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Spatial Performance of Location-Based Alerts in France

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Spatial Performance of Location-Based Alerts in France

Abstract

5 *This study experiments a method for estimating and mapping the alerting potential of two*
Location-Based Alerting Solutions (LBAS): messaging techniques (cell broadcast, CBC, or
location-based SMS, LB-SMS) and the smartphone push notification. Experiments have
been evaluated over metropolitan France, a heterogeneously populated and risky area,
considering that individuals are located at home. The rate of alertable individuals, calculated
at the municipal level, show very strong potential of CBC/LB-SMS. 94.21% of individuals can
be alertable using CBC/LB-SMS and 74.15% using the smartphone push notification. There
is a very strong homogeneity in the performance of LBAS at the national level, but also local
weaknesses exist. Mapping this potential of performance contributes to the discussion about
the use of LBAS in France and paves the way for a broader assessment of the effectiveness
of alerting solutions in order to propose a multi-channel system that will consider the
territorial characteristics.

Keywords

Alert; Location-Based Alerting Solutions; Performance; Spatial analysis

1. Introduction

20 Over the last few years, progress in communication technology has markedly improved
alerting systems [1]. High-performance sensor networks have made it easier to detect
hazards and quickly disseminate warning messages to citizens. Location-Based Alert
System (LBAS) brings a new dynamic alerting system, using multiple technologies for
people's safety. These alerting techniques can send location-based alerts to citizens using
telecommunication networks [2]. They are included in the Location-based Services (LBS),
25 which use the target location for adding value to the service [3]. Three main solutions exist in
2020: cell broadcast technology (CBC), Location-Based SMS (LB-SMS) and the smartphone
push notification (SPN; Table 1).

30 CBC allows the broadcasting of text messages to all mobile phones in a specific
geographical area without discrimination [4]. Developed in 1997, it is a standard feature for
the Global System for Mobile Communication [5]. The message is broadcast to a cellular
antenna (point-to-area) through specific channels, avoiding congestion problems [6,7]. The
antenna forwards message to the phones located in the cell without prior identification of the
phone numbers. Almost all mobile phones are compatible with the technology [2].

35 LB-SMS is a communication protocol allowing transmission of text messages to one or more
receivers (point-to-point, i.e. unicast or multicast). Telecommunication antennas are required
to support GSMS (through a "cell-ID" identifier [8]). The message passes through traditional
telecommunication channels, but is therefore subject to the risk of network congestion [2,9].
All mobile phones (included smartphones) are compatible with SMS protocol. Messages can
be written in different languages, since it depends on the SIM card nationality.

40 SPN is the receipt of an interrupt message usually associated with a smartphone application
[10]. A remote server of an application can send a message to all smartphones with the app,
taking into account user's location in real time. In most cases, the notification is displayed
even if the app is closed. Since 2010s, many alert apps have been created [11,12]. Some of
them are directly managed by authorities (FEMA©, RisqueNice®, Red Alert©), others by
45 private providers (Signalert©, MySOS©, Swelp©). Apps can also be a communication

interface between users and authorities, which breaks the traditional "one-way direction" of communication used by older tools [13]. A major issue of SPN alerting is the requirement for users to download the app. However, governments could send alert notification via third party (and massively downloaded) application, subject to agreements with the holders of these applications. Furthermore, the Covid crisis has prompted Google® and Apple® to develop the possibility for public authorities to send push notifications without going through third-party app¹.

Table 1. Main positive or negative settings of CBC, GSMS and SPN

Studied solution	Positive features				Negative features		
	Geo-targeted alert	Quick dissemination	Cellphone ability	Smartphone ability	Network congestion	Need for Download	Network failure
CBC	X	X	X	X			X
GSMS	X	It depends	X	X	X		X
SPN	X	It depends		X	X	Not necessarily	X

Many countries are equipped with LBAS [14]: Japan (since 2007), Chile (since 2011), Australia, Netherlands and the USA (since 2012), Belgium (since 2017), Romania and Tunisia (since 2020) among others. However, LBAS do not exist in France even though broadcast technology has been invented there in 1997. Sirens remains the traditional alerting tools since the end of 2WW [15]. Nonetheless, a European decree adopted in 2018 obliges member states (including France) to set up in June 2022 a messaging alert system based on the location of individuals in real time. So, given that LBAS will soon be set up in France, how can estimate their performance? What are the spatial consequences of using LBAS? Will some territories be disadvantaged? While feedback has shown how effective these solutions are in several countries [6,16], no study has been carried out on the LBAS potential over France. Moreover, no study has observed the spatial impact of these solutions at national scales.

To address these questions, this paper proposes a method to estimate LBAS spatial potential. The part I address an overview on the use of LBAS and alerting process in France. Part II presents the methodological protocol, and data used to estimate the LBAS performance. Results are presented in part III. Part IV concludes by discussing the interest of a multi-channel alert system and the required improvements in the short term.

2. Background

2.1. LBAS effectiveness

The LBAS's effectiveness depends on many factors: i) the performance or efficiency, referring to the penetration rates, i.e. the number of individuals reached in an area [6,17]; ii) the social acceptance [18,19] and related behavioural changes [20]; iii) the efficiency of the message [21,22], including the interpretation of the message by the public [23] and the need to lengthen LBAS messaging [4,24,25]; iv) the efficiency of the dissemination [26,27], or v) the technical robustness of the system [2,28,29].

Recent works aim at estimating or mapping LBAS performance at smaller scales. Gonzales et al. [30] estimates the number of people covered by telecommunication networks across an area impacted by tornadoes in Alabama in 2011. Parker et al. [31] uses simulation techniques in virtual city to estimate LBAS performance. Markwart et al. [32] uses virtual

¹ <https://www.theverge.com/2020/9/1/21410281/apple-google-coronavirus-exposure-notification-contact-tracing-app-system>

reality to test the effectiveness of messaging mobile alert on a small number of individuals. Samarajiva and Waidyanatha [33] tested the delivery of location-based alerts in 32 tsunami-affected villages in Sri Lanka. All this work has shown how LBAS is a high-performance solution.

5 This scientific literature reveals that the LBAS effectiveness is related to social and technical aspects. However, there is a substantial knowledge gap when it comes to understanding the spatial efficiency of LBAS at national scale and how this efficiency evolves according to territorial criteria. In the literature, most of the LBAS performance rates are based on people that are already equipped with mobile phones and experiments are concentrated in urban areas, where telecommunication networks are powerful [16,34]. Through tests, Klafft [35] compared the performance of an SMS alert in a rural area and then in an urban area, but the study is conducted on a limited scale and focused more on individual behaviour rather than providing a truly territorial comparison. Thus, it seems necessary to estimate the performance of these solutions on a broader scale, taking into account individuals who are not equipped and rural areas where telecommunication networks may not perform well [36].

2.2. Why study the potential of LBAS in France?

2.2.1. The French delay in the field of location-based alerts

In France, the national alerting system is based on a siren network and social media. The siren network is currently being modernised in a new system (SAIP system, for Alert System and Information for the Population). 5,445 SAIP sirens will cover the national territory in 2022. However, sirens are not effective enough: they are spatially inappropriate regarding the location of the population [37]; the beep tone does not indicate the nature of the danger; they are obsolete and rarely used [38]. Other solutions exist at local scales (messaging boards, telephone call system, megaphones, etc.), but their use depends on local public policies. Thus, warning is not standardised in France (unlike some countries using the Common Alerting Protocol) and there are wide territorial disparities in terms of alerting equipment.

