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Implementation of a GIS Database for the Management of the Road Network

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Abstract: ***This work focuses on the establishment of a coherent and functional road information system covering the road network of the District of Bamako, to ensure effective monitoring of the network and efficient management of road maintenance. The methodological approach adopted for the realization of this work revolves around the preparation of data, the modeling of data, the implementation of data and the creation of a spatial database with the ArcG is software. Some important results are: 1) Inventory of data on the road network of Mali; 2) Estimation of the impacts of the Geographic Information System on the activities of the DGR; 3) Creation of a map service; 4) The road information system operational and used by the DGR.***

Keywords: Geographic Information System, Road Maintenance, Spatial Database

1. Introduction

Improving roads is undoubtedly an essential factor for the economic development of a nation. Thus, previous governments and the current government of the Republic of Mali have all given priority to the preparation and implementation of transport infrastructure projects and programs. In particular, they gave priority to road transport, to facilitate the movement of people and their goods in order to ensure sustainable development [1] .

The city of Bamako with a strong population is faced with a significant need for transport infrastructure and particularly in the road sector. In 2016 the Government of Mali, through the Strategic Framework for Economic Recovery and Sustainable Development (CREDD), planned to develop a road development plan for the District of Bamako which also provided for the establishment of a road computer system [2] . The General Directorate of Roads, which is responsible for setting up and managing the geographical information system for roads in accordance with Law No. 2021-039 / of July 08, 2021, has a database whose structure does not does not facilitate cartographic manipulation and spatial analysis of road data [3] . Faced with the pressure exerted on the road network by vehicles, natural phenomena and the practices of the populations and also faced with the slowness of road maintenance, the state of deterioration of the roads is changing rapidly. An analysis of road networks integrating these different factors could help prevent or identify critical road sections, in order to alert the authorities and enable them to take adequate measures [4] .

However, the database of the DGR (Direction Générales des Routes) does not take into account the road network of the District of Bamako [5] . Our study on the "Design of a road information system in the District of Bamako, Mali" is part of the process of setting up a road information system (RIS) in Mali.

The general objective is to set up a coherent and functional road information system covering the road network of the District of Bamako.

More specifically, these are:

- Provide geo-referenced information on road deterioration;
- Provide information on the nature and characteristics (geometric and structural) of the roads;
- Provide information on degradation and traffic on the road network;
- Provide information on investments made for road maintenance;
- Develop a decision support tool.

2. Study area and Materials

The District of Bamako (capital of Mali) is located between -8°45' and -7°55' west longitude and between 12°30' and 12°45' north latitude [6], [7] . It extends from West to East over 22 km and from North to South over 12 km, for an area of approximately 267 km². Its average altitude is 350 m. Its weather provides 31°C as an average temperature, SW wind at 8km/h with a humidity of 59%. The population was estimated in 2023 at 2,929,000 [8] .

The key tools used are:

a) One (1) large capacity laptop on which Microsoft office software (Word, Excel and Access) and ArcGis 10.3 is installed;
b) Possibly the data collection tablets to supply the road data bank.

The design of a road information system in the District of Bamako, Mali, should be based on a number of guidance documents to provide reliable and necessary information on the road network, to anticipate future needs to which he must respond.

The data used are:

- Attribute data from the L2R database of the General Directorate of Roads;
- The Bamako District road map shapefiles provided by the Geographical Institute of Mali, which are in the WGS84 world geodetic system and projected in the UTM zone 29 coordinate system;
- The various road maintenance programs of the last three (3) years;
- Data from road deterioration surveys;
- Road count (traffic) data for three (3) years;
- Accidentology data;
- The coordinates and characteristics of the structures (bridge, culvert, etc.);
- The coordinates and characteristics of the intersections;
- The coordinates of road counting stations;
- The coordinates and characteristics of the landmarks (start and end);
- Road sign inspection data.

Figure 1: Study area

Table 1: Summary of data collected

Data	Kinds	Format	Source
The map of the Bamako District road network	Vector	.Shp	Geographical Institute of Mali
Road damage surveys	Tabular	.xlsx	Directorate General of Roads
Road maintenance programs	Tabular	xlsx	Directorate General of Roads
road count	Tabular	xlsx	Directorate General of Roads
accidentologies	Tabular	xlsx	ANASER
The coordinates and characteristics of the works of art	Tabular	xlsx	Directorate General of Roads and Land

3. Processing process

Our treatment process has adopted the approach detailed in the following diagram.

