Development of a Health Geomatics analysis framework to evaluate cardiac arrests in Lombardy

New information for decision-making

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Abstract—**Cardiac arrest (CA) is an unpredictable event whose deleterious consequences can be minimized only by an immediate medical intervention in the first six minutes from the event, including cardiac defibrillation with automated external defibrillator (AED). Knowledge of AED distribution on a specific territory is functional to potentially provide immediate assistance while waiting for ambulance arrival. Our aim was to apply a health geomatic framework to map CAs occurred in Lombardy region in Italy along the year 2015, and known AED locations to retrospectively obtain new information that could be used to optimize AED placement over the considered territory. Results showed 10686 CAs and 6212 AED in all Lombardy region, with CA incidence in the range 0.7-1.27 ‰ and AED availability in the range 0.4-1.24 ‰ of inhabitants in the 15 healthcare districts in which Lombardy was divided. For the city of Milan, connected points reached within the same time (i.e., isochrones) were created starting from the position of each known AED and considering the distance traveled in a 6 min roundtrip at different walk speeds, showing 14% of potential territory coverage. A retrospective analysis of the 4005 CAs occurred in 2015 in the city of Milan showed that, despite an AED was within a 3-min range of a CA in 55% of the cases, only in less than 2% an AED was utilized. Health geomatics approaches provide new ways to look at existing information that could be used in decision-making processes to guide resources distribution on the Lombardy territory, while improving CA emergency care.**

Keywords—geomatics; cardiac arrest; isochrone computation; decision-making

I. Introduction

Cardiac Arrest (CA) represents a global major health problem that, if not treated within few minutes, leads to the death of the patient. CA is not preceded by specific premonitory signs, and its major cause is represented by a temporary malfunction of the cardiac electric conduction system leading to arrhythmias that, in particularly facilitating substrate conditions, could start a cascade of events finally resulting in ventricular fibrillation and CA. In Italy, statistics indicate that one person over 1000 loses his/her life every year by CA [1]. In the case of CA, the appropriate first aid is of vital importance to avoid permanent damage, especially to the brain, coma or death itself. A series of actions, defined as "the survivor chain", should be performed as follows: 1) recognition and activation of the emergency response by the 112 emergency number; 2) proceed with cardiopulmonary resuscitation (CPR); 3) provide defibrillation by an automated external defibrillator (AED); 4) advanced assistance by an emergency rescuer; 5) advanced and post-arrest in-hospital assistance [2]. CPR in the form of cardiac massage (100 pushes/min) should be performed by laymen assisting to the event of CA while waiting for ambulance arrival, as this is fundamental in preserving brain cells with adequate oxygen flow. The use of AED is critical in treating the patient suffering from CA because this will restore the normal heartbeat. Knowing that an AED is located in proximity to a CA event is essential for possible rescuers (even among witnesses) to reach it in time, taking it back and performing defibrillation, all within 6 minutes. This implies having a proper distribution of AED in the area, taking into account population distribution and possible risk factors.

Geomatics is a scientific term for gathering, storing, processing, and delivering geographic information [3]. We hypothesized that approaches based on geomatics applied to CA and AED positions could provide useful information about the distribution of events and the definition of strategies for relocating emergency resources on a specific territory. Accordingly, the aim of this paper was to analyze by Health Geomatics methods the 2015 CA and AED database relevant to the Lombardy Region in Italy, and to focus on CA events distribution and AED potential coverage in the territory of the city of Milan, using spatial isochrones, i.e. connected points reached within the same time starting from the same origin.

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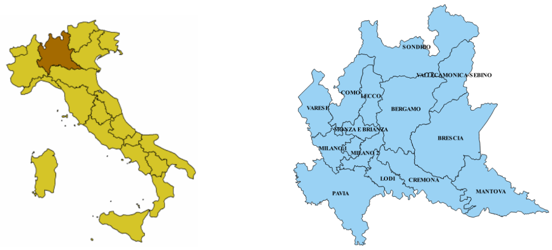

Fig. 1. Subdivision of the Lombardy region (highlighted in left panel) into healthcare districts (right panel). The map also shows the names of each of them. (http://www.geoportale.regione.lombardia.it)

II. METHODS

A. Databases

Resident population data for all towns in Lombardy at 31 Dec 2015, divided by sex and age, were collected by ISTAT, the National Institute of Statistics, and publically retrieved by http://www.istat.it.

