Information Needs and innovative Tools for Information Generation and Provision for Road Administration.

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ABSTRACT

Transportation is a crucial factor in the developing process, but the performance of the transportation sector is often sub-optimal, due to a lack of maintenance or demand-inadequate infrastructure provision. Transportation policy and the evaluation of policy alternatives aimed at improving this situation have to be based on up-to-date and reliable information about the transportation infrastructure and its usage integrated in *transportation management and information systems*. Generally speaking the *tasks* of transportation information systems may be defined broadly as

- infrastructure management including the planning, building and maintenance of infrastructure and the evaluation of policy alternatives and
- managing the usage of infrastructure including models of transport demand and traffic counts, models for network planning and for the organisation of network maintenance
  and
- defining and controlling the legal and economic framework for infrastructure use.

These tasks define the *information needs* of these management systems and have to be contrasted with the information situation, which often has to be characterised as one of

- low data availability
- heterogeneous data and corresponding problems with data reliability
- differing data requirements (e.g. details of infrastructure condition and seasonal influences)

This paper discusses different methods for building reliable (GIS)-database and sketches a *stepwise implementation* process. Besides technical problems different data requirements and the organisational and institutional frameworks will be taken into account.

The methods for the *generation* and *updating* of the database will increasingly rely on methods of remote sensing. This is due to the technological advances in this field, as well as the increasing availability of data and the methods of data processing. The necessary steps for creating and maintaining a reliable database can be found by complementing organisational measures, creating information as by-products of already implemented road administration procedures. Experiences from different developing and industrial nations will be compared in order to define best-practice models and avoid foreseeable problems.

The basic features necessary in the *implementation* of the management systems can be summed up as

- simple and extensible data structures
  (based on standards; possibility of country wide standard definitions and international data exchange),
- methods for the automated building and update of the database,
  (remote sensing and GPS-support enhanced to service process based information creation)

- simple instruments (visualization and database management) based on standard-GIS and database-systems at the start and
- an extensible system architecture (spatial detail in databases on a regional and sub-regional level, interfaces to more complex methods, e.g. transportation planning packages).

Existing information bases face the challenges of information provision and deployment as well as methods and questions of information access. Low investment costs, high reliability and ease-of information are shown to be crucial for information provision and usage. Systems and techniques for information access and information visualisation/querying/analysis/reporting will be shown and evaluated in examples.

Keywords: TRANSPORTATION GIS, INFORMATION GENERATION, REMOTE SENSING, WORK-FLOW INTEGRATION, STEPWISE IMPLEMENTATION

Problems and objectives:

Why to use GIS for road administration ?

In general the tasks regarding road infrastructure maintenance are kept in the responsibility of the public sector. Only recently – due to high maintenance costs – alternative models of financing the infrastructure have been adopted (e.g. road tolls and public-private-partnerships for financing new infrastructure). In addition, international donors demand the implementation of road information systems as a pre-condition for the allocation of funds, either for rehabilitation or new constructions. In order to fulfil these tasks issues like cost organisation and responsibilities have to be tackled, but also the transparency of working procedures and planning processes are important factors. A transportation information system should support the following tasks of a information and reporting system

- infrastructure management including the planning, construction and maintenance of infrastructure
  and
- managing the usage of infrastructure including models of transport demand and traffic counts, models for network planning and for the organisation of network maintenance
  and
- defining and controlling the legal and economic framework for infrastructure use.

More specific the tasks of a transportation information system are:

- provide an overview of the network and its status (including maintenance situation, administration, control issues and usage),
- avoid redundancy in data collection and data handling,
- control the investments (budget allocation) and plan network maintenance (due to the enormous maintenance problems Tanzania and Uganda have chosen to rehabilitate only parts of their deteriorated road network, so that a core network will result; AIREY u. TAYLOR 1993),
- set up models for network planning, starting from providing basic access, to provision of increased capacity and finally to improved operational efficiency and safety (HILLING 1996, 169) and
- grant (restrict) data access to all administrative units involved in road planning, construction and maintenance.

The benefits of using geographic information systems for road maintenance could be summarised as

- quick access on transportation infrastructure data from different places, locations and agencies

- displaying and making understandable the crucial issue of transportation infrastructure to broader groups of interest, planner, stakeholders and public and therewith…
- provides potential interfaces for participation in infrastructure planning and thus points out…
- the networking character of transportation infrastructure (not limited to road system: railways, water ways, etc.) for virtually all kind of agencies and investors and thus supports…
- “good governance” in helping to shift from hierarchical (vertical) administration culture to horizontal cooperate administrative culture and supports the…
- by international donors postulated transparency in management and maintenance of such public investments.

