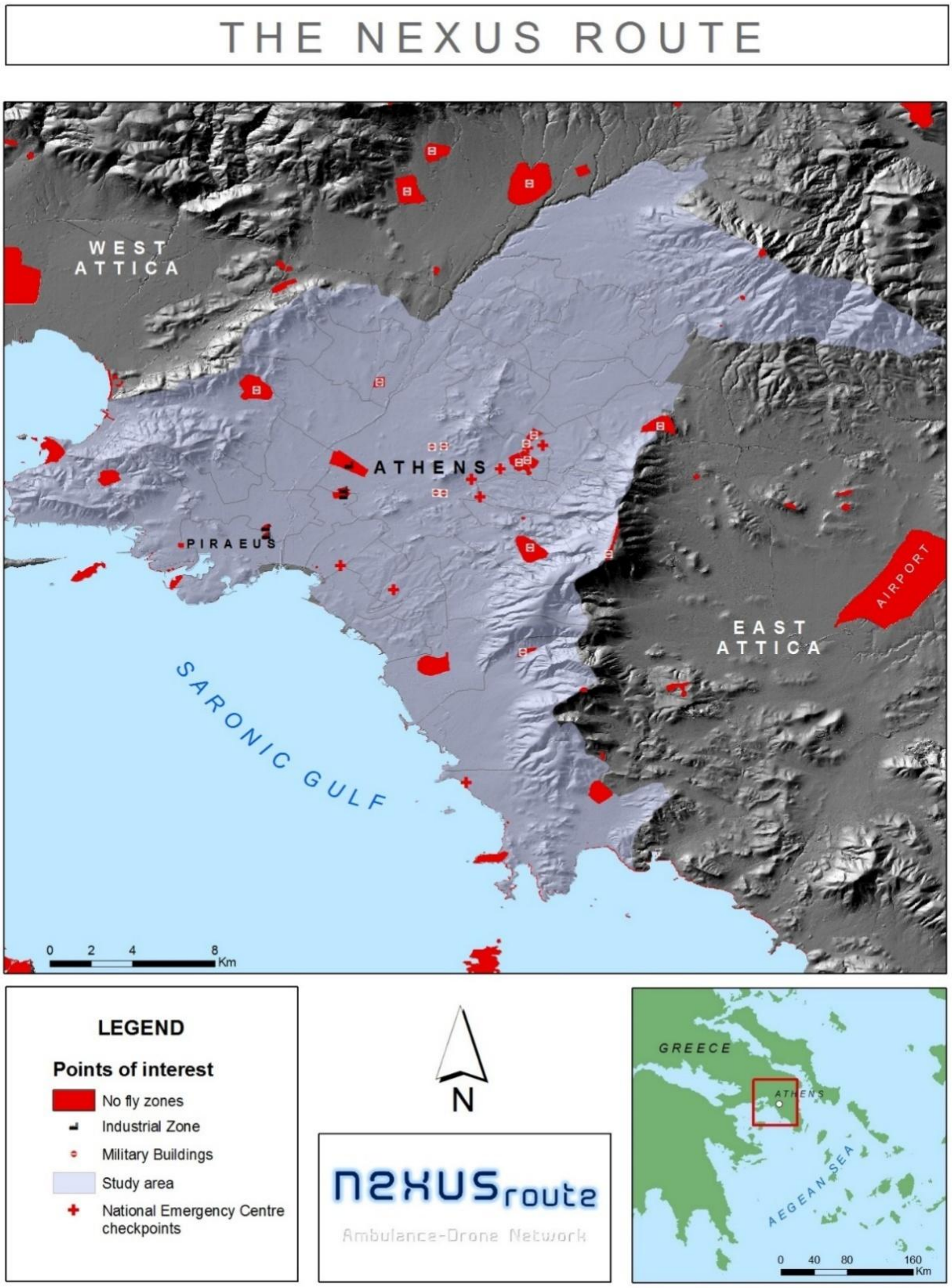
The demand of AED for out of hospital cardiac arrest victims is daily. Around 11,700 patients died from OHCA only in Athens, only in 2015. The Nexus Route aims to minimize that number. In this section, will be presented a range of investment options, and several scenarios. The investments split between two types. The first type focuses solely on ambulance demand. The drones locate in areas where there is:

- A significant density of recorded OHCA cases.
- A significant density of the total population.
- A significant density of the critical population; age groups over 50 years old.
- Much waiting time. The patient must retrieve first aid in less than 5 minutes.

In order to calculate the automated time distances, we used both the recorded deploys, and the statistical approach of *Eurostat*&*Statista*. In 2018, Eurostat conducted a research for traffic time, and average traffic speed in cities. Athens is amongst the slower cities in Europe.

City – km/h	**City – km/h**	**City – km/h**	**City – km/h**	**City – km/h**
Bucharest – 50	Marseille - 40	Manchester – 38	Warsaw – 37	Zurich – 32
Moscow – 44	London – 40	Paris – 38	**Athens – 37**	Cologne – 31
St Petersburg – 41	Rome – 40	Brussels – 38	Naples – 33	Berlin – 24

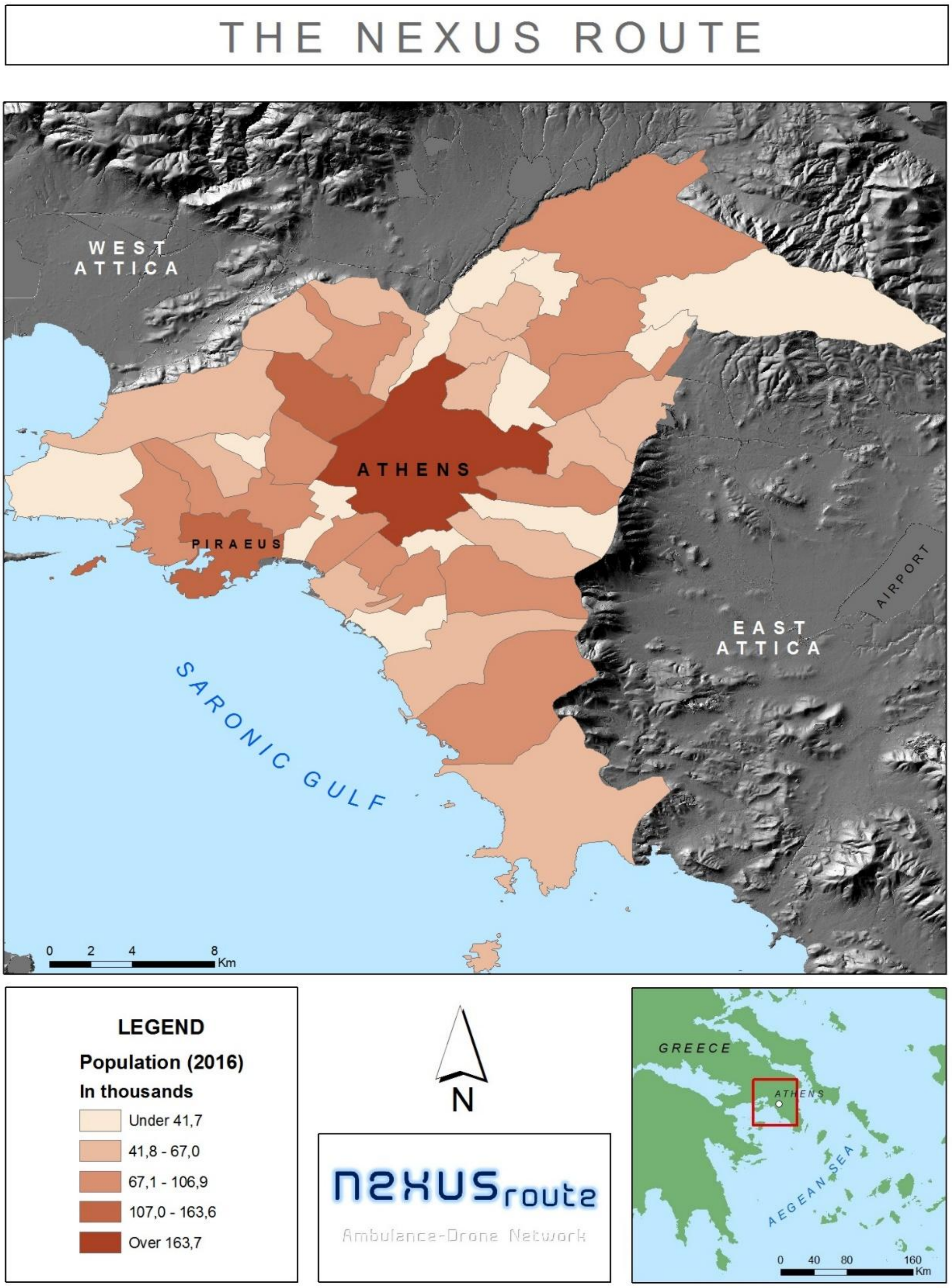
Table XIII: Average speed in European cities. Source: Eurostat, Statista