The French government has twice tried to switch its warning system to mobile phone tools. In 2010, two options (CBC and LB-SMS) were considered but rejected due to lack of agreement with the telephone operators. In 2016, a smartphone app (also called SAIP) was developed to alert in case of terrorist attacks. But the app was dropped in 2018 due to numerous malfunctions (missed alerts and false alerts) and too few downloads [39]. Since this failure, the Ministry of the Interior uses social networks. But this strategy did not meet with the expected success: 600,000 individuals follow the official Twitter account (i.e. less than 1% of the French population). The European directive adopted in 2018 obliges the government to reinvest the mobile phone alert strategy. In September 2020, the government announced the development of a hybrid alert system using both CBC and LB-SMS over the entire national territory (including overseas territories) for a budget of 50 million euros. However, it would seem that this system cannot be used by municipalities. This strategy raises questions, given that some municipalities choose to turn to private service providers to alert their citizens by SMS, LB-SMS, CBC or SPN. This is why it seems importance to analyse the performance of the different LBAS on a French scale, but using metropolitan municipalities as a reference unit.

2.2.2. A heterogeneous and at-risk territory

45 France is an interesting study area. The country is populated in 2019 by 66.99 million inhabitants heterogeneously distributed. The population is concentrated in “large” and “medium” urban areas, coastlines and river corridors, while mountain areas and hinterlands

are much less populated (Figure 1). 79.7% of the French population lives in cities and 13.7% lives in mountainous areas. Metropolitan France is also a territory highly exposed to risks. The Mediterranean region is exposed to flash floods [40], the coastline at risk of submersion (59 deaths in Vendée in 2010), mountain area at risk of avalanches (39 deaths in Savoie in 1970), landslides (171 deaths in Haute-Savoie in 1970), and earthquakes (46 deaths in the Bouches-du-Rhône in 1909). The whole territory is also subject to the risk of storms (140 deaths in 1999) and industrial risk (18 deaths near Lyon in 1966, 31 deaths in Toulouse in 2001).

5

Disparities in population and risk exposure make France a very interesting field of study for analysing the performance of a national alerting system.

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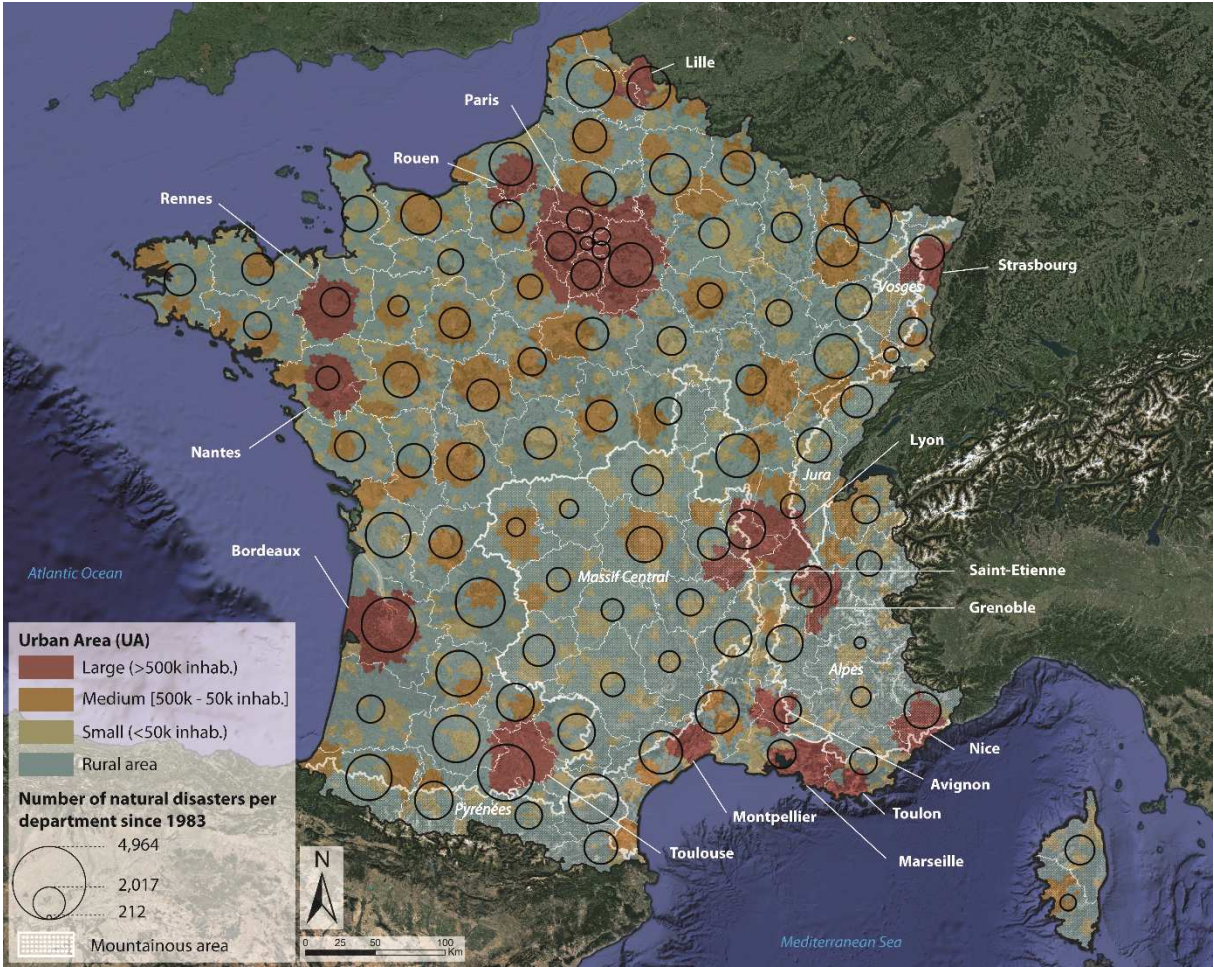


Figure 1. Classification of urban areas and number of natural disasters by departments in metropolitan France – 1.5 column fitting image

2.3. Research focus

The main objective of this paper is to quantify the spatial performance of LBAS to improve knowledge about LBAS and the spatial consequences of their use. This objective is divided into three additional supports: i) to quantify the LBAS performance at local scale (municipal) and national scale; ii) to locate the territories where LBAS are performing well and those where they are less performing; iii) to analyse the LBAS performance according to territorial characteristics. LBAS performance has been evaluated calculating the rate of individuals reached by different solutions (so-called the “alertability” rate). This ratio is estimated by

15

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combining different spatial data in a GIS. Results were analysed using territorial and spatial analysis tools.

According to the various feedbacks made in other countries, we think that a LBAS would be very efficient in France:

- 5 - H1: More than 75% of the French population can be alerted using a LBAS (regardless of the solution).

Two other hypotheses concern the link between the characteristics of territories and LBAS. Following up previous research [30,41], we postulate that the number of inhabitants or the urban or rural characteristic of a municipality could be linked to the LBAS performance .

- 10 - H2: LBAS performance increase as the number of inhabitants increases.
- H3: LBAS performance is higher in municipalities within urban areas than in municipalities outside urban areas.

Other hypotheses look at the impact of morphological conditions (such as topography and the vegetation) on the LBAS performance. LBAS would be less efficient in mountain or forest areas due to natural obstacles, perturbing the propagation of telecommunication networks [42]. Population density could then be an important factor as sparsely populated areas are less profitable for operators than densely populated areas.

- 15 - H4: LBAS performance is lower in mountain territory than in no-mountain territory.
- H5: LBAS performance declines as forest cover rate increases.
- 20 - H6: LBAS performance declines as density of the inhabited area decrease.

Our answers to these hypotheses will improve scientific literature on the three following points: i) knowledge of the performance of LBAS on a large scale (estimated on a sample of 50.4 million inhabitants ages 18 and over in metropolitan France; ii) an understanding of the spatial consequences of a location-based alert and a categorisation of the territories where LBAS are performant and those where they are not; iii) a reflection on the establishment of a multi-channel alert system which will take into account the characteristics of territories.

3. Data and methods

In this study, LBAS was considered as an opt-out system, i.e. automatically imposed on any mobile phone or smartphone holder. This means that it is not necessary for people to register on a platform in order to receive alerts, nor to download an application beforehand.