CA data in Lombardy for 2015 has been made available by the Regional Agency Emergency-Urgency (AREU, www.areu.lombardia.it). The database contains anonymized information related to the geolocation of the event, its date and time, time-to-intervention, who performed CPR, who performed AED, the outcome of the rescue. Also, the database containing the position of installed AEDs in the city of Milan was provided by AREU.

Maps with boundaries of towns, provinces and healthcare districts (Aziende Sanitarie Locali) were downloaded from the Lombardy region geoportal (www.geoportale.regione.lombardia.it), while data relevant to the streets and their intersections from OpenTransportMap (http://opentransportmap.info).

B. Data pre-processing

Starting from the CA database, containing 10880 events, incomplete data or non-correct data were manually eliminated, resulting in 10686 CA. All 6212 data provided by AREU for AED were kept for mapping analysis, while for the construction of isochrones only 1541 defibrillator data were present in the three districts considered in the city of Milan.

All geolocated information has been converted to the World Geodetic System 84 (WGS 84) - UTM (Universal Transverse Mercator) 32 Nord coordinate system.

C. Merging and summarizing information

The open software Quantum GIS QGIS (http://www.qgis.org) was used to first represent all the different information as separate layers in the same map. To summarize data into portions of territory, the boundaries of the 15 districts that in 2015 represented the healthcare subdivision of the Lombardy territory was choosen compared to using the 1530 towns boundaries (too much parcelization) or the eight new health care organizations (Agenzie di Tutela della Salute) boundaries. For each portion, the CA events subdivided into two categories, "occurred at home" and "occurred outside", were computed and relevant incidence in the population living in each district derived. The same kind of analysis was performed to evaluate the number of AED in each healthcare district, and relative coverage for living inhabitants.

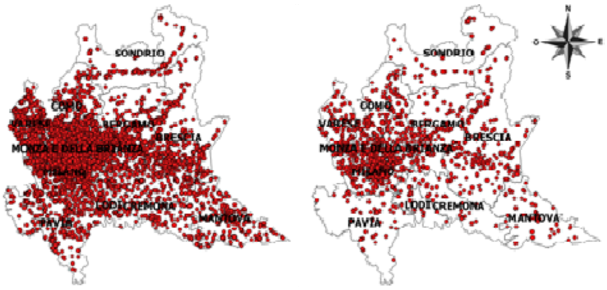

Fig. 2. Distribution of CAs in 2015 occurred at home (left) and outside (right) across the Lombardy region.

D. Isochrone computation

Isochrones are temporal lines that connect points that can be reached in the same temporal interval starting from the same origin [4]. In this work we applied realistic isochrones considering the real path between two points based on the distance traveled along the street (therefore not the trivial and incorrect Euclidean distance), to evaluate the portion of territory effectively covered by the existing AED distribution. The analysis was restricted to the three healthcare districts that refer to the city of Milan, representing the portion of territory with higher population density. To construct the isochrones, an object-relational database management system (PostgreSQL, http://www.postgresql.org) was used: specifically, the pgRouting (http://pgrouting.org/) extension to provide a geospatial data routing functionalities, and the PostGIS extension (https://postgis.net) for geospatial support.

The isochrones were created starting from the position of each known AED, using as parameter the distance that can be traveled in a roundtrip of 6 minutes - time considered maximum for the recovery of AED [1].- with three different walk speeds: 1,5 m/s, 2 m/s and 3 m/s. Milan's streets were considered as a graph, formed by edges – the lines representing the streets – and nodes – the intersection of two edges – [5]. The minimal path between two nodes can be computed by Dijkstra algorithm [6] that calculates minimum weight between two nodes. In fact, to each edge a certain weight is assigned as the distance between two of its nodes. Isochrones were built considering the closest nodes to each AED as starting points, using the *pgr_drivingDistance* function of the pgRouting

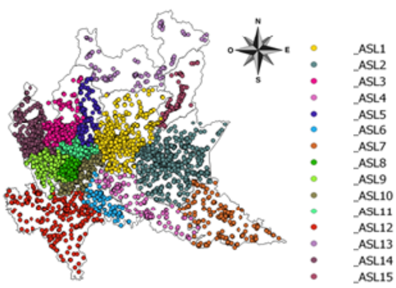

Fig. 3. Representation of the distribution of AEDs in the Lombardy region represented by a different color for each healthcare district.

TABLE I. INDICATION OF THE NUMBER OF CA, AED AND RELEVANT PERCENTAGE ACCORDING TO THE INHABITANTS (POP.) IN EACH LOMBARDY HEALTHCARE DISTRICT.

