Conceptualizing road safety management through territorialized complex system: context and goals

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Abstract

Despite many efforts to improve road safety, the road accident statistics remain a concern throughout the world. This work, after considering for France in particular the possible reasons for this, proposes to extend the issue of Road Safety to the land planning problematic which responds to the characteristics of a spatialized complex system. The methodology used in the ANR program CRITERE mixes interdisciplinary and multi-stakeholder purpose. It combines representations structured by explicit data models, and the more empirical concepts expressed by experts in charge of local public action. The tool provides a user-friendly mapping formulation of partners’ opinions and conclusions, highlighting the possible correlations between forms and characteristics of the area, road safety measures, accident and infrastructure observed. It gives the possibility to identify, spatialize, qualify and compare areas for treatment. This application is placed in the perspective of hoisting the issue of road safety among the strategic concerns of territorial management.

Keywords: Road risk; road safety; modeling complex systems; GIS; land management; participatory research expertise.

Résumé

Malgré de nombreux efforts en sécurité routière, les statistiques d’accidents de la route restent une préoccupation majeure. Après avoir examiné le cas français en particulier, cette étude propose d’étendre la question de la sécurité routière à celle de la problématique de la gestion de territoire qui répond aux caractéristiques d’un système complexe spatialisé. La méthodologie utilisée dans le programme ANR CRITERE mêle objectifs interdisciplinaires et multipartenaires. Il combine les représentations structurées par des modèles de données explicites de chercheurs, et les concepts plus empiriques exprimés par les experts en charge de l’action publique locale. L’outil fournit une formulation des opinions et des conclusions des partenaires à partir de cartographies conviviales, mettant en évidence les corrélations possibles entre les formes et caractéristiques de la zone, des mesures de sécurité routière, les accidents et les infrastructures observés. Il donne la possibilité d’identifier, de spatialiser, de qualifier et de comparer les zones de traitement. Cette application est placée dans la perspective de hisser la question de la sécurité routière parmi les préoccupations stratégiques de la gestion territoriale.

Mots-clés: Risque routier; Sécurité routière; Modélisation; Systèmes complexes; SIG; Gestion territoriale; Expertise en recherche participative.

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1. Introduction

In France, for many years, public stakeholding has been preoccupied with displaying road safety as an issue of major importance. Moreover, since 2002 (President J. Chirac official decision), road safety is announced as a “national concern”. However, even today, this engagement has not evolved into a clear strategic action at the metropolitan level, as opposed to other issues that emerged over the same period such as those related to sustainable development (pollution, noise…).

In road risk literature, safe travel is primarily addressed in terms of behavior and technical organization of road networks. Indeed, targeting these two groups of factors in the evolution of traffic regulation and control has undoubtedly contributed to the reduction of road deaths observed over the last 15 years in particular. However, the present level (around 4 000 killed people per year) does not look to decrease significantly any longer, suggesting that different other aspects of this problem operate, and they need to be analyzed as well.

One of them is the territorial dimension of road risk and road safety problematic. Geographers and accident specialists strongly suspect that factors resulting from the configuration of the territory on which mobility occurs need to be highlighted. Indeed, many of these factors significantly influence traffic conditions: morphology and structure of urbanized spaces, the organization of buildings (Engel, 1986), meshing shapes of networks, the visual characteristics of the user’s environment (Fleury, 2007), the distribution of functional areas that control flows and their itineraries, spatial ergonomics (Saint-Gérand, 2002), etc. A raising hypothesis is progressively admitted, not only among geographers but also among accidentologists and even some stakeholders: like many types of risks (health, industrial, social,…), road risk contains a leading socio-technical component. Thus, it takes part of a vast transdisciplinary reflection on the link between development and safety within territories, and on consistency-related problems in urban design relative to the risks and regulations made by the actors (users or managers) at different levels.

The study of relationships between the structure and the surface of a territory implies to question the management of Road Safety through public policy not only in behavioral (the competence and civility of users) or technical terms (safety planning) but at the strategic level as well, across various levels, based on the territory itself at a macro-scale. So, it is necessary to have access to territorial information that is both relevant for the problem and for the scales of analysis, and that is in line with its operational objectives. However, there exists one major challenge which hinders the constitution of such information: the undoubtedly reductionistic and deterministic nature of classical spatial analysis tools, such as those ordinarily used in this domain by both researchers and actors. The ANR (French Research National Agency) CRITERE program aims to overcome this major difficulty, trying to create an approach that is able to model as well as possible road risk and road safety in their spatial complexity.

