European Transport \ Trasporti Europei (2023) Issue 91, Paper n° 9, ISSN 1825-3997

https://doi.org/10.48295/ET.2023.91.9

Methods for infrastructure planning in areas close to hospitals at the regional level

Vittorio Ranieri[1], Nicola Berloco[1], Stefano Coropulis[1], Giuseppe Garofalo[2], Paolo Intini[1], Michele Ottomanelli[1]

[1]*Department of Civil, Environmental, Land, Building Engineering and Chemistry, Polytechnic University of Bari, v. Orabona 4,70126 Bari, Italy*
[2]*ASSET (Agenzia Regionale Strategica per lo Sviluppo Ecosostenibile del Territorio) – Regione Puglia, v. Gentile, 52, 70126 Bari, Italy*

Abstract

Healthcare emergency management is also an infrastructure problem, in terms of accessibility and safety but nowadays there is lack of consolidated method to solve this issue. Concerning accessibility, the access to the nearest hospital should be guaranteed from each city in the region in an acceptable time. Concerning safety, road arterials travelled by emergency vehicles should have high safety standards, for emergency vehicles and the reduction of congestion due to traffic crashes.

This study aims at providing a methodological framework (tested in the case of Apulia, Italy) to conduct accessibility and safety assessments at the regional level, in case of existing and new hospitals. Accessibility and safety were studied setting specific metrics, like time to reach the hospital and accident analysis at macroscopic level to plan safety interventions. The least safe road sites in the ranking obtained by applying the proposed indicators for new and existing hospitals can be improved.

Keywords: Emergency vehicle routes; hospital accessibility; safety of emergency routes; infrastructural planning

1. Introduction

Healthcare emergency system and the infrastructural one are necessarily linked. Indeed, management of a network of hospitals in a given area includes both planning new hospitals and rearranging existing ones. Both operations need to consider two fundamental aspects, which are accessibility of hospitals (in current and future scenarios) and safety of routes travelled (in current and future road network layouts) by emergency vehicles and general users during healthcare emergencies. Healthcare system management is often operated at the local level, i.e., at the regional level (such as in the case of Italy).

* Corresponding author. Vittorio Ranieri (vittorio.ranieri@poliba.it); Tel.: +39 0805963413; fax: +39 080 5963414.

Accessibility can be defined and measured in different ways. According to Geurs and van Wee (2004), it can be measured by considering four basic components: land-use, transportation system, temporal constraints, and individual factors. In summary, the concept of accessibility can be summarized as the easiness of reaching some opportunities ("active" form of accessibility) or the easiness of being reached by a group of users ("passive" form of accessibility). Thus, it is a key component of quality of life that combines performances related to the transportation network with land-use. In the case of hospitals, accessibility is crucial, with particular regard to emergencies.

At the same time, in general, the infrastructural network used by the emergency vehicles is the road network. Hence, in the hospital area, the network composed of road arterials (mostly urban) will be used by emergency vehicles and general vehicles also during emergency services. It is important to ensure that these routes comply with high safety standards as much as possible. In fact, Wiwekananda et al. (2020) pointed out that, among possible delays encountered by emergency vehicles, the role of traffic congestion and crashes is predominant. In the case of planning new hospitals, both the existing and new infrastructures close to the hospital to be built should meet safety criteria. On the other hand, while considering existing hospitals, the surrounding road network should be scanned to identify possible crash hotspots, to be treated with appropriate countermeasures.

Hence, both the accessibility and safety aspects are crucial when managing healthcare emergency systems. However, this aspect was rarely treated from such an integrated perspective in previous research. An integrated method for considering both accessibility and safety aspects while managing a network of hospitals (both for planning new hospitals and rearranging existing hospitals) is needed, in order to provide decision support.

This study provides a contribution in this sense. In fact, it attempts at providing a methodological framework for conducting safety and accessibility assessments at the regional level, based on the following objectives:

- for the accessibility goal, the hospital should be reached from each town/city in the region in a convenient amount of time;
- for the safety goal, the area close to the hospital should not show accident-related performance indicators higher than a predefined threshold.

