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# A primer ON TeleGeoProcessing and TeleGeoMonitoring

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**Abstract**

The goal of this paper is to define the potential and the characteristics of TeleGeoProcessing and TeleGeoMonitoring. TeleGeoProcessing, as child of geographical information systems and telecommunications, can be considered as a new discipline characterized by spatial database, cartography on demand, the exchange of information between different sites by any kind of telecommunication systems, and on-line spatial data analysis. TeleGeoMonitoring can be seen as an extension of TeleGeoProcessing by the use of positioning systems (global positioning systems [GPS] or GPS-like), real-time databases and real-time group decision-making systems. © 2001 Elsevier Science Ltd. All rights reserved.

*Keywords:* TeleGeoProcessing; TeleGeoMonitoring; Geographic information systems; Spatial databases; Real-time databases; GPS; Telecommunications; Internet

## 1. Introduction

From several years, new geographical, environmental and urban applications are emerging in which the characteristics of communications and real time are very important. In other words, we no longer have to deal with applications for which conventional cartography was the target, but in which spatial aspects are involved in management in real time or with very strong temporal constraints, such as mission-critical applications. For this kind of problem the intensive usage of telecommunications and positioning systems (such as global positioning systems [GPS])

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is the key element allowing vehicles to know their position and to exchange any kind of information by any kind of telecommunication means.

For instance, the management of fleets, such as for law enforcement or for rapid delivery, needs to know at every time the exact position of all vehicles. By means of GPS and on-board computers, they can communicate with some control centre, which in turn can send them other information. In this family of applications, a control centre is equipped with huge screens or large-format displays, which represent the moving objects' locations and trajectory superimposed over some base map.

In order to fulfil this task, the vehicles must have on-board computers, connected to GPS and to the control centre. In some applications, the control centre does not exist, and all sites exchange only information regarding their position.

Domains of applications are legion, e.g.:

1. management of fleets of vehicles (cars, lorries, taxies, ambulances, civil protection, boats, aircraft carriers, etc.) (Muro-Medrano, Infante, Guillo, Zarazaga, & Bañares, 1999; Valsecchi, Claramunt, & Peytchev, 1999);
2. monitoring of vehicles along motorways (Tanzi, Laurini, & Servigne, 1999; Valsecchi et al., 1999);
3. transportation of hazardous materials (Boulmakoul, Laurini, Servigne, & Idrissi, 1999);
4. monitoring of river/water pollution (Cambruzzi, Fiduccia, & Novelli, 1999);
5. monitoring of environmental risks (volcanoes, floods, landslides, etc.) (Cortopassi-Lobo & Guetter, 1999; Guarnieri, Jaber, Olampi, & Wybo, 1999); and
6. disaster management (Cochran & Power, 1999; Coutinho et al., 2000; Farley & Hecht, 1999; FEMA, 1998), etc.

So, we can see emerging novel computer applications, engendered by geoprocessing and telecommunications, all possessing common characteristics and with real world applications. We think that we are facing new disciplines respectively called TeleGeoProcessing (TGP) and TeleGeoMonitoring (TGM) (Laurini, 2000).

The goal of this paper will be to explain the scope of those disciplines, to describe their context explicitly and to define them.

## 2. Definition of TGP and TGM

First, let us present a few concepts, and then try to organize them into science. Finally, we will present some possible architectures for TGP and TGM systems.

### 2.1. Characteristics

In modern geographical applications, communication and real-time aspects are combined with spatial aspects. In TGM, the management in real time is integrated with spatial information. These are no more dealing with applications where traditional cartography is of central importance, but rather where real-time management, sometimes of mission-critical type. integrates spatial information. So, we are facing a new discipline characterized by:

1. the use of geographical information systems (GIS);
2. the use of modern techniques of location (such as GPS);
3. the exchange of information between multiple sites;
4. decision making in real time (Real Time Decision Support System [RTDSS]); and
5. remote updating of facilities.

Fig. 1 illustrates the main layers between GIS, TGP and TGM. TGP uses the GIS and any communications means aimed at sending the necessary information for the analysis. This analysis is done in real time. The final goal of the system is to produce the necessary information for decision making in real time. It is necessary to define the notion of real time. In our case we will use the notion of free real time (FAR Real Time) to define a time of reaction to the human scale. This delay will range from seconds to minutes.

A TGM system is composed of a TGP system, intended for decision making. However, it allows execution of actions produced by the decision. For this, it must have a system capable of transmitting orders and information to the different facilities that comprise the global system. It must also have the capacity to remote activation, i.e. of functionality of the classic domain of the automatic device.

