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A Proposed Framework for Using GIS to Enhance Traffic Safety in Sudan: A Case Study

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Abstract: The aim of this paper is to provide a framework for an effective use of geographic information systems to enhance traffic safety in Sudan. The paper identifies opportunities, evaluates the underlying needs and constraints so as to improve operations, reduce costs, facilitate new joint analysis in order to generate interest and lend support to the decision maker. Reference information is given to guide future efforts and support the organs of the State to develop and improve GIS programs concerned with traffic safety. Prospective users of the system will have access to the data at a low cost and without delay.

Keywords: GIS, Traffic Safety, GIS Framework, Geospatial

1. Introduction

Increase in the number of vehicles in cities is one of the most common problems faced by governments in most countries; leading to traffic accidents, carbon dioxide emission and waste of resources and money. Traffic safety has therefore become a global issue causing concern round the world. The World Health Organization reported that the total number of deaths of road accidents was 1.25 million in 2015 [1]; the majority of the dead were of young people, aged 15–29 years. This rate of accidents poses a serious challenge that requires the development of an effective strategy for the management of road traffic mode to improve safety and reduce traffic incidents.

Sudan is one of the countries that suffer from traffic accidents. The Directorate General of Traffic in Sudan (2010) reported 6397 incidents of serious injuries, 12230 incidents of simple injuries and 41880 damaged vehicles. Accidents caused by driving under the influence of alcohol were 5073. Most of the accidents were caused by public transport vehicles followed by commercial transport vehicles. According to unpublished figures there were about 2,000 people killed and 500 injured during 2015.

Although it is possible to quantify the costs associated with traffic accidents, it is important to highlight that the loss of a human life by accident is a tragedy and the value of a human life is priceless. [3]

The Traffic Safety Coordination Council was created in 2010 with the aim improving of traffic safety and coordinating the efforts for the preparation of a national strategy for traffic safety. The proposed framework is expected to help in the achievement of these goals.

2. Background

2.1. GIS

A geographic information system (GIS) can be defined as a special case of information systems where the database consists of observations on spatially distributed features, activities or events, which are definable in space as points, lines, or areas. A GIS retrieves and manipulates data for ad hoc queries and analyses [3]. GIS can provide different and distinctive services to the user, such as applications of spatial autocorrelation. Geographic databases store the data in several ways, giving the user the ability of analysis, reasoning, comparison and application. The system uses satellite images, aerial photographs and topographic maps in the preparation of base maps with all the precision required spatially and in terms of information.

GIS is designed to capture, store, manipulate, analyse, manage, and present all types of spatial or geographical data linked to a specific location. GIS tools allow users to create interactive queries, analyse spatial information, edit data in maps, and present the results of all these operations [2, 3]. The tools are capable of storing, manipulating, analysing and retrieving geographic information [5].

The main purpose of GIS is to help in decision-making related to managing the use of land, resources, transportation, retailing, oceans or any spatially distributed entities. The connection between the elements of the system is geography, e.g. location, proximity and spatial distribution [6]

A GIS consists of five major components: hardware, software, data, people, and methods.