4.3 MAP OVERVIEW

Map II: No fly zones

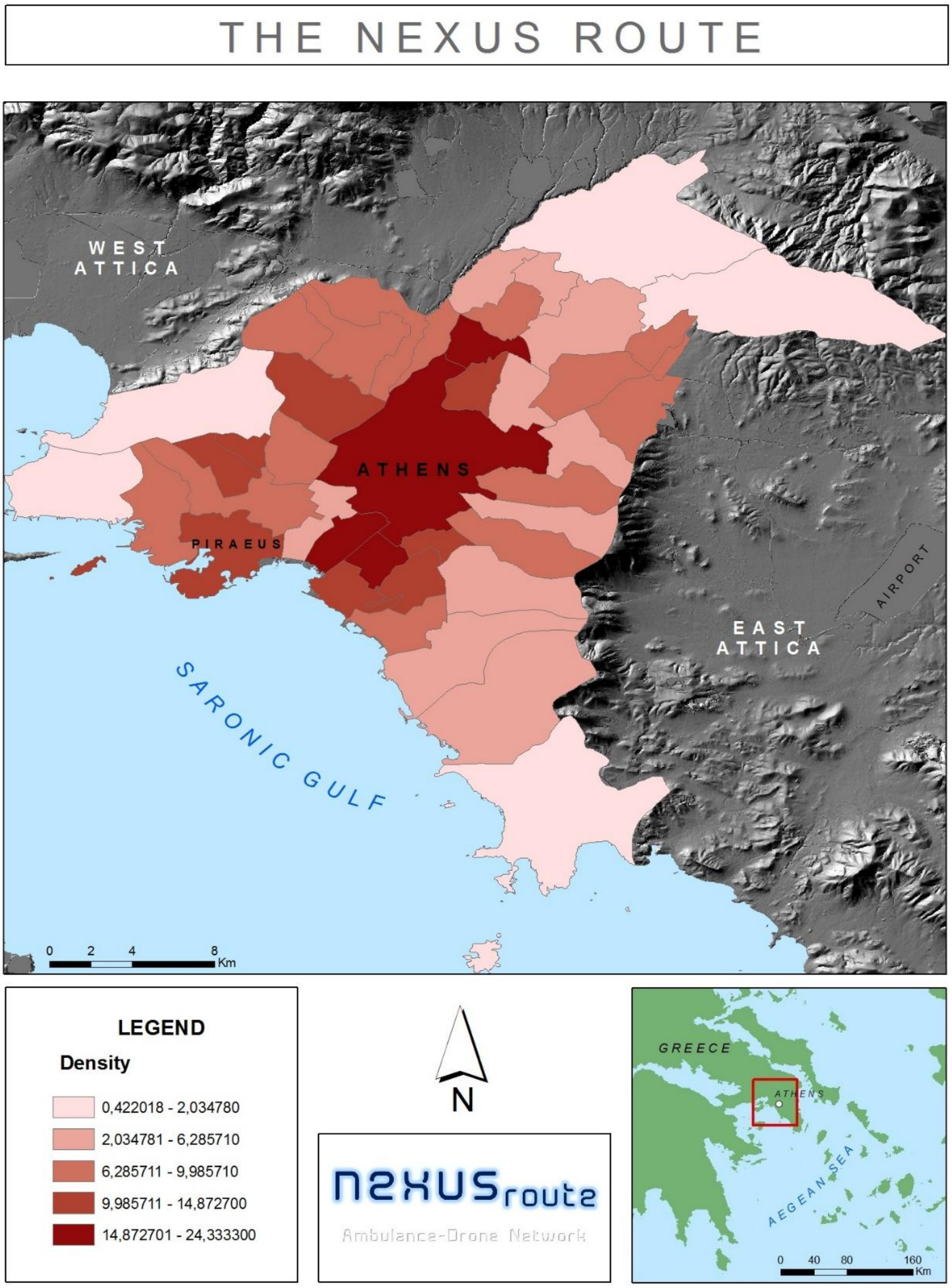
In the study area, there are some military sites, prisons and industrial areas are labeled as "no fly zones". These points of interest have a major role on planning the Nexus Route. The Civil



Aviation Authority forbids any drone flight above the red areas. Although, if the ambulance drones are considered as state entity, these restrictions could be ceased to exist.

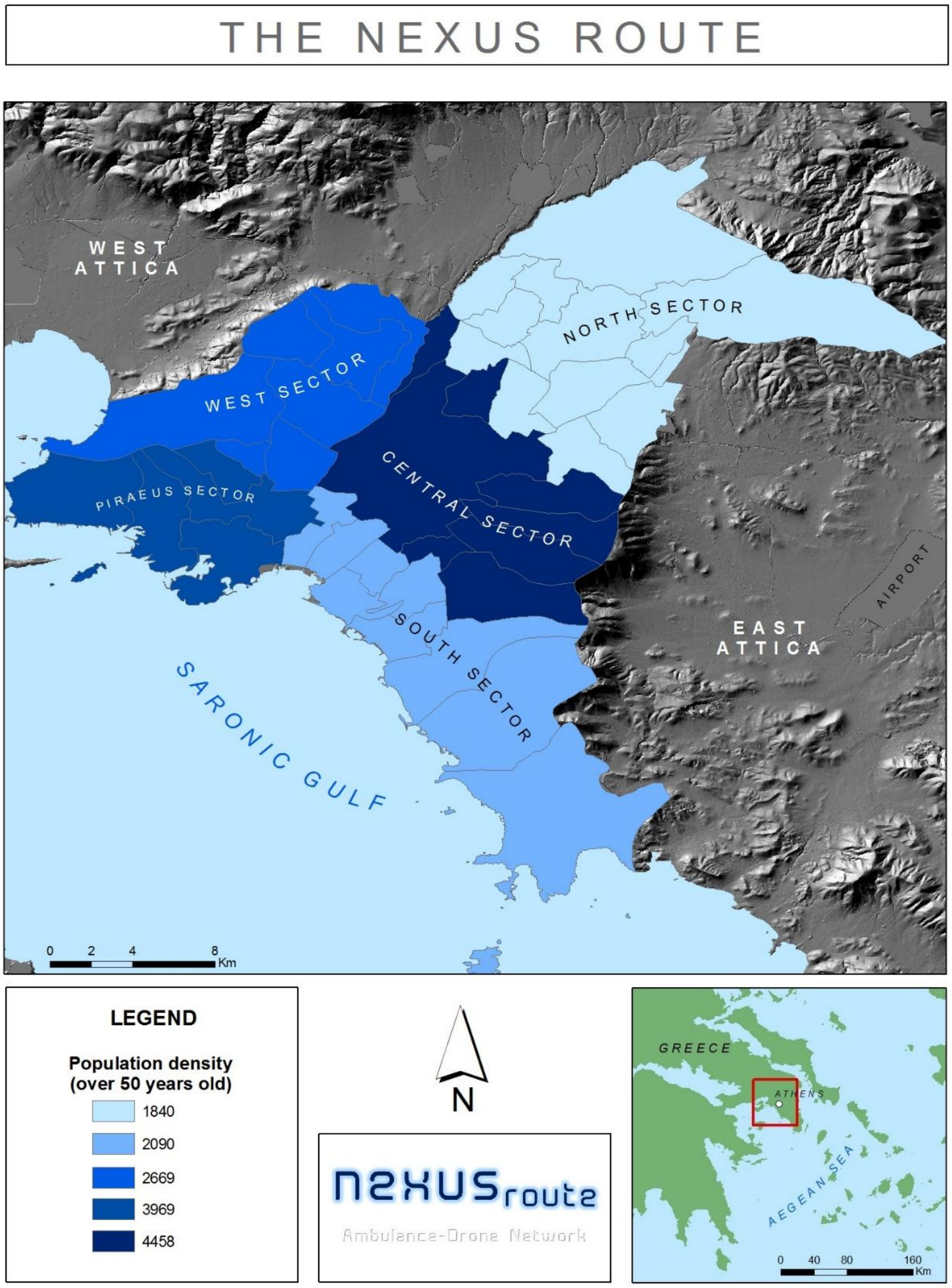
Map III: Population in thousands, by municipality

The population in absolute numbers give us a clear picture about the EMS demand. This is the reason why the eight operational EMS checkpoints (places where there is at least one