3.1. Estimation of the spatial potential of each LBAS solution

The evaluation of the spatial alerting potential for each solution (CBC, LB-SMS, SPN) has been founded on the equipment rate, the connectivity rate, and the population deduced from the most recent census data. "Alertable" people are aged 18 years or more. Figure 2 shows the characteristics of each indicator, and the method is detailed below.

3.1.1. Connectivity rate (CR)

The Connectivity rate (CR) gives the number of individuals included in the spatial coverage of telecommunication networks. The 2019 INSEE grid based on 2015 data was used to locate individuals. 2G, 3G and/or 4G coverage is necessary for the CBC and LB-SMS solutions to work. Only areas covered by all four main French operators (Bouygues®, SFR®, Orange®, Free®) were selected, since it is not possible to know the name of the operator for each person at a precise scale. 2G connection is not enough to operate a push notification of an app. Thus only the number of those connected via 3G or 4G was used. In addition, the

number of people who use Wi-Fi at home to connect their smartphone was inferred (according to the 2018 CREDOC survey²). The CR is obtained as follows:

$$CR = \frac{NC}{N} = \frac{(N2G \cup N3G \cup N4G)}{N}$$

5 With N , the number of alertable individuals; NC , the estimate number of connected individuals; $N2G$, $N3G$ and $N4G$, the number of individuals living respectively in areas covered by 2G; 3G or 4G. This equation is stated for CBC/LB-SMS, for PNS, $N2G$ must be removed and $NWifi$ (number of individuals living in an area not covered by 3G or 4G, but who connect their smartphone to their home Wi-Fi) must be added.

$N2G$, $N3G$, and $N4G$ are obtained as follows:

10
$$NxG = NxGa \cap NxGb \cap NxGc \cap NxGd$$

With N , the number of alertable individuals; xG , the category of network (2G, 3G, 4G); a , b , c , and d , the four French operators.

15 The approach is limited by the rapid evolution of data and the fact that individuals are “fixed” to their homes. This method is more realistic in a scenario where individuals are at home (during the night).

3.1.2. Equipment rate (ER)

20 The Equipment rate (ER) gives the number of those having a support (smartphone or mobile phone) in connected areas compared to the total number of individuals in the municipality. According to the CREDOC report, the probability that a resident owns a smartphone (for SPN) or a mobile phone (included smartphones for CBC and LB-SMS) depend on the age of individuals (Table 2). The 2019 INSEE grid gives the ages and the number of residents in a 200m grid. Age information is given either in real figures, or estimated if the number of households in the grid is less than 11 (a fixed threshold to protect individual identities). The ER according to the age of the individuals for each INSEE cell is implemented at the
25 municipal level as follows:

$$ER = \frac{NPage}{N} = \left(\sum_{x=1}^6 \left(\frac{Nx * NERx}{100} \right) \right) / N$$

With N , the number of alertable individuals; $NPage$, the estimate of the number of equipped individuals according to each individual's age group; x , the age group of individuals; NER , the national equipment rate given in table 2.

30 **Table 2.** Smartphones and mobile ownership (%) by age and municipalities. Source: CREDOC report 2019 (from a sample of 2,214 individuals representative of the population)

	Age group					
	18-25	25-39	40-54	55-64	65-79	80+
Smartphone	98.0	95.0	80.0	71.0	50.0	26.0
Mobile	99.0	99.0	97.0	95.0	88.3	80.0

3.1.3. Alertability rate (AR)

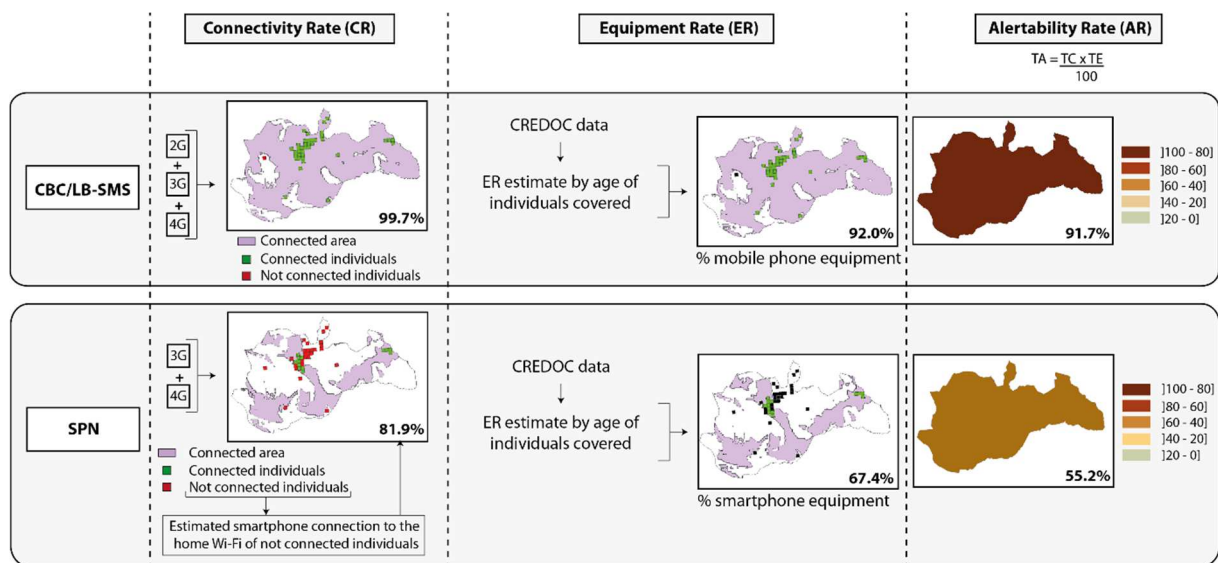
² Government study representative of the French population
(https://www.arcep.fr/uploads/tx_gspublication/barometre-du-numerique-2018_031218.pdf).

The spatial alerting potential (called the “Alertability” rate) estimates the percentage of people covered by each solution. The AR is calculated by multiplying the Equipment (ER) by the Connectivity (CR) rates for each municipality as follows:

$$AR = \frac{\left(\frac{NPage}{N} * \frac{NC}{N}\right)}{100}$$

- 5 With N , the number of alertable individuals; $NPage$, the estimate of the number of equipped individuals according to each individual’s age group; NC , the number of inhabitants covered by a telecommunication network.

10 Figure 2 explains the method. CBC and LB-SMS have the same AR because these solutions both work on cellphones and using a 2G, 3G and/or 4G connection: their potential performance is the same in this study.



15 **Figure 2.** Method used to estimate the spatial alerting potential in a municipality (estimations are presented for Barrême, Alpes-de-Haute-Provence, with 436 residents) – 2 column fitting image

3.2. Detection of spatial differences

Results must be detailed to discern whether there are variations in the spatial performance of the different alerting solutions.

3.2.1 Autocorrelation and hot spot analyses: are LBAS spatially equitable?

- 20 The spatial homogeneity between municipal AR being quantified through two indexes: i) Gini Index, in order to reveal the level of inequality in the distribution of the rates; this index ranged from 0, meaning equal distribution and referring to the dimension of justice between territories to 1, meaning unequal distribution and referring to high spatial injustices; ii) Moran index, to detect spatial autocorrelations and to measure the intensity of relationships
- 25 between proximity and similarity [43]. If the Moran index is close to 1, this indicates that municipalities tend to look more alike than other more distant places. On the contrary, if the Moran index equals -1, it means that nearby sites tend to be different from each other than the most distant places.

Hot and cold spot maps were also made to identify areas with spatial discrepancies of high/low alerting effectiveness. Based on CBC/LB-SMS alertability rate, the procedure was carried out using a GIS toolbox (with "Getis-Ord-Gi" statistics), which enables the display of statistically significant "hot/cold spots" by comparing the values of the municipalities with the values of their neighbours.