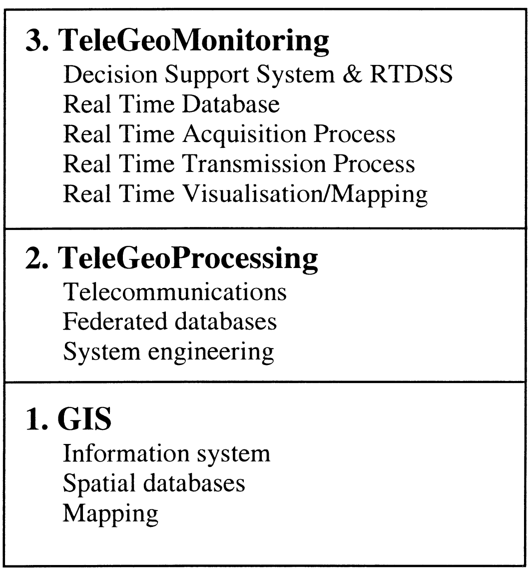


Fig. 1. Layers of organization between TeleGeoProcessing and TeleGeoMonitoring.

### 2.2. Definitions of some key concepts

Here are the definitions of several useful concepts (Fig. 2).

- *Database*: a database can be defined by sets of data implemented on one or several computers, which can be accessed simultaneously by different users. A database is managed through a tool named Data Base Management System (DBMS). Presently, relational databases are the more common (e.g. Oracle, Sybase, Informix) based on relational tables using the language SQL (Structured Query Language) for retrieving and manipulating data. Object-oriented databases are also fashionable in research institutions, but are less used in companies.
- *Information system*: according to Lemoigne (1977), any system consists of a control sub-system, an information sub-system and a controlled sub-system. The second encompasses all information, either under the form of a database, or informal such as systematic phone calls. In some cases, an information system can be defined as a database together with the organization surrounding it.
- *Spatial database*: a spatial database is a database integrating spatial or geometric data. Some of them have some proprietary data structures to represent geometric information (point, lines, areas, etc.) in order to efficiently implement spatial operators issued from computational geometry. The evolution is now to integrate spatial aspects into conventional databases.

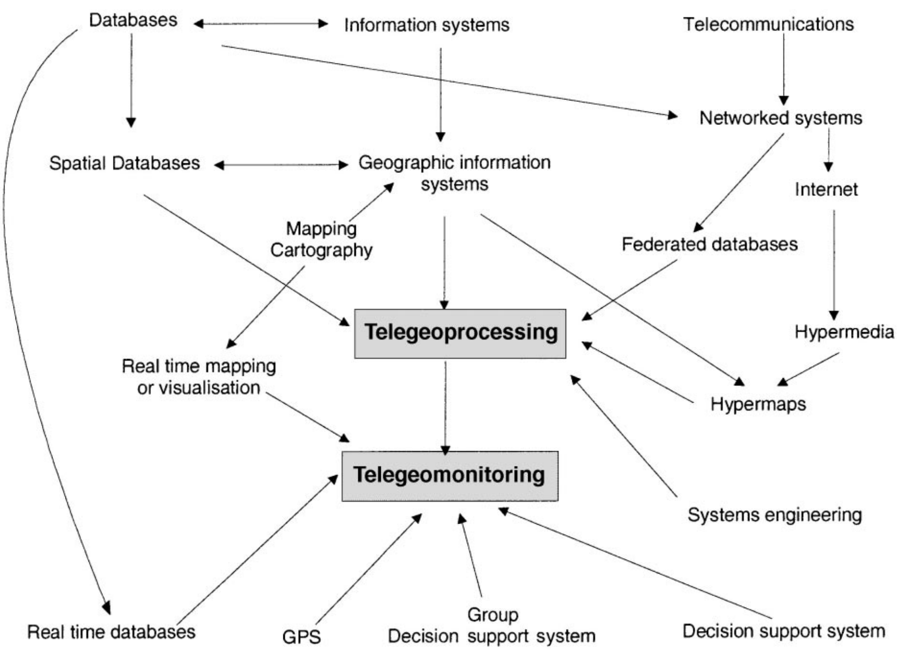


Fig. 2. Some key concepts for TeleGeoProcessing and TeleGeoMonitoring.