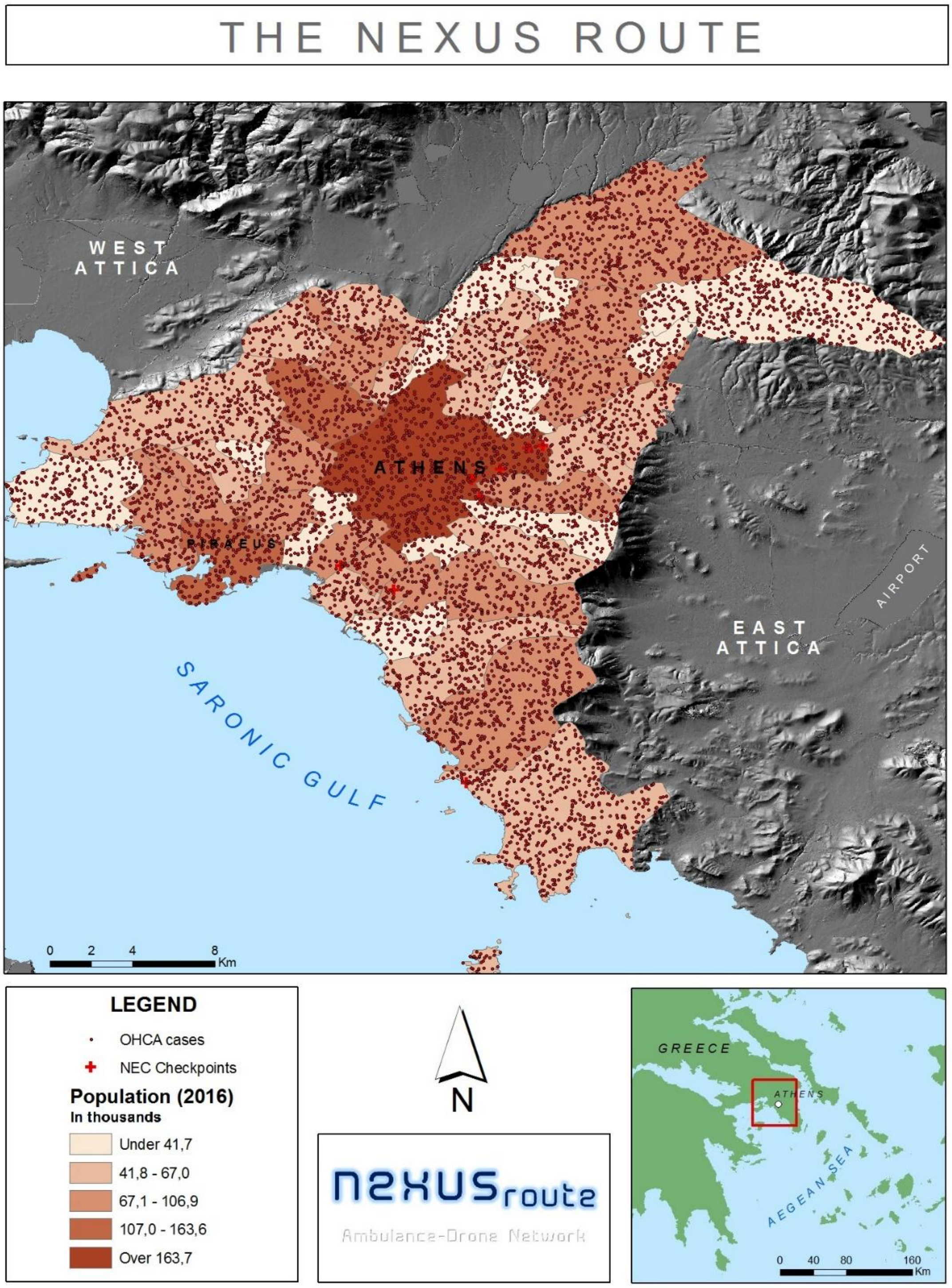
ambulance 24/7) are located around the most populated municipality, Athens. Eighty-five ambulances transfer 630 patients each day on average. Half of them locate at the city center.

Map IV: Population density by municipality. Source: HSA, 2015 census



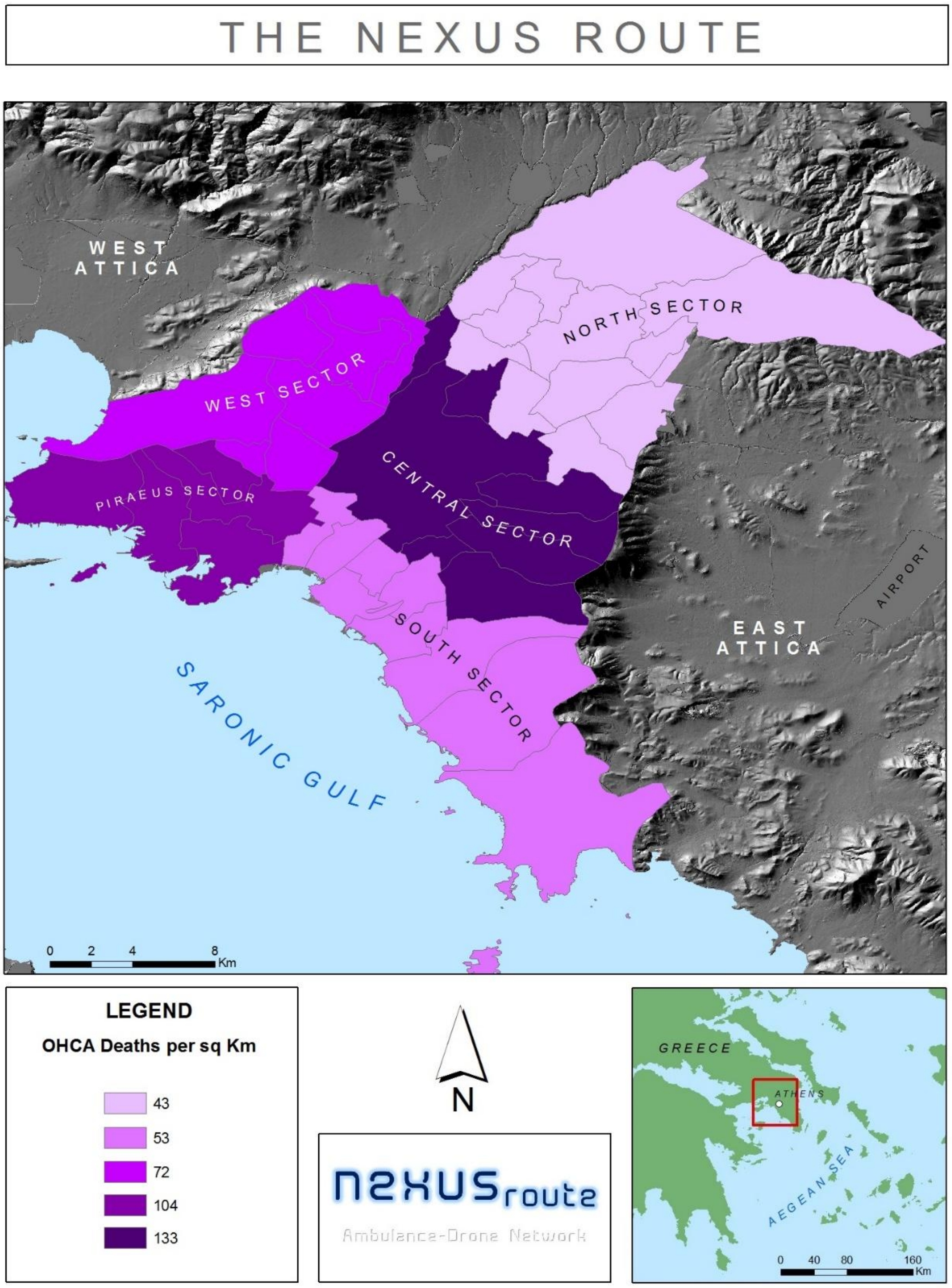
Density is one of the criteria of the MCE. Dense areas are more likely to be in need of an ambulance. Traffic in denser areas is more, and therefore response times are slower. Comparing the population and the density outputs, there is little difference in the distribution.

