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A GIS ANALYTICAL APPROACH FOR EXPLOITING CONSTRUCTION HEALTH AND SAFETY INFORMATION

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SUMMARY: *The successful implementation of an optimal health and safety management process in the UK construction industry has been impeded by the inadequate utilisation of information present in the construction environment. Consequently, this inability to adequately utilise construction environment information has contributed to the construction industry becoming one of the most dangerous industries to work in. This paper explores an approach that addresses the utilisation of construction environment information that can enable the UK's Health and Safety Executive (HSE) to utilise analysed information for various construction accident mitigation procedures. The approach is based on the utilisation of various analytical capabilities in Geographical Information System (GIS). The analytical capabilities are used to demonstrate the operation and benefits of the GIS-based approach system presented in this paper. The research illustrated that the use of the GIS-based approach for analysis of construction environment information could have major benefits for the HSE. Some of the benefits include bringing together fragmented construction environment information, ease of communication, ease of storage, ease of analysis of varied information. These benefits can inevitably in a positive way enhance accident prevention procedures.*

KEYWORDS: *GIS, Information Utilisation, Information Analysis, HSE, Accident Prevention*

REFERENCE: *David Manase , David Heesom, David Oloke, David Proverbs, Christopher Young, David Luckhurst (2011)* A GIS analytical approach for exploring construction health and safety information, *Journal of Information Technology in Construction (ITcon), Vol. 16, pg. 335-356, http://www.itcon.org/2011/21*

1. INTRODUCTION

Construction accident related deaths and injuries are major public health and safety issues in the UK. Efforts to improve health and safety on construction sites have been of paramount significance in the UK construction industry. In the last 25 years for example, over 2,800 people have died from injuries they received as a result of construction work while many more have been injured or made ill (Health and Safety Executive (HSE), 2009). Although the number of accidents has fallen in recent years, the UK construction industry still remains one of the most dangerous industries. Accident statistics represent not only the terrible human tragedies but also substantial economic and psychological costs (Stranks, 1998). As such, there remains an ongoing challenge to do more to improve construction health and safety in the UK construction industry.

2. BACKGROUND

Although there exists a large body of technical literature and various efforts made, such as, health and safety law formulation; implementation and management; the subject of accident causation and prevention on construction sites is a complex process as it is affected by various interrelated factors. According to Abdelhamid *et al* (2000), accounting for the interrelationship between the factors and their effect on accidents is critical for an effective accident prevention strategy. The HSE (2004a) notes that many accidents could be prevented if appropriate information was available at the right time and in the right place and that it is often not those parties involved in the accident that had the best opportunity or ability to prevent the accident, but on many occasions, decisions made long before an eventual accident can be identified are the primary cause. Moreover, this problem is exacerbated because often the potential for an accident is 'designed in' by individuals unaware of the effect their decisions were having on safety (HSE, 2004). However, data currently available on accident causation are, in many respects, inadequate for explaining the underlying and complex interaction of factors in the causation process. Although some of the causes of accidents are usually known (e.g. falls from ladders), the underlying factors causing the accidents are rarely accounted for (Abdelhamid *et al.,* 2000).

It is therefore clear that problems exist in safety planning when identifying hazardous situations in the construction industry. This is because a lot of information that would lead to the identification of hazardous situations is either too vast to be analysed at the same time or be available for consideration in time for inclusion at any particular stage of the construction process. Secondly, this information is not readily available for analysis or the vastness of the information sources inhibits vital health and safety information to be assimilated in the construction process. Essentially, there is a lack of bespoke tools to analyse health and safety information effectively for integration in the construction process. From the literature, it is evident that the current accident causation methods and systems yield highly informative material particularly as it underpins the identification of underlying root causes of construction accidents[(Abdelhamid et al, 2000), (Suraji and Duff, 2001), (Gibb et al 2001)]. However, this informative material is hardly utilised in the analysis of construction health and safety as there is lack of tools that would enhance the effective providence of properly analysed ready information for application in the construction process as illustrated in Figure 1. The tools currently available lack the ability to utilise construction information relating to health and safety, which can enable the identification of risks at the early stages of project planning. In the current analytical procedures, the user is limited to textual queries only. Kibblewhite and Fidderman (1998) state that safety applications broadly deal with single aspects of safety management, such as recording and reporting, or are component modular-based safety management systems that attempt to address every aspect of an organisations safety management system, from policy through risk assessment to auditing. These tools also suffer a lack of multi-sensory capabilities, as the output of the analysis is often based on textual information (Kibblewhite and Fidderman, 1998). According to Tim (1995), lack of an integrated framework to manage, manipulate, analyse, and present the large volumes of data generated by the various sources and systems has resulted in the majority of the data being poorly utilised. For example, statistically analysed results would particularly establish cause-effect relationships, but would fail short of representing other factors other than workplace safety and health conditions and this may affect the observed trends or the influence of the various parameters(Figure 1).

