

DEVELOPING A 3D ROAD CADASTRAL SYSTEM: COMPARING LEGAL REQUIREMENTS AND USER NEEDS

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ABSTRACT:

Road transport has always played an important role in a country's growth and, in order to manage road networks and ensure a high standard of road performance (e.g. durability, efficiency and safety), both public and private road inventories have been implemented using databases and Geographical Information Systems. They enable registering and managing significant amounts of different road information, but to date do not focus on 3D road information, data integration and interoperability. In an increasingly complex 3D urban environment, and in the age of smart cities, however, applications including intelligent transport systems, mobility and traffic management, road maintenance and safety require digital data infrastructures to manage road data: thus new inventories based on integrated 3D road models (queryable, updateable and shareable on line) are required. This paper outlines the first step towards the implementation of 3D GIS-based road inventories. Focusing on the case study of the "Road Cadastre" (the Italian road inventory as established by law), it investigates current limitations and required improvements, and also compares the required data structure imposed by cadastral legislation with real road users' needs. The study aims to: a) determine whether 3D GIS would improve road cadastre (for better management of data through the complete life-cycle infrastructure projects); b) define a conceptual model for a 3D road cadastre for Italy (whose general principles may be extended also to other countries).

1* INTRODUCTION

Mobility and transport represent two key components of economic development and human welfare of a country. Road transport promotes rural development, the transport and selling of agricultural products, industry and trade, the expansion of jobs, and access to health, education, and services (Parami Dewi, 2013). The role of roads is equally decisive at the urban scale, as they connect city parts and are a framework for the city structure (Sun and Chen, 2000). The number of reasons for people to travel between two locations (e.g. for work, leisure, family) has been increasing and road traffic has become very intense, a trend that will continue (World Highways. International Road Federation, 1990; Road Transport Forecasts, 2013): new roads are planned, existing road networks require daily maintenance, and safety, traffic congestion, and traffic-related air pollution have also to be properly managed. The above requires inventories/information systems in which roads are properly identified, classified and described, and where geospatial data, administrative and technical-functional road features are collected, with the recent development of different specialist transport-related topics (e.g. Intelligent Transport Systems (ITS)) adding to the need for digital road data infrastructures to integrate and manage road-related information (Sandgren, 2004). Real-time sensing of traffic and of the road surface to monitor and analyse road phenomena (e.g. to check the status of the road structure over time) can ensure a high standard of road performance - including durability, efficiency and safety (Burningham and Stankevich, 2005) - and forecast construction and maintenance costs.

In many countries both public and private road inventories have been implemented using databases and Geographic Information Systems (GIS) for registering and managing roads. This is used for the purposes described above at all stages of a road's life-cycle. However, standards for road inventories were established

before the emergence of three-dimensional (3D) GIS, and current GIS-based road inventories (2D) are not able to describe complex road information like 3D spatial features (e.g. overlapping and interlocking road networks, bridges, overpasses and tunnels, as well as the description of 3D road components, underground utilities, and 3D environmental and urban contexts) (Hatger and Brenner, 2003). Data is held in different systems and not integrated. Given this limitation of 2D systems, 3D road inventories may represent an innovative solution to road management complexity.

This paper illustrates the first step in an ongoing research project examining the theoretical and practical implementation of a 3D GIS-based road inventory. Focusing on the case study of the Italian road inventory (called a "Road Cadastre"), it aims to: a) determine whether, given its potential as a data integrator and as a mechanism to link to multiple, disparate, elements of information, the use of 3D GIS would improve road cadastre (for better management of data related to the complete life-cycle of infrastructure projects); b) define a conceptual approach and model for a 3D road cadastre for Italy (whose general principles may be extended also to other countries).

The remainder of this paper is structured as follows. Section 2 provides background on existing and experimental road inventories and data models, outlines current GIS uses related to road descriptions, and reviews international standards for road inventories. Italian road cadastral law is presented. Section 3 describes the methods and the workflow adopted. Several main issues and requirements for road descriptions and population of road inventories have been collected from a literature review, analysis of existing models, and questionnaires and interviews with road users. The conceptual model, user requirements and the results of comparison between the extracted requirements (especially the 3D ones) are illustrated in Section 4 and discussed in Section 5, leading to the conclusions relating to this first step of the study.