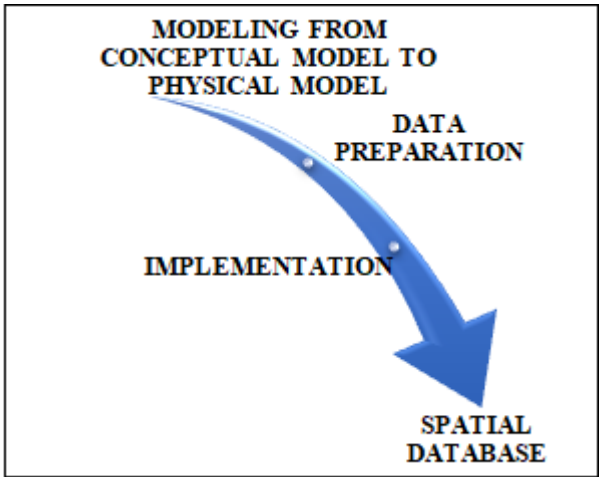

Figure 2 Flow diagram

3.1 Modeling from the conceptual model to the physical model

The modeling of a database includes three (3) phases that allowed us to describe the structure, the associations of the relations and the constraints relating to the available data [1], [9] . We also established standards for the organization and then coded them.

3.2 Conceptual model

The purpose of the conceptual data model (CDM) is to formally describe the data that will be used by the information system [10] . It is therefore a data representation, easily understandable, allowing to describe the information system using entities [11] .

In our conceptual model, we have:

- Group objects into classes and then identify them
- Creates links between objects based on their cardinalities