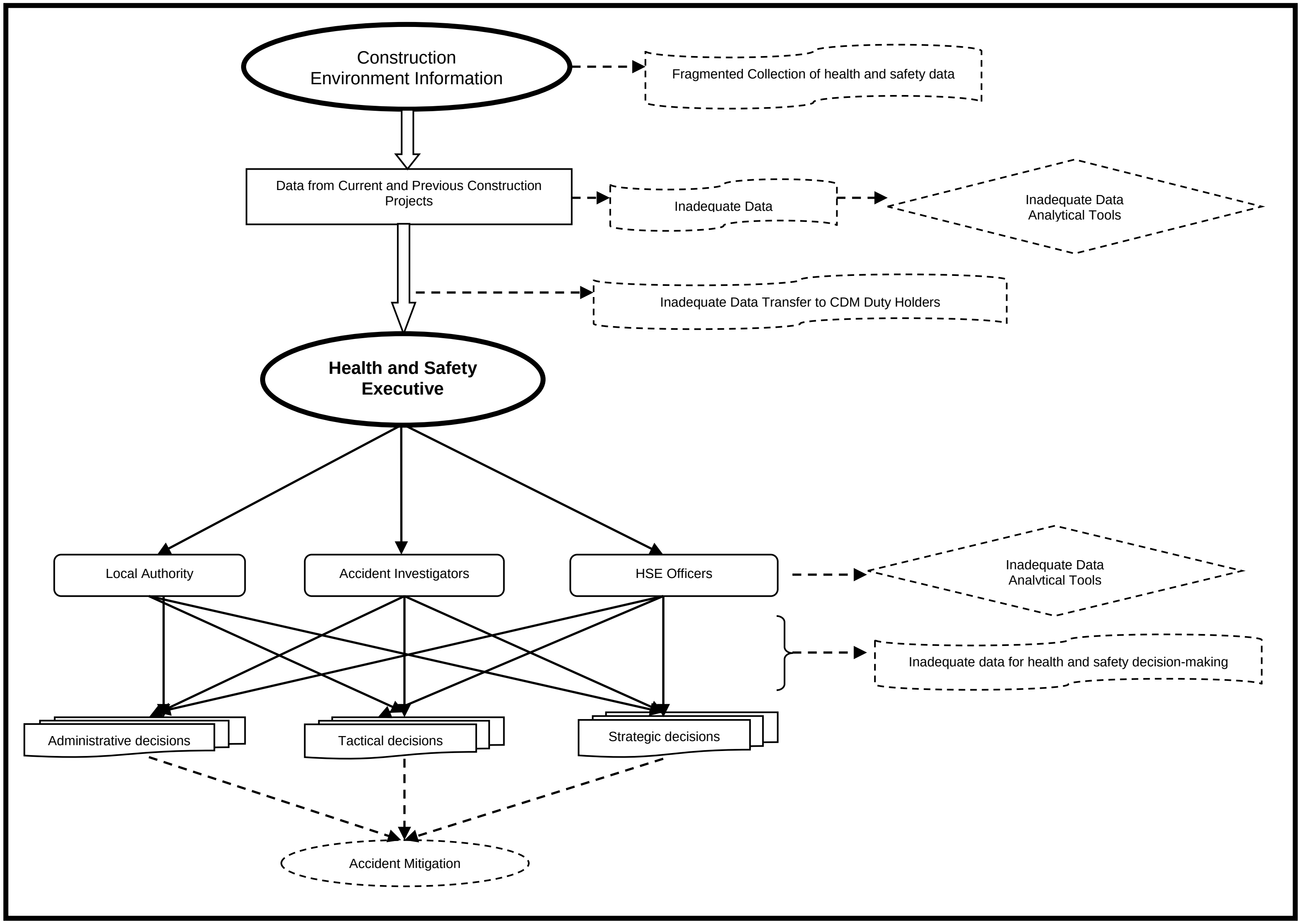


FIG 1: Current limitations in Utilisation of Construction Health and Safety Information