3.2.2 Territorial analysis

Results were analysed to verify if the alerting solutions studied are equally effective in urban and in rural areas, to meet our third hypothesis. Previous studies have pointed out that communication technologies are less effective in rural areas [45,46], even though they contribute to the revitalisation of such areas [36]. To find out more, we grouped municipalities in four classes depending on their classification as an Urban Area (UA), defined by INSEE as "a set of municipalities, contiguous and without enclaves, consisting of an urban centre with more than 10,000 jobs, whereas the rural municipalities or urban units are those where at least 40% of the resident population with a job working in the urban centre of one of its municipalities". The UA is used to map "catchment basins". Due to the non-parametric form of the results (verified using the Kolmogorov-Smirnov test) and heteroscedasticity of the data (non-homogeneous variances), an Analysis of Variance by Aligned Rank Transformation (ART, [47]) was used to compare results in urban area categories.

The classification of the municipalities as mountainous territory or according to the share of the municipal area covered by forests will make it possible to answer hypotheses 4 and 5. The classification of municipalities in mountain areas depends on criteria established by the French State. These are municipalities limited in their development by the topography or difficult altitude conditions. Forest zoning is taken from the government database Corine Land Cover that specifies land use on a national scale. The density within the inhabited areas was obtained for each municipality by dividing the sum of the inhabitants by the sum of the surface area of the inhabited INSEE cells (H6). Concentration or centralisation indexes [48] were not used because it is not possible to rigorously define the size of the smallest area in which the population could live at the scale of the 34,841 municipalities in the study area. A factor analysis will address hypothesis 2, 5 and 6 with a validation threshold of $\rho < 0.4$ (H5) or $\rho > 0.4$ (H2 and H6), often used in social science [49].

4. Results

4.1. A very high potential for CBC/LB-SMS in France

According to our estimates, 99.63% of the French metropolitan population is located in areas covered by 2G, 3G or 4G (which corresponds to the LB-SMS connectivity rate). 99.62% of the French metropolitan population is located in areas covered by 3G or 4G or connect their smartphone to their home Wi-Fi (for individuals not residing in a 3G or 4G area). 94.56% of the French metropolitan population is equipped with a mobile phone (basic and/or smartphone) while 74.38% of the French population owns a smartphone.

CBC/LB-SMS has a very high performance potential in metropolitan France: 94.21% of the French would be alertable by CBC or LB-SMS (Table 3). The mapping of results at the municipal level reveals the high performance of these solutions (Figure 2 & 3): 97.8% of the municipalities have an alertability rate higher than 75% and only 5 municipalities have an alertability rate of 0%. The SPN also has a high level of performance potential, but logically less than the CBC/LB-SMS. 74.15% of the French would be alertable using SPN. 26.5% of municipalities have an alertability rate higher than 75% of their population. As it is possible to

connect the smartphone to home's Wi-Fi in "blind areas" (without 3G or 4G), no municipality has a SPN alertability rate of 0%. H1 is accepted for CBC/LB-SMS but rejected for the SPN.

Table 3. Equipment rate, connectivity rate and alertability rate of LBAS in France and associated quartiles (Q) and deciles (D)

<i>Studied solution</i>	CR (%)	ER (%)	AR (%)
<i>CBC/LB-SMS</i>	99.63	95.56	94.21
<i>D10</i>	96.81	92.81	90.34
<i>Q1</i>	99.68	93.59	92.95
<i>Q3</i>	99.99	94.92	94.81
<i>D90</i>	100	95.35	95.28
<i>SPN</i>	99.62	74.38	74.15
<i>D10</i>	85.61	67.43	59.61
<i>Q1</i>	97.19	70.38	67.57
<i>Q3</i>	99.99	75.42	74.92
<i>D90</i>	100	77.15	76.81

5

Results seem visually homogeneous (Figure 2 & 3). However, some spatial aggregations emerge. Groups of municipalities with low CBC/LB-SMS alertability rate stands out in the Massif-Central and in Bourgogne. Municipalities with high SPN alertability rates seem to be concentrated in large urban areas (30.2% of the municipalities with SPN alertability rate higher than 75% are located on the 20 largest French urban areas). That's why these results need to be further analysed (from a territorial and spatial point of view) to fully understand the spatial implications of the use of national location-based alerting system.

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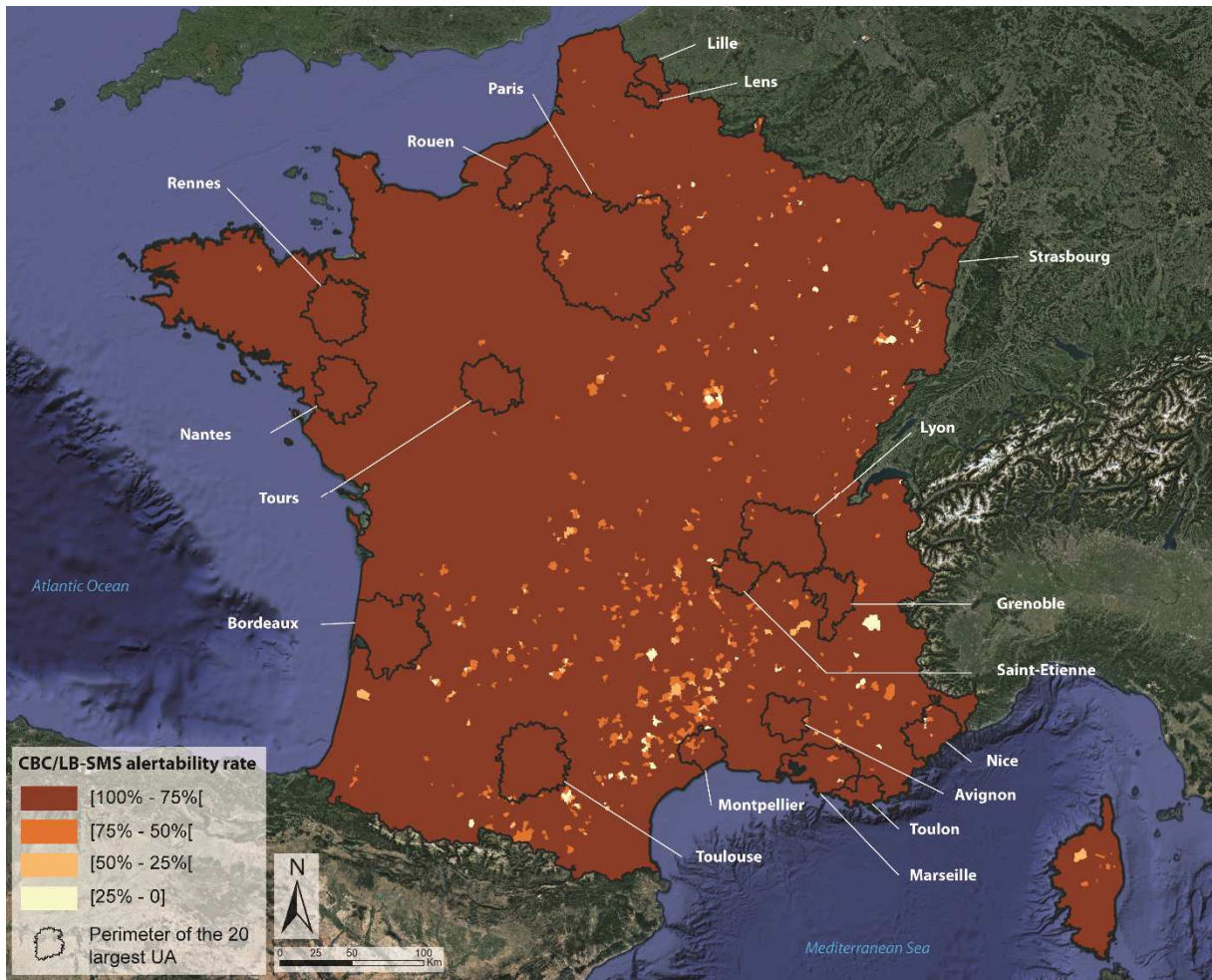


Figure 3. Alertability rate of CBC/LB-SMS at municipal level in France – 1.5 column fitting image