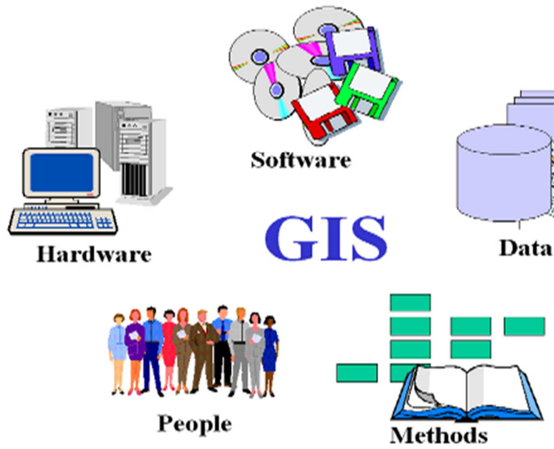

Figure 1. *Components of GIS.*

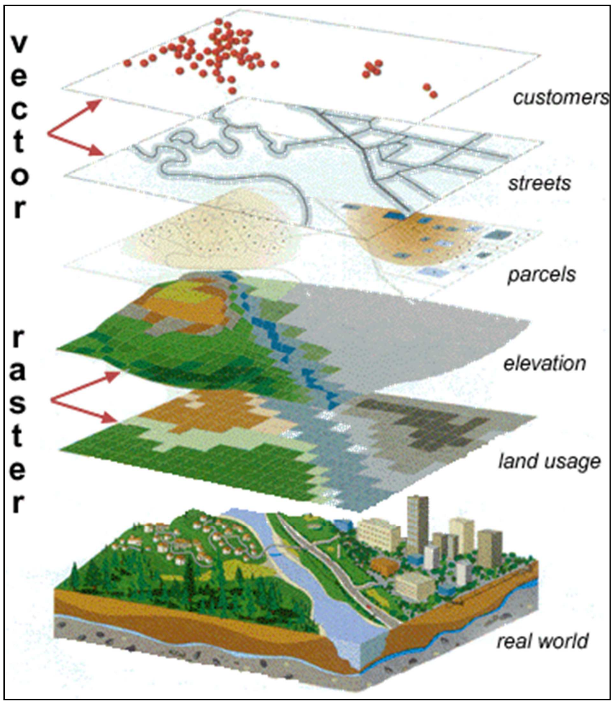

Figure 2. *The concept of layers.*

The steps that have to be taken to implement a GIS involve: data entry, data display, data management, information retrieval and analysis. A more comprehensive description defines GIS in layers (Figure 2). In this way it is possible to analyse GIS thematic and spatial characteristics so as to obtain a better understanding of the system.

The general architecture of a GIS can be divided into three major components: database; analytical engine and input, output and user interface. A GIS application automatically generates a spatially-oriented product or result needed by a user. The applications may include: map update or map production, data query and display, spatial analysis, or other processes that use GIS software and geographic data. These applications give users in the office and in the field effective and easy-to-use ways to access information, answer questions, generate products, and support decision-making. For public sector organizations, GIS applications are integrated with other systems (e-government, document management, permit tracking, asset management) to support operations and serve the public. [7]

The GIS is greatly used to support the integrated operations of road networks, including the design and facilities planning, construction and maintenance of existing infrastructure while playing a central role in the management of traffic operations. Some specific examples of the GIS applications include:

1. Project/corridor planning, visualization
2. Transportation planning and travel demand modelling
3. Performance and condition monitoring and reporting dashboards
4. Vehicle routing and permitting
5. Intelligent transportation Systems (ITS) integration

Most general collision prediction methods are not capable of answering one simple but important question in road safety: where are the hazardous road locations? To answer this question, the spatial pattern of collisions must be explored in a scientific manner [8].

People have anticipated GIS to be more powerful not only as an archival and data management tool but also as spatial models for supporting decision-making in intelligent cities. [9].

The power of GIS-based modeling we feel that regional councils and planning agencies should convert their transportation planning models to GIS-based transportation planning models and then choose to perform any aggregation scheme that operational constraints may dictate. [10]

Geographical Information System (GIS) technologies have become the most used tool to analysis and show the traffic accidents on highways in recent days [11].

The fast-growing GIS and GPS technologies also represent unprecedented opportunities to conduct research and to solve problems related to transportation and land use in the future [12].

The use of Geographic Information Systems (GIS) in road safety analysis has increased rapidly in recent years. They have proved to be effective in answering simple accident enquiries and identifying single sites with a high number of accidents [13].

2.2. Defining Safety

The traffic accidents that are one of the most important issues happened in our life. Due to the loss of lives and huge amount of money, the scientists aim to prevent the traffic accidents in the developing countries [11].

Traffic safety and road accidents are major issues of concern worldwide and in Gulf Cooperation Council in particular. This is due to the huge losses on the social (fatalities and injuries), economical, and environmental levels affecting most developed and developing countries' economies [14].

Traffic collision analysis is essential for reducing traffic injuries. While most traditional approaches focus on the time dimension of traffic collisions, the recent past has witnessed a growing awareness of the spatial dimension in a geographical context [15].

Transportation safety has received special attention due to the significant cost of accidents to society. Road safety programs include several strategies such as road improvements. The effectiveness of each strategy depends on the problems, improvement options, and conditions of the subjects [16].