Uy and O'Rourke (2000) also stress that construction health and safety management in the 21st century will be shaped and guided by effective graphical representation of complex systems, accurate network simulation, risk assessment, and graphical fusion of physical and social databases. The diversity of the data required for designing and maintaining health and safety management calls for a sophisticated way of accessing, storing, manipulating, analysing and combining the various elements as this aids one see the big picture, make the best decisions, and capitalise on the construction industry's vast data and resources and provide the necessary tools to deal with the complexities of health and safety management. The problem of lack of bespoke tools that take account of the vast health and safety related data and resources runs true with the HSE in the UK construction industry. It is clear from literature that the HSE in does not have robust frameworks for collection and analysis of vast amounts of interrelated data in the construction environment. As a result, the HSE are unable to realise the full extent of health and safety issues that ought to be considered when formulating vital health and safety planning mitigation documents such as risk registers, health and safety plans, and health and safety files, etc. Overall, in the UK construction industry, there has been a lack of appropriate support tools to assist the HSEs' decision-makers in assessing the risks of accidents and formulating effective frameworks for preventive measures (Figure 1). The challenges in health and safety planning demand understanding of the fundamental factors of accident causation and innovative tools techniques for management and analysis of data. In order to achieve effective coordination and integration of health and safety planning into the construction process, there is need for thoroughly analysed information from various sources that identifies accident and ill health factors and ensures that the information is available for inclusion at various stages of the construction process. The HSE (2004) underpins this notion by noting that the underpinning philosophy in health and safety is the identification of a wide a range of intelligence sources of information as possible and an ability to organise this information in a way that can be used to provide both insight and understanding of specific issues, to inform on future improvement and risk strategy.

The primary objective therefore is the need to utilise all historical health and safety information in the construction environment. This can be achieved by improving knowledge of accident or ill health causation through providing more with a high storage intuitive and comprehensible media for analysing and visualising of historical health and safety to be utilised and aid the HSE in supplying analysed construction health and safety information, thereby creating a well-formed decision-making platform in safety planning for the construction industry. Such media should also provide a coordinated methodology for drawing together a wide variety of data sources under a single, visually oriented umbrella, allowing for better understanding of the data and make them available to a diverse user audience.

3. AIM OF THE STUDY

The aim of this study was to explore the potential of a methodology for the analysis of vast amounts of fragmented construction environment information.

The methodology provides an efficient platform for analysis of information on various interrelated factors in the construction industry for mitigation of construction accidents. It was envisaged that the objective set in the study could be realised through the utilisation of a decision support system. The purpose of the decision support system was to provide a set of tools to help in the analysis and interpretation of data. The decision support system should grant decision makers an appreciation of the risks implicit in particular decisions, and the factors, which can be varied or queried to modify those risks.

Following Jones (1997), it was recognised that the power of the GIS to integrate information within a spatial context is potentially useful in assisting in the search for causative links between events. In this study, it was then recognised that since all construction related information is geographically linked in one way or the other, taking advantage of the information spatial characteristic or component would aid in the integration and analysis of construction environment information. Thus, the GIS approach was initiated as a core component of the decision support system to develop a comprehensive analytical information system that embodied all of the objectives set in the study. Thus, the need for a decision support tool that had the capabilities to fulfil the requirements identified in this study, i.e., presentation of analysed information in formats that are easy to comprehend and the need to understand the dynamics of the accidents in a spatial context. Since all construction environment information can be seen in a spatial context, it was envisaged that adopting a methodology exploring, evaluating and analysing the potential capabilities of Geographic Information System (GIS) would realise the aim set in this study.

4. GIS –ORIGINS AND STRUCTURE

GIS has its origins in automated mapping systems (Maidment and Djokic 1990).A GIS can be simply defined as an organised collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyse, and display all forms of geographically referenced information (Goodchild, 2000). Holdstock (1998) defined a geographic information system (GIS) as an organised collection of computer hardware and software, geographic data and personnel designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographical referenced information. Parsons (1998) highlighted that GIS enabled the user to store, retrieve, sort and displayed information according to its spatial characteristics (i.e. topology). It is therefore evident that a GIS is a tool for making and analysing using spatial information (Burrough, 1986; Longley *et al*, 1991; Antenucci *et al,* 1991; ESRI, 1997).

