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Application of Location-Based Services as Part of an Integrated Natural Disaster Risk Management System

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Abstract

This paper examines the role of location-based services within the framework of integrated natural disaster risk management, with a particular focus on their application in the telecommunication and geospatial guidance and tracking of fire-rescue units, specialized civil protection units, and the civilian population in crisis situations. Integrated natural disaster risk management is intrinsically linked to the availability of geospatial information, which suggests that such information should be regarded and utilized as a decision-support resource — both within integrated risk management systems and at the individual level, in the context of directional guidance and self-evacuation. The fundamental premise advanced in this paper is that technical and technological infrastructures — specifically, platforms supporting location-based services that are publicly available and widely adopted — can serve as a source of relevant orientation and navigation information, playing a significant role in integrated natural disaster risk management by providing users with access to pre-standardized geospatial data, such as geospatial zones affected by natural disasters, evacuation routes, and checkpoints, in appropriate formats. The objective of this paper is to provide a scientific description of the possibilities for the active integration of LBS, primarily for professional purposes through current platforms, as well as through alternative commercial solutions, and to explore the potential for incorporating the civilian population into the integrated natural disaster risk management system by utilizing location-based services as a tool for crowdsourcing and the dissemination of personalized alerts. To this end, the methodological approach is based on content analysis of existing literature on location-based services and natural disaster risk management, as well as on the conceptual synthesis of geospatial and information models. The results indicate that such integration of location-based systems can contribute to enhanced collective and individual situational awareness, improve the monitoring and communication processes of professional personnel within the integrated risk management system, as well as of the civilian population in geospatial areas subject to risk — thereby creating conditions for more effective and efficient resource allocation in order to maximize operational outcomes.

Keywords

Location-based services; geospatial information; integration; tracking; civilian population guidance; resource allocation

1. Introduction

Given that this paper addresses location-based services (LBS) within a specific context, namely, the application of LBS in integrated natural disaster risk management systems it is important to define the relevant terms and clarify that the subject matter pertains to Automatic Vehicle Location (AVL) systems and personnel tracking, specifically applied to fire-rescue units and specialized civil protection units. The essence of this application lies in the continuous and permanent monitoring of units based on real-time geospatial information, delivered through appropriate technical and technological solutions designed for this purpose.

The practical value and significance of LBS is reflected precisely in its capacity to provide geospatial information, which in turn enables adequate coordination of activities, resource allocation, and informed decision-making within the integrated natural disaster risk management system, thereby underscoring the importance of LBS implementation in this context. LBS represents an applied domain of Global Navigation Satellite System (GNSS) technology, augmented by geoinformation and telecommunication technologies, whose practical utility lies in decision support through the provision of high accuracy positional data (2–5 metres) on personnel and vehicles in real time (Milojković et al., 2014).

For the purposes of this paper, LBS will be examined from the general to the specific — that is, through its constituent elements followed by a discussion of the hardware components and the user interface. The research objective is to highlight the significance of LBS implementation, examine current solutions and system limitations, and substantiate the premise that the application of LBS in integrated natural disaster risk management constitutes a constitutive element of the system that, in accordance with advances in technical and technological capabilities, offers new modalities of application. In support of this, it is necessary to describe the system architecture (Figure 1).