Details about the methodological framework proposed are included in next section. In particular, both the travel time and accident indicators requirements are specified. After, the framework is applied to a specific case study related to the Apulia Region, Italy. The results from the application are thus described, by also discussing the practical implications of the results. Finally, some conclusions from this study are drawn.

2. Methodological framework

In this section, the proposed methodological framework is presented. The presentation is divided according to the two different objectives: the accessibility goal and the safety goal. Results obtained from the application of the methodological framework to the network of public hospitals in the Apulia Region (Italy) are presented in the next section.

2.1 Accessibility goal.

Considering the definitions of accessibility provided in the introduction section, in this study, the accessibility is considered in light of users' opportunities (see e.g., Kim and Kwan, 2003). In particular, a non-behavioural model based on isochrones is used to represent health-related opportunities. Isochrones are defined as the lines connecting points which can be reached in a given amount of time starting from a given place, through the fastest path (in this case by considering road transport). In order to identify isochrones with reference to the hospital as central point (see next figure), a traffic assignment model should be necessarily developed, to simulate the interaction between the infrastructural supply and the traffic demand in the area and thus obtain travel times on the network.

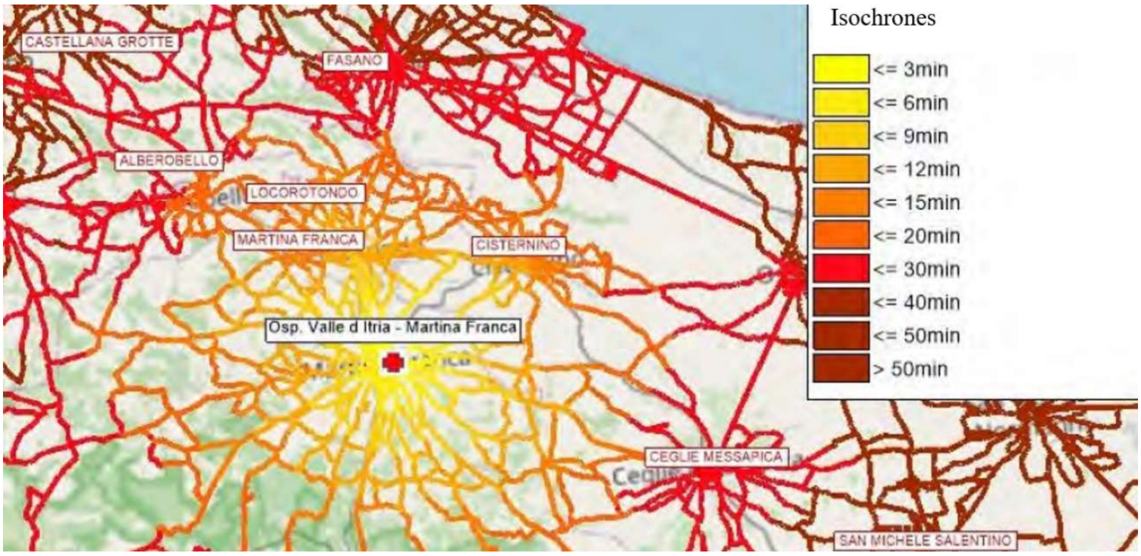

Figure 1: Example of isochrones referred to a single hospital obtained from a traffic assignment model.

The cost functions for each road link of the road infrastructure network (mainly composed of rural links) are determined according to the following equation (from the US Bureau of Public Roads):

$$t_i = t_0 \{1 + a\, [q/(c\, q_{\max})]^b\} \tag{1}$$

where:

- t_i= travel time in case of conditioned flow by the traffic assignment on the network [s];
- t_0= travel time in case of free-flowing conditions on the network [s];
- q = actual traffic flow [unit of vehicles/unit of time];
- q_{max}= link capacity [unit of vehicles/unit of time];
- a, b, c = calibration parameters.