2. Methodologival challenge: integrate different road safety conceptions into territorial complex system modeling

Two approaches can be mobilized to develop an approach that is able to model as broadly as possible the complexity of road risk/road safety problematic:

- The theoretical construction by geographers of accident-prone spaces by combining relevant variables based on given assumptions.
- The compilation of local actors’ (experts) know-how which is based on observed concrete case studies.

Thus, the challenge is in the building of a relevant method suitable to associate these two different approaches.

In direct collaboration with LMCU ('Lille Métropole' Urban Community in Northern France, 1 100 000 inhabitants), the ANR CRITERE program seeks to develop an interactive researchers/experts dialogue tool. This tool must articulate the spatial generalizations of the experts’ know-how acquired empirically and in an “ad hoc” manner on the ground, and relate them to other spatial generalizations resulting from the models developed by the researchers. The tool is designed to disseminate this knowledge at the metropolitan level, then at different levels of disaggregation that are significant from the Road Risk and Road Safety perspective (sector individualized by experts, the neighborhood, interchange, intersection, route, accident scenes, road safety...).
planning, etc…). A Geographic Information System (GIS developed using ArcGIS 10.1 ESRI) constitutes the core of this application. The geodatabase is based on an Hypergraph Based Data Structure (HBDS) conceptual model. It collects space-time and semantic scales (infrastructures, transport, flows, speeds, buildings, land use, population, activities, habitat, recreational and services’ spaces, environment …) and link them. This provides a structured basis of localized data, to model the territory. It integrates these data, combines them, weighs them and develops cartographic representations which give rise to interpretations, or even to new explorations that are discussed through consultation.

To implement this protocol, data must have been designed, developed and calibrated in advance. This paper presents the approach that guides the construction of such a tool. The objective of this information system that is both scientific and participative is to position road risk and its management through Road Safety at a strategic level in relation to urban action. We will present a few results as demonstrative examples.

First, we will present the methodological approach: the first principle, using intermediate GIS, consists in placing at the centre of the research, a face to face encounter between the researcher and the expert and the analysis tools and spatial complexity. In a second phase, we will present how the GIS was developed to map potential accident-prone locations identified by the experts and analyze their territorial configuration at different levels. This information is likely to help us understand their location within the territory, and grasp the associated factors relevant to our problem.

The beginning phase involves collecting the discourse of actors (developers, researchers or specialized technicians on the operational issues of road safety) and encoding them into GIS entities. The second phase involves generalizing the statements across the territory, mapping them and proposing them anew to experts in order to jointly develop a systemic understanding that is action-oriented in relation to risk at different territorial levels. An example on accident-prone zones involving vulnerable road users (pedestrians, cyclists) will further illustrate this approach.

Any territory, as geographical area driven by a system of interactions that are primarily internally regulated, is inherently complex. This complexity results from reciprocal, diversified and volatile influences which come between all key elements, notably human, material, immaterial and organizational, even environmental. For their part, risk systems are mainly socio-technical systems that are complex as well, and are therefore dynamic and non-linear. Numerous interactions and regulations operate at different levels between the components and the actors of the system. Addressing this double complexity using classic analysis tools highlights a major methodological problem. In the field of road risk/road safety where control by the user and the planner constantly interacts and evolves, this tensioning is very hazardous, producing disappointing results at the macro level of territorial analysis.

Road risk systems arise from dysfunctions within transportation systems. So, three forms of regulation are at work inside and are interrelated:

- the socio-economic planning that determines the morphology of urban (and suburban) networks, flows, and the resulting itineraries
- specific planning by road safety managers
- the adaptive spatial behavior spontaneously adopted by users (pedestrians and drivers)