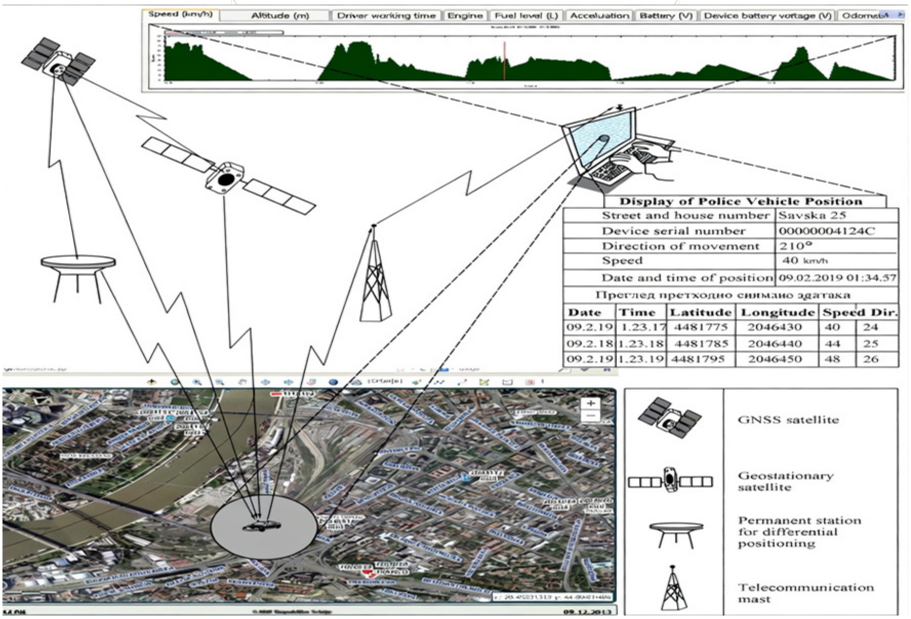

Figure 1. *Architecture of the LBS system* (Adapted by the author)

As previously noted, LBS is an applied domain of GNSS, which consists of satellites positioned at approximately 19,000 to 23,000 kilometres in Medium Earth Orbit (MEO). The most widely known and adopted GNSS systems are GPS (USA), GLONASS (Russia), Galileo (Europe), and BeiDou (China) (Kaplan & Hegarty, 2017). The fundamental principle is based on the method of trilateration, that is, the use of satellites as reference points for determining a position in geospace. This theoretically requires three satellites, though in practice four are needed to obtain data on coordinates and altitude.

It is also important to mention geostationary satellites, which are located at approximately 36,000 kilometres in Geostationary Earth Orbit (GEO). Although they appear fixed above a single point as observed from Earth's surface, they in fact travel at a velocity equal to the Earth's rotational speed. Their role within the Satellite Based Augmentation System (SBAS) is to enhance precision and availability at the local level within systems covering a defined geospatial area (WAAS for the USA, EGNOS for Europe, SDCM, BDSBAS, and others for Asia, etc.).

Furthermore, and of equal importance, is the Differential GNSS (DGNSS) ground station. Located on the Earth's surface, its primary function is to compare a calculated position against a precisely known ground position, thereby improving accuracy and correcting potential errors. As noted above, the communication element — that is, the communication infrastructure responsible for transmitting geoinformation data obtained through the aforementioned methods constitutes another essential component of the overall system architecture. Recent research in the context of LBS communication has introduced Low Earth Orbit (LEO) satellite networks as an alternative or complementary solution to existing approaches, a topic that will also be addressed in a subsequent section of this paper.

Additionally, the user interface must be adapted to real operational needs in order to facilitate purposeful integration. This requires a structured approach to the presentation of data, with particular attention to the graphical load imposed on the selected geotopographic material on which the data are displayed. In the context of research on the application of LBS in natural disaster risk management, it is necessary to address questions concerning technical characteristics, advantages, and the practical limitations and trade-offs among the various implementation options that LBS affords.

Given the aforementioned components of handheld and vehicle-mounted receivers, it is important to consider various aspects of use in order to arrive at an optimal conclusion regarding the application of LBS within integrated natural disaster risk management systems. GNSS receivers used in these systems are divided into vehicle-mounted units (integrated into a Mobile Logic Unit; MLU) and handheld (personal) units. The MLU is capable of providing a wide range of data, including fuel consumption, total operating time, fuel tank level, and other parameters. Several researchers have highlighted the requirements placed on vehicle-mounted receivers in terms of construction, arguing that such receivers must demonstrate high resistance to vibrations, temperature fluctuations, and electromagnetic interference, along with stable power supply and integration with vehicle sensors (Portillo, 2008). Handheld receivers, intended for members of fire-rescue units and specialized civil protection units engaged in rescue operations, must be compact, lightweight, and energy-optimized to ensure sustained field operation (Lee et al., 2022).