The goal of the transportation industry is to promote the movement of people and goods in a safe and efficient manner. Researchers have developed ways to evaluate safety on our roadways and identify ways to mitigate unsafe conditions. For instance, in the United States each state is required by the FHWA, as part of the Highway Safety Improvement Program (HSIP), to submit an annual report describing not less than 5 per cent of their highway locations exhibiting the most severe safety needs, as well as develop a plan to remedy those hazardous locations, all in an effort to provide a safe and efficient transportation network [17, 18].

Safety is often quantified or measured by tracking the raw number (frequency) of fatalities, injuries, or crashes, or by calculating injury, fatality, or crash rates which are crash frequencies normalized for exposure as shown in Equation 1. Each method has its advantages and disadvantages that depend on the intended use and audience of the data [17, 19].

Crash rates are most often measured by the number of crashes occurring per million vehicle miles travelled (MVMT) for roadway segments, or crashes per million entering vehicles (MEV) for intersections (AASHTO 2010). Equation 2 shows the crash rate equation for a section of roadway [16, 19].

$$R = \frac{C * 100{,}000{,}000}{V * 365 * N * L}$$

Equation 1: The crash rate.

Where:

R = Roadway Departure crash rate for the road segment expressed as crashes per 100 million vehicle-miles of travel,

C = Total number of roadway departure crashes in the study period

V = Traffic volumes using Average Annual Daily Traffic (AADT) volumes

N = Number of years of data

L = Length of the roadway segment in miles

$$CRsec = \frac{N * 10000000}{V * 365 * L}$$

Equation 2: crash rate equation for a section of roadway.

Where:

CRsec = crash rate for section (in crashes per MVMT).

N = number of crashes per year.

V = average annual daily traffic (AADT) of road section.

L = length of section (in miles).

3. GIS Framework

With the highway infrastructure under strain, there is a need to collect and analyze traffic volume, vehicle classification, and weight data in an integrated manner [21].

The use of GIS in road management, particularly for safety issues, allows performing a wide range of spatial analysis and a graphical representation of the results for subsequent interpretation [22].

The frame is a way to build the infrastructure of national spatial data. It collects geographic data at the national level to serve a variety of users and traffic safety partners and therefore has frequent need for multiple threads of data. The frame builds a database for the geographic area, utilising all the national strategy for traffic safety components. It represents a model for sharing resources, improving communications and increasing efficiency.

The Framework consists of four main components: environment, data, procedures, and technology. Its main function is to facilitate the production and use of geographic data design, reduce costs and improve service and decision-making. It is expected to improve the performance of the functions of the various sectors of the traffic safety partners. It can also be of benefit in the construction of different applications under the umbrella of a single database from which various data applications are shared, providing a reliable reference for each data at a low cost.

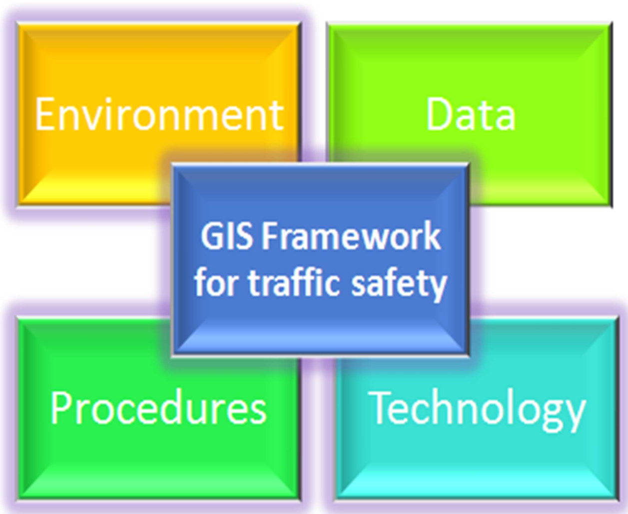

Figure 3. *The Elements of GIS Framework for traffic safety.*

3.1. Environment

GIS environment consists of:

1. The external environment represents the main source that supplies the system resources, including the factors that affect each system. These factors can be: political, economic, cultural, social traditions, legal or related to technology. These factors will influence the identification of opportunities, goals and the types and quantities of resources that can be obtained. Any limitations must be considered when determining the values and standards that are influenced by them.
2. The internal environment: composed of elements of the system (energy, material, human, financial) current and future. These elements directly affect the goals of the system by presenting the strengths and opportunities that should be exploited. On the other hand, they can be a source of weakness by imposing restrictions on the system.