On the ground, mobile users – motorists, two-wheels users, pedestrians – adapt their behavior very efficiently in almost all the encountered circumstances (speed, circumventing…) in real time; planners, observing behavior, redesign the space in non-real time in order to improve security. However, the capacity of adaptation of the users is highly varied, and this implies that the results of a public policy can never be totally predictable across the entire territory (Asmussen, 1984; Fleury, 1998). At a scientific point of view, such a process occurs an operational constraint: the simple causality is replaced by a complex non-linear causality that is rather relational and multifactorial, where effects can provide feedback on the causes (Morin, 1977). Indeed, this raises questions on the scope of the study which is always difficult to define a priori, owing to the fact that configurations evolve, itineraries change, accident locations “migrate”. This indicates the need to examine spatial representations across several levels that enable to adjust the scope and the focus of observation, instantly modifying the boundaries of the study area as well as the scale of analysis.
Temporal activities and adjustments carried out to tackle these rhythms also raise questions: some land planning decisions can lead to unexpected or even dire consequences on risk. For example, a wide road designed to prevent traffic congestion during peak hours attracts significantly higher flows and increased speeds notably during off-peak periods (Millot, 2003). This dynamic reality as well as the resulting incertitude projects actors into a prospective dimension rather than promoting reliable forecasts (Lecoze, Trémières, 2006). This calls for taking risk into account at the strategic level of urban action, the level where the global coherence ought to be considered. All this points out the crucial question of tools suitable for that purpose.

Considered today as most convenient spatial analysis tools, Geographic Information Systems (GIS) are largely used within the geographer community because they make it possible to model spatial system structures and underlying interactions across different scales. Among administrators, despite increasing usage of GIS, applications remain primarily sectorized and managed for internal use. In their institutions, developing a global, integrated and shared approach among the concerned actors is not identified as an objective. The major challenge to overcome today concerns the integration of knowledge of “those who know” within the spatial analysis tool designed by researchers in such a way that it becomes, not a simple analysis and visualization tool of the risks on a territory, but indeed an agent of the decision-making process.

The originality of this GIS based complex system modeling lies in the way used to tackle the territorial complexity of road risk/road safety: extraction and confrontation of a wealth of experience coming from two sources:

- The wealth of experts (local risk managers, technicians of regional authorities, the State, the private sector,….) who possess substantial knowledge obtained from concrete accident cases, action and the observation of effects.
- The wealth of researchers who possess spatial theories, methods and systemic analysis and generalization tools.

The experts on the ground develop an empirical and inductive approach based on their experience with concrete cases; the researchers develop global methods, concepts based, formalized in a rather hypothetico-deductive manner. Although fundamentally different, these two visions are today to be put into perspective as they are likely to complement each other and even constitute appropriate means of mutual validation of their logics and the results that they produce. Through CRITERE, we undertake the construction of a platform that enables this enrichment and mutual validation.

The platform’s architecture is of modular design (Fig. 1). It includes:

- The spatial analysis module (GIS) : it expresses the territorial problem of the Road Risk/Road Security interface at different scales of time, space and representations (points of view). On one hand, the “actual Territory” comprising physical and socio-economic road risks (buildings, infrastructure, population, mobility, itineraries, transport systems, etc.) and on the other, road accidents that occur there.
- Local expertise extraction module : this expresses at different levels the "cognitive Territories" of road safety stakeholders who have their own experience, visions and priorities based on their activities and objectives within political and / or technical structures.
- Integrating the two previous modules and redefining dynamic areas of road safety interest. It is necessary to reformulate discussions in order to identify two types of spatial representations: the "sensitive territories" for road risks and "prioritized territories" for road safety action. The objective is to create the conditions for consistency across the different development and control measures.
- The user interface (GUI under Human Machine Interface) for visualization and interactive dialogue: the tool must be able to visualize and develop the territorial representations instantaneously in order to keep up with the discussions with the actor.

Loop iterations compare the discourse level by level, the concepts of expert partners / geographers and the resulting spatial entities. Surveys make it possible to map the potential accident-prone locations based on the information according to the experts, and to analyze their territorial configurations. In parallel, formalized processing of spatial analysis using GIS is carried out by researchers (the typology of multifactorial spaces, computing network accessibility, analyzing the road environment, visibility indices…) in order to provide complementary elements for dialogue.
Discussing the representations via the interface module sets off the confrontational process. The loop stops, in other words, the progressive reformulation of the empirical spatial entities by the experts and the theoretical spatial entities by the geographers comes to an end, when convergence (agreement) is reached: the experts accept the GIS formulation of their entities as reconstructed by the geographers, while the geographers validate the methodological consistency of the experts. In this way, the expert broadens his/her knowledge on the territorial articulation of road risk/road safety and the geographer validates his/her assumptions and the tested cognitive schema from the field.