Since the spatial scope of this paper and of the LBS application itself pertains to the territory of the Republic of Serbia, it is important to note the TETRA system (Terrestrial Trunked Radio), which is in active operational use within the integrated natural disaster risk management system to meet communication requirements, where trunking refers to the use of a reduced number of channels to serve a large number of users (Vratonjić, 2010). With regard to LBS in the Republic of Serbia, the AVL system operating over a conventional radio network consists of equipment installed in vehicles or carried by personnel, as well as equipment located at the dispatch centre.

From the perspective of straightforward implementation and low material resource expenditure, one of the most viable solutions for the needs of the Ministry of Internal Affairs of the Republic of Serbia is the TETRA system, used in conjunction with the Portable TETRA AVL application, an appropriate software solution developed by practitioners within the Ministry of Internal Affairs of the Republic of Serbia. Its primary function is the display of positions and monitoring of movement on selected geotopographic material, necessarily in digital format, thereby fulfilling the requirement for a functional user interface. The development of the Portable TETRA AVL software application encompassed several phases, including the elaboration of a conceptual design, development of the technical solution, its realisation, system implementation, and subsequent functional testing.

Handheld and vehicle-mounted TETRA radio station models feature integrated GNSS receivers, thus eliminating the need for additional external positioning devices. The recorded coordinates are then transmitted wirelessly via an RS-232 connection to the operations centre in the form of Short Data Service (SDS) messages. Upon receipt, the coordinates are converted and processed using the Portable TETRA AVL software application, enabling the display of positions and the tracking of vehicle and personnel movement on digital geotopographic maps of the relevant area. In this way, the dispatcher at the operations centre is able to monitor the disposition and movement of personnel and vehicles in real time and, in accordance with operational needs, to direct and regroup them effectively and efficiently (Milojković et al., 2014).

In 2019, a study was conducted on TETRA SDS performance and positioning accuracy. The system offers multiple communication modes over the TETRA network operating in trunked mode, including intra-cell communication, where the calling and responding terminals are within the same base station, inter-cell communication, where terminals are served by different base stations, as well as stationary and mobile real-use scenarios. Two field experiments simulating real rescue operations were conducted, and the results clearly indicate that SDS service performance in terms of message transmission delay depends on the size of the transmitted data packet. In addition to the data transmission component, the authors also analysed the accuracy of the GPS receivers integrated into TETRA handheld radio stations. Field measurements revealed that positioning accuracy is limited, particularly in comparison with modern smartphones, which employ more advanced GNSS chipsets and support for a greater number of satellite systems (Umlauft & Raffelsberger, 2019).

To place these technical findings in context, it is important to consider the actual operational requirements as well as the capabilities offered by current systems along their development trajectory. In order to meet practical needs and demands, ETSI is developing TEDS, essentially an enhanced version of TETRA, known as TETRA Release 2, which represents an improvement, though not an optimal solution. Considering current capabilities and contemporary requirements, and given that data transmission in these systems is measured in kilobytes, the use of TETRA in combination with LTE offers significant advantages: with data transfer rates exceeding 50 megabytes per second, it enables rapid delivery of photographs and video calls, which in the context of integrated natural disaster risk management can be of considerable operational value (Esmaeilifar, 2025).

Beyond advances in hardware, it is important to note progress in software platforms, as these constitute an integral component of the system that consolidates all information in a single operational environment. Having addressed the Portable TETRA AVL system in the context of rapid-response force tracking, it should be noted that such platforms can also serve other purposes of critical importance. For instance, during the 2010 Haiti earthquake, platforms such as Ushahidi, CrisisCamp Haiti, OpenStreetMap, and GeoCommons were used for crowdsourcing, that is, for obtaining information from the civilian population on a voluntary basis, which significantly supported and facilitated the functioning of the integrated natural disaster risk management system by providing relevant and timely geoinformation that enabled a realistic operational picture of conditions on the ground (Zook et al., 2010).