3.2. Data

The steps in the construction and use of geographic data require meticulous effort. Data specification is defined by the rightful users, and must include geospatial data and metadata, which plays a crucial role in the development of all the framework and applications data because it is the reference source for all data. It also represents a valuable resource for analysis and geographic operations.

The framework data: is composed of all the GIS data necessary for basic reference maps, geocoding, some statistical analyzes may serve as a database allowing them to hold all database operations. Frame data provide the spatial identification descriptions, attributes, and relationships. Users can also add more on the application of these to meet their own needs.

The most important characteristics that must be contained in the data provided to the decision-maker can be classified according to three main dimensions: the temporal dimension, content dimension, and form dimension.

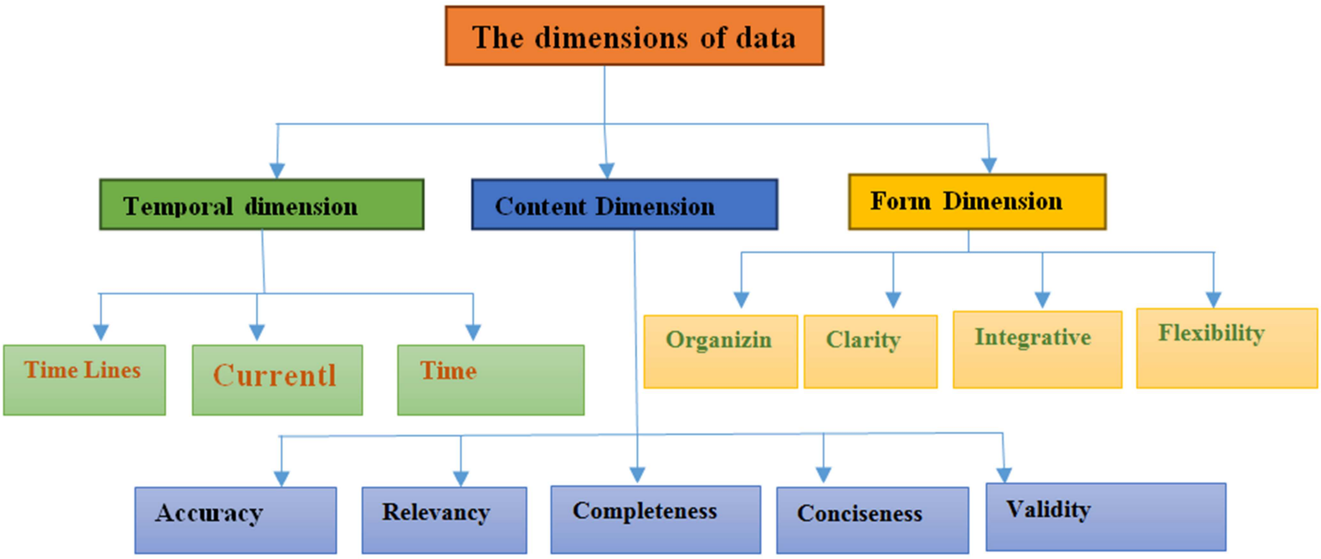

Figure 4. *Shows the elements of each dimension.*

3.3. Procedures

Procedures rely mainly on traffic safety strategy set by the Traffic Safety Coordination Council, which can be transformed into operational measures that include four key areas:

1. Data collection: concerns collecting data on the reports of the accumulated over previous years with the aim of contributing to a deeper understanding of the problems of roads, With GIS software, you can bring data straight from the field into a geodatabase in a seamless workflow. This may include local road data with the engineering specifications, intersections and ramps.
2. Data Management: Traffic safety systems must contain ample data and maps of the incidents, in addition to information on the volume of traffic, the characteristics of the road, weather conditions, and even video records. All information will be assembled in databases for use by analysts. The GIS can then be integrated to provide the framework to achieve the required goals.
3. Spatial Analysis: GIS has the ability to detect spatial relationships in accidents that can not be detected by traditional methods of statistical data. There are many spatial statistical tools now in GIS software to enable analysts to build complex models in a simple process.
4. Data Dissemination: There is a necessity for coordination between the master plans of operations to make sure that all parts of the various processes used data in a standard format to complete the analysis. GIS technology will therefore facilitate the production and dissemination of reports of improving traffic safety initiatives through traffic safety partners.