2* LITERATURE REVIEW

2.1 Road Inventories – Definitions and Uses

Several definitions of a “road inventory” can be found in the literature, with all of them describing it as a register of streets within a given area or jurisdiction. In particular, Wathen (1991) defines a road inventory as “a book containing information to answer legal questions about roads”; according to Mammarella (2014) it is “a compiled data resource that can provide various categories and layers of information based on the structural conditions and status of roads”, while the Oregon Department of Transportation (2012) describes it as “a compilation of information about the status and condition of the road system”. The multi-purpose nature of a road inventory is also highlighted by examining varying uses: Wathen (1991) highlights its importance in a juridical perspective, i.e. to inform citizens on road maintenance and on legal liability and legal rights related to it. Mammarella (2014) emphasised its role in planning maintenance of safe surface transportation and, particularly, in forecasting costs; while Higuera and Castro (2014) defined road inventories as a key component in the planning of road networks “as they allow for efficient management and a better return on the investment”, with a particular focus on those parties interested in designing and building road networks.

2.2 Existing Digital Road Inventories

The use of databases and road inventories based on GIS permits storing a wider range of different type of data (including text, vector, and raster) required for managing road infrastructure (e.g. geometrical and physical elements, administrative and technical road classifications, and specific attributes), and meeting the spatial nature of road data analysis (Kiema and Mwangi, 2009).

An example of a road inventory for data integration can be found in Oregon, as illustrated by King and Kratzchmar (2010). In this case, the Public Road Inventory is used by the Transportation Data Section to collect and maintain information on status and condition of the road system as well as data necessary to classify and monitor highways, roads, and streets in the country. Through the “TransInfo” database, users have access to mileage statistics and traffic counts.

Data integration, together with an inventory of categorised road features based on collaborative evaluations (i.e. stakeholders participation in evaluation), has also been a focus of models developed to improve road inventories for safety purposes: in the last decade, in USA, the Federal Highway Administration (FHWA) Office of Safety has created and progressively improved MIRE (Model Inventory of Roadway Elements) (Lefler et al., 2013). It is a listing of more than 200 roadway features and traffic volume elements important to safety management.

Road network models to simulate traffic have been also implemented, such as the AVeSi Project, based on the generation of 3D scenarios from data describing real city roads. It is composed of a 3D model, consisting of a 3D mesh of road geometry and material properties for visualisation and physics simulation and also includes a detailed road network model (Haubrich et al., 2013), which contains data required for the traffic simulation (e.g. road geometry, priorities, speed limits).

2.3 Use of GIS for road inventories

2.3.1 2D GIS: 2D GIS technology has been widely used in the road management field due to its capability to link both geospatial and descriptive ('attribute' or 'semantic') information to represent and analyse spatial phenomena, understand the spatial relationships of data (viewable on maps), and perform

spatial and network analysis through queries. GIS has been extensively used for: pavement and bridge maintenance management (Xiao et al., 2012), modelling disaster response plans (Cheng et al., 2014) as well as analysing impacts of transportation infrastructure construction (Cai et al., 2012), routing of overweight and oversized vehicles (Steere, 2012), identifying high-crash-risk road segments (Mohaymany et al., 2013), high safety and truck traffic analysis (Schultz et al., 2012), the management of rural highways network (Manyazewal et al., 2014), and others. GIS is also a useful tool to support decisions on the construction of new roads, as it facilitates analysis of the effects of new infrastructure on an area's accessibility, optimising the route, and minimising the possible environmental and visual impact of new roads (Seguí Pons and Ruiz Pèrez, 2003).

2.3.2 3D GIS: A Road Cadastre registers data relating to existing roads, which in turn provides information for new road projects. Yuan (2008) notes that 2D systems do not enable the comprehensive description of road networks in their full three spatial dimensions and that 3D objects presented in 2D may lose properties such as texture, graphic, height, and their spatial relationships to other objects. A 3D GIS Road Cadastre has the potential to improve the management of roads (both for construction and maintenance) (Burchi et al., 2009). Luliang and Quinguan (2004), Yuan (2008) and Fredericque et al. (2011) note that 3D GIS can additionally: simulate the landscape of a road and visualise 3D structures such as overpasses and on-ramps, simplifying the communication of complex situations; improve the planning, construction and maintenance of roads and bridges; allow complicated road designs to be modelled and tested in a virtual environment before construction; demonstrate in 3D any features requested by stakeholders; integrate geospatial data with heterogeneous documents like legal documents, urban plans, technical reports, images and existing scanned plans, allowing the 3D model to serve as an index to other data; permit 3D operations such as distance measurement.

2.4 Standards to harmonise road inventory data

Existing standards are developed by the CEN (the European Committee for Standardization) and the ISO (the International Organisation for Standardization) and relate to ITS (CEN TC/278 and ISO 14825:2011), as well as providing reference data models for public transport (CEN Transmodel v5.1, 2006; IFOPT (Identification of Fixed Objects in Public Transport), 2009). Also INSPIRE (INfrastructure for SPatial InfoRmation in Europe), an EU project requiring each member state to capture and share metadata and data relating to environmental issues, takes advantage of the work developed by standards bodies and expanded this to the public transport network. Standards for road design are also provided by CEN/TC226 Road equipment.