Map V: Over 50 year-olds density, by sector. Source: Eurostat, 2015 census



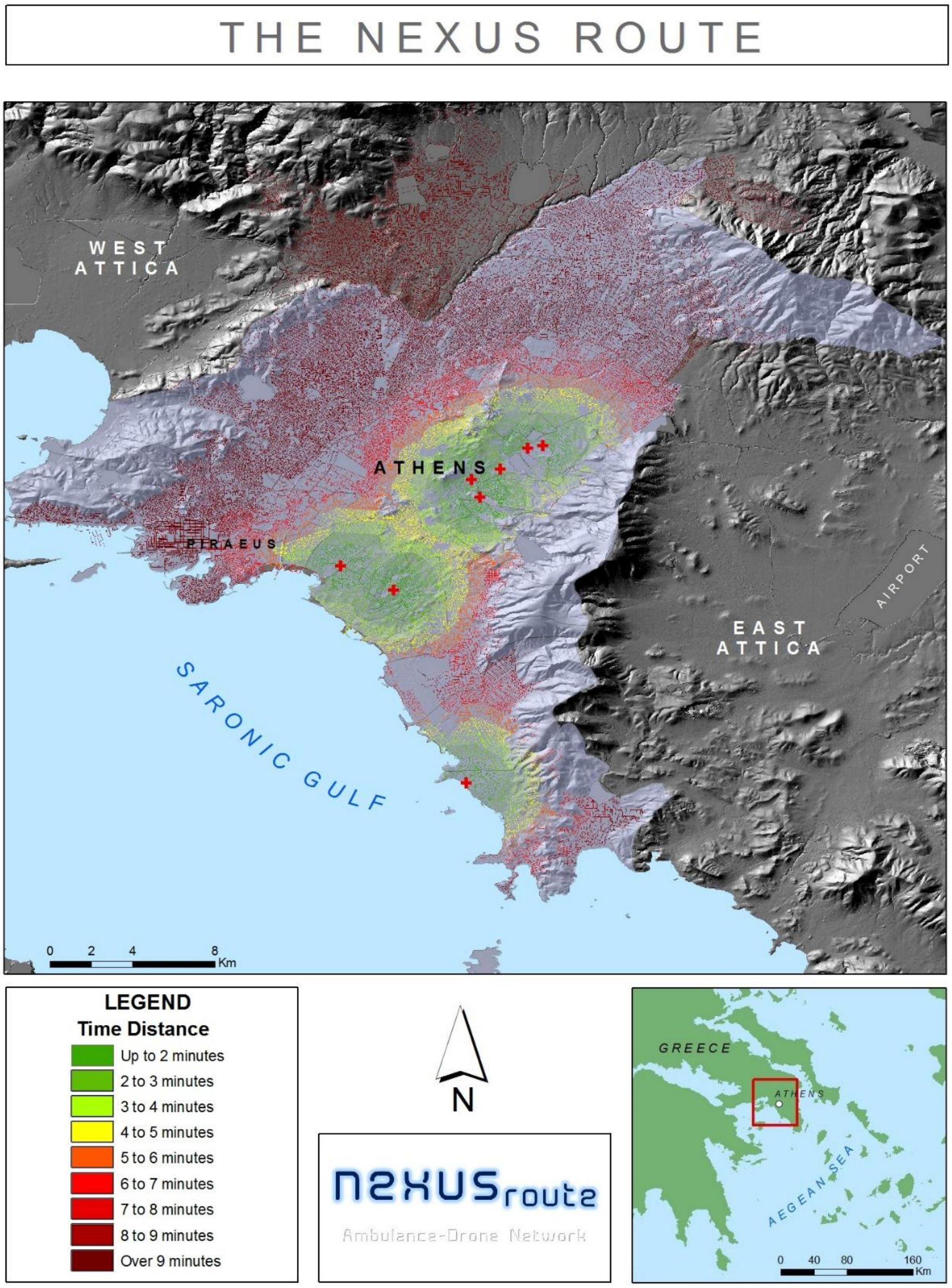
The critical age a person who could suffer a cardiac arrest is over 50 years old. The critical-population density is vital to our MCE. The West sector and the Piraeus sector have many 50 year-olds per km^2, where there is little to none coverage from the EMS. These areas will expose the EMS weakness, and will need ambulance drone stations.

Map VI: OHCA cases, by municipality – 2015. Source: NEC



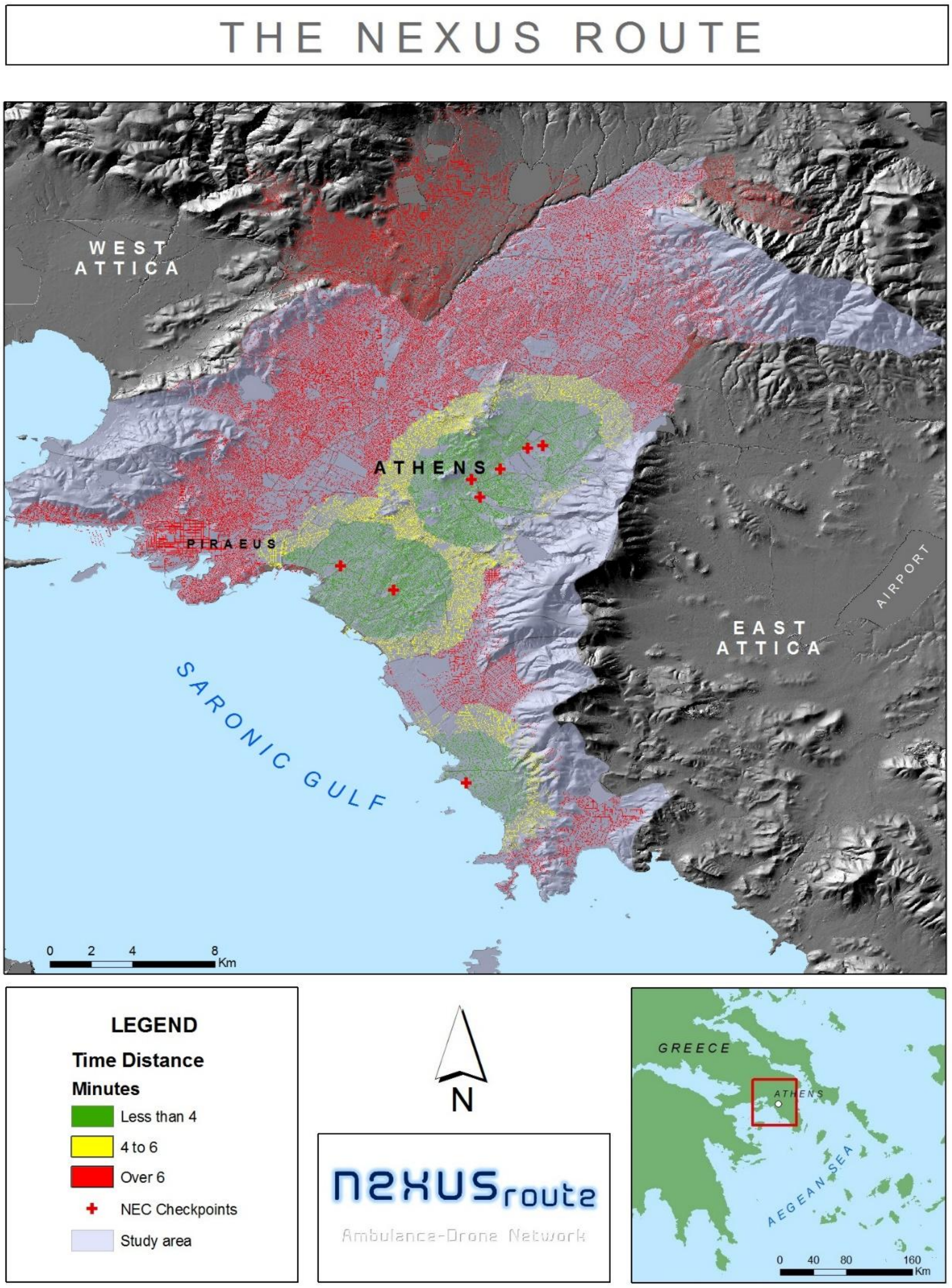
Out of hospital cardiac arrest cases, are lethal at over 10,000 occasions annually. Their distribution varies, but there are clusters at the city center, as well as at areas with high "critical age" population. This could be expected since that is where most people are located, both by living working and by passing errands.

Map VII: OHCA deaths density by sector



The mortality density caused by cardiac arrest was also expected to be at the city of Athens where 664,046 people live and/or work there. The West and Piraeus Sectors have high mortality rates due to the lack of EMS stations at those areas. There are some General Hospitals but there are not ambulances stand by at all times of the day.