As the approach is based on dialogue between the experts and the spatial analysis tool, it is necessary to:

- Collect the discourse of actors (planners, researchers or technicians specialized in operationalization issues of road safety)
- Distinguish the key notions that emerge from the relationship between development and road safety in order to transform them into GIS components (layers, spatial entities or data attributes).
- Insert them inside the GIS, in coherence with the big amount of factual data previously collected by geographers.

The way used by experts to express their own territorial representations through job-oriented terms needs attention. In his/her profession, the expert has his/her own language which must be deciphered. These examples are based on real accidents from specific situations observed. By describing a concrete case, he/she activates a logic, a syntax, a vocabulary that is different from that of the researcher. In this way, the expert uses relative and synthetic notions whose meanings are more or less nuanced, but also terms that are ambiguous, vague, pictorial, even intuitive within the semantic (strong local life, intense city, commercial atmosphere, high traffic routes...
disconnected from their urban environment…) as well as the localization domain (“near”, “next to”, “above”)…
and which must be put back into context and placed within the territory. These experts’ concepts are entities of high-level synthesis. Transcribing them into GIS entities implies a methodology that restructures variables of lower levels.

A series of interviews among experts, completed by technical reading (CERTU documents, development documents…) made it possible to identify and define the key notions or expressions prominent in the technical and operational discourse on road security. We analyzed the discourse in order to extract spatial entity concepts (singular spatial objects – a train station – or aggregates – a neighborhood, a residential area… -) that we could reconstitute in the spatial analysis tool using query syntax. For example, the “generators/attractors” of population (and subsequently of users’ mobility) can be defined by the weighted combination of spatial representations relative to where consumption areas are located, transit stops, train stations, hospitals, schools… Obviously, this does not mean explaining all useful technical knowledge (concerning traffic signal cycle or nature of a road surface) but rather focusing on the elements that make it possible to describe the space for preventive measures identified at the strategic level. We grouped the variety of notions into five items based on convenience (“Network”, “Traffic and speed”, “Environment”, “Mobility-Travel”, “socio-spatial characteristics”). The nature of these items clearly shows that road safety is a global issue that falls within the strategic level.

In order to translate them into cartographical representations, these notions must be measureable. Based on how the terms are defined – and the issues involved - indicators are proposed in order to adapt them into criteria that could be used within GIS. This phase is reflected on by the LMCU experts who also forward proposals in order to align each viewpoint concerning the possibility of translating the notions, in view of the technical capacities of GIS and the available data. The development of a semantic and syntax structure made it possible to construct discourse on the state of insecurity.

3. A practical example: ZIVAG

A series of interviews among experts, completed by technical reading (CERTU documents, development documents…) made it possible to identify and define the key notions or expressions prominent in the technical and operational discourse on road security such as the areas that “generate/attract” population (and subsequently user mobility). In GIS, these areas can be identified and located by using the weighted combination of spatial representations relative to where consumption areas are located, transit stops, train stations, hospitals, schools…

The study consists primarily in analyzing the discourse of experts in order to extract spatial entity concepts (singular spatial objects – a train station – or aggregates – a neighborhood, a residential area… -) that can be reconstituted in the spatial analysis tool using query syntax. A semantic network is obtained. This is in the form of formal language (dictionary) of spatial entities and of their relationships. This semantic network makes it possible to simultaneously reconcile quantitative and/or qualitative spatial data attached to accurate geometrical shapes of GIS entities (buildings, road sections, etc) and data that is imprecise but relevant from the experts’ perspective, in the form of qualitative spatial relationships (neighborhood relations, distance, orientation, etc.).

Based on how the terms are defined – and the issues involved – we proposed indicators in order to adapt them into “spatial variables” useable within spatial analysis tools. This phase was subjected to the reflection and the propositions of the project partners as well as to the LMCU experts. It was indeed the occasion for numerous discussions between the partners in order to align each vision on how to translate the notions, based on the technical capacities of GIS and the available data.

The « ZIVAG » (Vulnerable Severely Damaged Involved Zones) concept was created following discussions with stakeholders: this is a priority zone for security action which targets vulnerable road users (pedestrians, cyclists) and the severity of their injuries. Consequently, to address this issue, a zoning action must be defined in which specific security arrangements can be elaborated. ZIVAG is the result of crossing zones of high urban density and those of high traffic flows.