On the other hand, two-way communication is also possible through personalized messages, which can be tailored according to defined parameters and delivered to a targeted number of individuals, a measure that may contribute to, and to a degree relieve the operational burden on, fire-rescue units and specialized civil protection units by reducing the number of disaster-affected civilians through timely risk notification (Chan, 2023). In such situations, the content of the message plays a significant role in enhancing self-evacuation capacity and raising the individual's situational awareness. In addition to content, the form of the notification delivered to the civilian population is equally important (Carlson, 2024).

Accordingly, the potential applications of LBS are broad and numerous; however, certain limiting factors exist, including the destruction of infrastructure in geospatial areas affected by natural disasters, which fundamentally highlights the necessity of identifying one or more alternatives with respect to LBS. In recent research, satellite communication via Low Earth Orbit (LEO) satellites — positioned at altitudes of 160–180 to 2,000 kilometres has become an increasingly prominent topic. Although 160–180 kilometres represents an approximate minimum threshold, most LEO constellations orbit at altitudes of at least 500 kilometres. Satellites operating below 500 kilometres are referred to in the literature as Very Low Earth Orbit (VLEO) satellites, a distinction that is partly conditioned by the fact that at altitudes below 500 kilometres, stronger and continuous propulsion is required. LEO satellites are primarily employed for telecommunication purposes, where their principal advantages over traditional geostationary satellites in terms of implementation include potentially lower costs, lower latency, and higher bandwidth (McMahon, 2025).

2. Methods

This paper presents a qualitative study grounded in the theoretical content analysis of relevant scientific and professional literature, descriptive and exploratory in character, directed towards an assessment of the capabilities of current technical and technological solutions in the domain of location-based services, as well as alternative solutions and prevailing research directions. All of the above pertains to the possibilities for applying LBS within integrated natural disaster risk management systems, along with an examination of the potential for implementing certain alternative, widely available solutions.

Content analysis of secondary data sources and deductive reasoning enable the interpretation of relevant scientific knowledge with the aim of better understanding and presenting the solutions currently in use within the Ministry of Internal Affairs, the possibilities for their upgrade, as well as the implementation of new, alternative solutions. The research was conducted in accordance with the methodological standards applicable to the study of security phenomena, examined through the lens of geoinformation technologies with a focus on LBS. The analysis of available literature was carried out through qualitative content analysis, which required the identification of relevant literature, the selection of sources based on scientific reliability and thematic relevance to this study, the comparison of specific technical and technological solutions and architectures described in the paper, as well as the extraction of key elements pertinent to LBS.

3. Results

The results of the content analysis indicate that, although TETRA devices can provide basic user location information, limitations in the quality of integrated GNSS receivers and the lower frequency of position updates may lead to significant positional deviations relative to reference devices. Despite the high reliability and security of the TETRA system, which continues to justify its place within integrated natural disaster risk management systems, its data transmission and positioning capabilities remain considerably limited. For this reason, contemporary systems are increasingly considering the integration of TETRA networks with broadband communication technologies, such as LTE or 5G networks, which enable higher data transfer rates and more precise user positioning (Umlauft & Raffelsberger, 2019). An additional limitation of the TETRA system is the fact that the geospatial territory of the Republic of Serbia is not fully covered by the network signal (Milojković et al., 2015). Furthermore, focusing on the relationship between message transmission intervals and message loss rates, it has been established that the message loss rate is largely negligible when messages are sent at intervals of 1.5 to 2 seconds, whereas at a shorter transmission interval of 1 second and a message size of 190 bytes, the message loss rate can reach approximately 1.6% (Esmaeilifar, 2025). TETRA is designed for use on land, as well as on bodies of water, including rivers, lakes, and at sea at distances of up to several tens of kilometres from the shore and in the air at lower altitudes, which for helicopters means up to 4,000 metres, as well as for vehicles operating at limited speeds. Among its noted advantages is Direct Mode Operation (DMO), which enables communication between two terminals without the use of network infrastructure, although the effective range of DMO is largely conditioned by geospatial factors. In open terrain, it can enable communication between terminals at distances of up to 5 kilometres; however, the range is substantially determined by the terrain profile and its configuration. The construction requirements for MLU and handheld terminals were previously addressed; however, when considering the AVL and personnel tracking system, it must also satisfy specific functional requirements. These primarily relate to the ability to display the precise position of a vehicle on selected digital geotopographic material, the provision of a panic button that is readily accessible for sending an emergency message in any situation involving threat or danger, and the capacity for efficient alerting in cases of vehicle theft, zone boundary violations, and similar events. In addition, the system must transmit other vehicle data to the control centre, such as low engine oil levels, excessive speed, odometer readings, and related parameters. It is further necessary that the control centre be able to issue commands to the vehicle enabling it to be immobilised through fuel cut-off or similar mechanisms. The system must also support the exchange of short messages between the vehicle and the centre, as well as comprehensive vehicle movement analysis, encompassing location and duration of stops, deviations from assigned routes or designated zones, data on road segments where speed limits were exceeded, and other relevant parameters (Milojković et al., 2014).