Based on the origin-destination matrices for the reference morning peak hour (including the demand of private and public transport on roads), traffic volumes on the network are obtained in this study through the stochastic user equilibrium assignment method. Travel times can then be computed between each two points in the road network based on the traffic assigned to all road links and then, the isochrone map can be obtained as well.

The isochrone map (see Figure 1) is useful to identify the "user base" related to each hospital, that is identifying the people who can reach the hospital in a given amount of time. In case of regional-level planning, a convenient maximum travel time should be uniformly set, so that from each point of the region, the nearest hospital can be reached in that time. This particular time can be defined as based on local/national standards and regulations. In the case study to which this methodological framework is applied (as documented in next section), the maximum travel time is defined in 40 minutes (even if less than 30 minutes should be preferrable), according to regional regulations. Thus, the "user base" is defined by the 40 minutes isochrones (the 30 minutes isochrones are used as well to identify the optimal area). As a results of this process, it is possible to identify the "disadvantaged towns/cities" that are the areas outside the user base of the nearest hospital, thus needing interventions for improving accessibility.

Moreover, at the local level, thanks to the outputs from traffic simulation, it is possible to identify specific problems related to traffic congestion in the area of both the existing and the planned hospitals.

2.2 Safety goal.

The safety goal concerns keeping an adequate road safety level in the surroundings of the hospitals, especially for emergency vehicles. This implies the following steps:

- define the width of the area to be analyzed;
- localize traffic crashes on the road network in the area;
- overlap GPS tracks of emergency vehicles to the highlighted network;
- identify the main routes traveled by emergency vehicles;
- study traffic crashes occurred on the above identified routes;
- highlight road sites (segments and intersections) which need road safety interventions.

These steps are valid for existing hospitals. The width of the area to be analyzed is defined in this case by the 3 minutes isochrone. The meaning of isochrone was explained in the previous section even if, in this case, less minutes are considered (3 minutes instead of 30 minutes), since the hospital surroundings should be analyzed.

In case of new hospitals, the routes to be analyzed can be identified as the main routes in the studied area around the hospital (there are no available GPS tracks of emergency vehicles related to a hospital to be built). However, in this case, it is not possible to rely on consolidated data since there will be a traffic system reconfiguration after the construction of the hospital and correlated road infrastructures.

Moreover, concerning the methods to highlight sites requiring road safety interventions, the areas around the hospital delimited by the 3 minutes isochrone are too wide (e.g., in the order of 5-10 km^2) to conduct specific safety analyses at the single segment or intersection level. In fact, in that case, specific data about traffic volumes, road geometric and traffic control data are needed, which are often unavailable at the planning stage. Hence, at the planning level, macro-indicators or generally available micro-indicators can be a valid solution to compare different areas in terms of traffic safety.

Safety performance macro-indicators express the safety level of a given spatial unit (see e.g., Ziakopoulos and Yannis, 2020) as a function of different possible parameters. In this case, given that the area around the hospital (delimited by the 3 minutes isochrone) is assumed to be the spatial unit to analyze safety performances, the relationship between the population in the area and the traffic crashes can be used (population can be used as a measure of drivers' exposure to risk in macro-analyses, see e.g., Lee et al., 2019). In particular, the overall relationship between population (of cities, counties, or other areas) and traffic crashes can be derived at the state/region/province level. After, considering a given area and its population, it can be defined if (Figure 2): a) traffic crashes in that area exceed a predefined high percentile of the prediction interval, b) traffic crashes in the area are higher than the predicted mean but lower than the high percentile, c) traffic crashes are below the predicted mean. Clearly, the sites prioritized for safety interventions are those in the condition "a" (similarly to the Level of Service of Safety method proposed by Kononov and Allery, 2003). On the other hand, the threshold definition may vary according to local factors, in the further application it was set to the 90^{th} percentile.