The benefits in a more technical sense would be:

- Bridging different parallel systems of transportation infrastructure measure systems and management within one country, with the possibility to preserve various systems in certain areas and for certain groups(e.g.traditional vs. modern)
- Bridging different systems of transportation infrastructure measure and management within different countries (e.g. different colonial past)
- Current (automated) updating of various measure systems with up to date technology like GPS
- Centralized storage , maintenance and update of infrastructure data but…
- With the possibility for various workstations around the country
- Is open to all kind of existing data import e.g. analogous data like
    - Old – traditional maps
    - accounting records etc.
        - but also to “state of the art” digitally data like
- RS Data
- GIS Layer
- Other digitally recorded information like database tables and excel sheets, CAD files and hand drawings as well as photographs.

These tasks define the information needs for management systems. However, the provision of information is characterised as one of

- low data availability
- out-dated data
- heterogeneous data and corresponding problems with data reliability
- differing data requirements (e.g. details of infrastructure condition and seasonal influences)
- lacking culture for data sharing between departments and agencies concerned
- insufficiently trained staff and experts dealing with data

The organisational situation: best-practice models available ?

Traditionally road administration in industrialised countries has been based on analogue systems of information presentation and information exchange. These systems are still in partial use, due to a reluctance of some departments of complex organizations to change to digital documentation. One reason for this reluctance may be the often centralised nature of database management, which means more work for the department’s employees but less control over their own information base.

The experiences of many European countries and in Northern America may be exemplified on the basis of just one (but central) category of information: the digital road network.

The diversity of datasets and data formats produced and still in use is an outcome of organisational problem of cooperation on data infrastructure issues. Datasets often were developed by different public and private organisations and with very different aims in mind, so that an integration of these datasets is often impossible. So a homogenization of diverse data sets is usually a necessary and time consuming step. In Austria with its 8 million inhabitants for example a variety of street network data sets do exist .To name only a few:

- Network by the BEV (Federal geodetic agency; derived from aerial photos at a scale of around 1 : 10000), covering main roads and continuously expanded to include minor roads.
- Networks by private companies built for car navigation systems (complete and detailed spatial coverage, initially making use of the BEV network; no recognition of specific requirements of public road administration, like administrative route names or milepost information).
- Networks digitized by provincial governments (scale usually 1 : 50000), usually used for planning purposes (e.g. regional accessibility or transportation modelling). Usually facing considerable update problems.
- Networks in use by communes, usually based on one of the networks named above but with revised geometry and additional specific attributes. Backward compatibility to data source is usually no longer available.
- Networks prepared for special purposes
  (In the ministry of transportation alone exist more than three networks of the high-level street network, with different attributes and without any update mechanisms in place).

All of these networks are mutually incompatible and do cost enormous of money for preparation, digitization, editing, attributizing and so on. There seems to be a clear waste of efforts for building these redundant datasets. Update problems are common to all these networks because the processes of constructing and maintaining the road network are not considered in the update procedures of the digital network.

In contrast to this situation the Swiss approach has been to generate a high-standard homogenized database in a concerted effort of central administration (national road authority) and federal institutions. Due to the very ambitious goals standards of high quality were defined but also enormous sums have been invested (> 10 Mio US$ implementation costs). These standards as well as the excessive costs of such an approach seem to be far beyond the reach of most developing countries but also of most European administrations.

Examples show that information collection without a definite procedure of database maintenance in place will not be successful. This has not only been shown in public agencies but as well in the private sector. A leading navigation information provider had to re-digitize one of the big European capital cities only three years after initial data collection – update procedures had not been sufficiently defined and the changes in the network (esp.: traffic regulations) were too numerous and their exact location was unknown !

The only possible solution to these problems seems to lie in a joint effort of public and private institutions. This would involve a cooperation of all public organisations which have road building or management responsibilities, so that immediately after a change in the network or in the legal framework (like a new speed zone) has occurred this event would be an element of the database. This kind of cooperation has started in pilot projects in two Austrian provinces (Lower Austria and Carinthia, each involving data exchange of institutions previously interacting only on an analogue base). The procedures set up for this aim will be described in the next chapter.

The information base:
Current status and how to improve
The problems of database creation and database maintenance seem to be very similar to the problems of the physical road networks. Building the base infrastructure is costly but nevertheless often receives adequate funding. The ongoing problem of maintenance costs are often overlooked and lead to serious devaluation of the infrastructure. One of the main criteria of an administration information system is reliability which depends on regular and procedures to assure quality standards.