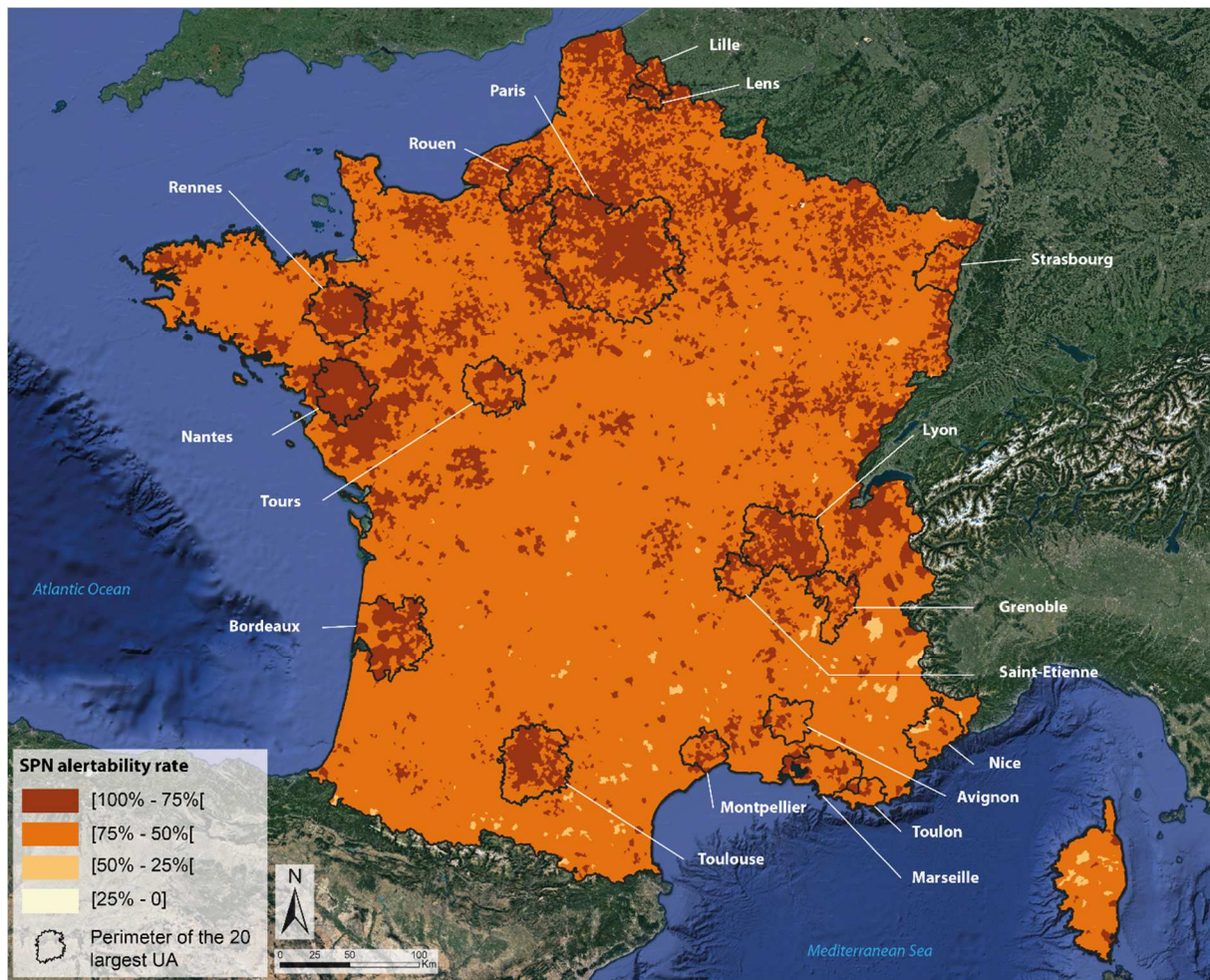


Figure 4. Alertability rate of PN at municipal level in France – 1.5 column fitting image

4.2. Spatial differences in alertability rate

4.2.1 Highly egalitarian alerting tools at the national level

5 LBAS have a small spatial difference at the national scale. Gini values are very small for both solutions (Figure 4). So LBAS may render the alerting process very equitable in France. They seem to be a credible solution to the disparity in the alert organisation currently observed between the French municipalities (diversity of means and lack of planning policy). These tools may drastically reduce the number of non-alertable areas. In addition, the national spatial autocorrelation value shows a trend towards similar performances between neighbouring municipalities for SPN ($I_M=0.43$). This trend is less strong for CBC/LB-SMS ($I_M=0.14$). This trend towards local homogeneity in the SPN performance is an interesting issue, particularly because disaster often impact several neighbouring municipalities. This result also feeds the hypothesis of the existence of high-alert and low-alert clusters. These clusters now need to be located using other geostatistical tools.

4.2.2. But regional disparities that raise questions

Discrepancies in LBAS performance at departmental level need to be considered. For CBC/LB-SMS, the difference between the most alertable department (Seine-Saint-Denis, 95.67%) and the least alertable department (Lozère, 86.66%) is 9.01%. For SPN, the difference between the most alertable department (Seine-Saint-Denis, 78.86%) and the least alertable department (Creuse, 66.99%) is 11.87%.

- At the municipal level, the mapping of the Local Moran Index shows local homogeneity (in the north-west and east of France) and local disparities (in the south) in alertability rates (Figure 5). Zones of local disparities in alertability rates are more marked for the SPN. These zonings are superimposed on the hot and cold spot zonings: the zones of high alertability are located in the north-west and east and the zones of low alertability are located in the south (Figure 5). This means that alertability hot spot is also characterised by a high degree of homogeneity in the rates of alertable individuals between neighbouring municipalities. On the contrary, the zones of lower alertability are characterised by a greater instability of the rates of individuals who can be alerted between neighbouring municipalities.
- 5
- 10 The mapping of alertability rates raises questions. High and low alertability zoning seems to correspond to the dynamics of the territories. Zones with good alertability rate are globally located in dynamic zones and urban centres, while zones with lower alertability rates are located in rural, depressed and less dynamic territories. Areas of low alertability seem to correspond to the “empty diagonal”, which is considered a low dynamic area [50]. Now, effort
- 15 must be made to characterise the territories with low alertability rates.