Macroscopic indicators are useful to define if an entire area can be highlighted for safety improvements (see e.g., Intini et al., 2022). However, within the area, other indicators may be used to preliminarily highlight specific sites (segments and intersections) requiring safety interventions. In particular, considering that, also in this case, specific segment and intersection related variables may be unavailable, other immediate spatial indicators may be used. Assuming the population to be equally distributed among the area and proceeding to spatially clustering crashes into "crash areas" having a predefined radius (i.e., areas of a defined width in which more than one crash occurred), the following indicator can be adopted for both segments and intersections:

$$I = F/P \quad (2)$$

Where:

- F = annual average crash frequency on each segment or intersection belonging to the main network traveled by emergency vehicles (total crashes/years);
- P = reference population assigned to the cluster of crashes [(total population/(total area/total area of crash clusters having a defined width on the segment or intersection)].

In this way, after that the overall areas can be classified according to their safety performances, also single segments and intersections can be preliminarily highlighted for safety interventions. Those indicators were computed for each segment and intersection showing clusters of crashes in the areas around the hospitals. However, to compare sites in areas having different population densities, the ranking of sites should be separately conducted for groups of areas (classified according to their density). In this application, three density groups were considered and clusters were defined according to the K-means clustering algorithm (high-density urban areas, with more than 9500 habitants/km^2; urban areas, with density included between 3500 and 9500 ab./km^2 and low-density areas, with less than 9500 ab./km^2). The segments and intersections highlighted in this application show an I index (eq. 2) exceeding the 90^{th} percentile of the distribution (see the graphical explanation in Fig. 2) of the I index for each of the three density groups.

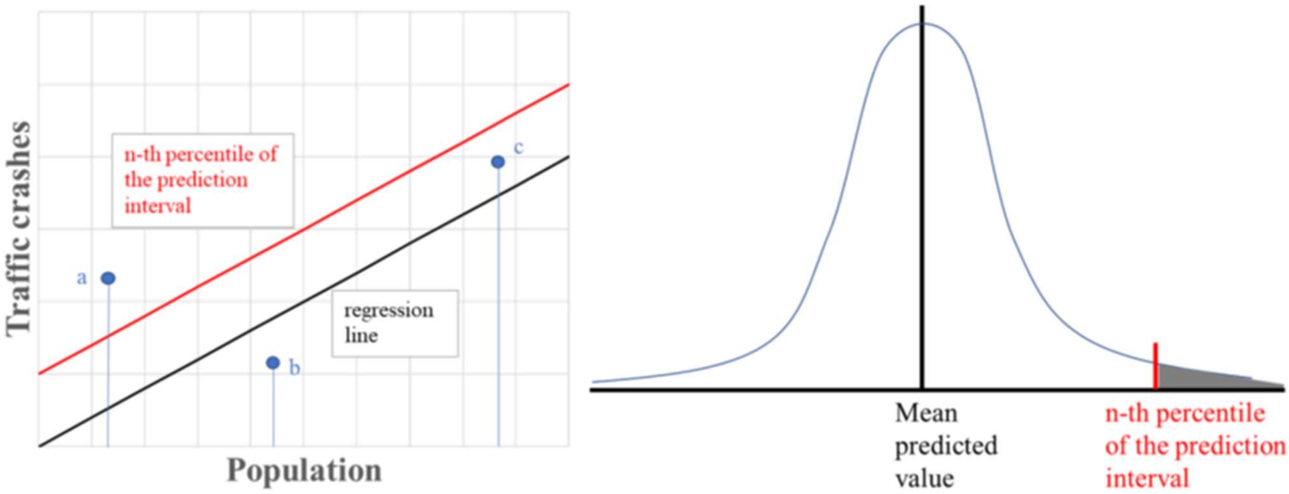

Fig. 2. Graphical definition of the relationship between population and traffic crashes and related percentile threshold (90th in this study).

Given the approximations of using such indicator, the simple crash frequency indicator (F) was used as well and the sites exceeding the 90th percentile of the F indicator for each of the three density groups were also highlighted. Clearly, further detailed studies should be needed to confirm those results (e.g., by using at least crash rates). However, at the planning level, these preliminary information on safety performances are important as well.