The problem centres around two issues:

- Data homogenization
  A consistent and homogenous database has to be built, which allows the logical representation of all transport related phenomena. Such a homogenous database should be able to serve as a nation-wide standard.
- Data update and data consistency
  In order to build up such a database the issues of regular update and consistent data structuring (which are directly related) have to be dealt with. They can be seen as the basis of any database generation, because without them a major reconstruction or even a complete regeneration of the database could be necessary within a few years.

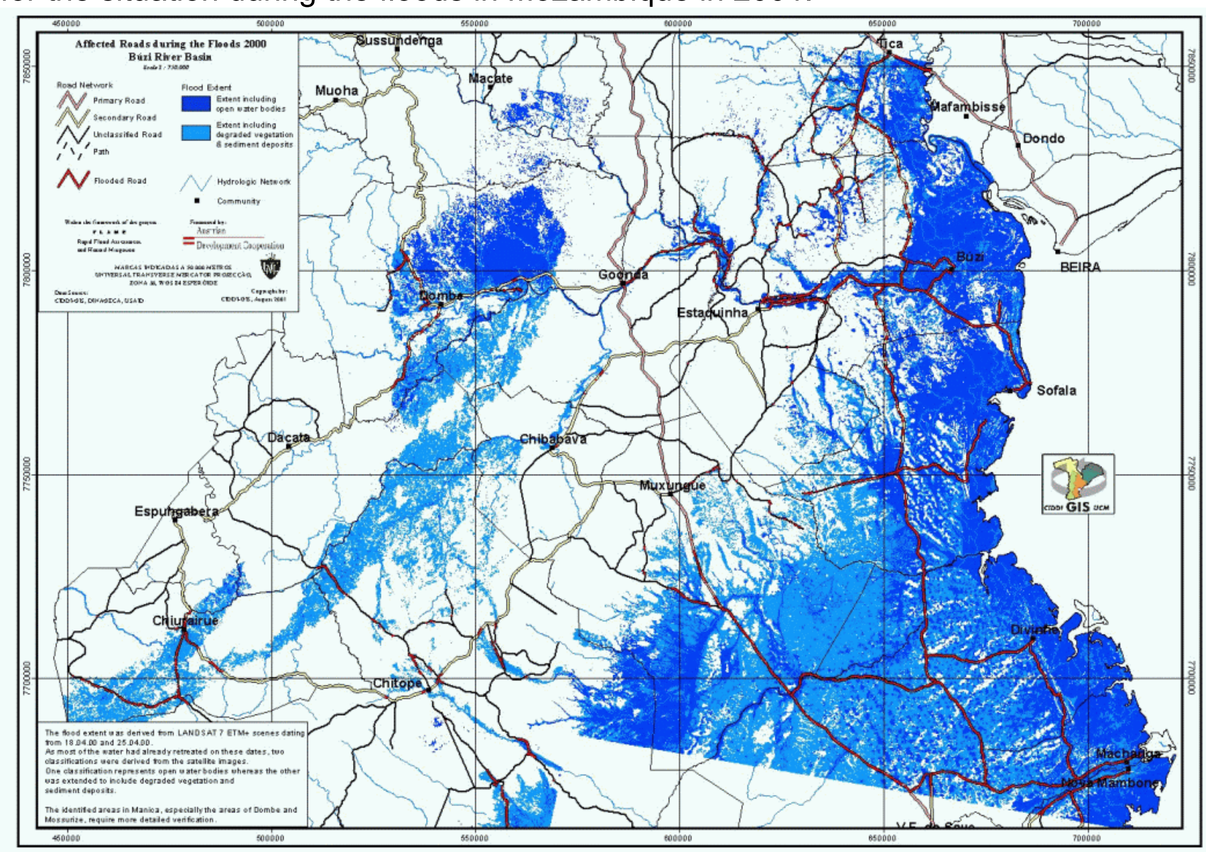
The most promising and innovative (but not new !) procedures of data collection and regular update are remote sensing and work-flow integration.