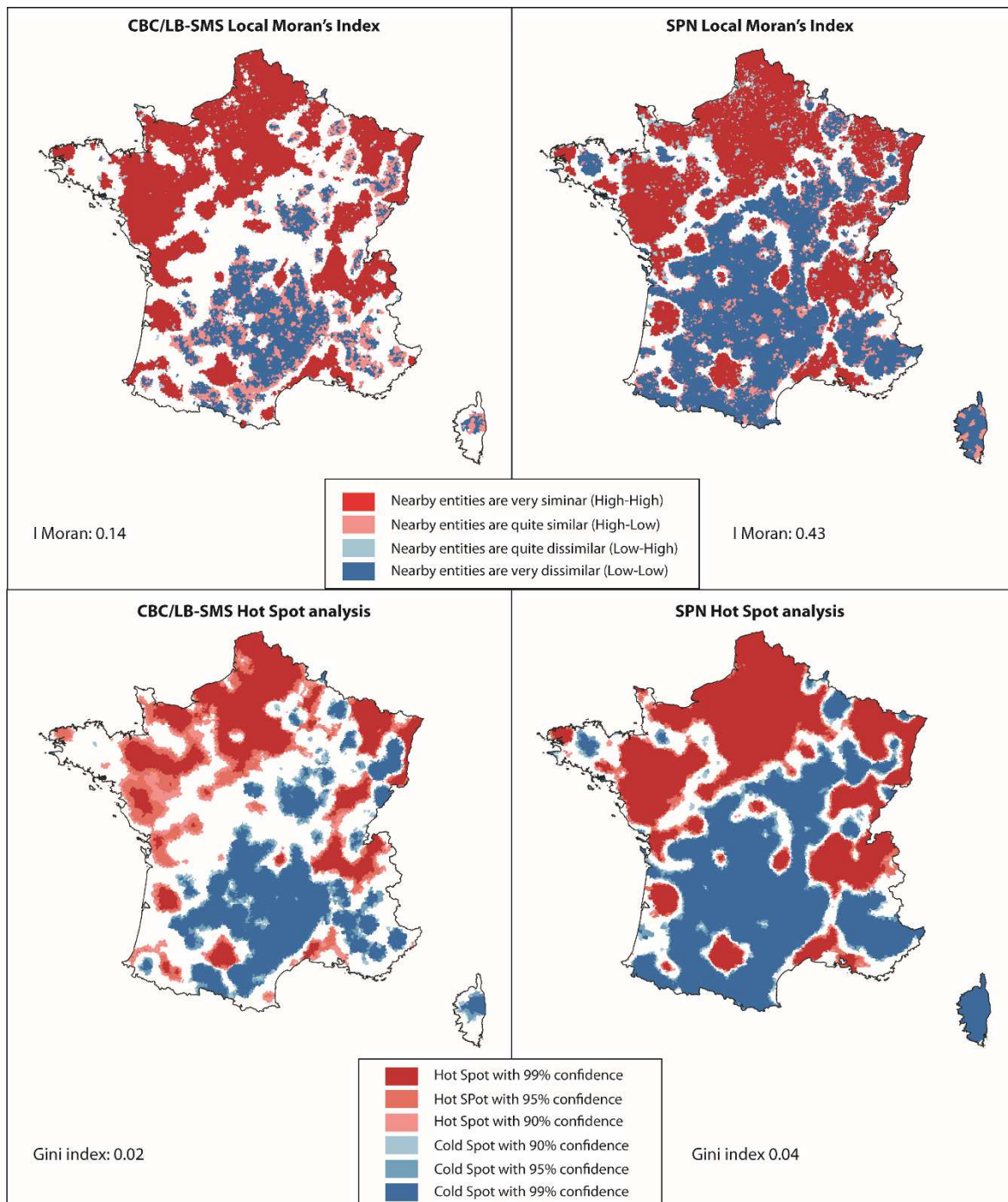


Figure 5. Spatial analysis of CBC/LB-SMS and SPN performance – 2 column fitting image

4.3. LBAS are less performant in rural, mountainous, and sparsely populated areas

5

There is a positive relationship between population size and LBAS performance (Spearman's rho of 0.29 for CBC/LB-SMS and 0.33 for SPN). However, the coefficients are insufficient and the H2 is rejected. Otherwise, the performance of LBAS increases with the size of the urban area (Table 4). LBAS are less performant in municipalities in rural area than in municipalities belonging to an urban area: H3 is accepted. Thus, the urban or rural nature of

10

a municipality is a determining factor in the performance of a LBAS even if they remain overall very efficient in rural areas.

LBAS are less efficient in mountain areas: LBAS perform less well in the mountainous areas of cold spots, neutral zones and hot spots than in areas not considered as mountainous in the same points (Table 5): H4 is accepted. LBAS performance declines as the share of the municipal area covered by forest increases (Table 5), but the correlation coefficient is not stronger enough and H5 must be rejected. The municipality size is negatively related to the performance of LBAS ($\rho=-0.28$ for CBC/LB-SMS and $\rho=-0.24$ for SPN), but the most decisive parameter is the population density in the inhabited areas. Municipalities with low density in inhabited areas are characterised by lower LBAS alertability rates than municipalities with high population density in inhabited areas. This is a territorial-determinant factor because the correlation coefficients are relatively strong: H6 is accepted.

Table 4. Alertability rates classified by the Urban Area (UA) size

Studied solutions	ART ANOVA	Rural areas (n=17,345)	Small UA (n=6,394)	Medium UA (n=6,319)	Large UA (n=4,783)
CBC/LB-SMS	F=2901.3 P<2.22e-16*** Df=3	91.4%	93.0%	94.0%	94.2%
SPN	F=3130.6 P<2.22e-16*** Df = 3	69.6%	71.9%	74.1%	75.0%

Table 5. National and territorial performance of LBAS according to morphological factors

Studied solutions	Number	Mountainous area			Forest covers rate	Pop. density in inhab. areas
		Wilcoxon Mann Whitney test	Mountainous area	No-mountainous area	Spearman's rho	Spearman's rho
CBC/LB-SMS	34,841	P>2.2e-16***	90.0	93.4	-0.35	-0.47
CBC/LB-SMS hot spot	14,775	P>7.4e-11***	94.2	94.5	-0.15	-0.19
CBC/LB-SMS neutral	7,759	P=2.2e-05***	92.5	92.8	-0.09	-0.32
CBC/LB-SMS cold spot	12,298	P>2.2e-16***	87.7	89.8	-0.28	-0.48
SPN	34,841	P>2.2e-16***	68.2	72.7	-0.33	-0.48
SPN hot spot	16,933	P>2.2e-16***	73.9	74.7	-0.17	-0.15
SPN neutral	6,229	P=0.068	71.4	71.6	No correlation	-0.15
SPN cold spot	11,670	P>2.2e-16***	66.0	68.4	-0.28	-0.42

Finally, rural, mountainous and sparsely populated municipalities are less well alertable by LBAS than the other French municipalities. However, it should be remembered that these are comparative results and LBAS are non-performant in a limited number of municipalities. Only 242 municipalities have a CBC/LB-SMS alertability rate lower than 50% of its population (average of 229.5 inhabitants) and 223 municipalities have a SPN alertability rate lower than 50% of its population (average of 146.2 inhabitants).

5. Discussions

5.1. Methodological limitation

The method used in this study can be reused for other territories and at other scales if the data are available. It might be interesting to expand the work to territory where telecommunication network is less developed so as to observe whether the urban/rural opposition is reinforced or whether other logic take precedence. French overseas territories, in particular Mayotte and French Guiana, could be experimental study areas. But telecommunication data are not available in all overseas territories today.

5.1.1. What performance when people are at work?

It is very complex to know the exact number of people who can be alerted at local scales and for a given type of tool, due to the regular changes in the individual's position in space and time. We have tried to go beyond the residential position of individuals. Since there is no data on the location of jobs, we located all workers randomly in urbanised area from the OCSOLPACA database³. This land-use database is only available at the scale of the Sud-PACA region (in the south-west of France) because open access land-use data in France is not sufficiently detailed ("urbanised areas" are not referenced for a number of rural municipalities). The number of individuals working in each municipality is taken from INSEE database and is added to inactive, unemployed and retired individuals to obtain an estimate of the number of individuals present in the municipality during working hours.

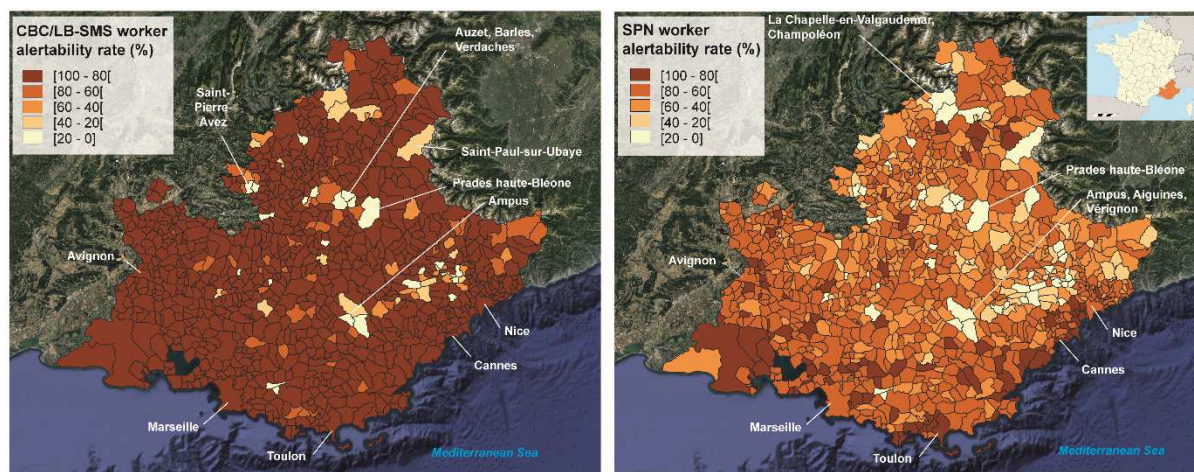


Figure 6. Alertability rate of LBAS at the municipal level in Sud-PACA region for a scenario where individuals are located at their workplace (n=946) – 1.5 column fitting image

With this method, 93.8% of workers would be alertable using CBC/LB-SMS and 69.8% using a smartphone application (Figure 6). The difference between the two scenarios is relatively small, but more noticeable for SPN (+3.04% for resident scenario) than for CBC/LB-SMS (+0.41% for worker scenario). In addition, the difference does not exceed 10% between the two scenarios for nearly 90% of the municipalities for CBC/LB-SMS, whereas for SPN this is the case for only 50% of the municipalities (Table 6).