- *GIS*: a geographic information system is an information system devoted to geographic applications. Beside a spatial database, it has some mapping potential and sometimes some analytical capabilities.
- *Environmental information systems*: a kind of GIS devoted to environmental issues.
- *Telecommunication systems*: increasingly, any important computer system is linked to other computer systems by means of communications (networks) or telecommunication systems. Often, information pieces are transmitted via different sub-systems along with, for example, optic fibres, satellites, cellular phones, etc. Some of them are wireless. Sometimes, one speaks about networked computer systems by distinguishing Local Area Network (LAN) and World Area Network (WAN).
- *Real-time database*: a database is said to be in real time when data are captured in real time, especially by means of sensors.
- *Decision support system (DSS)*: a DSS is a system whose goal is to help one or several decision makers. Generally speaking, it is composed of an information system, and of mathematical models in order to make analyses and projections. Often, they have some graphical capabilities (business graphics) to depict data evolution, or to emphasize some regularities.
- *Group DSS (GDSS)*: this is a DSS in which several decision makers can interact cooperatively.
- *Metadata*: metadata are data describing data. More and more often, data need to be described with details in data dictionaries. Some data providers, when they sell data (e.g. geographic data), also sell the corresponding metadata. Ordinarily, metadata are collected into a metadatabase. As an example, see the structure of metadata according to the Federal Geographic Data Committee (FGDC) standard.
- *Open system*: an open system (as opposed to a proprietary system) is one that adheres to a publicly known standard set of interfaces so that anyone using it can also use any other system that adheres to this standard. As a consequence, theoretically one can 'plug and play' without any difficulties.
- *Interoperability and interoperable systems*: by interoperability, one means the ability of a system to use parts or component of another system. One objective is transparency, i.e. the difficulties are masked to the users.
- *Federated databases*: a database is said to be federated when it is composed of several databases existing before the federation. Generally speaking, each database belongs to a different institution or company. By nature, federated databases consist of heterogeneous databases, i.e. the contents and the structures are very different. In this case, a phase of schema integration is necessary is order to show the user as the databases were a unique database.
- *Cooperative systems*: these are systems targeted to several decision makers in order to help them to reach their goal. Sometimes they are synonym of a GDSS. The core of a cooperative system is a federated database. In case of conflict, some co-operative systems can be transformed into a kind of negotiation system.

- *Client–server architecture*: the architecture of networked computer systems in which a system named client asks for services to another system named server. Increasingly, federated databases are built within a client–server environment. Generally speaking, applications are installed on the client, whereas data management is made by the server. In object-oriented environment, CORBA (Common Object Request Broker Architecture) is the standard.
- *Internet*: this is a network linking all computers. The more used standard is HTTP (hypertext transfer protocol). Various telecommunication systems are used to transfer information.
- *Hypermaps*: hypermaps or clickable maps are maps in which pointers are embedded in order to spatially access to multimedia information; in other words, hypermaps represent a variety of GIS allowing the access of spatially referenced or coordinate-based multimedia documents within digital libraries via Internet or Internet-like protocol.
- *Cartography on-demand*: any kind of mapping system from which maps can be constituted and sent through the Internet.
- *Real-time animated mapping*: when tracking a phenomenon, a map evolving in real time is an important indicator, which can help decision makers. Generally, data to be visualized come in real time from sensors.
- *Mobile queries*: usually when a query is made against a database, the position of the user does not matter. But in several contexts, a mobile query is a recurrent query in which the querier is mobile, such as from a running vehicle: e.g. along its path, a lorry would constantly know its five nearest gas stations.

## 3. TeleGeoInformation

Data used in TGP or TGM systems have special characteristics. They will be defined in the following subsection.

### *3.1. Nature of information*

TGP/TGM data are referenced in space and located in time, and vary in these dimensions. For example, observation of the evolution of a river flood requires spatial and temporal data. To determine the course of the stream, it is necessary to use some spatial information. But the height of water depends on the time of year and takes the temporal aspect of data into account. Data fluctuate over time. Another characteristic is the duration of the meaning of the data. The life span can be very short or very long and depends on the phenomenon. We must take life span into account in information transmission. The transmission time is never equal to zero. For example, a communication of a signal to any place on planet Earth using two satellites and one ground control station implies a propagation delay of about 1 second. In this case, if the satellites used are positioned on a geostationary orbit (36 000 km), signals are going to browse about 144 000 km. If the system is not adapted to the lifespan of the data, or if the time of propagation is too important, processing will not be able to use this information.