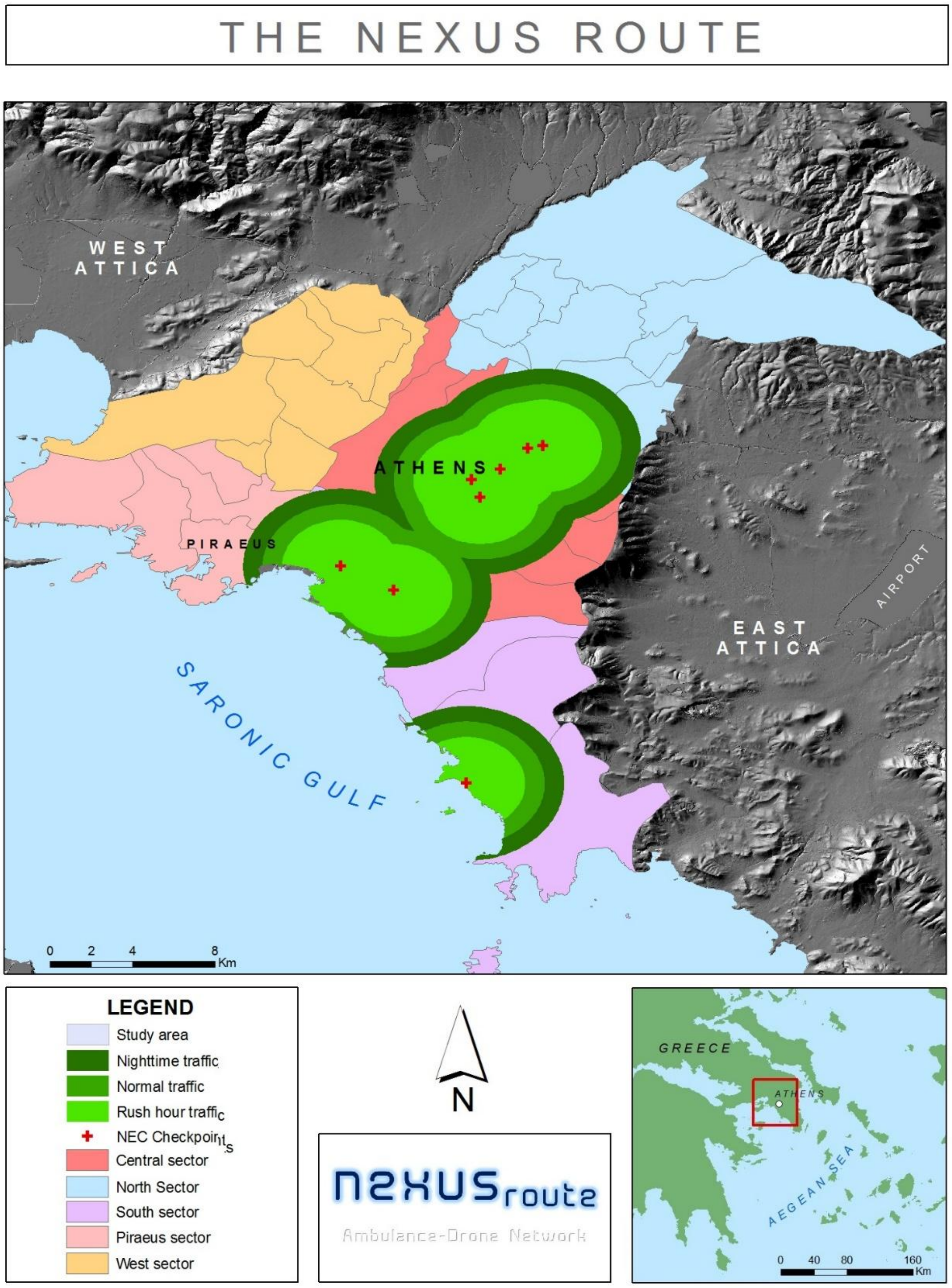
Map VIII: Ambulance response times



There are few areas where an ambulance can reach the victim within 5 minutes. Since the chances are depleted from then on, this could be considered a critical problem. It could take even 45 minutes at an ambulance to arrive at the emergency at the outskirts of the study area. This is why the response time has a weight of 50% or 60% depending on the scenario.

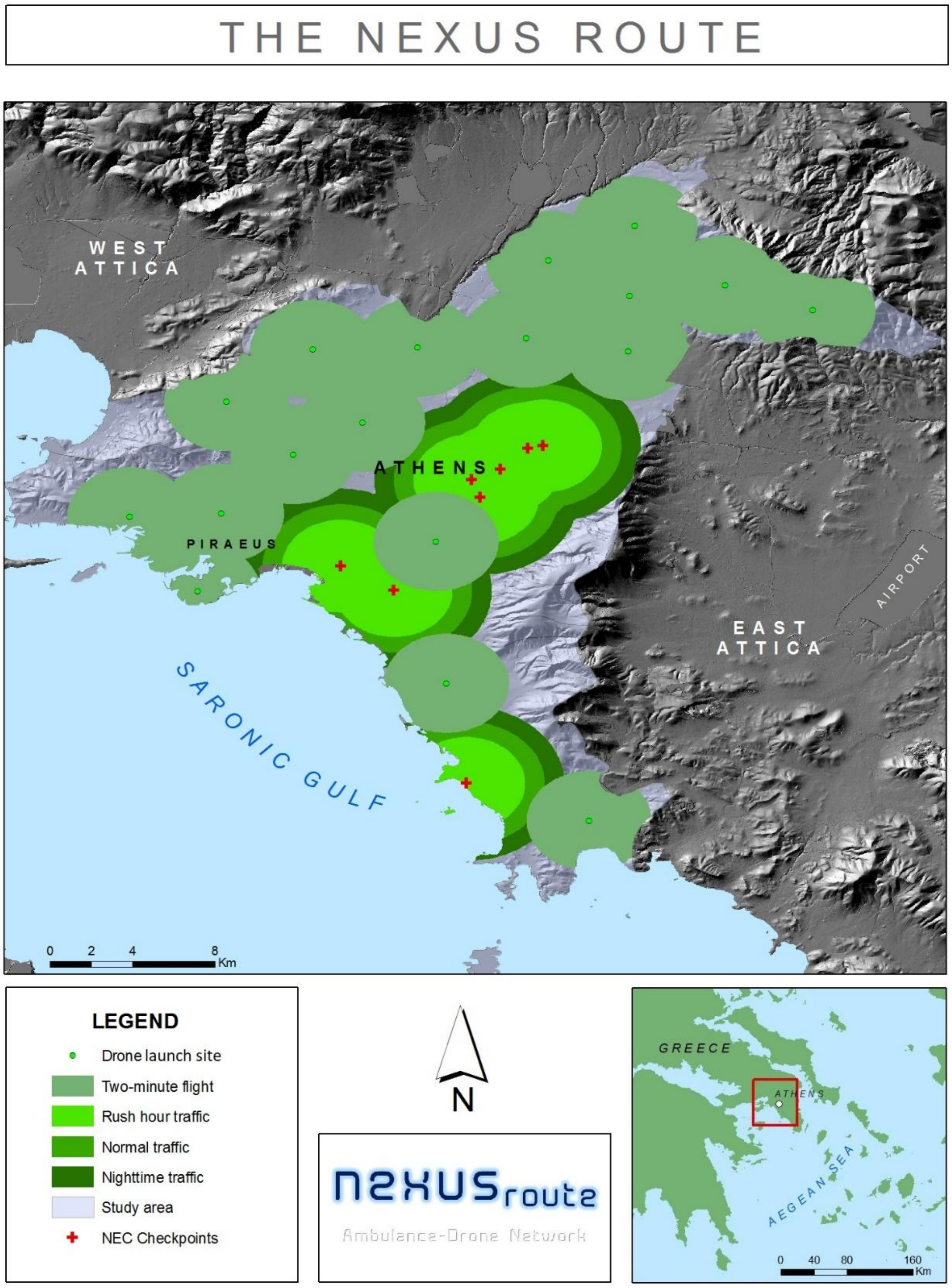
Map IX: Reclassified ambulance response times

This map shows the response times reclassified, from suitable to critical to lethal response times. Furthermore, the ambulances cannot reach victims within the 6-minute survival window at 71% of the study area. Entire municipalities' inhabitants are exposed to red marked areas, representing the 50% of the population, and the 57% of the "over 50 year-olds".