All of these once again highlight the range of applications making use of road data. Nevertheless, as Caroti and Piemonte (2010) explain relating to the Italian case, the groups who set the standards do not include those organisations who will eventually be tasked with the daily population of databases. Thus, their application in practice is often limited and in many cases they are replaced by local standards.

2.5 Italian road cadastre law

The link between road property/management and road maintenance responsibilities is central to the definition in law of the Italian road inventory. The road inventory is defined by the New Road Code (1992) as a “Road Cadastre”, a name that evokes the concept of road property (i.e. aimed at identifying the owners who are required to pay for road maintenance). The Act of the Italian Ministry of Public Works (June 1, 2001) also defined the road inventory as “the inventory of all public roads

in the national territory” aimed at describing the status of the national road network. The “New Road Code” introduced an administrative classification of roads and a technical/functional one. It states that each institution that owns or manages public roads is required to implement a “Road Cadastre”. As Italy is divided into administrative areas (Regions, Provinces and Municipalities), each responsible of a part of the road network, each one should have its own cadastre. In addition, ANAS (the company managing the Italian network of highways and national roads) has also produced its own Road Cadastre, covering the entire country.

The Italian Road Cadastre collects and provides administrative and technical features (both geometrical and structural) related to roads. Standards for registering and updating road data were provided by the subsequent Ministerial Act of June 1, 2001. The basic road dataset includes: a) geometric features of roads and related appurtenances, b) infrastructure and permanent services related to road traffic demands. The geographic dataset is compliant with the CEN/TC 287 standard. Additional data related to roads – such as maps, traffic data, incidents, state of conservation of structures like bridge, tunnels and viaducts, paving and complementary works, environmental monitoring, signage, distance markers, financial aid received – can also be associated with the Road Cadastre (Di Mascio et al., 2004) and then collected in a National Road Archive, which should also include data on traffic, accidents, and geometrical and structural features of roads.

2.6 Limitations of Current Approaches

As noted above, current road inventories and related standards are based around 2D GIS. However, as Bokyo and Funkhouser (2012) explain, semantic tagging and 3D modelling of roads “is crucial to understanding the complete structure of a city, since roads provide a continuous surface spanning an entire city, segment the city into blocks, and provide contextual cues for recognizing smaller objects (e.g., fire hydrants are usually a fixed distance from a roadside)”. In addition, the situation on the ground is complex and very difficult to represent in 2D as required by standards. The emergence of ITS and smart cities also suggests that existing systems will need to be extended to incorporate newly available information, as well as to integrate information from all phases of road design, construction and maintenance and from multiple sources. In this, the information management and integration requirements for roads resemble those for buildings, where a similar integrative approach (offered by Building Information Modelling, BIM) is predicted to save the industry £2bn per annum (Wix and Nisbet, 2008).

3* METHOD AND WORKFLOW

3.1 Research methods used and Requirements gathering

Sharp et al. (2011) have suggested a number of different approaches that can be taken as part of a requirements gathering process, including interviews and workshops, as well as focus groups and studying documentation. A number of these have been employed within this research and are described here.

In order to define a conceptual approach and model for the implementation of smart road inventory based on 3D GIS, this study started with the collection and analysis of requirements (especially in a 3D context) related to road networks. These have been collected from literature, existing models, and users, with Italy as the focus of the study, and in particular Sicily as the focus of more detailed practical work.

Literature review: The literature review described in Sections 2.4 and 2.5 was used to understand the legal requirements for a Road Cadastre in Italy.

Data Requirements Review: As current road inventories include data relating to existing roads only, a literature review relating to the data required for new road projects was also carried out to identify information required to support the road building process. Road maintenance is closely related to many other road issues (e.g. safety, roads ownership, road services, civil and environmental protection) and deals with roads both existing and to be built: therefore, manuals on road maintenance were also reviewed (such as the guidelines on the Road Asset Management by the European Union Road Federation (2014)).

Review of the existing ANAS Road Cadastral System: The ANAS Road Cadastre has been studied and compared with the Italian Road Cadastre as defined by law to highlight similarities and differences among aims, datasets, and techniques for recording and accessing data of both systems.

Questionnaires: These were designed to collect information on current road inventory functionality and limitations from current users, as well as to identify their needs with regard to 3D road data and general inventory systems. Users were selected from stakeholders involved in various stages of the road life-cycle (both construction and maintenance), from one Italian engineering company, as part of a pilot study. The questionnaire was given to 2 project managers (1 engineer and 1 quantity surveyor) and 7 designers (6 engineers and 1 quantity surveyor) dealing with project design (both new construction, and upgrading and maintenance). The questions (open ended and closed, and with explanatory images where required) focused on topics including the existence and use of Road Cadastral systems, and whether these were fit-for-purpose or required additions. They also sought the respondent’s opinion on the adequacy of the information held in the Road Cadastre, and whether a 3D road cadastre would be beneficial. A third aspect explored was the potential integration between road construction project data and Road Cadastral data, with a final focus on the existence of any projects currently making use of 3D data.