The generation and – to a less extend – the updating of the database will increasingly rely on remote sensing methods. This is due to the technological advances in this field, as well as the increasing availability of data and improved data processing methodologies. The necessary steps for creating and maintaining a reliable database can be found by complementing organisational measures, creating information as by-products of already implemented road administration procedures. The methodology established for the Swiss project ATOMI (Automated reconstruction of Topographic Objects from aerial images using vectorised Map Information) is one very advanced example for the use of remote sensing data for the update of road networks. With a combination of image classification, existing road data and the integration of a knowledge database, the recognition of roads is possible even when they are obscured by shadows and trees. Based on the extracted roads the road junctions are generated and therefore a complete road network is updated for management applications (ZHANG et.al. 2002). The paper clearly demonstrates the state-of-the-art of automated road extraction from remote sensing data under conditions of excellent data provision in a developed country. For an application in other areas the case study highlights the general need for the capture, storage and maintenance of accurate baseline such as vector data bases of topographic information, digital terrain models, etc.
Existing information bases face the challenges of information provision and deployment as well as creating facilities for access to and sharing of information. Low investment costs, high reliability and ease-of-use -information are shown to be crucial for information provision and usage. Systems and techniques for information access and information visualisation/querying/analysis/reporting will be shown and evaluated in several case studies.

Case 1:

The Ministry for Transport in Peru has been supported by the project: GIS Strengthening to Support Regional Transportation Studies, Highway Planning, and privatization (GAF 2001) The project focused on the development and implementation of GIS tools and spatial databases to assist in highway planning and privatization. For the establishment and maintenance of a highway inventory system satellite-based GPS (Global Positioning System) technologies were used. The project's webpage offers an insight into the map server (different road levels, settlements a.o) and outlines the capacity building program which was carried out to ascertain the sustainable use and maintenance of the road database.

Case 2:
Roads are the most important access routes for the rural population. Especially in developing countries where railways are either scarce or non-existing the distribution of goods from or to rural areas is completely dependent on maintained road networks. Information on level and status of the network becomes particularly crucial in situations of emergencies. At the onset of the present food crisis in Southern Africa the World Food Program WFP established an information system for logistics to improve the delivery of food supplies to the most affected regions (www.wfprelogs.org). The system is used to plan WFP shipments to the region and will make timely and cost-effective arrangements for port discharge and overland transport from the entry ports to in-country delivery points throughout the region. The road database used is still basic and does not offer the possibility for updating. How important timely information on road conditions are, is shown for the situation during the floods in Mozambique in 2001.



Graphic: Main roads in Sofala Province, Central Mozambique, and flood extent for peak water levels during March 2001 derived from satellite imagery and ground surveys (GALL 2002).

The main road network in Central Mozambique could not be used for rescue and food aid operations during most of the emergency period as essential parts were flooded. Due to timely and accurate information on the accessibility, emergency and recovery operations had to be carried out by using helicopters. Integration of recent information, however, requires the existence of operational geoinformation units in the region.

Case study 3:
The use of established work-flows for data generation can be shown in regard to traffic regulations. These kind of regulations are clearly defined in the Highway Code and are important for actual traffic flows as well as road safety. These regulations could provide a valuable information source, since they define – based on an officially defined work-flow – the most important traffic signs. But in practice the information is not often kept in adequate information order, due to their number of traffic signs as well as to the complexity of responsibilities (different regulatory authorities vs. different maintenance providers). Using the already established work-flows between regulatory authorities and maintenance providers on the basis of GIS functions can produce the following results:

- automatic production of regulation documents
- GIS data about traffic signs and their locations (and their meanings on the transportation network) as by-product of the regulation definition
- intelligent check mechanisms for conformity of regulation and installed traffic signs with Highway Code specifications (“Traffic logic”), based on GIS locations and formalized rule sets

This kind of work-flow use is supposed to result not only in datasets (“automatically” generated) but will also help in achieving legal security (for both the authorities and the road user), road safety (by helping to reduce traffic sign numbers) and documentation (of legal documents as well as traffic signs).

work-flow for
traffic regulations
(abbreviated):