3. Application of the methodological framework

3.1 Results from the application of the methodological framework: accessibility.

Results from the traffic simulation (conducted considering the traffic peak hour of the working day) have revealed that, from 42 towns/cities (out of the total 257) of the Apulia Region, the nearest hospital cannot be reached within the considered 30 minutes threshold. In 15 cases (out of 42) the nearest hospital can be reached in a travel time included between 30 and 40 minutes, while in the other 27 cases travel times are greater than 40 minutes.

These results can be graphically represented in order to depict the identified areas having accessibility problems. An example of this representation is reported in next Figure 3, where disadvantaged towns/cities with respect to hospital accessibility in the Apulia region are highlighted. In particular, for towns/cities filled with the orange color (travel times to the nearest hospital greater than 40 minutes), solutions to foster accessibility should be designed.

Moreover, considering additional local analyses for traffic congestion, it was noted that in some cases, congestion (that is a 100% link saturation) is reached in the area surrounding the studied hospitals.

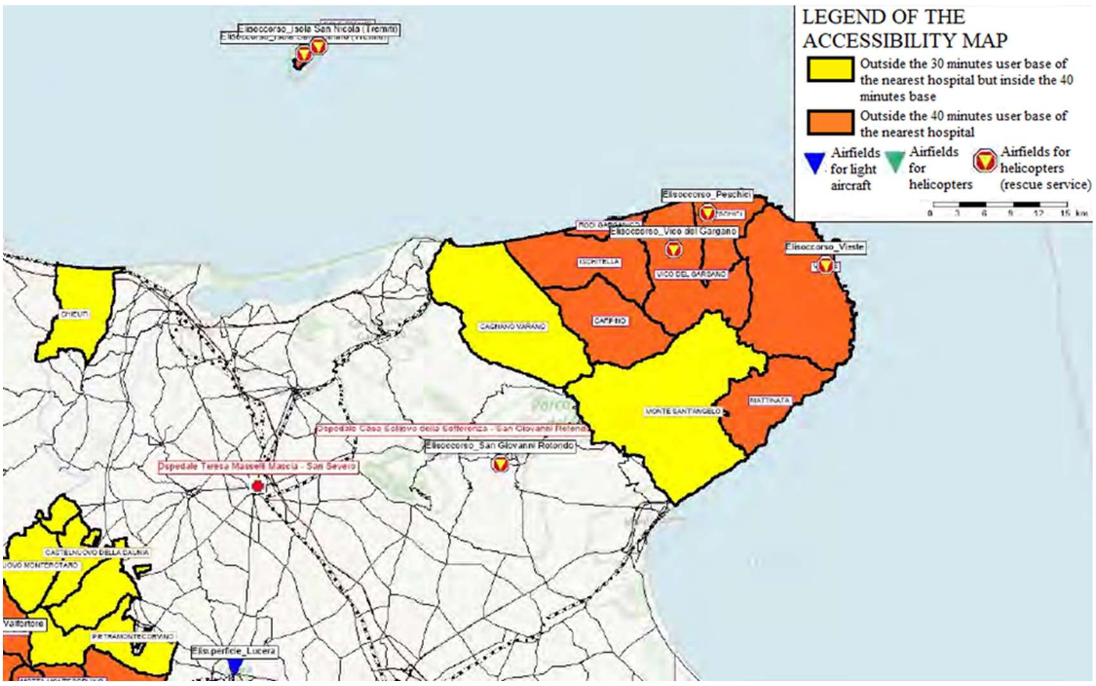

Fig. 3. Example of identification of the uncomfortable towns/cities in the Puglia Region, with respect to hospital accessibility.