Data have public and private parts. Data security is very important. In risk monitoring, for example, critical data must be protected against unauthorised uses. In certain cases, the use of uncontrolled information can make more damage than the event to which data relates. The protection of people, the respect of privacy and, the law, impose the protection of data which are relevant to them. Modern technology allows implementation of security procedures. But the integration within processing always represents an increase of the complexity of the final application. Data are used as information (data acquisition) or to command or control devices.

### 3.2. Information representation

To build a correct representation of TGP/TGM data, it is necessary to take into account:

1. location in space and time;
2. the typology and value of data;
3. the originator and the user of the data;
4. the quality of data depending on the acquisition devices; and
5. the reliability of transmitted data.

Following the previous example, the height of the water of the river will fluctuate over time and over space. Every sample observation corresponds to one very precise moment. Each point that defines the bed of the river must be identified perfectly by its position in the space ($x$ and $y$, possibly $z$) and its location in time, that characterizes the precise moment of the measure. The typology and the value of data constitute the kernel of information. The identification of the data originator procures information on the means of acquisition. The identification of the creator and the user of information permits implementation of security procedures.

The quality of data allows the adjustment of problems or conflict due to the difference of precision of the various means of acquisition. One can mention an inconsistency, for example, between two values, one measured manually, and the other using a high-precision automatic device.

The reliability of the data characterizes the capacity of transport means used to accomplish their mission in the prerequisite conditions. This information can also help to adjust conflicts or in case of doubtful data values. It allows, along with measures of data quality, definition of the confidence that one can attribute to information.

### 3.3. A complete cycle of information

The TGP/TGM information cycle data starts from the location of the data acquisition. Let us take an electronic station of traffic data acquisition located on the side of the motorway, for example. An accident occurs on a lane of motorway, and a traffic jam situation is detected. Conditions of traffic change. The electronic station continues the information acquisition and after the acquisition is performed, data are transmitted to be analysed at the management centre of the motorway.

In this example the analysis is made in the local management centre of the motorway, named *District*. Analysis provides information used in the decision process. For example: a decision might be to reduce the traffic flow. These decisions require actions. To reduce traffic it is necessary to turn on a red light that forbids access to the motorway on the area affected by the accident. It is also necessary to address information messages to users on the various display panels of the concerned area. Actions defined by the decision process are transmitted to be executed by the various facilities. On the location of devices, a control process executes the decided actions. In our example, actions correspond to turning on a red light to stop traffic flow and to display messages. A new cycle starts, so as to estimate effects of the emergency plan. Fig. 3 represents the cycle of information. The first three phases of the cycle (acquisition, analysis, decision) constitute the system of TGP. The two last (action, control) constitute the TGM subset of the system, if any.

### 3.4. Information uses

Fig. 4 depicts an overview of information. Acquired information is usable with various phases in time. The needs from exploitation require some uses in delayed time. Information is used to make decisions in real time. However, in a complex action plan. the decision can be to require actions which are not immediate. Actions can also be delayed according to the strategy or to the availability of resources (i.e. usable devices). The same information must be used to constitute the collective memory of the organization (organizational memory). Then its analysis makes it possible to correct the various action plans in order to prevent the incident it reproduces. If that is not possible, we will use this experiment to reduce the consequences in time of the next kind of event. The resource definition (i.e. hardware and management), must take incident experiences into account.

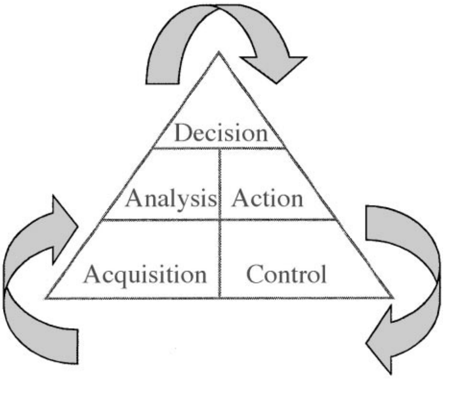


Fig. 3. A complete cycle of TeleGeoProcessing/TeleGeoMonitoring information.