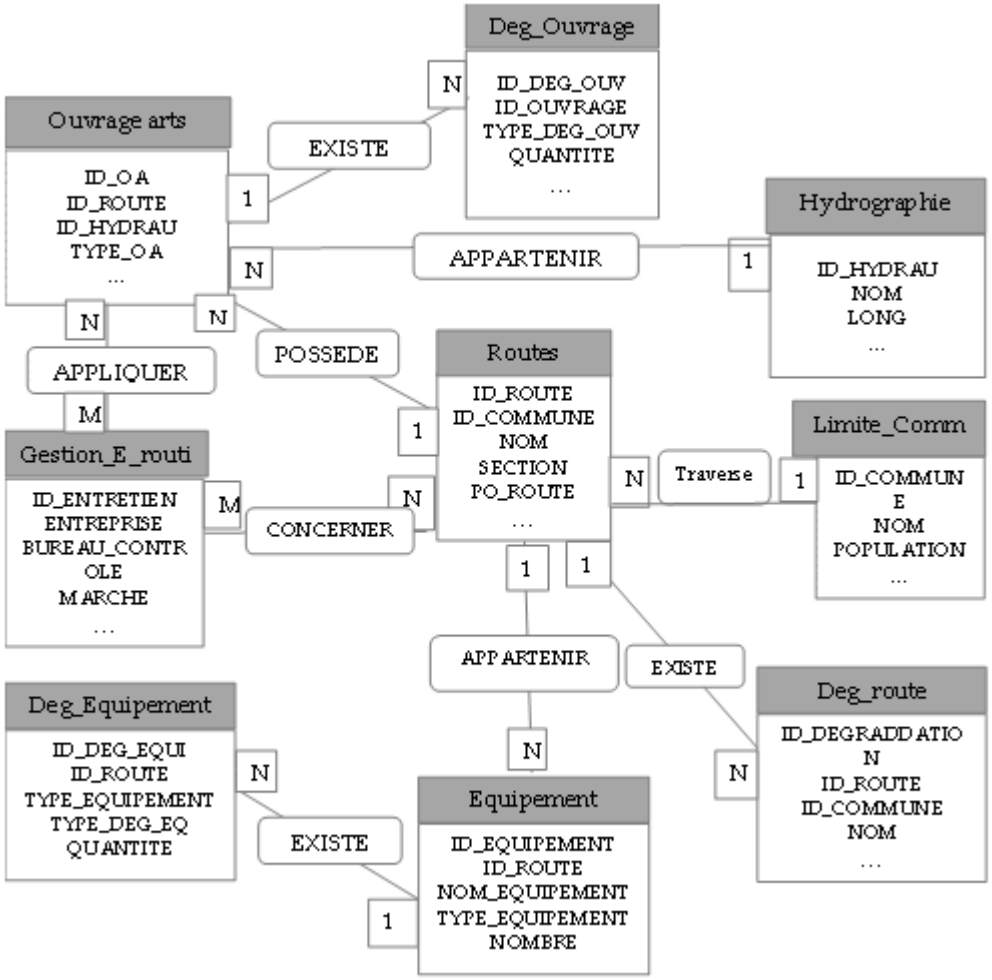

Figure 3: Conceptual model

3.3 Logical model

Our logic model mirrors our conceptual model. It is composed of four (4) spatial tables in yellow color and seven (7) non-spatial tables in gray color. With the existence of two many-to-many (NM) cardinality relationships we created two more tables (Apply and Concern) in our logic model to make our conceptual model readable and usable for the computerization step [11] , [12] .

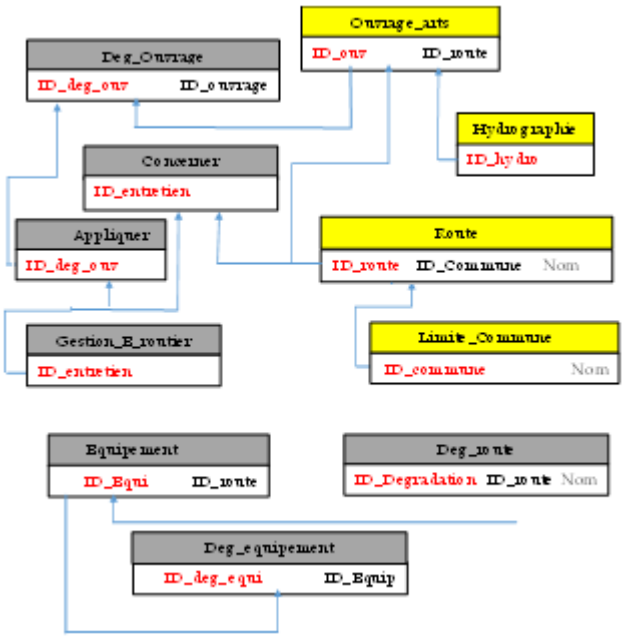

Figure 4: Logical model

3.4 Physical model

At this stage, we have implemented the model in the DBMS, ie translated it into a data definition language. In this case, the physical model was created on Arcgis 10.3 software, which uses a utility for creating relationships between layers based on the primary keys of the attribute tables. This utility is a tool of the ArcCatalog extension of the Arcgissoftware [12] . With this utility you can realize all the relations of cardinality 1-1, 1-N and NM.