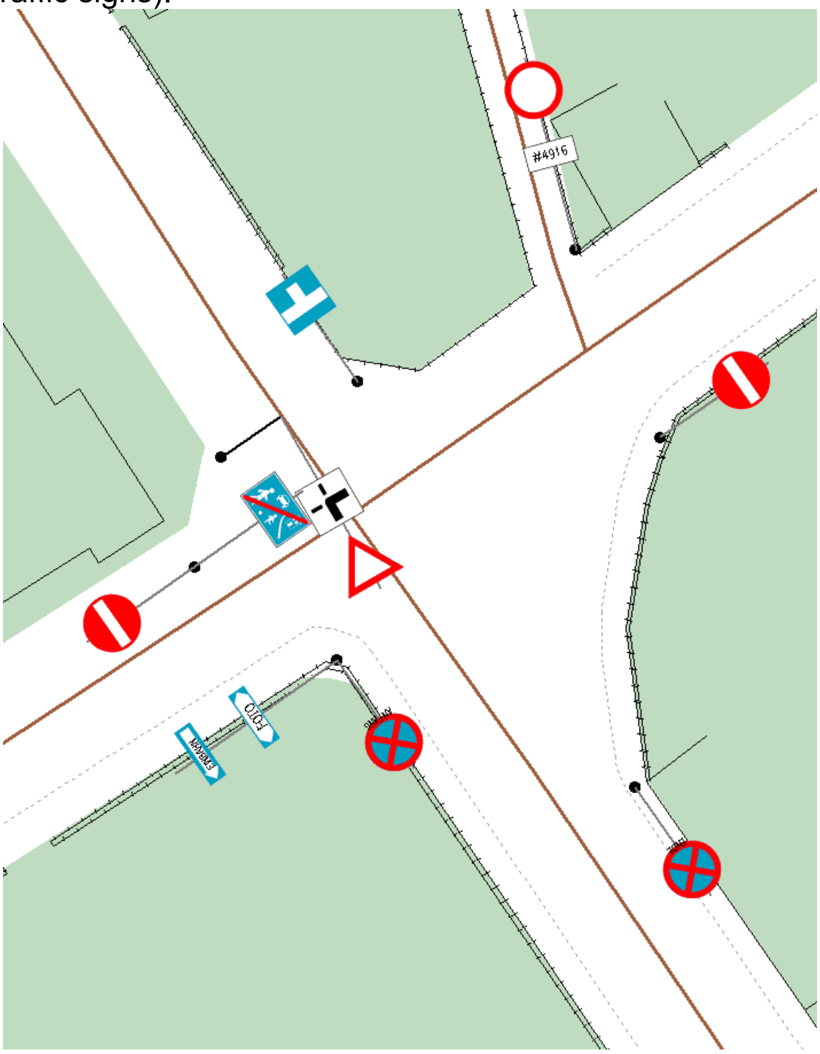
problem
(accident accumulation,
noise, traffic jams,…)

proposal for regulation

authority :
regulation (decree)
➔ produces legal document
➔ by-product: traffic signs in database

road maintenance
provider:
affirmation of traffic sign
installation

traffic regulations become
effective



Graphic: Automatically generated map of traffic regulations from GIS database. Direct link to original decree via work-flow.

This kind of work-flow integration and interaction between different responsible bodies is currently being tested in the pilot projects named above (Lower Austria and Carinthia).

System development: baseline and objectives

The baseline of system development for road administration systems is widely differing. It depends on data availability, definition of objectives, preparatory work and available funds. One of the most important issues is the definition of objectives. They should not be set overambitious and will strongly depend on existing or ongoing project efforts of related organisations (e.g. central informatics services or geoinformation services of an administration) and the nature of relations between these organisations.

The basic features necessary in the implementation of management systems can be derived from the discussion above and summed up as

- Simple and extensible data structures
- Documentation and metadata
- Methods for the automated building and update of the database
- Simple tools for visualization, database management and reporting
- Extensible (modular ?) system architecture
- Training of experts and staff

Data structures have to be simple but extensible. Complex data structures may well serve the purposes of scientific data modelling – but they also increase risk of dependency on (external) software developers. Complex structures may also lead to low data input rates and poor database maintenance, due to high costs of training and a lack of self-explaining input mechanisms. Simplicity does not replace training but it helps to facilitate training and the often long process of capacity building. Data structures have to take into account existing international standards which experience high support from the software industry and international organisations. The adopted standards have to be (possible) country wide standard definitions and allow for international data exchange. The data structure thus should rely on the „simple features geometry" – definition of the OpenGIS-committee (e.g. GANTER 1995) and clearly define a one-dimensional reference system. This basic reference system should include definitions for the integration of data in different reference systems (e.g. O'NEILL and HARPER 1997). The database structure should be extensible and from the start define update procedures and responsibilities as well as the rights for defining certain categories of data. As a starting point (with lower costs involved) a secondary reference system (based on an edge/nodes data structure) can be used, but it should from the beginning be fully compatible with the later linear reference system.