NAME healthcare district	# CA	CA/POP. (‰)	# AED	AED/POP. (‰)
Bergamo - 1	790	0.71	806	0.73
Brescia - 2	856	0.74	951	0.82
Como - 3	560	0.93	426	0.71
Cremona - 4	240	0.67	168	0.47
Lecco - 5	309	0.91	202	0.60
Lodi - 6	170	0.72	148	0.63
Mantova - 7	387	0.94	252	0.61
Milano - 8	2057	1.27	642	0.40
Milano 1 - 9	923	0.97	559	0.59
Milano 2 - 10	576	0.91	341	0.54
Monza e della Brianza - 11	805	0.93	557	0.64
Pavia - 12	524	0.96	393	0.72
Sondrio - 13	134	0.74	117	0.64
Varese - 14	855	0.96	437	0.49
Vallecamonica-Sebino - 15	82	0.81	125	0.124

extension, which extracts all the nodes that have costs less than or equal to a given distance, in this case 270m, 360m and 540 m, corresponding to the reachable roundtrip range for the considered walk speeds. Once the nodes within a given distance were computed, the *pgr_alphaShape* function identified the vertices of each AED isochrone, using the alpha shape algorithm.

An alpha shape is created as the polygon generated by a series of empty disk of radius alpha that touch a couple of points each time. [7]. These alpha shapes are obtained from the Delaunay's triangulation if the circle circumscribed at each triangle is empty. [8]. The *pgr_pointsAsPolygon* function draw an alpha shape using the vertices identified in the *pgr_alphaShape* function. The SQL code developed for the creations of the isochrones can be found at https://github.com/carolinarias/AED_isochrones, under a GNU General Public License.

III. RESULTS

A. Cardiac arrests in 2015 and AED in Lombardy

Regarding the categories of CAs based on the location of the event, 9.268 (87%) of the events occurred in private homes, while 1.418 (13%) were outside. The data obtained were mapped (see Fig. 2), and the CA number was calculated

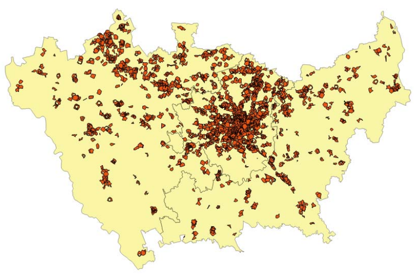

Fig. 4. Computed isochrones overimposed to the city of Milan territory computed by considering a six-minute round-trip time at 3 m/s speed.

TABLE II. % OF TOTAL AREA RELEVANT TO DISTRICTS 8, 9 AND 10 POTENTIALLY COVERED CONSIDERING THE THREE TYPES OF ISOCHRONES BUILT WITH A 3 MINUTE ONE-WAY TIME SPAN WITH A WALKING SPEED OF 1.5 M / S (270 M), 2 M / S (360 METERS), 3 M / S (540 METERS).

TYPE OF ISOCHRONES	TERRITORY AREA COVERED BY ISCHRONES (m^2)	%COVERED AREA OVER MILAN AREA
270 m	60,435,411	3.88
360 m	110,699,279	7.10
540 m	220,908,830	14.17

for each district together with its incidence in the respective population, as shown in Table I. Considering gender subdivision, there were 4.842 CA in males and 4.000 in females among CAs at home, and 1102 males and 252 females among CAs occuring outside. For each healthcare district, the number of available AEDs and the ratio considering the relevant population was also assessed. Figure 3 shows the corresponding map of AEDs to appreciate their realistic distribution across the territory.

B. Isochrones results

As regards the city of Milan, the median time of arrival of basic rescue vehicles (a driver/rescuer and one or two rescuers) from the moment a call is made by the witness to the event was about 9 minutes (25^{th};75^{th} percentiles: 7;12 minutes). The isochrones were constructed considering a 6-minute temporal round trip with the previously mentioned walking speeds of 1.5 m/s, 2 m/s and 3 m/s (Figure 4). For each type of isochrones that was built, the percentage of Milan area potentially covered by the presence of at least 1 DAE in relation to the total Milan area of the three considered districts (1,558,679,122 m^2) was also calculated (Table II). For each type of isochrone, the CAs of 2015 in these districts were retrospectively studied to evidence in how many cases an AED could have been potentially available and in how many cases it was effectively utilized. Figure 5 shows the number of CAs that fall in one, more or none isochrones, for the different speeds considered in our analysis. The total number of CA occurring at home and outside was 3556 and 449, respectively, for which the AED was used by witnesses in 43 (1.2%) and 17 (3.8%) cases, respectively, and not used in 1664 (46.8%) and 172 (38.3%) cases, respectively. For the remaining 1849 and 260 cases, respectively, the information was not available. From a retrospective graphical analysis of AED overlapped by one or more isochrones, relevant to the fastest speed, it resulted that only 43% and 47% of CAs at home and outside, respectively, were not potentially covered by AED. On the contrary, 57% and 53% of CAs were happening potentially in a 3-min range from an AED. Of these, AED was effectively used by witnesses only in a 0.7% and in a 2% of cases, respectively, at home and outside.