In the context of the aforementioned vehicle movement analysis, it should be noted that the individual responsible for fleet monitoring must have the capability to track all vehicles in a fleet on selected digital geotopographic material, while also being able to utilize textual, graphical, and tabular reports to facilitate the most comprehensive analysis possible, both at the fleet level and for each individual vehicle separately. In practice, such capabilities exist and are in commercial use, fulfilling a portion of the aforementioned requirements. In addition to the capabilities already described, the telecommunication modem can also be used for voice communication and messaging with the driver. Beyond basic parameters (speed, heading, acceleration, battery voltage, ignition status, odometer reading), the system can monitor a wide range of additional telemetry parameters, including fuel level and consumption, door open/close events, engine RPM, hydraulic system operation, cargo compartment and coolant temperature, the presence of co-drivers and passengers, and other relevant data (Vojinović, 2012).

With regard to satellites, in addition to the advantages and limitations of deployment in the aforementioned orbits, recent research indicates that beyond the capabilities widely known to the general public, there exists the possibility of employing algorithms that enable the detection of flooding, even under conditions of significant cloud cover, using limited computational resources aboard small satellites. In this approach, rather than transmitting large volumes of raw imagery, the algorithm autonomously generates a flood mask of the affected area, substantially reducing the volume of data that must be transmitted (Mateo-Garcia et al., 2021). From a telecommunication and real-time positioning standpoint, LEO satellites offer advantages that derive, among other factors, from their considerably closer proximity to the Earth's surface. As a result, the signal propagation path is shorter and there is less opportunity for interference in signal transmission. Furthermore, LEO satellites travel at higher orbital velocities, which means that the observation angle continuously changes, thereby enabling more complete and precise determination of the user's position (Foreman-Campins et al., 2025).

4. Discussion

This paper analyses the findings of research on the application of LBS within integrated natural disaster risk management systems. The primary subject of analysis is the LBS platforms currently in active operational use in the Republic of Serbia and beyond, namely, TETRA. The research findings unequivocally indicate that this system remains in active use principally due to the balance it offers between meeting basic positioning and telecommunication requirements on the one hand, and operational efficiency with respect to material and technical resources on the other. Taking into account the significance of integrated disaster risk management as a mechanism for the protection of the population, the environment, and material assets, the author holds that it is insufficient to merely strive towards satisfying minimum requirements.