Map X: Five-minute response time by ambulance

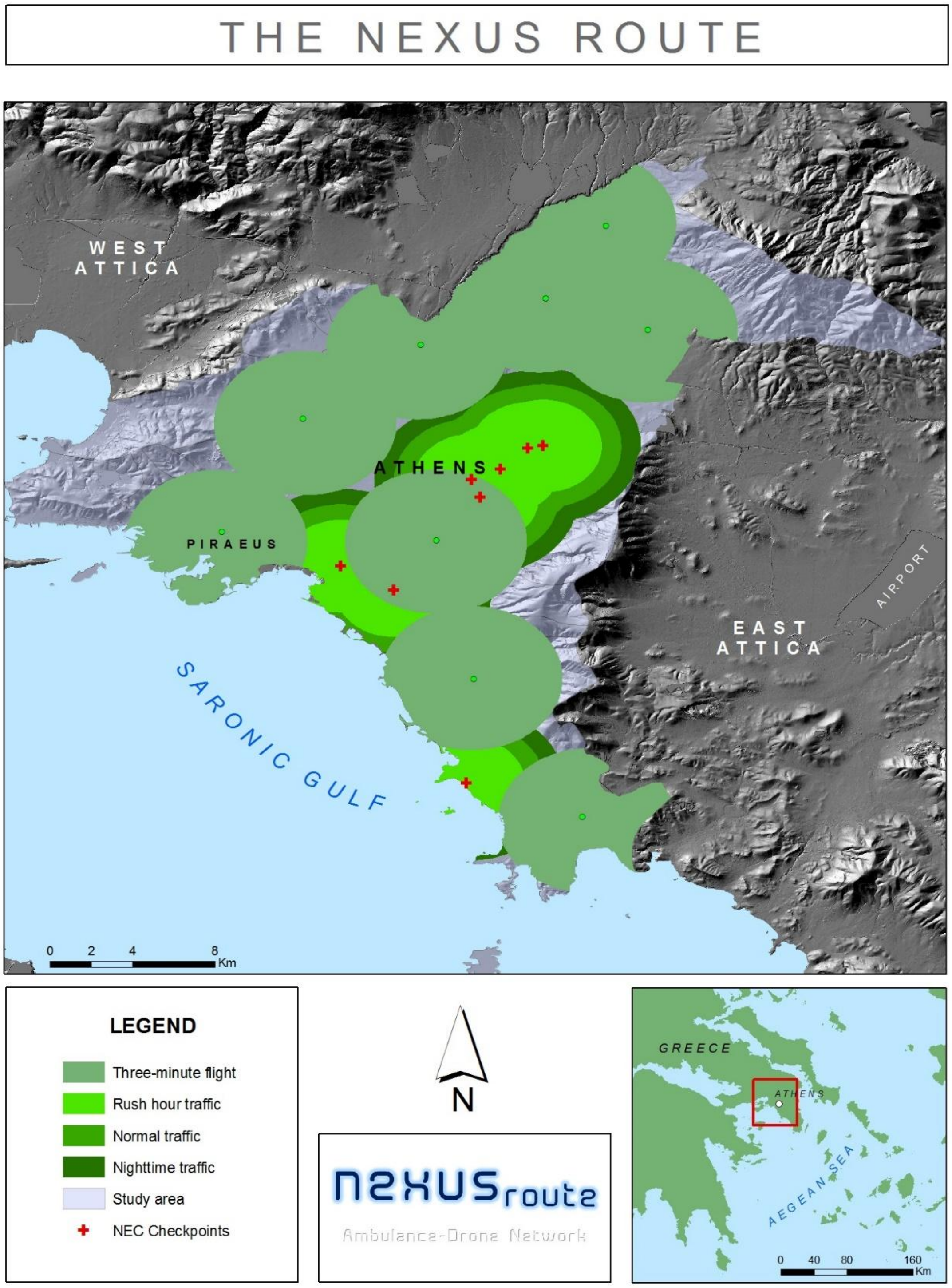
The calculated data of our field research provided us with three main types of traffic. The *Nighttime Traffic* where ambulances deploy on empty or nearly empty streets. The *Normal Traffic* where the ambulances have an average speed of ~37km/h and the *Rush-Hour Traffic*



where the ambulance go relatively slow. The green areas are the five-minute survival window.

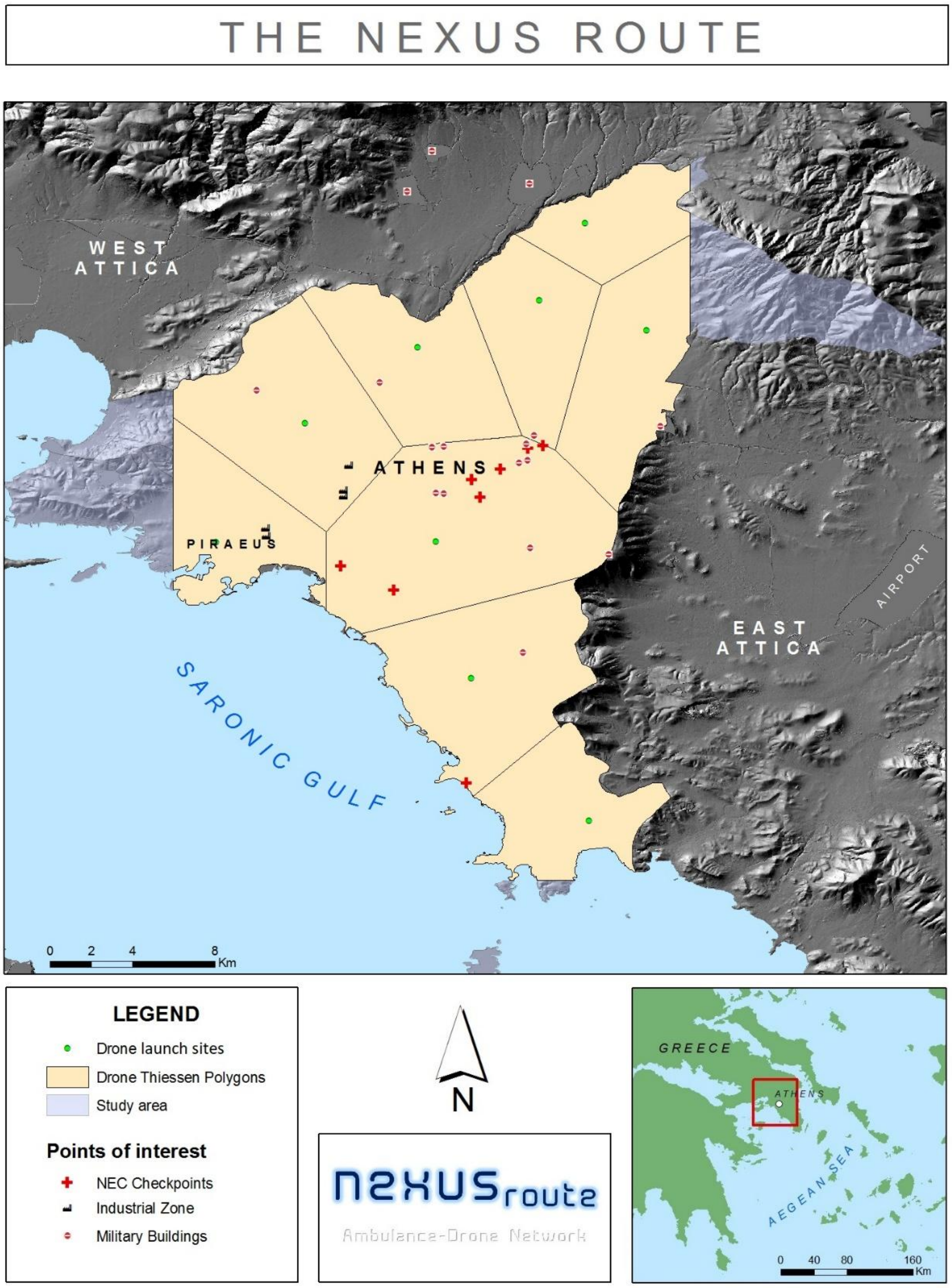
Map XI: Scenario 1 – Two-minute response time by drone

The first scenario following MCE and IDW shows a drone network of two-minute flights. It includes 18 ambulance drones covering 90% of the populated area, and 95% for the