Interviews: A number of semi-structured interviews have also been carried out with stakeholders. Eleven questions were prepared to elicit information directly from users involved in *Road design* (the CEO and project managers of the Italian Civil Engineering company where questionnaires were distributed) and *Road management* (the Operational Manager of the ANAS road cadastre for Sicily). The interviews focussed on collecting more detailed information about the type of road data required, including issues encountered when implementing the legal Road Cadastre, any current use of CAD and GIS relating to road projects/construction/maintenance/management. In addition the adequacy of current approaches when documenting 3D road situations and relationships between roads and environment, as well as potential usefulness of 3D GIS, and the relevance of International Standards, was explored.

3.2 Analysing the Resulting Data

The outputs of the various processes described here were transcribed and analysed for specific references to data and functionality requirements for road cadastres, both for 2D and 3D cases. Analysis involved using both quantitative methods (e.g. for closed questions or questionnaires) and qualitative approaches (open interviews, observations) (Sharp et al., 2011). Qualitative analysis firstly involves gaining an overall impression of the data and examining it at high level for patterns and trends, followed by a process of categorisation, which can take place at multiple levels and, importantly, should be replicable (ibid). Where the qualitative data is extensive (e.g. a full recording of a workshop) critical incidents can be identified - i.e. facts that make a significant contribution to the activity (ibid).

3.3 Comparison between the Italian Road Cadastre data structure and needs of users

The needs of the stakeholders (including social and technical requirements), collected via the questionnaires and interviews, have been compared with the Road Cadastre data structure proposed by the standards, in order to highlight where the standards meet requirements, and also identify missing elements and possible improvements (including its 3D development).

3.4 Definition of a conceptual approach and model

The results of the comparison have been used as guidelines to draft a preliminary conceptual model extending the current Road Cadastre to meet the identified needs of stakeholders, as well as to frame a broader approach to road data management.

4* RESULTS

4.1 The Italian Road Cadastre

4.1.1 Required Structure of the Road Cadastre Information System: As established by the Italian Act of June 1, 2001, the physical model for the Road Cadastre should consist of a network-based, multi-user, client-server system, based around a relational database (whose structure is also defined by the Act and is partially based on a pre-standard version of CEN/TC 278) and a GIS, which allows the representation of the map of the area and the graph of the road network at three different levels of detail (LoDs).

4.1.2 Status and current uses – Literature review, questionnaires and interviews: Currently in Italy just ANAS and six regions out of twenty (not including Sicily) have produced their own road inventory relating to the regional road network (SITECO, 2008; Burchi et al., 2009; ASTRAL, 2016). These are based on the requirements established by law, but extended and customised in accordance with specific local needs. Issues in implementing the system include difficulties in updating changing data (e.g. signage, and details of the institutions managing each road) or that are not accurate (e.g. the position of milestone markers after road changes) or clearly defined (e.g. property boundaries, i.e. start and end of the road) (Vella, 2008). From the questionnaires it emerged that 8 out of 9 respondents consider the current inventory adequate, though the full implementation of the June 1, 2001 Act and attachments has not yet been achieved. 6 out of 9 road designers do not in fact use the existing road cadastre data at all, whereas the remaining 3 (who are senior road designers) use it for road design, road alterations and to identify any expropriation of land required for new roads. Interviews confirmed the main uses of Road Cadastre by road designers, i.e. for managing projects of road maintenance or upgrade, or new projects on existing roads.

4.2 Requirements from Literature and Experts Users

4.2.1 Requirements from literature review – Road Design: In Italy in 1980 the Official Bulletin of the National Research Council (CNR) n. 77 provided the first “Instructions for drafting road projects”. This was followed by the Law 109/1994 on the Public Works (the so-called “Merloni Law”) and its Implementing Regulation Act (D.P.R. n. 554 of December 21, 1999) that defined a list and characteristics of documents and data required for all construction projects (including both building and infrastructures) during three different stages (preliminary, final and executive). Finally, the Act of November 5, 2001 by the Italian Ministry of Infrastructures and Transport established “Functional and geometrical standards for road design”. The following data (derived from GIS and CAD) is requested (Table 1):