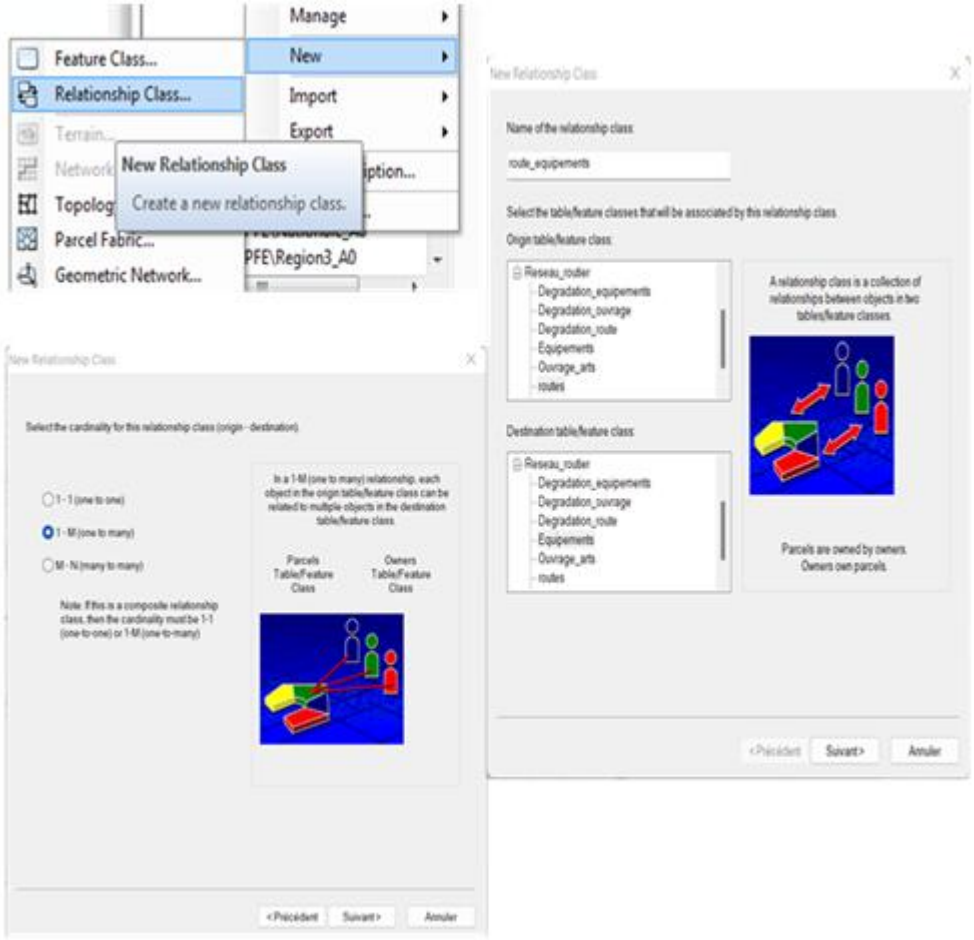

Figure 5: Physical model

3.5 Data preparation

To be able to use and integrate into our spatial database the data collected from different sources (Geographical Institute of Mali and General Directorate of Roads), we have adapted them to our needs for storage in the database.

For example, we identified, selected and renamed the roads of the District of Bamako according to the national classification, in the database provided by the Geographical Institute of Mali, to which we added thematic data. The hydrographic data and the limits of the communes of the District were also selected from the base of the Geographical Institute of Mali. Then we digitized the works which are the points of intersection of the roads and the rivers.

3.6 Data implementation

Our database is made up of four layers of data, namely roads, structures, hydrography and municipal boundaries. Each of these layers constitutes one or more data tables.
Data management rules have been defined to create the data tables and the relationships that may exist between them. The roads crossing several communes have been divided into communal sections in such a way as to have one road network per commune.

3.7 Spatial Data

For the creation of the database in ArcGis , we first have to create a directory in a hard partition of the computer in which the IGM shapefile file is stored. A connection is then created with this directory in ArcCatalog in which the database will be created (file geodatabase). Thus, after the creation of the database we have created as many entity datasets and entity classes according to the elements which must be represented by a class, to feed the database. Next, we created the relationships between the different entity classes according to the relational logic model.

In this case a directory named SIR PFE22 database has been created in the partition (F) of the computer . From the ArcCatalog application , a connection with said directory was made using the Connect To Folder tool, to create our database named SIR_DISTRICT_BAMAKO. So we then created the feature class sets (Feature Dataset) road network, hydrology, neighborhoods and administrative boundaries and other attribute tables exported from Excel.

These feature class sets combine the following feature classes and relationship classes:

- Roads (line primitive);
- Work of art (primary line);
- Equipment (point primitive);
- Road degradation (primitive point);
- Degradation of the structure (primitive point);
- Equipment degradation (primitive point);
- APPLY;
- CONCERN;
- Administrative boundary (polygon primitive);
- River (polygon primitive);
- Watercourse (primitive line)
- Structure _ hydrology relationship;
- Road _ road limit relationship;
- Route _ Equipment relationship ;
- Road relationship _ Road degradation;
- Road _ structure relationship;
- Equipment relationship _ Equipment degradation;
- Structure relationship _ Structure degradation