Tim (1995) stresses that within the definition, GIS encompasses a fundamental and universally applicable set of value-added tools for capturing, transforming, managing, analysing, and presenting information that is geographically referenced. Tim (1995), notes that by combining the capabilities of a relational database management system with its spatial referencing capabilities, a GIS is capable of storing, processing, and efficiently presenting large volumes of data. GIS incorporates both database and mapping technology, and adds a spatial element to data generation and analysis. Miller (1999), states that although a GIS often serves as both a database and a source of maps, these aspects alone do not fully explain its capabilities when used by persons who are trying to quickly understand large amounts of data. Goh (1993) further states that the fundamental difference of a GIS from any other information systems is that it has the knowledge of how events and features are geographically located, i.e., there is a geographical relationship between the various types of data that may be incorporated into a database. This capability of a GIS to relate various types of data in a meaningful way becomes important as one transcends beyond using a GIS to simply create a pin map of locations. Jones (1997) stresses that most commercial packages provide a range of functionality, which are categorised into five areas and include the following:

- data acquisition;
- preliminary data processing;
- data storage and retrieval;
- spatial search and analysis and
- graphical display and interaction.

Eastman *et al* (1993) state that a GIS installation is made up of several different components. Figure 2 gives a broad overview of the software components typically found in such a set-up.

Figure 2. illustrates, a typical GIS that links data from different sets, using geo-referencing, i.e., spatial coordinates, as a common key between different databases. In the analysis of information a such a GIS would utilise multipurpose tools that are integrated into a system that can be capable of performing database management techniques diverse analysis, and comprehensive graphic representation (visualisation) of results. Not all systems have all of the elements illustrated in Figure 2, but to be a true GIS, a system must contain an essential group, that includes cartographic display, map digitising, database management, and geographic analysis (Eastman *et al.,* 1993).