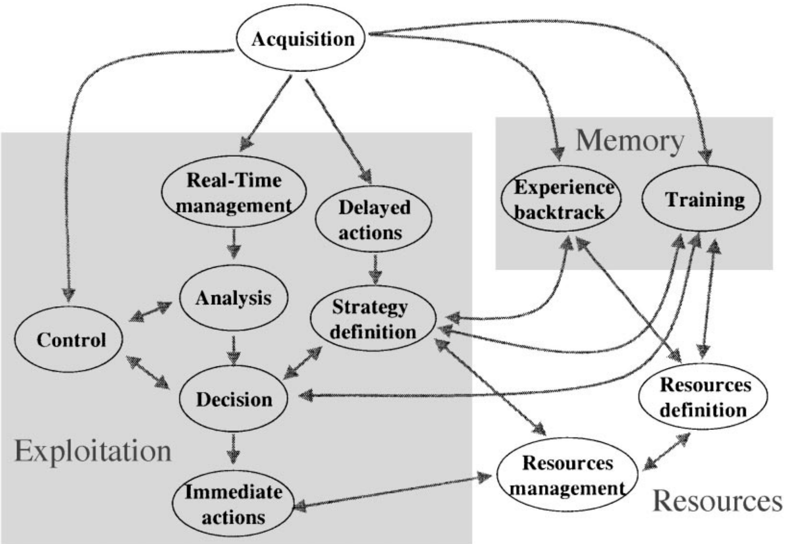


Fig. 4. Global view of information uses.

## 4. Architectures

Generally speaking, we can consider two types of sensors, fixed sensors and embarked sensors. Indeed, in addition to GPS receivers (which can be considered as special sensors), vehicles can possess cameras or other type of apparatus, for instance to measure external temperature. In the sequel, both sensors and embarked vehicles will be integrated into the concepts of vehicles, and only the notion of isolated sensors will be dealt.

The control centre and the other components exchange data which are multimedia and coming from different sources, by using extensively wireless telecommunications, perhaps with several satellites. All those information pieces will be stored in a real-time geographical database from which some other more elaborated information can be derived.

Another way to classify TGM systems is to take the number of persons in manned vehicles, namely, one-man vehicles, or multi-man vehicles. When there is only one pilot, the programme is much more complex than when there is a co-pilot. Indeed, when the pilot is only by himself it is difficult for him both to drive the vehicle and to interact with the computer, whereas when a co-pilot is present this person can be in charge of the computer. For a one-man vehicle, an interesting solution is vocal cartography replacing conventional graphic cartography. The important consequence is that one-man vehicle solution is presently too complex from a computer point of view.

Bearing all that in mind, it is possible to distinguish three kinds of architecture for TGM systems, centralized, co-operative and federated.

### 4.1. Centralized architecture

Centralized architecture (Fig. 5) shows the existence of a control centre where data are converging to, and which sends data and statements both to mobile vehicles and fixed sensors. Let us mention that in this architecture only the control centre has a global vision of the system at all times. Of course, a different copy can be sent to the other components when necessary. The great weakness of this architecture is that in case of a crash at the control centre, this TGM system does not function any more.

When a new vehicle enters this system, it informs the control centre which in return sends adequate information. Among operations at initialization, the control centre must update the local database so that the new vehicle can function efficiently.

Let us remark that presently this architecture is the more common. In order to palliate crashes a solution is to create a mirroring control centre; this solution is often taken for crisis-management teams.

### 4.2. Co-operative architecture

In the co-operative architecture (Fig. 6), i.e. without any central site, all fixed and mobile components are exchanging information between themselves. As a consequence, all sites have a global vision of the context. When a new vehicle is entering into the system it informs all vehicles, which when necessary will send them information.

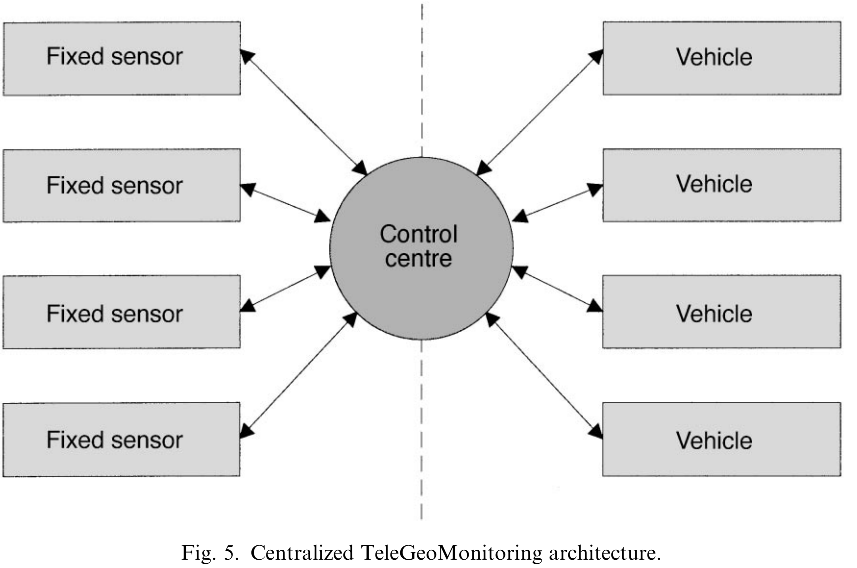


Fig. 5. Centralized TeleGeoMonitoring architecture.