3.2 Results from the application of the methodological framework: safety.

Results from the road safety analyses revealed that:

- there are five areas in which the total traffic crashes are considerably higher (more than the 90th prediction interval) than the expected mean, according to the area population (see Fig. 2);
- there are several segments and intersections which need safety interventions in most of the areas surrounding the existing hospitals, since the calculated I index (Eq. 2) and/or the calculated crash frequency exceed the 90th percentile of the distribution (among the reference density group);
- some punctual criticalities were highlighted with respect to the infrastructural network connecting planned hospitals to be built.

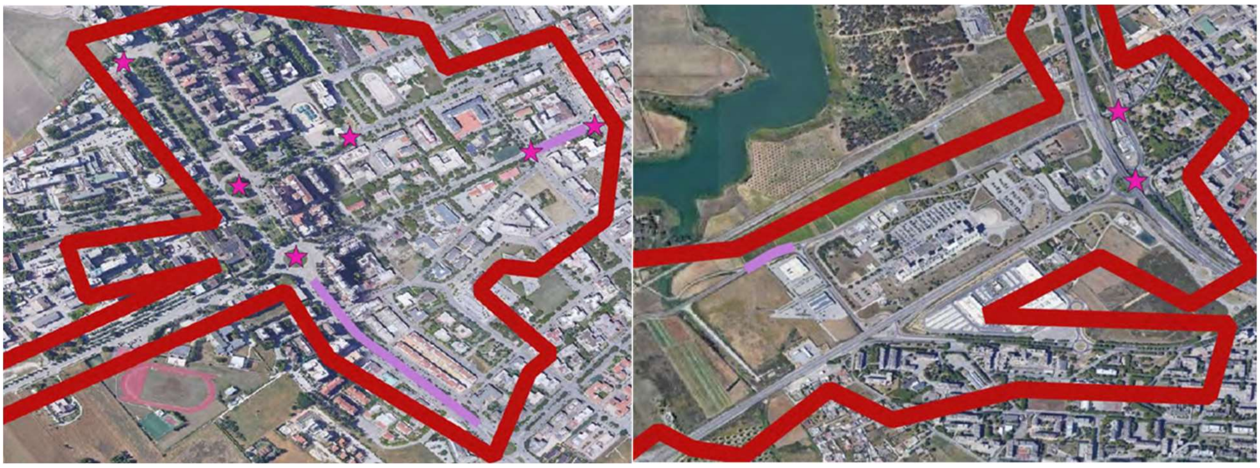

Fig. 4. Examples of identification of segments (violet lines) and intersections (violet points identified by stars) which need safety intervention in the area close to the hospital (delimited by the red line corresponding to the 3 minutes isochrone).

4. Practical implications

4.1 Practical implications for accessibility from the results of the methodological framework.

Results depicted in Fig. 3 indicate that there are some areas which cannot reach the nearest hospital within 40 minutes. Hence, it is possible to consider the following practical solutions for improving accessibility:

- Improving the road network connected with the hospitals (i.e., designing new faster infrastructures and/or enhance existing infrastructures to reduce travel times);
- Planning and managing a dedicated helicopter rescue service (i.e., providing new helicopters and helicopter pads and/or use existing helicopters and areas).

In the case study analyzed, most of those areas correspond to small towns in hilly/mountainous areas with few habitants. Hence, the second option was preferred. If the following hypotheses are considered: a) helicopters which are always available for rescue service at each hospital; b) helicopter travel time (return journey) less than 40 minutes (3 minutes for take-off/landing, 15 minutes of journey in each direction, safety margin: 4 minutes; c) helicopter flying speed of 270 km/h; then the maximum distance which can be travelled by the helicopter rescue service is 67.5 km.

Hence, it should be checked that the existing rescue service pads are within this radius from the nearest reference hospitals. At the same time, it should be verified that the existing rescue service helicopter pads can be reached in a travel time less than 15 minutes (equal to the helicopter travel time from the hospital) from the "disadvantaged" areas which should rely on this service: Hence, isochrones from traffic simulations are useful in this case as well, having as reference point the existing helicopter rescue service pads (see next figure).