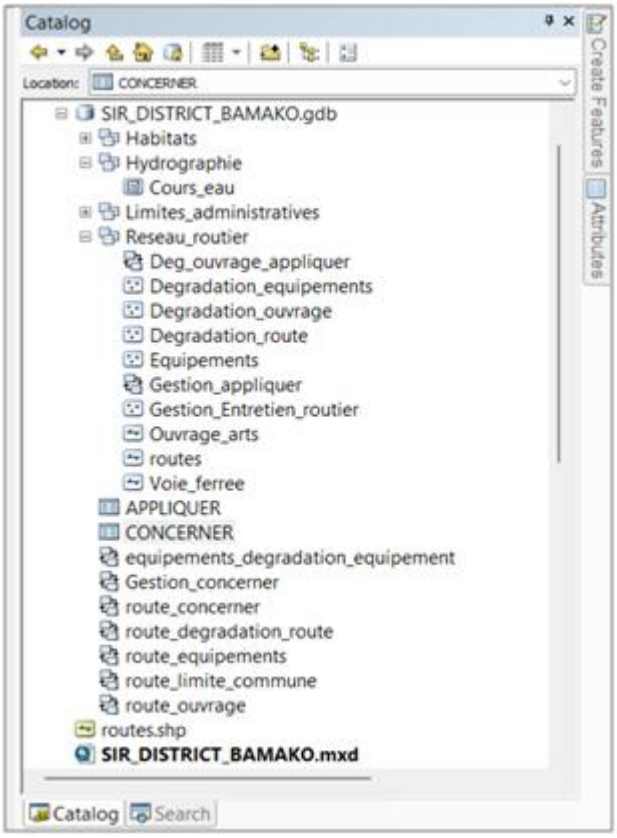

Figure 6: Database

4. Results

4.1 Spatial analyzes

The designed database is the source of queries according to one or more criteria. It is much more dependent on the computer system, especially software. These queries allow precise visibility of the areas of the thematic maps and to extract data from the database in a format that can be used in relation to the user's needs.

The database initially provides direct information on road sections, structures, degradation and maintenance.

For example:

- Structure: gives the number of types of structures existing on this section, information on the types of degradation on these structures and the service providers (company and control office) who are in charge of correcting their degradations;
- Road degradation: provides information on the types of degradation existing on this section in a qualitative and quantitative way;
- Degradation of equipment: provides information on damaged equipment in a qualitative and quantitative way;
- Hydrography: gives information on the number of watercourses crossing this section of road;
- District: indicates the municipality where the road section is located.

Figure 7: Bamako District road network (data source: IGM)

4.2 Spatial analyzes

The base map of the database is always necessary for the visualization, location, identification of road sections and the inventory of the road network of the District of Bamako. The thematic maps produced from this background represent roads, structures, road traffic and degradation.

From this base map we have developed some thematic maps which are:

Figure 8: Deterioration of the road network in the District of Bamako (data source: IGM)

5. Conclusion and Perspectives

Seeing the many obstacles concerning access to data affecting our study, the design and implementation of the database for the management of the road network was successfully carried out.

The Geographic Information System not only makes it possible to set up a database which ensures good archiving of ever-increasing road data and optimization in the processing and use of this data. It also makes it possible to publish and share geographic information to the public. The GIS through its tools facilitates the collection and integration of multi-source data in a single database. This added value to the processing and analysis of data will help provide a rapid response to questions of monitoring road infrastructure and related equipment as well as their maintenance.

Thus, its contribution to the monitoring and management of road maintenance will be a great asset for decision-makers in the development of effective strategies for road maintenance and network monitoring. Proper monitoring of road infrastructure makes it possible to consolidate the achievements and partially solve the problems of opening up and urban mobility.

The major challenge remains to establish at the national level an updated and reliable database allowing the preparation of dynamic road maps for possible explorations and static for other needs.

In perspective We plan to improve our DBMS (Database Management System) for monitoring and managing network maintenance in the District of Bamako, namely:

- Companies executing new roads or maintaining them
- The budget injected into each route by company
- Execution times of each route
- Lifespan of each new or renovated road
- Addresses of the key technical personnel of the executing companies

Finally, the database will be the subject of publication in open access of the various maps of road networks on the Web

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