IV. DISCUSSIONS AND CONCLUSIONS

The use of mapping tools for representing both the position of health-related events and the emergency resources needed

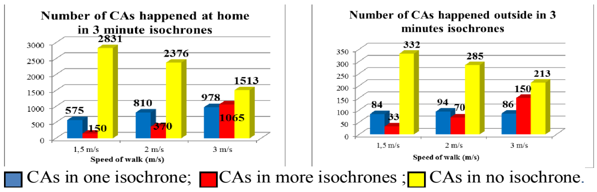

Fig. 5. Number of CA happened at home (left) or outdoors (right) in the city of Milan during 2015 potentially covered by one isochrone relevant to an AED, by more than one isochrones or by none, according to different walking speed of 1.5, 2, or 3 m / s over a round-trip time of 6 minutes.

for their treatment represent an additional resource to assess the incidence of a disease on a specific territory, and to evaluate the distribution of resources, generating spatial optimization strategies. In the scenario of studying CA in Lombardy during 2015, Health Geomatics tools were innovatively applied to generate maps describing the geolocation of events and the current AED distribution on the regional territory.

As shown, most of the CAs were concentrated in urban areas around Milan, where CA incidence reached 1.27 ‰, while lower values were observed in the other districts. Regarding the coverage of the inhabitants with AEDs, the district of the Vallecamonica - Sebino resulted having the largest number of defibrillators (1.24 ‰) in proportion to the resident population (Table I), about twice as measured in other districts in Lombardy. From the analyses using isochrones applied to the three districts covering Milan, taking into account a round-trip time of 6 minutes, only 14% of the considered territory appeared covered by an AED. This analysis, combined with the retrospective analysis of the effective use of AED in CAs occurred in the city of Milan, showed that defibrillators were very rarely used by the witness to the event, while waiting for ambulance arrival. This may be due to several factors: 1) there is only one witness on place, thus hopefully practicing CPR without having the opportunity to reach an AED; 2) lay men are unaware of the presence of an AED nearby, or they are not in the conditions to reach one within a reasonable time interval; 3) the AED is placed in a location that is not always accessible to the public; 4) lay men do not know how to or are not confident in using an AED.

As observed, the distribution of AEDs in the Milan area does not appear to be homogeneous. Possible strategies for improvement could focus on: a) increasing the number of AEDs in order to potentially cover a larger territorial area, repositioning some of them to avoid overlapping; b) make this device more accessible by positioning it in public places, or by improving the signposts diffusion around it, to better inform the citizens about its position; c) as the majority of CA happens at home, residents of a particular area should be updated by specific communications about presence of AED in adjacent areas. Also, possible presence of AEDs not included in the AREU-118 database could be detected by specific actions involving the population through information campaigns or mobile applications to stimulate their engagement (e.g., citizen cyber science). Possible future developments may also involve active tools to alert possible rescuers of the presence of a CA nearby, and automatic navigation modes to drive the witness to the nearest AED.

The current work suffers from some limitations: the topology of the road network of the districts in Milan could be not completely accurate, as the utilized open data is collected by volunteers: topology errors can create inaccuracies during isochrones computation. Also considering the node closest to the AED, instead of their actual position, could have led to some imperfections in the creation of the isochrones. Moreover, the time to reach an AED was computed from ground level, so computed isochrones cannot be applied as is for coverage of CA occurring at higher stores in buildings. As regards effective use of AED by lay men, in >50% of the cases the information was not available.

In conclusion, a Health Geomatics analysis framework to evaluate cardiac arrests and AED in Lombardy for the year 2015 was developed and applied. This study provides the basis for future research by including environmental factors evaluation and, by using big data analytics techniques, to extend the results from the descriptive to the predictive field.

Acknowledgment

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