If those conditions are not met, it is possible to enhance existing infrastructures to reach existing helicopter pads within 15 minutes or to plan new helicopter pads in convenient places around the disadvantaged areas. These decisions depend on cost-benefit analyses, which are highly locally dependent. In any case, if new helicopter pads should be planned, they should be optimally located, in order to serve the highest number of disadvantaged areas possible.

On the other hand, the identified local problems related to traffic congestion on the network around the hospitals should be analyzed as well, in order to identify possible solutions to improve local accessibility.

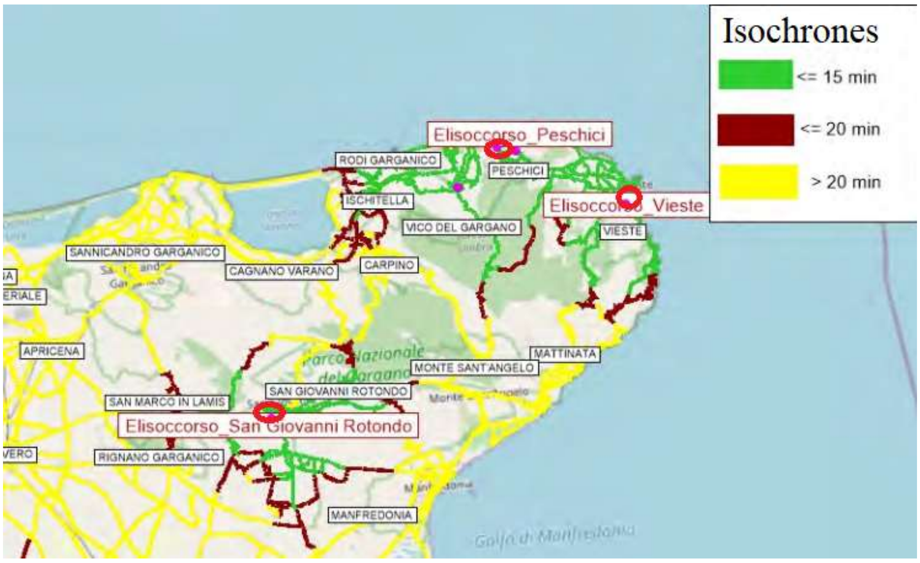

Fig. 5. Example of identification of the isochrones with reference to the existing helicopter rescue service pads (red circles).

4.2 Practical implications for safety from the results of the methodological framework.

The results from the application of the methodological framework revealed that the highlighted safety issues can be divided into three categories: 1) area-wide road safety issues, with respect to macro-indicators; 2) safety problems related to specific segments and intersections, with respect to average segment/intersection crash indicators; 3) specific safety problems related to local analyses in case of planned infrastructures.

In all cases, safety countermeasures are needed. However, at the planning level, it is not possible to design specific countermeasures for all the identified sites, since this should be based on detailed analyses. Hence, at this level, it is advisable to consider possible groups of countermeasures divided according to the safety issues and, parametric costs for each countermeasure type, if cost estimates are needed.

Concerning the first category of safety-problems, the whole identified area around the hospital is targeted for area-wide countermeasures. Those countermeasures involve the integration of specific traffic safety policies and measures (e.g., implementing traffic calming schemes: Elvik et al., 2001). Hence, at the planning level, if costs should be estimated, it is possible to rely on parametric costs i.e., area-wide countermeasure costs per square kilometer.

Considering segment- and intersection-specific countermeasures, solutions should be related to the specific site geometric and operational conditions. However, also in this case, at the planning level, it is possible to consider groups of possible countermeasures according to the environment and the segment/intersection importance, i.e., rural/urban large intersections, rural/urban small intersections, rural/urban main arterials, rural/urban secondary segments. Parametric costs may vary according to the different categories.

Concerning the third category of safety problems, they should be punctually related to the local conditions of the new infrastructures planned. In fact, the new planned hospitals to be built may involve geometric and operational variations in the existing infrastructural network. Thus, safety issues should be assessed with specific regard to the new planned conditions.