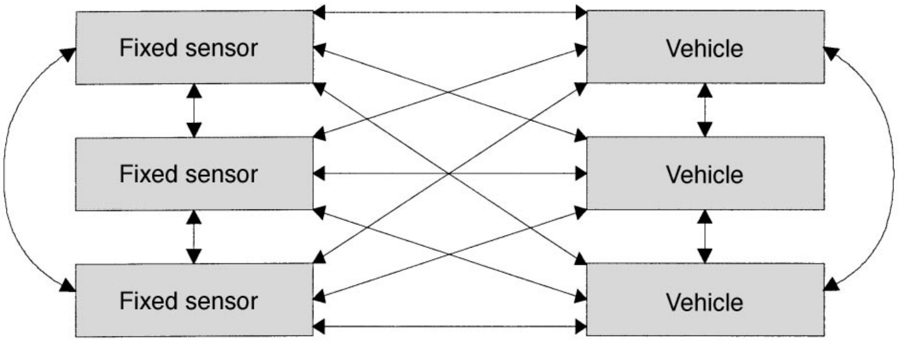


Fig. 6. Co-operative architecture for TeleGeoMonitoring.

This architecture is much more robust to crashes than the centralized architecture. On the other hand, the quantity of information to be exchanged is much more important. Indeed, one of the priorities is the updating of all databases; if one copy is different from the others, some difficulties, sometimes drastic, can occur. In those cases, similar problems as those encountered in distributed database system exist. Apparently, Date's rules applies (Burleson, 1994).

However, the more serious case is called the Byzantine situation in which one or several components are either defective or always sending erroneous messages, especially due to the drifts of the sensors (e.g. see Simon, 1996, for more details). In this crucial case, the defective components must be detected as early as possible, and the messages must be corrected. Another problem is the authentication of received messages. Think for instance of the hijacking of a lorry transporting hazardous materials which sends messages which do not reflect the gravity of the situation.

### *4.3. Federated architecture*

But some vehicles can be connected to several TGM control centres. For instance, a lorry transporting petrol must be in connection with its haulage contractor, the motorway system, and a more general system for hazardous material surveillance. In this case, must the lorry have three distinct embarked computers, or a single one implying problems of interoperability between the three systems?

As an example, Fig. 7 depicts the case of a vehicle belonging to three TGM systems (Fig. 7a). From a general point a view, one TGM system consists usually of several vehicles, and one vehicle can belong to several systems. First, the vehicle (Fig. 7b, c) belongs to system A, then to system B, and finally to C; then it exits from A, then from B, and so on. We can thus see that, according to the number of system and their nature, the kinds of interoperability problems will differ.

As a consequence, we will state that the belonging can be successive, e.g. for airplanes which pass successively from one air traffic control tower to another one, or simultaneously, as in the example presented in the previous paragraph.

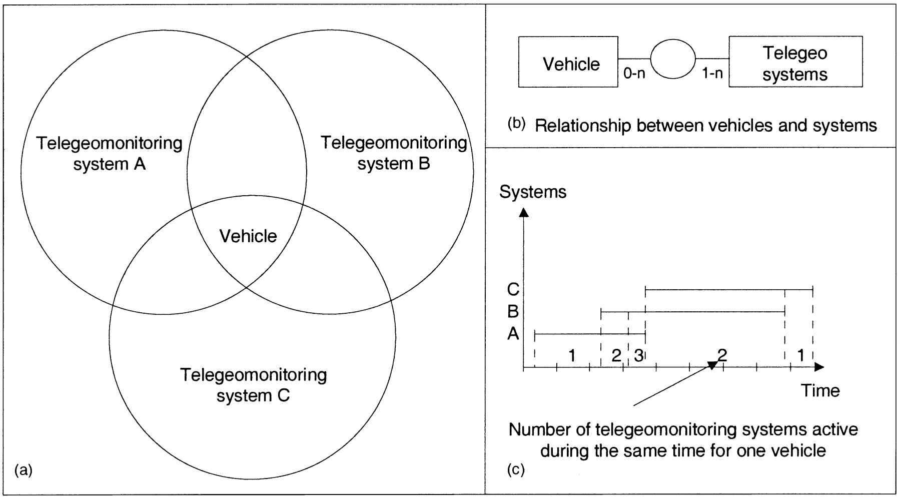


Fig. 7. A single vehicle can belong to several TeleGeoMonitoring (TGM) systems. (a) Ownership diagram; (b) relationship between vehicles and TGM systems; and (c) temporal sequence.