Requirements from the Merloni Law (1994)	Required by the legal Road Cadastre
Environmental, archaeological, historical, topographical, geological, hydrological, hydraulic, geotechnical and interference investigations, related reports and graphic designs, Project Technical Reports and Environmental Impact Reports	No
Maps at different scales: from 1:100.000 to 1:500	No
Altimetry drawings. Longitudinal profiles at different scales (from 1:25.000 to 1:100) and Cross-sections (1:100)	No
Photos	No
Interchanges and intersections	No
Location of construction lots, interferences and permits	No
Main road structures and plant	No
Signage and Expropriation of lands	No
Special Specifications, Maintenance Plan, Environmental Monitoring, Other documents	No

Table 1. Requirements from Merloni Law (1994)

Similarly, Table 2 refers to road data requirements from the D.P.R. n. 554 of December 21, 1999:

Requirements from D.P.R. n. 554/1999	Required by the legal Road Cadastre
Administrative and Technical road category	Yes
Speed limits, Design speed range and speed diagrams	No
Constructive elements of road (roadway, shoulder, pavement, etc. with size, position, spatial relationship)	Yes
Geometry of the road axes and Geometrical and traffic features of road sections	Partially
Road structures (bridges, tunnels, etc.)	Partially
Barriers and lighting elements	Yes
Signage	No

Table 2. Requirements from D.P.R. n. 554/1999

4.2.2 Requirements from literature review – Road Maintenance: These include “Road Asset Management - An ERF position paper for maintaining and improving a sustainable and efficient road network” from the European Union Road Federation (ERF) (2014), providing guidelines to create a data structure for road maintenance and to implement a road inventory to be updated regularly. The “Transport Notes of the World Bank” (Burningham and Stankevich, 2005) also require financial information (Table 3).

Requirements from the ERF (2014)	Required by the legal Road Cadastre
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All the constructive elements of roads (e.g. Asphalt lanes, Walking path, Parking area)	Partially
Equipment (e.g. Signs, Street lighting, Barriers)	Partially
Structures (e.g. Bridges, Tunnels)	Partially
Historical data on construction and Use of roads	Partially
Elements related to the management of public transport services, energy, water and telecommunication (only urban roads)	No
Requirements from the Transport Notes of the World Bank (2005)	Required by the legal Road Cadastre
Surface (paved, unpaved)	No
Type of maintenance (routine, periodic, urgent), Work type and Description	No
Financial Unit Cost	No

Table 3. Requirements from the guidelines on road asset management by ERF (2014) and Transport Notes of the World Bank (Burningham and Stankevich, 2005)

4.2.3 Users' requirements from surveys and interviews (compared with the existing cadastral law and literature):

The literature review above has been compared with the results from the questionnaires issued to road designers and the interviews of road designers, maintainers and managers as described in Section 3. Table 4 summarises the comparison results. In the table, "RD" refers to "Road Designers" while "RM" means "Road Managers/Maintainers".

Requirements	Cadastral Law	Existing Review	Literature Review	Surveys RD		Interviews	
				RD	RM	RD	RM
Geometry							
Geometry (planar geometry, elevation, lane sections, coordinates)	✓	✓		✓	✓		
Plano-altimetric survey				✓	✓		
Measurements of roads, tunnels, walls	✓	✓		✓	✓		
Road Elements							
Constructive elements of roads (roadway, median, curbs, pavement, etc.)	✓	✓		✓	✓		
Road structures	✓	✓		✓	✓		
Interchanges/ intersections/ accesses		✓		✓			
Road Equipment							
Barriers	✓	✓		✓	✓		
Signage		✓		✓	✓		
Lighting elements	✓	✓		✓	✓		
Plant/utilities data	✓	✓		✓	✓		

Advertising signs					✓
Underground utilities			✓	✓	
Maps/Papers/ Reporting					
Maps (also thematic: e.g. geological, geotechnical, archaeological, hydraulic, constraints, quarry sites and storage), cadastral plan		✓		✓	✓
Urban plans				✓	
Legal text		✓	✓	✓	
Design reports and drawings		✓			
Structural calculations				✓	
Results of surveys					
As built				✓	✓
Ortophotos				✓	✓
Photos		✓		✓	✓
Laser scans				✓	✓
Underpass survey data				✓	✓
Construction/ Maintenance					
Road surface quality		✓	✓	✓	✓
Time of construction/ maintenance			✓	✓	
Maintenance works		✓		✓	✓
Detailed defect monitoring					✓
Materials				✓	
Costs		✓			
Safety data					
Sight distance		✓		✓	
Road traffic and accidents		✓		✓	✓
Speed limits		✓	✓	✓	
Summary tables of data				✓	
Environment					
Terrain (and relationship with roads)		✓		✓	
Environmental data and monitoring		✓		✓	
Others					
Administrative data (road owner, road manager, road classification)	✓	✓			✓
3D model of terrain and road				✓	✓