The results point to the need to combine TETRA with newer LTE/5G technologies. This direction is well justified, particularly given that it is unacceptable for technical and technological solutions in widespread civilian everyday use to feature more capable integrated GNSS receivers and faster geoinformation transmission capabilities. There is little reason to limit development to the strictly necessary, especially when certain authors have noted the possibility of integrating additional sensors, in the context of personally issued equipment, enabling the monitoring of health and other physiological parameters (Lee et al., 2022). In this regard, it is important to consider the use of commercial alternative solutions in the domain of LBS, as well as the development of structural solutions modelled on such alternatives, taking into account real operational geoinformation and telecommunication needs. In the context of such solutions, Garmin may be cited as a provider offering several relevant capabilities. Although this research primarily concerns the tracking of personnel and vehicles, a similar principle can be applied to search-and-rescue dogs, where collar-integrated GNSS receivers enable real-time positional tracking of the animals, along with the display of the handler's own position. With regard to satellite communication, the inReach technology merits mention, as it leverages the Iridium LEO satellite constellation to enable two-way text communication and SOS transmission with coordinate display, that is, real-time positioning data, all within a highly compact form factor, thereby fully satisfying the previously stated requirements for portability and minimal device dimensions. Although it does not fulfil all functional requirements, the implementation of this technology may serve as a useful alternative. Other, denser satellite constellations also exist, such as Starlink, whose advantages relate primarily to high-speed satellite internet with data transfer rates reaching up to 400 megabytes per second. Although at the time of writing this paper the Starlink service is not available for the territory of the Republic of Serbia, it is important to highlight the potential offered by satellite constellations, as the telecommunication component is severely limited without such access — being contingent upon the survival of ground-based infrastructure. In the context of this paper, with regard to two-way communication with the civilian population, in addition to the standardized alerts that are transmitted, consideration should be given to the possibility of planning and delivering personalized navigation routes. This does not imply that the routes included alongside the textual component of the notification should themselves be standardized; rather, the relevant file should be converted into an appropriate format to accompany the textual notification. In terms of content, such a file should contain predefined checkpoints, with navigation to those checkpoints facilitated through one of the widely available commercial navigation services.

This research also has certain limitations. First and foremost, the security aspects of integrating the aforementioned technologies have not been fully addressed. Furthermore, the material and technical component has not been taken into account, nor has the time required for implementation — which includes, among other elements, planning, procurement, the availability of financial resources for the undertaking, equipping, the allocation of training resources in terms of both time and personnel, system-wide optimisation, and related considerations. These matters should be addressed in future research, with a view to the continuous improvement of LBS and its application within integrated natural disaster risk management systems.

5. Conclusions

The Location-based services are not merely a navigational tool; they enable the real-time tracking of personnel and vehicles, thereby fulfilling, among other functions, a decision-support role. LBS is today widely accessible and is employed across the majority of mass-market platforms. Its significance lies in the availability of geospatial information, which is of considerable importance — a fact reflected in the broad integration of LBS into widely available technical and technological devices, with particular relevance to contemporary integrated natural disaster risk management. In light of the exponential development of technical and technological platforms and telecommunication infrastructure, the implementation of LBS is necessary in order to enhance both the efficiency and effectiveness of operations across all fields of security.

It is essential to continue with the implementation and integration of new scientific solutions alongside existing ones, in the interest of the continuous improvement of integrated natural disaster risk management systems and the maximisation of their operational capabilities. There is a clear need to meet the highest standards with respect to LBS, given that natural disasters demand the pursuit of the highest standards in the execution of necessary actions — an objective that is difficult to achieve without modern technical and technological platforms for LBS deployment. Naturally, real limiting factors exist, pertaining to personnel and material constraints. It is necessary either to find means of overcoming these limitations, or to continuously seek a balance between meeting genuine operational needs and minimising the margin for error, which, in the context of this paper, refers to the existence of geospatial areas lacking signal coverage, thereby precluding positioning and communication with fire-rescue units, specialised civil protection units, and the civilian population, who may frequently serve as a source of relevant geospatial information and who are often the subject of rescue operations in the event of natural disaster manifestations.

The paper has also addressed the context of commercial navigation and telecommunication solutions. The key point is that certain limitations exist in this domain as well, and these must be duly acknowledged; however, the very fact that a solution to a given problem exists and is commercially available should serve as a positive and motivating factor in overcoming the barriers to the implementation of such a solution within an integrated natural disaster risk management system.

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