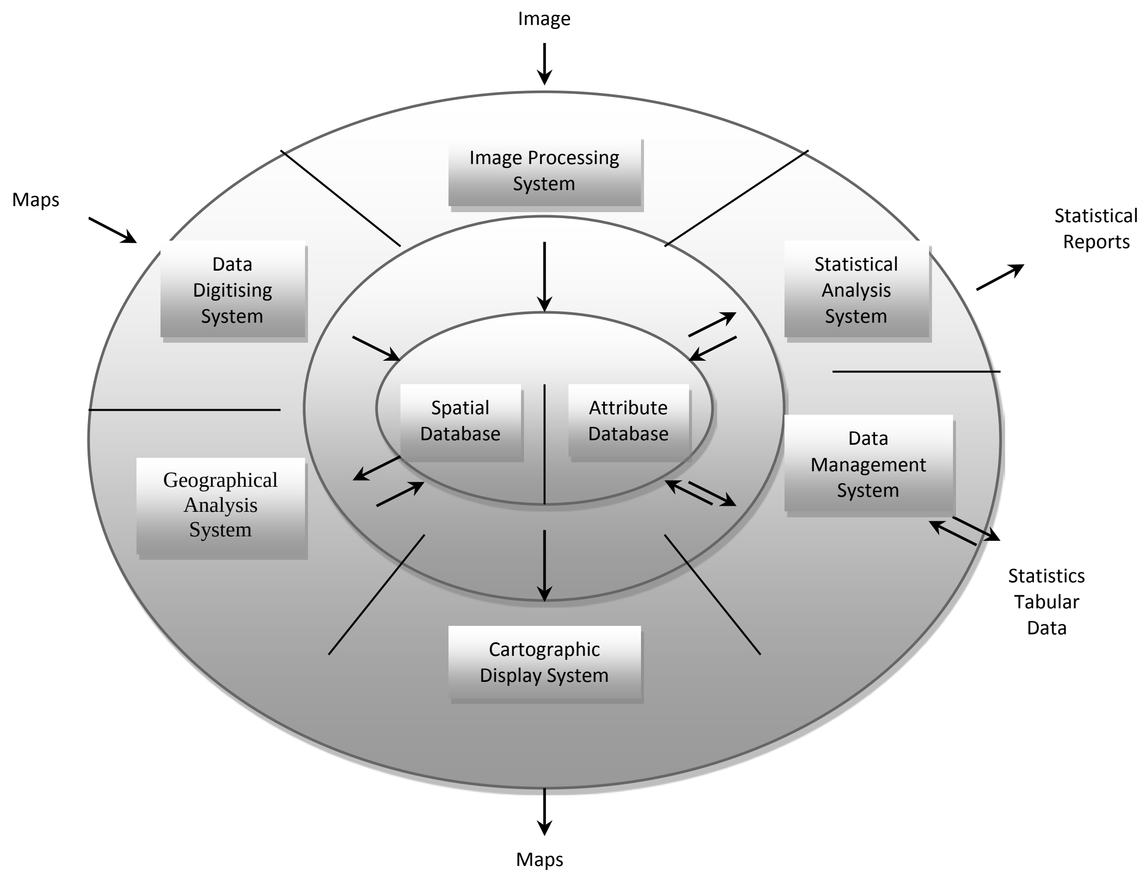


FIG 2: Software Components of a GIS
Source: Eastman et al (1993)

5. THE GEOGRAPHICAL INFORMATION SYSTEM FOR ACCIDENT PREVENTION (GISAP) ANALYTICAL SYSTEM FRAMEWORK

The potential capabilities of analysis, visualisation, and display of spatial and non-spatial data exhibited by GIS illustrates how these could be applied in analysis of historical construction environment information for the prevention of accidents or ill health on construction sites. Utilising the capabilities exhibited by GIS, an analytical system coined as the Geographical Information System for Accident Prevention (GISAP) Analytical system was developed.

5.1 System Decomposition

The advanced decomposition of the system processes presents the system functions, process description (Figure 3) (Heesom 2004). The principle system function is the analysis of construction environment data from varied sources that include health and safety data, demographic data, climatic and spatial data and other non-spatial data. The health and safety regulations and the data formatting and classification are the mechanism on which the inputted data would be worked on. The user and the GIS tool are the mechanism by which the design and implementation of the process is performed. The output of this process includes the provision of analysed health and safety information to users on accident trend and pattern analysis in form of accident density maps reports showing changes in accident occurrences, statistical data on accident and the relationship to other factors in the construction environment.

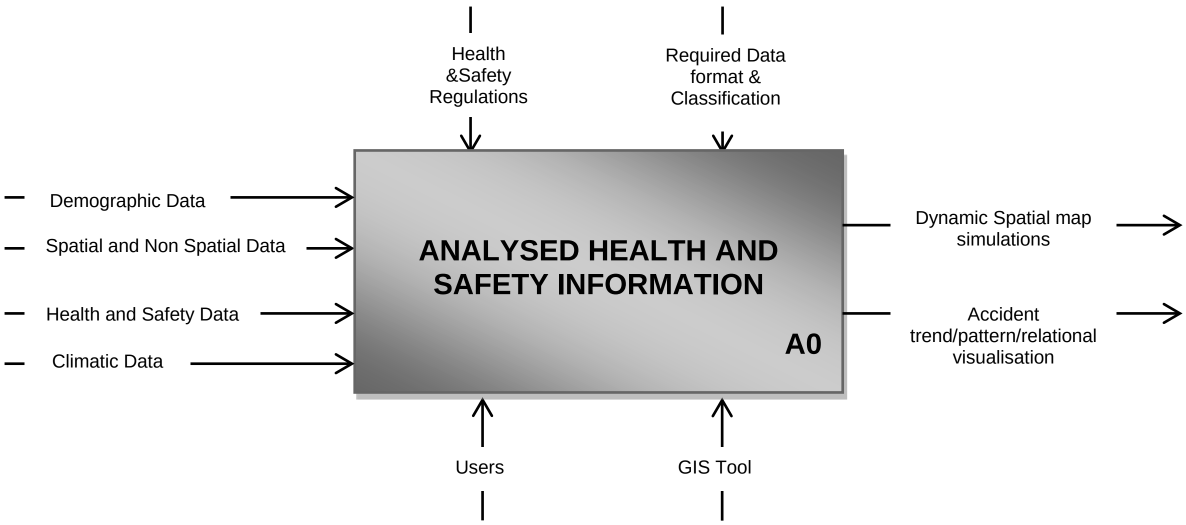


FIG 3: IDEF0 A-0 Process Diagram for GIS Based Construction Health and Safety Information Analysis

5.1.1 Description of the Main Processes within the Proposed GIS Based Health and Safety System

The main function of the proposed GIS system is to collect, to classify and to analyse data related to accident occurrence. Thus the main identified processes are: data collection; data formatting and classification; data analysis processes and visualisation process of construction analysed data (Figure 4).