The documentation of existing data as well as adding important new items of information has to be carried out in a metadata base,. This documentation should also be based on existing standards (e.g. FGDC or ISO19115) and thus include inter alia data about

- purpose of dataset creation and intended use,
- who (contact, distribution point and methods,…)
- where (spatial extent)
- what (contents, attributes described in detail)
- methods (of data creation and update, lineage)
- measures
- quality (consistency, completeness, reliability,…)An enhanced meta information base can serve additional purposes. With the definition of certain minimum requirements of data by data categories and the definition of methods how to define objects in this data

category (rule set) metadata can be used in the input or analysis process of system usage as well.

Simple tools (visualization and database management) based on standard-GIS and database-systems at the start. Since the generation of a complete high-quality database will not be financially feasible in the short-run a concentration on the most important network features seems to be inevitable (i.e. on the interregional highway network). But a total neglect of the rural feeder roads in the beginning would mean to ignore the information needs of the most remote and transportation disadvantaged population. In order to counter that danger a complementary pilot project in a test-area (with complete road coverage of all road categories) seems helpful. This selective database generation with different devices and resulting different data qualities needs to be complemented by a metadata management system which includes detailed quality information and thus allows a successive improvement of the data quality.

An extensible (modular ?) system architecture. Extensibility in this context means to allow different levels of spatial detail in databases (for example on a regional and sub-regional level), to start with simple methods and procedures and to interface them later on with more complex methods, e.g. transportation planning packages. The technical success of defining an extensible system architecture depends strongly on fulfilling the first two features: using standards and relying on data documentation by metadata.

Information for road management can only be produced reliably and timely by local institutions. Data bases on location, road condition and use have to be updated regularly and require local knowledge. National centers for remote sensing and geoinformation need the strong support by regional and local governments. The staff requires continuous training and scientific exchange to improve information provision and apply new methodologies for updating datasets. In many cases the assistance by the international community is required to achieve the establishment of these centers. In this sense, the cooperation between GIS industry and international agencies is highly appreciated. In a recent development, the software provider ESRI and the United Nations Human Settlements Program joined hands to strengthen local capacities to establish and maintain geographic information systems for town planning and infrastructure management (http://www.unhabitat.org/programmes/guo/support.asp).

Outlook: a virtual time schedule.

A key feature of successful transportation information systems implementations is a step-wise process of system development. It allows for a long-term perspective on capacity building as well as for short-term achievements. They increase motivation and make fund raising easier.

This stepwise procedure has to take into account

- the organisational structure
- costs of database development and immediate use of information
- costs and user groups of tools to be used/developed
- stepwise extension of the system and time scales
- the value of information, which can often be used also outside the road administration.

Information systems have to be integrated into existing organisational structures. Disregard of this fact usually leads to unsuccessful implementations. Support for this problem can be found in training measures, awareness raising and especially by directly involving end-users in the set up process (providing them with direct information access and thus enhancing their capabilities).

The database generation may use a mixture of methods, including GPS, photogrammetry, remote sensing, digitization of analogue maps and creation from within of existing work-flows. In areas with a very low coverage or a very poor standard of maps the automated extraction of a road network from remotely sensed data might prove to be the most efficient way (GRUEN et al. 1997). A specific problem in this context is posed by the great importance of the road category „earth-road or gravel-road“ in developing countries, which is difficult to distinguish from its natural surroundings.

An alternative to this can be found in the integration of the data collection process into road maintenance. A starting point for developing countries could be to collect data by road sections, which constitute road surveillance sections, kept up by lengthmen (as practiced in Kenya; AIREY u. TAYLOR 1993). Integration of work-flow procedures into the information collection process should thus not be restricted to industrialised nations (where this is still not often the case). The specific advantage of using existing work-flows are the comparably lower costs of information collection and the improvement of data update (and thus: reliability).

The implementation must rely on a stepwise procedure, so that available data can be used, checked with quality attributes and then enhanced. The application architecture should start with a simple environment, consisting of a combined database system (for data structuring, organization of data access and for checking the data consistency) and a GIS (for providing base maps and querying the data). The visual and logical checking of the database seems to be of great importance, since the described data collection procedure does not exclude errors. In an extension phase the deployment of data access rights (decentralized access) and additional analytical tools (for accident analysis, routing or transportation planning) are possible steps.

A comparison of costs and benefits should also take into account the potential value of the information collected – taking into account for example the severe problems of information updating for car navigation systems.

Thus a system can be built which allows at (comparable) low initial costs to perform the major tasks of transportation monitoring and road construction / maintenance. The costs of such a system have to be weighed against the costs of road building / maintenance and the potential efficiency gains in performing these tasks.

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