Table 4. Requirements for documenting roads (design, upgrade and maintenance stages)

Requirements from designers and maintenance engineers:
Data on road structures such as viaduct, tunnels and bridges

5* DISCUSSION

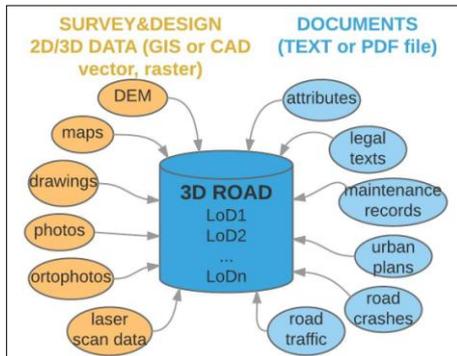


Figure 6 – High Level Overview of the 3D Road Cadastre

The 3D model proposed includes a wide range of different data (Fig.6). Within the model spatial entities (i.e. environment, road infrastructures and the elements they are made of) are modelled in 3D and queryable providing data as text, images and maps as PDF and JPG files, which can be linked to a road, a section of road or a specific element in the model. This mixed data types approach is fundamental as the questionnaires and interviews, as well as emerging Smart Cities and ITS requirements, highlight the importance of a flexible approach to modelling. Thus, not only does 3D enable realistic modelling of real world objects, the 3D environment also facilitates access to other data, serving as a data indexing mechanism.

4.4 3D GIS utilities in implementing Road Cadastre – Questionnaires and Interview Results

As noted above (Section 2.3.2), a number of authors have investigated the potential of 3D GIS in a Road Cadastre situation. Both the results from the questionnaires and the interviews confirmed the validity of the approach, with all respondents to both noting that having access to a 3D model, integrated with the road inventory/cadastral data, would be useful. Respondents to the questionnaires cited uses including: a) feasibility studies - to assess in the preliminary planning stage the possible effects and consequences of interference (interviews and questionnaires); b) to have a complete set of information to support road maintenance or subsequent road designs (questionnaires) or maintenance tasks (interviews); c) to carry out possible designs additional to the core project – e.g. relating to neighbouring areas – more rapidly, especially in case of emergency interventions (e.g. to know the sequence of ditches, manholes, etc.) (questionnaires); d) to carry out preliminary tests on the road (safety, visibility) (questionnaires and interviews) and carry out a performance evaluation of the road structure (interviews); e) to have a visual and practical record of the project (questionnaires); f) to identify and resolve problems of clashes between plant, road elements, underground utilities and structures (questionnaires); g) to access to elevation/altimetry data, and provide an immediate view of the morphology of the land, the geometry of existing works and how this may be altered (interviews); h) to understand the composition of the road bed (interviews).

Eight out of nine questionnaire respondents would also like to see the integration between 3D and 4D representations of roads within a road inventory resulting in a single model able to describe the infrastructure's life cycle and to confirm and support the planning of road maintenance programs. Interview respondents also noted that maintenance activities would benefit from 3D GIS for documenting and analysing minor works (e.g. walls) and road surfaces (that ANAS currently records after maintenance interventions on paper).

The literature review, questionnaires and interviews seem to confirm that the use of 3D GIS would improve road cadastre for better management of data related to the complete life-cycle of infrastructure projects. The model and approach proposed to be all encompassing – i.e. to model every single possible element and feature of a road network. Indeed, this may not be possible and would not take into account emerging future requirements such as ITS and Smart Cities. Instead, through its many different elements, the model aims at being consistent with the multi-purpose nature of a road inventory discussed in Section 2.1, taking into account the “multidimensional” – from 1D (linear reference) to 4D (including 3D space and time) - and “multifaced” (Ndandiko et al. 2013) nature of a road. The proposed model extends the existing road cadastre concept, which deals only with ownership and maintenance, to include 3D modelling and to cover the entire life-cycle of a road network, from conception onwards. Importantly, the model is extensible and flexible, allowing for different levels of detail in the geometry and links to the attributes and other information (documents, survey results, photographs, video and so forth) – thus this supports a wide variety of existing data. The 3D-based approach also provides the potential for the 3D model to act as an index and integrator for other data – where associating data with a location in 3D space allows it to be linked to other data where this would otherwise not be possible. The ability to visualise and explore data in 3D also adds not inconsiderable value. The approach also takes into account the need to provide information in different formats to different users from one central source, allowing multiple representations if necessary – e.g. a laser-scanned survey of the terrain may be useful to a road designer planning a new road, as well as a 3D vector model of the same location to a road safety expert or the person installing signage. In this, the approach described here mirrors that of emerging BIM processes (where there is a concept of a ‘single source of truth’ datastore). As with BIM, this centralised source of information can assist in communication between various design teams (traffic safety, construction teams, drainage engineers, utilities engineers) and also helps to minimise re-capture of data – the ‘as-built’ information resulting from the road construction phase can be directly used by any maintenance engineers. Both the questionnaires and interviews revealed that there is some familiarity with GIS in the community, but both designers and maintenance engineers would prefer to work with tools with which they are familiar: a database-centric approach could permit this. In many cases, simply having access to an interactive 3D visualisation of the data, with links to further information, may be sufficient.