### 4.4. Conclusions about architectures

The various architectures hereafter presented can be used in TGM activities. The first one (centralized) is the easier to design whereas it is not really robust: it could be an interesting starting point followed by a co-operative architecture which is the more robust. In the future, when several co-operative TGM systems will exist, the federated approach will be the target providing a high level of interoperability.

## 5. Application examples

In this section, various characteristic applications of TGP/TGM systems are briefly analysed:

1. traffic management applications;
2. fleet management;
3. risk assessment on hazardous transportation;
4. flood monitoring;
5. seismic and volcano activities monitoring;
6. research and operational uses; and
7. image place in decision process.

### 5.1. Traffic management

In traffic management applications, data describe, principally, vehicle counting and weather information. Many electronic equipment, distributed along the border of motorway, acquire these data. On typical stretches of motorway several hundreds of acquisition stations can be used. Fig. 8 represents an example of facilities used on the motorway.

To reduce the transmission flow it is necessary to collect and compute data in a local technical area. Such processing aims to distribute processes of evaluation on the location where the events occur. This architecture allows reduction of transmission delay and decrease of the necessary processing power while distributing it. Only the synthetic information is transmitted when it is required by the situation.

The management centre receives information for analysis, makes decision and transmits data to run the process located on the equipment, corresponding to actions required by the management plan. The main objective of the transport layer is to allow the transmission of control/commands information to the remote equipment. The transmission itself must be done without deteriorating the information and within a delay compatible with their execution. Principal aspects of this kind of application are its real-time nature, and the availability to support some important quantity of information.

### 5.2. Fleet management

Fleet management requires the knowledge of the location of the different mobiles (vehicles) managed. To obtain location, one of classical means is the use of GPS. GPS uses a satellite-based constellation. A control centre is generally equipped with a cartographic system, which allows the visualization of a vehicle location over a map layer. A control centre acquires vehicle location for each period. The time duration can be dependent on the situation.

Communication between the control centre and vehicles can be made by several means. In Fig. 9, we propose the use of a satellite link. Data are received on ground

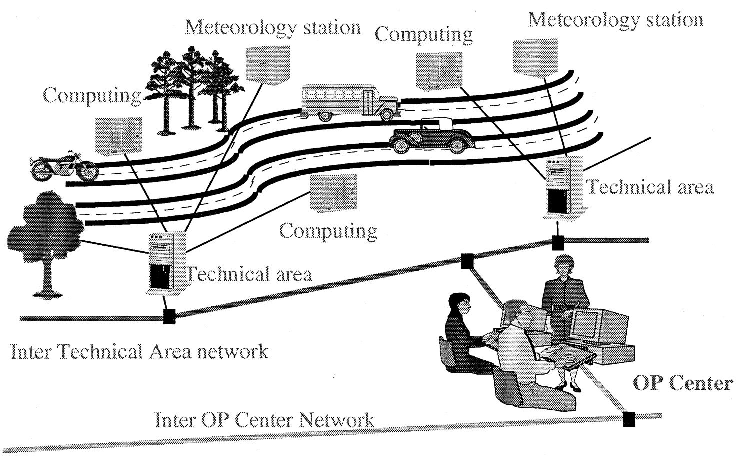


Fig. 8. Example of motorway traffic mangement.

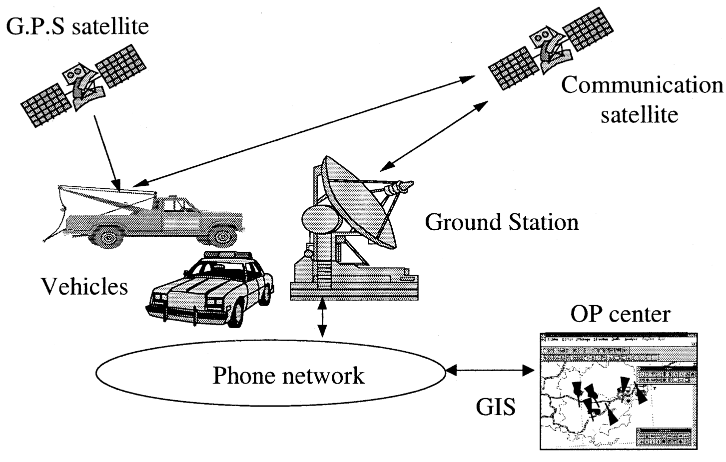


Fig. 9. Example of fleet management implementation system.

station, and a classical phone communication is established evenly for update location on the computer. Other means and architectures are possible. One main characteristic is the difficulty to establish a continuous communication with vehicles.