In view of our problem, urban density can be defined as a measure of the density and interferences in a specific area, of elements, factors and sets of forces that generate potentially hazardous movements. It regroups:
"Local Life": elements of urban living orientated towards leisure and consumption, generators of pedestrian flows, for instance points of activity (restaurants, post offices, pharmacies, museums, bars, shopping facilities, etc).

"road users main Generators": particular elements of high urban activity that generate important mobility flows (large hospitals, train stations, universities)

"Public Transport" ("PT"): Common public transits (Bus, Tram, Metro (subways)).

The mobility vectors are comprised of elements that describe traffic flows: elements of the network with traffic of over 6000 vehicles per day.

Each layer of vector objects from the two groups is first converted into a regular network (raster) based on the density of points (kernel method, Silverman 1986, p.76, equation 4.5). Each resulting layer of raster data contains a single value per cell, representing the local value of the criteria for which the layer is intended. The sides of the cell measure 25 meters, chosen following control tests in order to adjust effectively to the variations of urban areas. For each criterion, we obtain a surface of intensity with zones of varying concentration relative to the criterion considered. Each criterion is then standardised to obtain the same representation but with intensity values varying from 0 to 100. Criteria combination functions through sums (Fig. 2a) that can be weighted (Fig. 2b).

Subsequently, we identified four zones:

- "10": Zones with the highest density representing 10% of the total LMCU zone
- "25": Zones of average density
- "50": Zones of low density
- "100": Zones with the lowest density

A percentage of accidents involving the most vulnerable users was calculated for each zone. The criterion representing "urban intensity" was tested using several types of weights (Fig. 3).

There are four possible representations of the urban intensity concept that we then combined to the representation of traffic with two possibilities as well: high values in relation to traffic, or to urban density. Both the maps below therefore represent ZIVAG based on different weighting choices. The first test map (Fig.4a) represents ZIVAG by crossing:

- The "Urban intensity" criterion based on a simple sum of the elements of “local life”, “substantial generators” and “PT” (homogeneous weights are shown on the map legend by the triangle, square and circle of similar size).
- The “Traffic flow” criterion where weighting values are high (the focus placed on traffic is represented on the map legend by a black arrow).

The second test map (Fig.4b) represents ZIVAG by crossing:

- The "Urban intensity" criterion based on the weighted sum of elements of “local life”, “substantial generators” and “PT” (focus is on the factor “Local Life” which is represented on the map legend by the triangle which is larger than the square and the circle),
The “Traffic flow” criterion where weighting values are low (the focus placed on urban intensity is represented on the map legend by a black arrow)

Fig. 3. “Urban Intensity” modelling.

Fig. 4(a). First test map
4. Conclusion and followings

The objective of the research presented here was to design a tool able to position road safety strategically, at all necessary levels, in line with the development of metropolitan areas.

A study that seeks to better account for risk in socio-economic planning policies must be placed in the complexity domain. Indeed, integrating risk (and notably road risk that is specifically covered here) at the local level comes up against interactions and controls by both the users and those in charge of spatial planning across varying scales. The proposed approach juxtaposes two forms of distinct conceptions: that of researchers, theoretical, elaborated in a conceptual model of road risk and road safety environment, and that of field experts expressed in implicit vocabulary that is meaningful to insiders (local technicians, the State…).

The entire approach is considered to be a “circuit” of an iterative task which emerges between the spatial analysis tool and the expert: the experts’ knowledge and their own language are translated in GIS, the multifactorial analyses and generalizations are re-examined depending on different dimensions. The tool is therefore involved in the decision making process.

Our objective is therefore to show the significance of new forms of local practices of cooperation between researchers/experts in order to better take into account road risk within urban action strategies. However, to ensure dialogue between researchers, experts and decision makers, information must be also easily and rapidly accessible, via user-friendly and flexible interfaces which enable the users to instantaneously exploit their content depending on the current needs.

This condition is now satisfied: this systemic approach, action-oriented, is encapsulated in “CRITERE software” (Fig.5), an easy-to-use ad-hoc program, ArcGis station based, and especially designed to quickly and efficiently support live discussions among the different urban services of Lille Urban Community. The first experimentations in situ are convincing, and a number of improvements are being investigated.
Fig. 5. Screenshot of CRITERE user interface.

References