6* CONCLUSIONS AND FURTHER WORK

As noted above, there is a good correspondence between the 3D-related requirements highlighted in literature (Section 2.3.2) and in the questionnaires and interviews (Section 4.2.3), further supporting the potential 3D in the context of a road cadastral system, but not reflected in the current road cadastral standards. Future work will include understanding how to represent each road part (e.g. as a geometry or just as a PDF or point cloud) and which data capture to prioritise to meet most requirements, then developing physical models for 3D road cadastres related to the technical and social requirements emerged.

REFERENCES

ASTRAL, 2016. www.astralspa.it/?page_id=83, (04 June 2016).

- Bokyo, A. and Funkhouser, T., 2012. Extracting roads from dense point clouds in large scale urban environment. *ISPRS P&RS*, 66(6), pp. S2-S12.
- Burchi, A., Cina, A., Rosso, D., Piras, M., 2009. Il Catasto Strade della Regione Piemonte. *Le Strade* n. 5, pp. 132-139.
- Burningham, S., and Stankevich, N., 2005. Why Road Maintenance is Important and How to Get it Done. Transportation Note No. TRN-4. World Bank, Washington, DC.
- Cai, H., Oh, J., and Yang, D., 2012. Integrating GIS and Microscopic Traffic Simulation to Analyze Impacts of Transportation Infrastructure Construction. *J. Comput. Civ. Eng.*, 26(4), pp. 478-487.
- Caroti G., Piemonte A., 2010. Standard per la generazione del grafo stradale a cui appoggiare rilievi di catasto strade: il caso della Toscana e del Comune di Pisa. *Bollettino della Società Italiana di Fotogrammetria e Topografia* n.3, pp. 69-80.
- Cheng, T., Xu, L., Su, G., Yuan, H., 2014. GIS Based Spatial Collaboration in Urban Critical Infrastructure Emergency Response. In: *2014 International Conference on Information GIS and Resource Management*, Lancaster, Pennsylvania, U.S.A., pp. 85-91.
- Di Mascio, P., Cera, L., Palermo, C., 2004. Road Sign Management System of Teramo Province, Italy. In: *Proceedings of the 2nd European Pavement and Asset Management Conference*, Berlin, 21-23 marzo 2004, pp. 1-12.
- ERF, 2014. Road Asset Management. An ERF Position Paper for Maintaining and Improving a Sustainable and Efficient Road Network.
- Fredericque, B., Lapierre, A., Byrn, P., 2009. 3D City GIS for sustaining city infrastructure: the Bentley approach. In: *ISPRS Archives*, Lund, Sweden, Vol. XXXVIII-2/W11.
- Hatger, C., Brenner, C., 2003. Extraction of road geometry parameters from laser scanning and existing databases. In: *ISPRS Archives*, Dresden, Germany, Vol. XXXIV-3/W13, pp. 225–230.
- Haubrich, T., Seele, S., Herpers, R., Muller, E.M., Becker, P., 2013. Semantic Road Network Models for Rapid 3D Traffic Scenario Generation. In: *Tagungsband ASIM/GI-Fachgruppentreffen STS/GMMS, Workshop Simulation technischer Systeme - Grundlagen und Methoden in Modellbildung und Simulation*, pp. 51–55.
- Heemskerck, M., Wilson, K., Pavao-Zuckerman, M., 2003. Conceptual models as tools for communication across disciplines. *Conservation Ecology*, 7(3), p. 8.
- Higuera de Frutos, S. and Castro, M., 2014. Using smartphones as a very low-cost tool for road inventories. *Transportation Research Part C: Emerging Technologies*, 38, pp. 136-145.
- Kiema, J.B.K., and Mwangi, J.M., 2009. A Prototype GIS-Based Road Pavement Information and Management System. *J Civil Eng Res Pract*, 6(1).
- King, H, Kratzchmar, M., 2010. TransInfo Project Replacing a Legacy System: Institutional Adventures in COTS Software Acquisition and Implementation. Presentation at 2010 GIS for Transportation Conference Charleston, West Virginia. <http://www.gis-t.org/files/QJXUe.pdf> (11 Dec 2015).
- Lefler, N., Fiedler, R., Abbott, D.E., 2013. Presentation at 92nd Annual Meeting of the Transportation Research Board, Washington D.C. “Using GIS to develop an intersection inventory for safety”. <http://docs.trb.org/prp/13-4663.pdf> (11 Dec 2015).
- Luliang, T. and Qingquan, L., 2004. The Research of Transect-Based Three-Dimensional Road Model. *ISPRS Archives*, Istanbul, Turkey, Vol. XXXV, Part B5, pp. 174-177.
- Mammarella, J.J., 2014. Road Inventory. In: *Encyclopedia of Transportation: Social Science and Policy*, SAGE Publication, Los Angeles, California, pp. 1165-1169.
- Manyazewal, A., La, Anil M., Prasad, CSRK, 2014. No.201/ISRS Proceedings 2014/ISPRSTCVIII Mid-Symposium, Hyderabad, India “Advanced Information System for Planning and Maintenance of Rural Road using GIS”. http://www.isrsindia.in/isprs_doc/isrs_p_201.pdf (1 May 2016).
- Mohaymany, A. S., Shahri, M., Mirbagheri, B., 2013. GIS-based method for detecting high-crash-risk road segments using network kernel density estimation. *Geo-spatial Information Science*, 16(2), pp. 113-119.
- Oregon Department of Transportation, 2012. Analysys Procedure Manual Version 2. http://www.oregon.gov/ODOT/TD/TP/APM/APMv2_%20Ch1.pdf (11 Dec 2015).
- Parami Dewi, A.A.D., 2013. Framework for implementing design build project delivery system in road infrastructure projects in Indonesia, Queensland University of Technology, Australia. <http://eprints.qut.edu.au/61741/> (13 May 2016).
- Road Transport Forecasts 2013. Results from the Department for Transport's National Transport Model, 2013. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/260700/road-transport-forecasts-2013-extended-version.pdf (1 May 2016).
- Sandgren, U., 2004. EURORoads – PAN-EUROPEAN ROAD DATA SOLUTION. Proceedings of the 10th ECGI & GIS Workshop, ESDI State of the Art, Warsaw, Poland, 23-25 June 2004. http://www.ec-gis.org/Workshops/10ec-gis/papers/23june_sandgren.pdf (13 May 2016).
- Schultz, G. G., Johnson, E. S., Black, C. W., Francom, D., Saito, M., 2012. Report No. UT-12.06 “Traffic & Safety Statewide Model and GIS Modeling”, Utah Department of Transportation Research Division, Salt Lake City. http://ntl.bts.gov/lib/45000/45600/45614/UT-12.06_FINAL_REPORT.pdf (16 May 2016).
- Seguí Pons, J. and Ruiz Perez, M., 2003. Geographic information systems and intelligent transport systems: technologies used to form new communication networks. *Networks and Communication Studies*, 17(1-2), pp. 53-70.
- Sharp, H., Rogers, Y., Preece, J., 2011. *Interaction Design - Beyond Human Computer Interaction*, John Wiley & Sons Ltd, New York.
- SITECO INFORMATICA SRL, 2008. Catasto Strade: panoramica, tendenze e innovazioni. *MondoGIS*, nov-dic 69/2008, pp. 52-56.
- Steere, A., 2012. *Automated GIS routing network for oversize/overweight vehicles*. Proquest Umi Dissertation Publishing, USA.