3.4. Technology

The importance of GIS as an integrating technology is also evident in its pedigree. The development of GIS has relied on innovations made in many different disciplines: Geography, Cartography, Photogrammetry, Remote Sensing, Surveying, Geodesy, Civil Engineering, Statistics, Computer Science, Operations Research, Artificial Intelligence, Demography, and many other branches of the social sciences, natural sciences, and engineering, all have contributed [19].

There are dozens of software systems that provide GIS decision-making capabilities, but the main problem lies in that most software systems do not provide specialized support to fit the process of decision-making for traffic safety. They are generally dedicated to meet specific needs such as: predict the population, planning, transport, and analysis of environmental resources. The systems for planning might respond well and achieve the objectives set in the strategy.

The challenge still remains in the production of software suitable for the Sudanese reality and which can achieve the strategic objectives of traffic safety. This will only come through political unification in the first place and then the provision of an appropriate environment for the production of the required software.

4. The Traffic Control Information System

In order to achieve this vision of traffic safety databases, which supports the integration of data between traffic safety partners, changes must begin with regard to how data is originally collected. One way is to collect traffic safety data electronically, which allows capturing data electronically and sending it by wireless networks and Internet. The captured data will be automatically integrated data into all existing records in the database. All of this information can be sent wirelessly from the field to the server stores and relays and sent to the competent authorities. The stored data is accessible to authorized users for billing and research purposes through the Web (Figure 5).

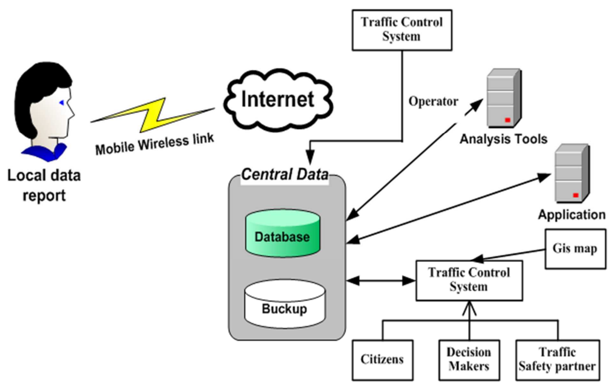

Figure 5. *Traffic Accident Information System.*

This system offers a range of services such as: informing police operations in the event of a traffic accident, calling an ambulance and informing any relevant authorities. The system also helps to solve traffic congestion problems. This is accomplished through the control system of traffic which collects information through sensors and cameras stationed on major roads and sends reports to motorists on request.

5. Conclusion

From the above, it can be concluded that it is of vital importance to design and implement a framework that uses GIS for the achievement of traffic safety strategy. The framework will identify opportunities, promote and support the use of this technology to improve traffic safety. The framework will make use of various dedicated databases to achieve traffic safety. The framework will be regularly maintained to overcome any limitations that might have appeared on application.

Recommendations

1. Implementation of GIS and associated database to support the process of decision-making for the purpose of traffic safety. This includes the use of tools for analysing and processing spatial and geographic data in different locations.
2. Application of Object Oriented Modelling for the analysis of multi-dimensional data as well as the storage of spatial data. Spatial Multimedia can be used for dealing with the remote sensing tools to portray the remote geographical areas and store the captured data.
3. Simulation of various scenarios to improve the system efficiency.
4. Exploitation of Global Positioning System-based GIS applications for GPS Global Position System (GPS) to collect and analyse geographic data in remote areas, and use remote sensors to monitor and record data.
5. Development of plans and programs that aim to use modern information and communication technology in the development of traffic safety culture.
6. Use of successful experiences in foreign countries in the use of geographic information systems for the development of traffic safety systems.

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