### 5.3. Flood monitoring

Each year, many people are victims of floods. This type of disaster is representative of the confrontation between man and nature. Weather reports are used to make a simulation of damage and to define an action plan. Some animated panels display an image of the situation, and are updated when new events occur. Each time, real-time video transmission provides a real view of the situation, and allows a visual control of acquisition devices and simulation results. Links with databases, network and the Internet, allow useful information pieces for the decision process to be found. For example, it might be interesting to find historic data on an event which occurred 200 years ago.

### 5.4. Natural hazard monitoring

Seismic or volcanic activity data are produced by electronic acquisition equipment. These information pieces are transmitted to the control centre by different means. But, according to the importance of this information during crisis phases, the communication link must be more secure. In several cases, satellite links can be used for this reason.

Main characteristics of this kind of application is the continuation of the process when the devices are successively destroyed. Another important aspect is the protection of critical data. Any unauthorized use of this information could cause panic, and the results would be more injured and dead.

### 5.5. Research and operational uses

For instance, in the forest fire domain, knowledge of the burning process is required to make a digital model characterizing the evolution of fire. Firemen can use instrumented burning area to make a fire simulation. Physical data and real-time video movies are transmitted from the fire location to the firemen's command car. Let us also mention that *replay of stored information* allows better understanding of the phenomenon. This architecture is also useable in real forest fire conditions. In this case, information is used in real time on the decision process to build the action plan.

### 5.6. Real-time image and decision

The main goal of motorway intervention staff is to assume safety at the accident location. To reduce time spent to make a vocal report (by phone or by radio) with the control centre of the motorway, operators send a photograph of the situation. Numeric cameras provide photos or movies and the transmission link generally used is cellular phone or radio (Fig. 10).

From the site of the accident an operator in charge of the security of the motorway can take a photograph and send the image to the centre of control in a few minutes. The various actors who intervene in accident management (motorway, police, firemen, mechanical engineers, crisis management team, etc.) can share dialogue based on the same information. Complements can easily be requested from the operator by communication (use of vocal GSM[1] link). So, rapidly, we can obtain a single and total vision of the scene. Moreover, a transmitted message is not disturbed by the culture or the psychic state of the operator (especially in a serious accident).

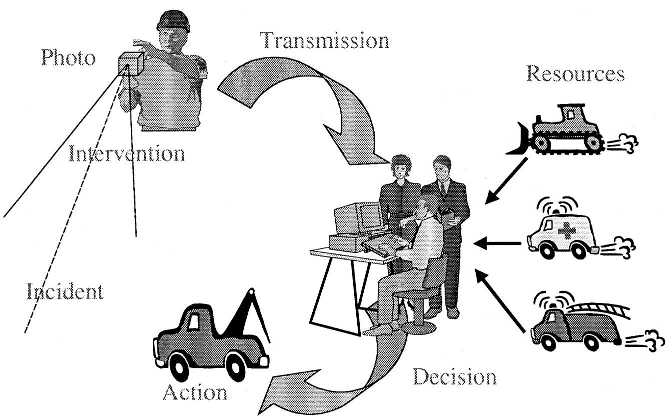


Fig. 10. Image information acquisition.

[1] GSM stands for Global System for Mobile Communications. It is a standard for mobile telephones and telecommunications.

Fig. 11. Operational conditions images.

Data acquisition requires time, and *drawing is better than a long speech*. Fig. 11 presents images produced in operational conditions of exploitation. We can see the wealth of the message content in the image. In the case of the forest fire, the image produces a global overview of the disaster. So the photograph is taken, if possible, of a place overhanging the site of the fire. The photograph can also be taken from a helicopter or plane. In these two examples, which are not exhaustive, the image produces a better message than that available by a radio or telephone dialogue. This kind of application also requires a confidential link, and encrypted processes are used to encode and to identify the origin of the image.

## 6. Conclusion

The objective of this paper was only to give some founding elements of TGP and TGM, to describe some classes of typical problems, in order to stress the similarities between problems and solutions. Obviously, other reflections must be made in order to provide a very satisfactory conceptual starting basis (Laurini, 2001).

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