Table 6. LBAS performance comparison between the scenario where individuals are at home and the scenario where they are in their workplace

	Alertability rate		Gap between scenarios		
	Residents (A)	Workers (B)	A>B by at	[-10-10%]	A<B by at

³ <http://www.crige-paca.org/projets-en-cours/bd-ocsol-paca.html>

			least 10%		least 10%
CBC/LB-SMS	93.37%	93.78%	9.09%	89.96%	0.95%
SPN	72.86%	69.82%	44.40%	50.21%	5.60%

5.1.2. The individual scale in question

- Another possibility would have been to use the household's position at the municipal scale, rather than using data on people. The latter implies that one alerting tool per household could be sufficient to alert all individuals present in the household. However, an estimation of the accurate possession of alerting tools in use would have been impossible, given the existing data. The absence of one person from the home could have modified the "alertable" quality of that household. So it was decided to work at the individual level, even if this meant underestimating the number of people alerted rather than overestimating them.
- The method used in this study gives another look at the performance of LBAS compared to empirical methods that test LBAS in given territories. While the implementation of national data at the local scale may involve approximations if the results are observed municipalities by municipalities, the sample size allows for a rigorous and unprecedented spatial analysis of LBAS alertability at the national scale. Furthermore, this work takes into account individuals not equipped with mobile phones or smartphones who are not included in the results (number or rate of individuals reached) of tests carried out in other countries or by private companies.

5.2. LBAS limits

5.2.1. LBAS vulnerability

- LBAS are vulnerable despite their performance. Telecommunication or power networks are vulnerable in times of crisis. Networks can be physically damaged by a disaster or saturated by the increase in communication commonly seen in times of crisis [51]. This has been observed in the Sud-PACA area during the floods of 15 June 2010 where rescuers had to perform multiple rescue operations without a functional transmission device (no wire-line telephone, no mobile phones, no analogue radio, and a few SMS messages were sent over time). These problems disrupt the responsiveness of operational actors, and it reduces the bandwidth available for broadcasting an alert. Future research needs to be conducted to more accurately define the congestion and failure risks (i.e. due to physical damage to infrastructure and network congestion), and the quantification of the increase in communication in times of crisis.

5.2.2. Mistrust and privacy issue

- Location-based alerting solutions are also subject to legitimate fears among some individuals. Secondary use of private data is a major concern [52]. For example, in May 2020 in the Netherlands, the government asked citizens to delete the NL-Alert® app (complementary to the cell broadcast) because personal data had been hacked. In France, the implementation of the STOP-Covid® app which locates people in real time was strongly criticised because of fears related to the tracing of individuals. Only 2.3 million people have downloaded Stop-COVID® in France (compared to 12 million in Germany) and there were 900,000 for the old SAIP® app. Considering that a new alerting app would be downloaded by 3 million individuals, the potential performance of this solution would be 2.2% in France, compared to 74.2% with a push opt-out notification system.

Privacy issues need to be considered by governments to reduce legitimate fears about LBAS. The CBC is a "blind" solution (no way of knowing who has received the alert) and

respect individual privacy. For the LB-SMS, phone numbers and personal data are not shared outside the operators network [53]. Authorities are aware of the number of individuals who have received (or not) the alert but not of their identity. Smartphone app is more cautious to privacy issues, because it is possible for authorities to identify citizens. Some app can also record user data without their knowledge [54]. The European legislation mentions that the implementation of an alert app has to be done with privacy laws [53]. However, people's trust in these solutions need to be improved, and the solution is more political than technical [55]. First, information campaigns must be financed by the authorities despite the growing mistrust of government rhetoric. To do this, we should not wait until the tool is operational because the population must be accustomed to these solutions as early as possible [19]. Second, users' identities must be truly anonymized (and not just "pseudonymised", as the identity of a pseudonym can be retrieved using additional information according to the General Reglement on Data Protection⁴,[55]). There is a wide variety of anonymization method (i-diversity, noise addition, k-anonymisation, etc.). Some of them (k-anonymisation) allow a real anonymization of data coming from mobile applications [56].

5.2.3. Non-accessibility of LBAS

People with disabilities (deaf, blind, mentally handicapped, very old people) may not be able to interpret an alert message on a mobile phone. In France, 0.3% of the population is completely deaf, 0.3% of the population is completely blind and 1.0% have mental health⁵ (including Alzheimer's disease). However, the proportion of disabled people with a mobile phone or a smartphone and who have been taken into account as alertable individuals is unknown. It is up to the municipality to identify these individuals and take them into account when issuing alerts, but this effort is not sufficiently achieved [57]. Some private companies offer alert solutions adapted to these categories of population, such as calling them by phone rather than sending them an SMS. Other countries have experimented with the designation of guardians neighbours, who ensure that a person in difficulty has received and understood the alert [58].

5.3. Prospects: towards the modelling of a multi-channel system

Performance is a strong parameter of the effectiveness of an alerting system, but the equation is more complex. The adequacy between alerting means and territory, the acceptability of warning means and their usability (ability of the authorities to use an alerting means and implement it in a system) must be assessed. Three complementary works were undertaken (and their analysis are in progress): interviews with decision makers, a survey on the social acceptance of alerting mean and a spatial analysis on the adequacy between LBAS and sirens.

5.3.1. A stakeholder will?

The vulnerability of LBAS and the local strengthening of warning are arguments for setting up a multi-channel alerting system. In a recent project funded by the French Ministry of the Interior, 24 interviews were conducted with nationwide stakeholders and decision makers in Australia, Belgium, France, Indonesia and the USA. The aim was to analyse strengths and weaknesses of the warning systems in other countries, and to lay the foundations for a coherent and efficient warning system in France. Most of stakeholders and decision makers (21/24) underline the need for adapting the alert to territories and people. The various discussions with stakeholders from the Ministry of the Interior during the restitution of the

⁴ Art. 26 of RGPD: <https://www.cnil.fr/fr/reglement-europeen-protection-donnees>

⁵ According to government data : https://travail-emploi.gouv.fr/IMG/pdf/donnes_chiffrees_par_handicap.pdf

project lead us to believe that the discourse of centralised warning, as a governmental competence, seems to be gradually declining in France in favour of a more flexible approach.

5.3.2. The need to assess social acceptance and mean/risk adequacy

5 Questions of social acceptance and usability (both on the part of individuals and decision
makers) must be asked in order to fully assess the effectiveness of an alerting system
(Figure 7). A nationwide survey is currently in progress to quantify the social acceptance of
different warning means including LBAS and sirens. The first results show a strong
attachment to sirens which is the most widely accepted alerting mean by a sample of 878
10 individuals. While LBAS also score well in terms of acceptance, this finding nuances the
doctrine of a single national LBAS.

Adequacy between alerting means and risks must also be considered. The temporality of the
hazard is a key factor in the choice of means (speed of activation). The time of the arrival of
the phenomenon can also determine the means to be activated according to the location of
individuals (residence areas, work areas, leisure areas, commercial zones, etc.).