Sun, M. and Chen, J., 2000. Data structure research of 3D city road network. In: *ISPRS Archives*, Amsterdam, Netherland, Vol. XXXIII, Part B4, pp. 1025-1032.

Vella, M., 2008. Conference paper at XVIII Convegno Tecnico ACI, Roma, June 26-27 2008 “Il Catasto stradale e i dati di traffico: limiti attuali e proposte di adeguamento”. http://www.aci.it/fileadmin/documenti/studi_e_ricerche/monografie_ricerche/XVIII_Convegno_Tecnico/VELLA.pdf (1 May 2016).

Wathen, J., 1991. Developing A Road Inventory. *Maine Townsman*. Legal Note, April 1991. <http://www.maine.gov/mdot/csd/mlrc/documents/pdf/DevelopingARoadInventory.pdf> (1 May 2016).

Wix, J. and Nisbet N., 2008. Internal DTI report “Study into the Business Case for Interoperable Building Information Modelling (BIM)”, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/34710/12-1327-building-information-modelling.pdf (23 May 2016).

World Highways. International Road Federation, 1990. Vol. XLI, No. 8, Wahington D.C.

Xiao, F., Hongyu, Z., Caixia, Y., 2012. Development of Road Maintenance Management System Based on WebGIS. *IJCEE*, 6(5), pp. 294-298.

Yuan, L., 2008. 3D Hierarchical Road Network. *GIM International*, 22(8), pp. 49.