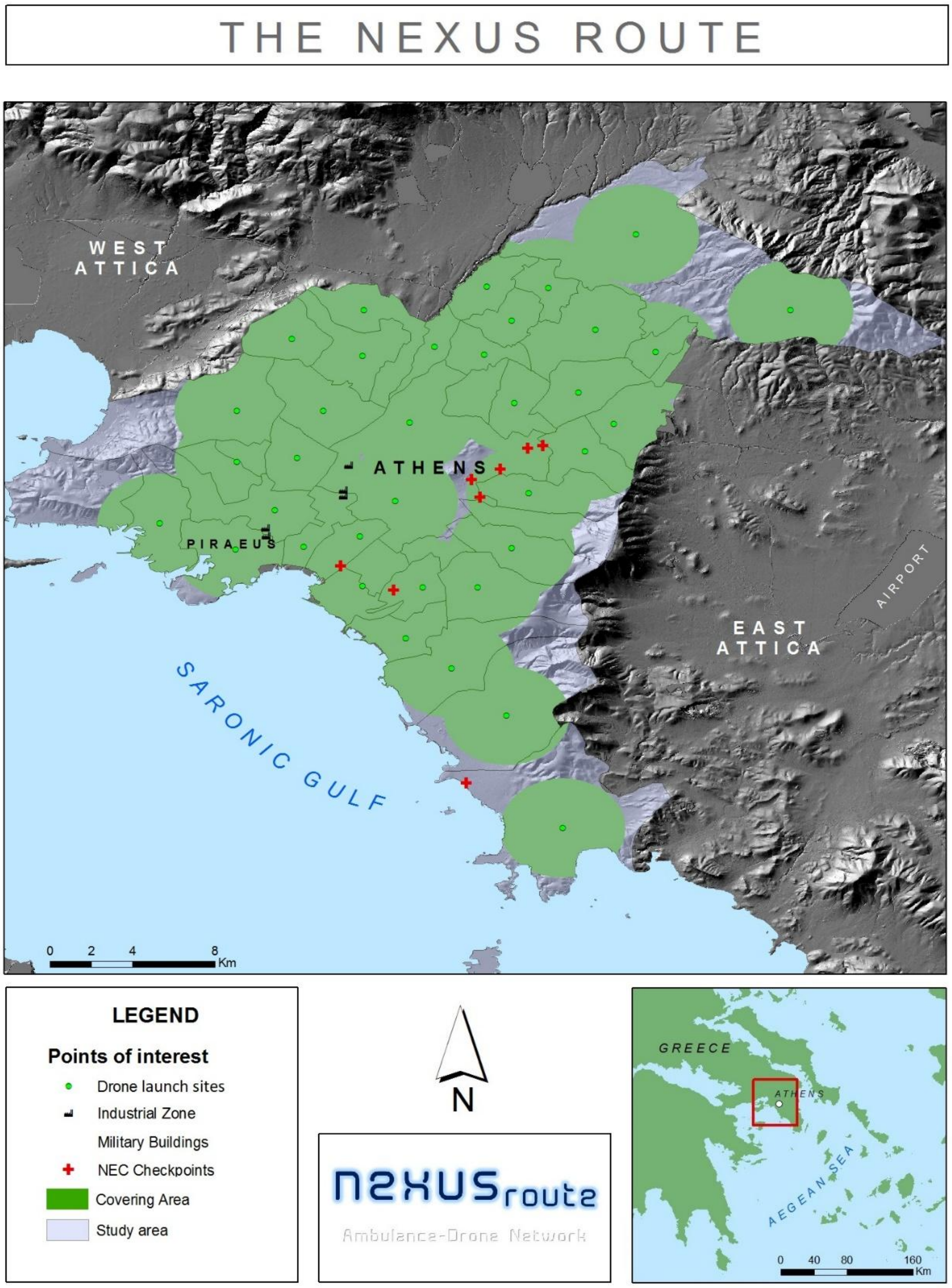
population. Any OHCA case can be reached in less than two to three minutes. The EMS "safe zones" (green areas) are excluded from the drone placement as ambulances do fast response time.

Map XII: Scenario 2 – Three-minute response time by drone



The second scenario is cost effective, as it presents a network of nine drones (half the drones of the 1st scenario). These drones fly over the city and cover the 83% of the study area in three to four minutes. The population covered is as much as the first scenario, with 92% of citizens locate inside the network.

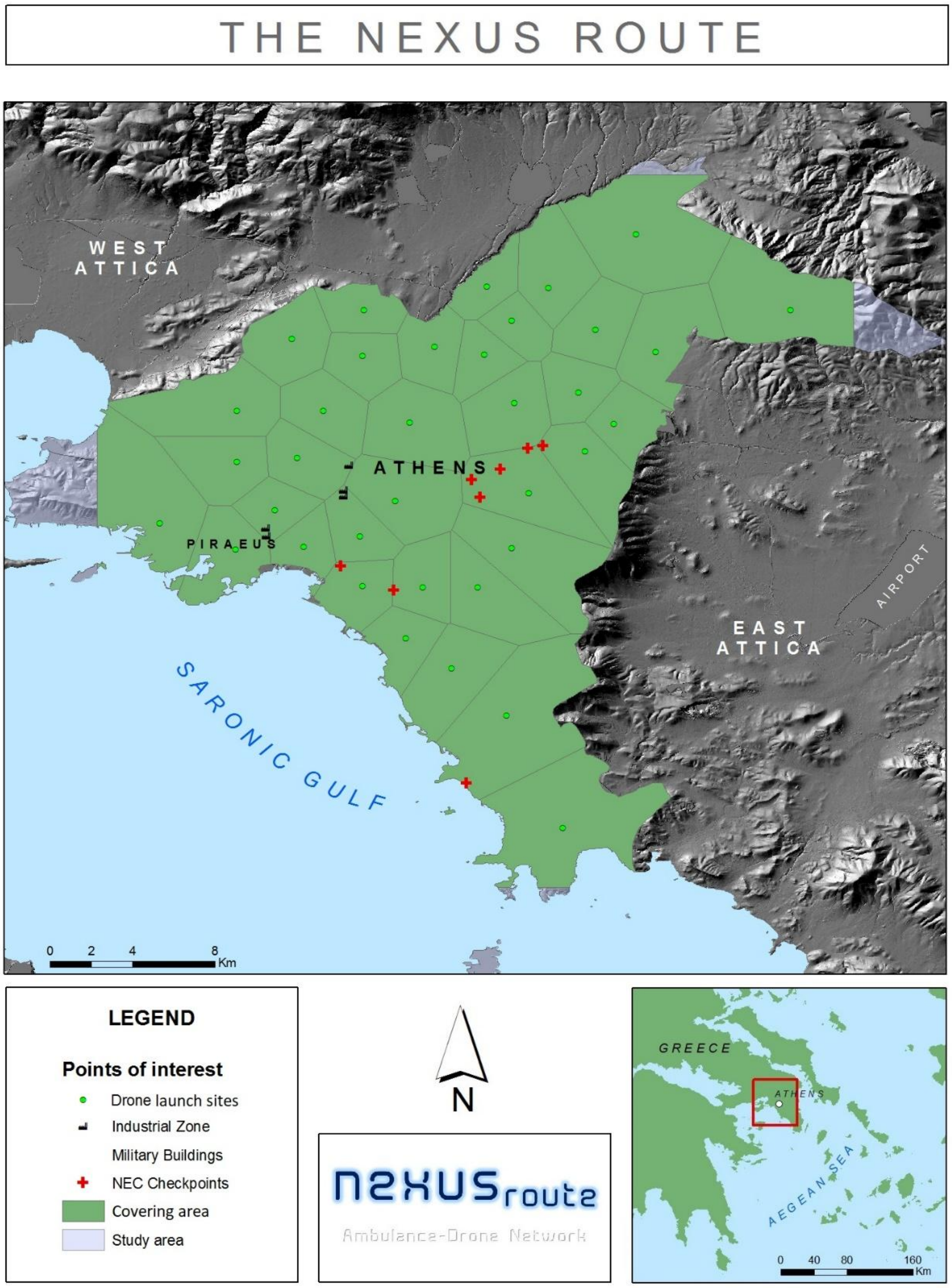
Map XIII: Thiessen polygons – Drones' three-minute flight covering area



The Thiessen polygons show where the drones' boundaries are when they need to fly "off limits" to reach an emergency. Because the drones form a circle of a 3-kilometer radius, we need to cover any *sliver* polygons created. Unifying the 3km buffer zone and the Thiessen polygons, the network has all areas covered. Nevertheless, the response times increase.

Map XIV: Scenario 3 – Drone locating by municipality

The third scenario is a two-minute-flight network of “municipality-drones”. Each drone covers the area of the municipality where it launches. There are some exceptions where there are two drones in one municipality (Athens – due to population), or one drone serving two municipalities (due to small area). It covers 95% of land and 98% of population with 36 drones.



Map XV: Thiessen polygons – Drones by municipality

These Thiessen polygons apply on the third scenario, where the network has a number of sliver polygons we need to clear. The slivers may create confusion on which drone should deploy. The boundaries of the Thiessen polygons will be uploaded to the drones' geo-fence and fly solely inside those.

4.4 COMPARING SCENARIOS

A total of 71% of the study area is exposed to over 6-minute response times. This timing is almost always lethal in cardiac arrest victims. In that area 57% of the critical aged population is located (over 50 years old). This is a concerning turnout of the analysis.This is possibly the reason behind the low surviving rate of OHCA cases. The multi-criteria evaluation showed slightly different results in both weighs-scenarios. The first scenario had 50% weight on the response time, while the second one had slightly more weigh on response time (60%) than the first. The population (total population multiplied by 0.25 and critical population multiplied by 0.75), was 10% less important in the second scenario where we focused more on ambulance response times.

The results were slightly different, but we chose the first scenario of 50-30-20. The reason was the West Sector. In the second scenario the population had less importance and thus, areas with more elderly population were ignored. On the other hand, the 57% of the elderly population lives at the West Sector, and thus giving a high weigh on population is more acceptable.

Following, we made three other drone-locating scenarios. These scenarios represent the strategic location of ambulance drones. The first scenario locates drones with two-minute radius. This scenario needs 18 drones to cover the entire study area. The population coverage is 95% which means the survival rate would increase from 7% to 83,56%.

The second scenario locates drones with three-minute radius. It needs only 9 drones to cover the critical areas. That is half the drones comparing to the first scenario. The population coverage is 3% less. Although the uncovered population lives mainly in the South Sector where the elder population is less, the survival rate is 2,6% less than the first scenario. Nevertheless, the three-minute flights can create a network that will increase the survival rate up to 80,93%.