15 5.3.3. Strengthen local alert by sirens: an example of multi-channel approach

We tested the complementarity of the CBC/LB-SMS-Siren pair in the Sud-PACA region where
94 municipalities belong to a CBC/LB-SMS performance cold spot. We modelled the
installation of a siren in the town hall of each of these municipalities and compared their
performance with that of the CBC/LB-SMS. Given the rural nature of these municipalities
20 (with an average of 484 inhabitants), we have modelled only one siren per municipality. The
area of audibility of sirens is equivalent to a buffer with a radius of 1,413 m calculated
according to their power (in decibels), the attenuation of the sound with distance and the
crossing of the sound of an obstacle (a 10 cm wall since individuals are considered to be at
home). The results show an improvement of alert for 51 municipalities (+29.7% of the
25 population alertable on average). On the other hand, the siren remains less efficient than a
CBC/LB-SMS solution for 44 municipalities (-20,8% of the population alertable on average).
At the scale of 94 municipalities, modelled sirens improved the number of individuals that
could be alerted by an average of 6.0% compared to the CBC/LB-SMS but this difference is
not statistically significant ($P=0.721$).

30 In order to improve CBC/LB-SMS-Siren complementarity, it would be necessary to be below
the municipal level. Sirens should be located in groups of habitats not covered by
telecommunication networks (for example in Figure 7). This runs counter to the government's
strategy of equipping municipalities with sirens, which is essentially concentrated on densely
populated areas, where LBAS are performant. Moreover, the siren remains a relevant means
35 of warning in the face of rapid kinetic hazards [59]. Efforts must be made to raise public
awareness of the danger revealed by the siren sounds. This is what has been done in the
valley of Val Montjoie, exposed to the risk of glacial outbursts (glacier de la Tête Rousse)
and where an early warning system using sirens was set up.

40 Finally, all these works raises the question of a multi-channel warning system, but most of
the results have not yet fully analysed. It is now necessary to build the model of a multi-
channel and territorialised alerting system that can be applied at the municipal level.

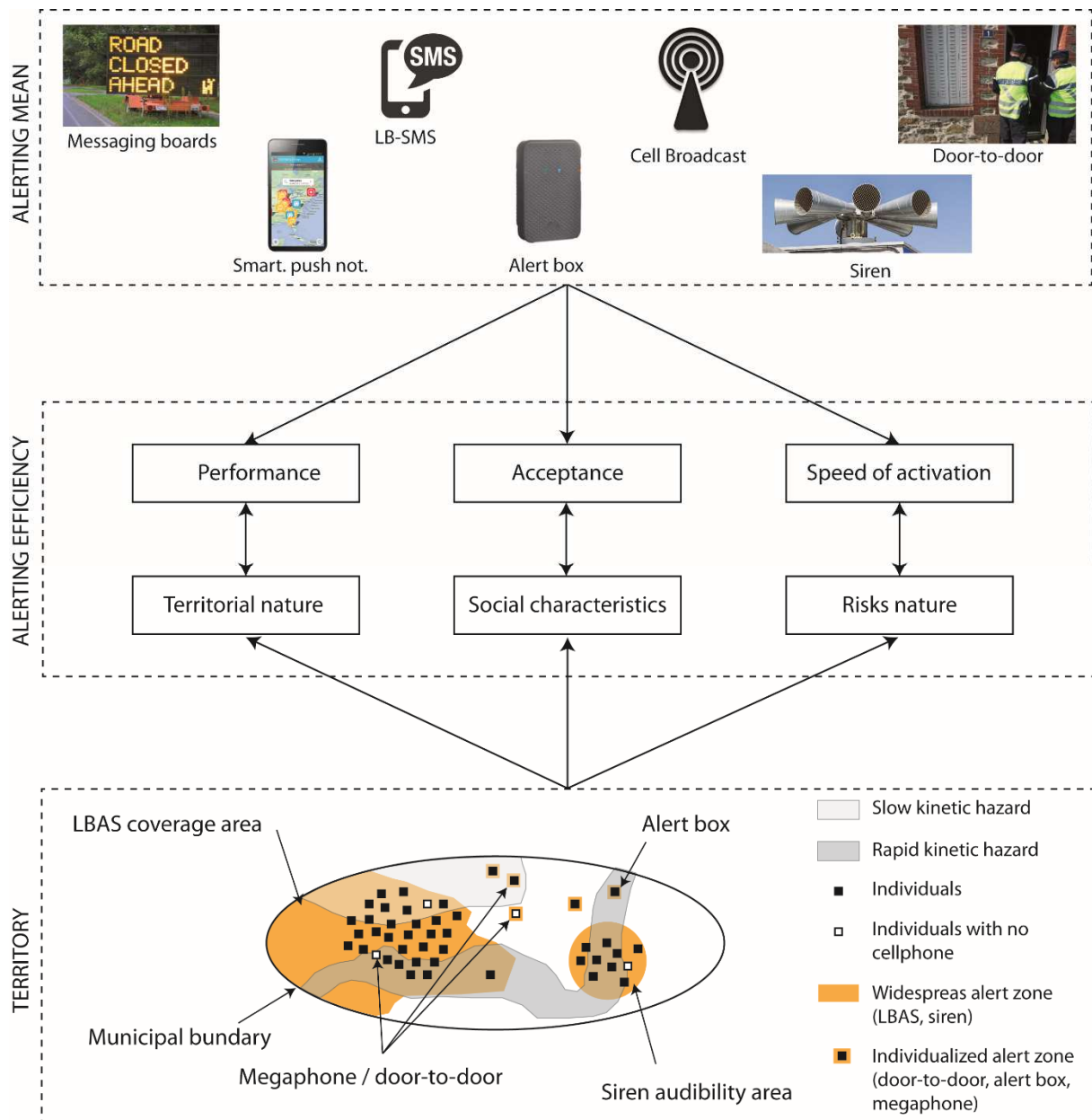


Figure 7. Parameters to study the adequacy between alerting means and territories – 1.5 column fitting image

6. Conclusion

5 In this paper, we experimented a method to evaluate the spatial potential of LBAS solutions (cell broadcast-Location-based SMS and smartphone app), compared results according to territorial parameters, and identified inequities and territorial differences. Some originality lies in the use of methods for the estimation and mapping efficiency potential and their application on a national scale. This led to a greater understanding of the impacts of territory structure on alerting process, while such an idea is often neglected by authorities or in previous research. The LBAS performance has been proven on a large scale: 94.21% of the metropolitan French population can be alertable using CBC/LB-SMS and 74.15% using SPN. This level of performance is unprecedented at the national level. The use of LBAS will considerably improve the alert in France.

10

The performance of LBAS is also very homogeneous at the national level. However, local variations exist and groups of municipalities would be disadvantaged through the LBAS use (rural, mountainous, and/or sparsely populated municipalities). In particular, LBAS are less performing in municipalities with a low density of individuals within inhabited areas. Such fragilities in addition to physical vulnerabilities (vulnerability of telecommunication infrastructure in time of crisis, hacking) and social vulnerabilities (non-acceptance) reinforce the interest of a multi-channel warning system that would make it possible to optimise the implementation of alerting tools according to the specificities of territories. In any case, the adoption of an alert system based on smartphones or mobile phones must be considered before mid-2022 in France and for all European countries thanks to the 2018/1972 European decree. The forthcoming adoption of LBAS in France coincides with the organisation of the Rugby World Cup (2023) and the Olympic Games (2024), both of which represent major challenges for public safety. This is why there is a major interest in setting up a LBAS that can be activated at several levels (national, zonal, departmental and municipal).

15 **Data Availability**

Dataset's related to this article is open-source online data and can be found:

- ARCEP's website: <https://www.arcep.fr/> (for French telecommunication coverage);
- INSEE website: <https://www.insee.fr/fr/statistiques/1405815> (for the location of individuals);
- CREDOC website: <https://www.credoc.fr/publications/barometre-du-numerique-2019> (for the data on mobile phone and smartphone equipment).

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