- **Data Collection Process**

This process collects spatial information that includes topological maps; land use maps; administrative boundary type maps; aerial photos; rail and road networks maps and construction site geographical coordinates. Furthermore, the data collection process involves acquiring statistical data on construction accidents; location demographical data and climatic data. Information on health and safety laws was also collected during this process. Therefore, the primary functions of this process include the requests of data and information from the users and key data providers, collecting and storing of all data in data store bases.

- **Data Formatting and Classification Process**

This process validates formats and classifies all collected information into three major groups: spatial (digital format, geo-referenced and original data sets); non-spatial data (statistical and analogue type) and documentation (proposals, documentation, plans, text, etc) data. Validation in terms of data quality, its completeness, consistency and validity is also conducted. The formatting process consists on digital data conversion from binary and ERDAS *.lan format to ERDAS IMAGINE *.img format; maps scanning, digitising; vector to raster conversion and geo-referencing process. A digitiser or similar device is used to convert a compiled map data to a digital form in order to make it computer compatible. This transformation allows the storage, retrieval, and analysis of the mapped data to be performed by the computer. Maps produced by a GIS are typically displayed on computer monitors or are printed on paper. For a GIS to accurately represent occurrences on the earth's surface, data must be reliable, accurate, and pertinent.

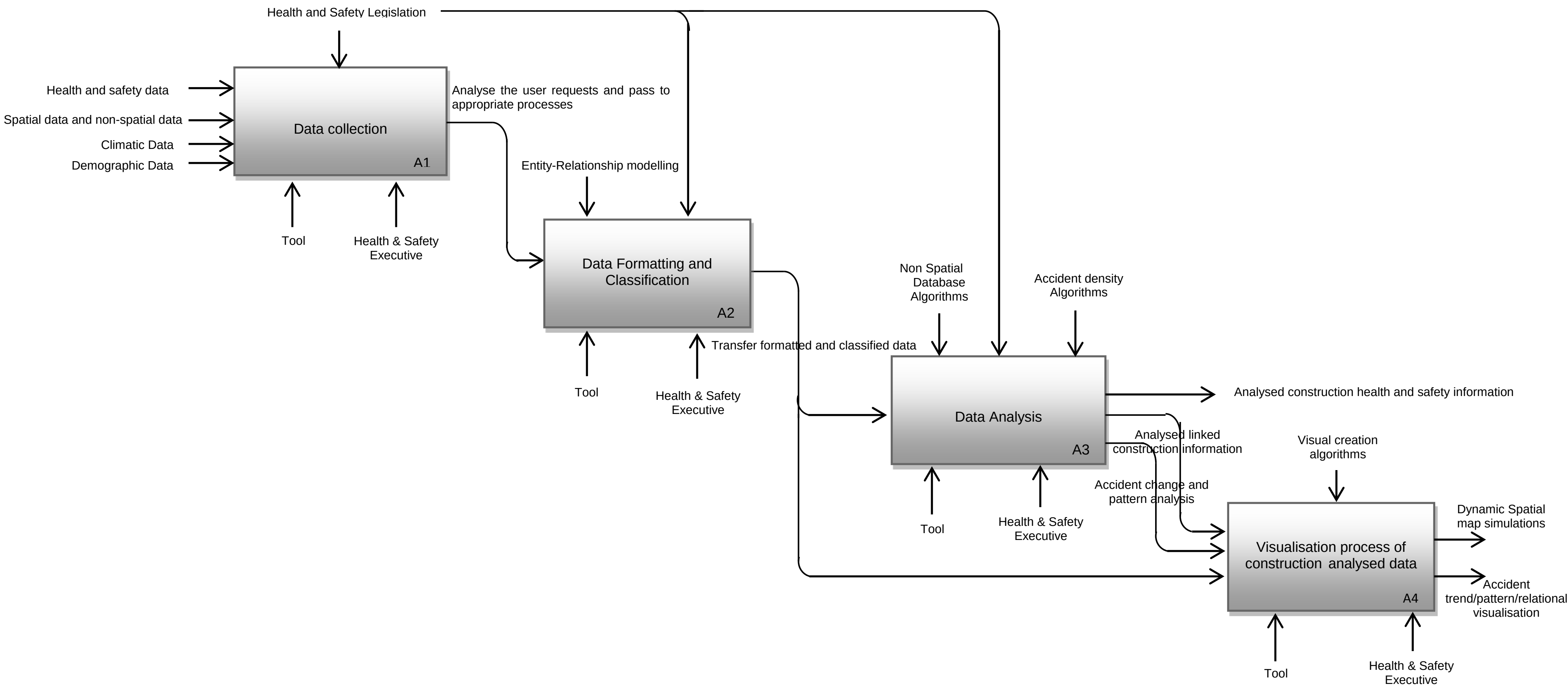


FIG 4: Health and Safety Information Analysis Process

As a result of the success of the GIS, all decisions based on it ultimately, rests on the integrity of the data. Thus, the GIS must be capable of compiling, updating, and maintaining its data. Furthermore, statistical data on accidents, population, climatic conditions are classified and modelled in tabular spreadsheets and later arranged in entity relationship models. Thus the principle function of this process includes validation of provided information according to the system requirements (information and data format requirements); and the classifications of all received information to separate groups, within their format – maps, images, spatial data; non-spatial and documentation data stores.

- **Data Analysis**

The main process of the proposed construction health and safety system is the data analysis process because it produces the main outputs of the system. The main function of the process is to analyse available spatial and non-spatial information according to potential user requirements. The data analysis process identifies various algorithms performed at this stage and includes among others accident changes analysis and pattern recognition analysis. The data analysis is undertaken on both the spatial and non spatial related data.

- **Visualisation Process of Construction Analysed Data**

This stage of the process involves visual creation of the analysed information. This entails the creation of varied maps and reports based on the user parameter and criteria requirements. The resultant maps and reports can thus be those that depict trends, patterns and relations, accident causation factors or variables.