The third scenario is more municipality centered. It locates a drone on each municipality (with little exceptions where there are two municipalities that share a drone). This scenario needs 36 drones to cover 92% of the critical population, resulting an increase of 92,14% of survival rate, in case of out-of-hospital cardiac arrest. On the other hand, the drones of the third scenario are two times more comparing to the first scenario, and four times more than the second one.

Scenario	Area coverage	Population coverage	Number of drones	Budget (approx.)	OHCA deaths decrease	Survival rate
Scenario 1	90%	95%	18	€47,400	90.25%	83,56%
Scenario 2	83%	92%	9	€24,400	87.4%	80,93%
Scenario 3	95%	98%	36	€88,800	93.1%	92,14%

Table XIV: Scenarios comparison

The difference of the number of located drones is considerable big in the third scenario. This depends on the radius the drones have. As previously stated, the analysis of the Nexus Route is cost-effective. A network of 36 drones would be unbearable economically speaking. Even though it covers the most of the population, it is not a viable solution.

Given the 11,800 OHCA cases, which occur annually inside the study area, it means that 32 to 33 OHCA cases happen every day by average. Therefore, there will be days that some of the drones of the Nexus Route will not deploy a single time. This is not acceptable, as we want to invest on drones that will fly several times a day. In addition, a large number of drones means more failure risk, resulting a greater possibility of land crash. With that in mind we exclude the third scenario which locates a drone per municipality.

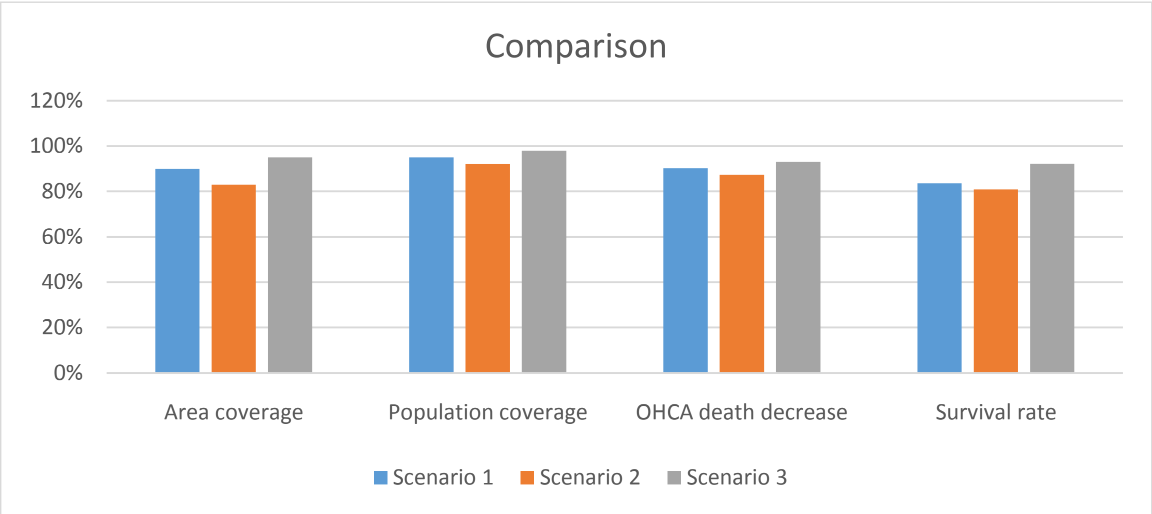


Figure IX: Comparing scenarios

Scenario 2 has less area covered, less population covered, as well as less OHCA death decrease. Nevertheless, a first investment on ambulance drones would be safer if the drones were as less as possible, covering a great amount of EMS demand. Scenario 2 is more preferred than scenario 1 for that matter (scenario 3 is excluded as the least wanted). This decision was made because scenario 2 can save 9,870 more patients than the current emergency management system, decreasing out-of-hospital cardiac-arrest mortality by 87.4%, and thus, the surviving rate of an OHCA patient increase from 8% to 81%. This scenario exceeds our expectations, favoring it amongst the other two. Currently the exposed population is 71%. By operating the Nexus Route this percentage drops to 4%

4.5 LIMITATIONS

There are some issues worth further discussion. Primarily, the nature of the research. A realistic investment would try to combine the most possible illnesses in one model. As we focused solely on cardiac arrest, this is not done. Making a network of drones for more than one use would be better for the investment itself as well as for the public, covering even more EMS demand. A further research is needed in order to accomplish such vision. Our vision is to make a network of drones that save people from CVD, an illness that kills 92% of its victims.

This study does not address the practical issues regarding possible misuse of an AED from a bystander to a patient. Quite often bystanders are relatives to the patient, and so they may be not calm, resulting a possible AED misuse, and eventually, the patient’s demise. Another limitation is the actual response time of an ambulance drone. All results are theoretical, as there is no ambulance drone available, and no published research to obtain such data.

Another issue requires more parameters to discuss. The drones’ launch sites must be a public building that has a flat roof. It is not known which public building could have the authority to operate a launch site, as the bureaucracy is confusing.

Another factor is the budget add-ons. Launch sites must be safe for take-off or landing and safe from vandalism. A landing base should be made, protecting the drone, resulting a budget increase. Such expenses are not included in our study. The budget as a whole is indicative to network-programming and drone-built expenses.

5. CONCLUSIONS

5.1 CONCLUSIONS

The Nexus Route will operate more efficiently with a network of 8 drones covering 92% of the total demand. Meaning that the survival rate of currently 7% will increase up to 80.93%. This saves more than 9,500 patients who suffer cardiac arrest, as the ambulance drones will bring an AED at the emergency site in less than three minutes. The investment is economically viable, as it exceeds our first goal, which is the increase of the survival rate up to 80%. It is a reasonable first expenditure of around 25,000 euros.

Although there are still some factors to consider, the Nexus Route shows potential of saving human lives in a way we cannot do with the current EMS. Some of the things to consider are:

- How quickly will the public become familiar with drones?
- Will the current federal aviation laws exclude our drones from flying restrictions?
- What if an accident occurs by a flying drone?

These can be answered with further examination on the issue. Generally, an optimized drone network as the Nexus Route, will aid the current emergency management system, decreasing significantly the response times of automated external defibrillator, to an OHCA victim. Drones have always getting better, and thus, the use of drones in rural areas to deliver an AED in OHCA cases may be safe.

Through our analysis, we found that it is possible to enhance the current emergency management system by decreasing the response times up to 25 times at the western sector if the study area, decreasing OHCA deaths. As well as we can decrease logistic costs, as the unfinished transfers will cease to exist. It is possible to autonomously and safely deliver an AED via drone even in out-of-sight flights. Even though the operator will have a visual through the camera attached.

Other projects have shown significantly optimistic results, making ambulance drones the next step in public health services. This approach promotes spatial/social justice, in a world of inequalities, the Nexus Route will provide the same service to every patient with ultra-fast response times.

The drone network can provide more medical support in the future, by delivering first aid supplies, such as injections, blood supplies etc. In addition, we can use medical drones in simple transfers. Greece is a country of sparse areas with low healthcare services to none in some occasions. Delivering urgent packages related to human health is the next step.

The Nexus Route is a universal type of analysis. This means that the methods we applied for the case of Athens metro area, can be used in all cities and regions. That kind of analysis notes down thespatial diversity a city has, and equals the outcome with covering relative needs. Therefore, if a different city is about to create an ambulance-drone network in the future, we can use the same methods as here and place strategically the drones. They should give us relatively the same survival rate increase of 80% at least.

5.2 FURTHER RESEARCH

Some parameters are not included in our research. Although they do have significance in various cases, as the availability of public buildings. It is shown that the Nexus Route will locate drones in certain areas, nevertheless it is not known if there are any secure buildings that could “give home” to ambulance drones. And if there are available buildings, the bureaucracy is so tight, that could delay a placement even months, depending on which type of state agency owns the building. There raises another question. In which way is the NEC able to use the building? It is known whether the NEC will buy, rent or use for free by donation the roof of the building.

One more parameter we did not account in the research, is the application that will deploy the drones. The application will include an algorithm that will have as input the coordinates and as output it will deploy the drone. The one who calls to 112 or 166 number for emergency (166 applies only in Greece), will give information about the place of the emergency and the patient.The caller will additionally give a name to the calling center. When the calling center identifies that the call is about an OHCA, they will start the application. It will insert automatically the coordinates via the calling signal, and the nearest ambulance-drone will dispatch immediately.

In addition, continuous research must be done in order to constantly develop the network, as technology improves. This will help us maintain the stunning results of the Nexus Route and materialize its potential fully. New drone technologies will soon emerge and thus, we will need to use them if needed. On the other hand, the population density may not be the same, as the OHCA cases may change their accumulation in spaceover time. Thus, we should update the placement of the ambulance drones by the needs of the population. Further research can be done by using different tools of applied geography, like regression, or even machine learning.

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