5. Practical implications

In this study, a methodological integrated framework for simultaneous accessibility and safety assessments for managing healthcare emergency systems at the regional level was proposed. It was applied to the case study of the Apulia Region (Italy). Results obtained from the case study and the related practical implications can be useful for further research and similar applications in the same field.

References

Article in a journal:

Coffee, N., Turner, D., Clark, R. A., Eckert, K., Coombe, D., Hugo, G., van Gaans, D., Wilkinson, D., Stewart, S., Tonkin, A. A. (2012) "Measuring national accessibility to cardiac services using geographic information systems", *Applied Geography* 34, pp. 445-455 (https://doi.org/10.1016/j.apgeog.2012.01.007)

Elvik, R. (2001), "Area-wide urban traffic calming schemes: a meta-analysis of safety effects.", Accident Analysis & Prevention 33 (3), pp. 327-336 (https://doi.org/10.1016/S0001-4575(00)00046-4).

Geurs, K. T., Van Wee, B. (2004) "Accessibility evaluation of land-use and transport strategies: review and research directions.", Journal of Transport geography 12 (2), pp. 127-140 (https://doi.org/10.1016/j.jtrangeo.2003.10.005).

Intini, P., Berloco, N., Coropulis, S., Gentile, R., & Ranieri, V. (2022) "The use of macro-level safety performance functions for province-wide road safety management.", Sustainability, 14 (15), pp. 9245. (https://doi.org/10.3390/su14159245)

Jones, A., Bentham, G. (1995) "Emergency medical service accessibility and outcome from road traffic accidents.", Public health 109 (3), pp. 169-177 (https://doi.org/10.1016/S0033-3506(05)80049-6).

Kim, H. M., Kwan, M. P. (2003) "Space-time accessibility measures: A geocomputational algorithm with a focus on the feasible opportunity set and possible activity duration." Journal of geographical Systems 5(1), pp. 71-91 (https://doi.org/10.1007/s101090300104).

Kononov, J., Allery, B. (2003) "Level of service of safety: Conceptual blueprint and analytical framework." Transportation research record 1840 (1), pp. 57-66 (https://doi.org/10.3141/1840-07).

Lee, J., Abdel-Aty, M., De Blasiis, M. R., Wang, X., Mattei, I. (2019) "International transferability of macro-level safety performance functions: A case study of the United States and Italy." Transportation Safety and Environment 1(1), pp. 68-78 (https://doi.org/10.1093/transp/tdz001).

Missikpode, C., Peek-Asa, C., Young, T., Hamann, C. (2018) "Does crash risk increase when emergency vehicles are driving with lights and sirens?", Accident Analysis & Prevention 113, pp. 257-262 (https://doi.org/10.1016/j.aap.2018.02.002).

Ohta, K., Kobashi, G., Takano, S., Kagaya, S., Yamada, H., Minakami, H., Yamamura, E. (2007) "Analysis of the geographical accessibility of neurosurgical emergency hospitals in Sapporo city using GIS and AHP.", International journal of geographical information science 21 (6), pp. 687-698 (https://doi.org/10.1080/13658810601135692).

Ray, A. F., Kupas, D. F. (2005) "Comparison of crashes involving ambulances with those of similar-sized vehicles.", Prehospital Emergency Care 9 (4), pp. 412-415 (https://doi.org/10.1080/10903120500253813).

Wiwekananda, K. S. S., Hamukti, R. P., Yogananda, K. S. S., Calisto, K. E., Utomo, P. S. (2020) "Understanding factors of ambulance delay and crash to enhance ambulance efficiency: an integrative literature review", Journal of Community Empowerment for Health 3, 213-222 (10.22146/jcoemph.57338).

Ziakopoulos, A., Yannis, G. (2020) 2A review of spatial approaches in road safety.", Accident Analysis & Prevention 135, 105323 (https://doi.org/10.1016/j.aap.2019.105323).

Acknowledgements

This research was conducted also thanks to the ASSET, that we would like to thank for the availability in sharing data and collaborating to the development of this project.