6. SYSTEM ARCHITECTURE

In the GISAP analytical system (Figure 5), the main software packages, ArcView GIS 3.3, Microsoft Access 2000 and Microsoft Excel/Word were selected as core software as they provide capabilities in geographic processing, database management system, spatial analysis and Graphic User Interface as well as having several enhanced plugs or extensions that add and improve functionality to the system. ArcView formed part of the Spatial database. The benefits of the ArcView as the main GIS application included the fact that it is one of the most easily available and widely used commercial GIS package developed by Environmental System Research Institute (ESRI, 2006). Furthermore, ArcView GIS provides smart tools to capture and edit spatial data, which enables visualisation, querying and analysing of data spatially. As a desktop GIS application tool, ArcView GIS was utilised in this study because it provides a variety of data management and analysis capabilities. With its open architecture and live data integration, users can bring all the GIS data into a single environment and turn it into valuable information. Its flexibility, scalability, and open standards deliver productivity gains for collecting and modifying data and speeding implementation of GIS databases.

The Monitoring database of the GISAP Analytical System was organised by using Microsoft Access 2000, which is the most basic of the current versions of Microsoft Access software (Microsoft, 2007). The software was chosen because of its capabilities to retrieve, store and query non-spatial/attributes information efficiently and can handle the relatively large data sets in database. This software allows enforcing key constraints and referential integrity constraints thus, guarding against errors in the database by ensuring integrity of the database. In the designed database, the properties of the desired data for each field are specified and if data with wrong properties is entered, it is rejected by the DBMS. The attribute tables can also be linked through a unique identifier i.e. primary key and foreign key concept. Microsoft Access also allows integration of different data formats e.g. Access Data base file can be converted to other formats like Arc View database and Excel files. In addition, Microsoft Access possesses a powerful macro language that is essential if a menu driven interface is to be developed. Furthermore, basic forms of Microsoft Office Software such as Microsoft Excel 2000 and Word 2000 were also used in the input of accident data from various sources. Microsoft Word and Excel are very good data-editing tools, which were used in most data integration steps because they are user-friendly and easily create intermediate text based data formats. The software are utilised by the HSE in their collection and collation of historical accident data and are commonly used by all construction stakeholders in the analysis of data. By and large, each of the software components was selected for their ability to integrate with other components and construction industry uptake possibilities. It should also be noted that the software components selected can be easily upgraded as respective software updates are released. Above all, the software products selected for the

GISAP analytical system accept ODBC as the Application Programming Interface (API) for database access and utilises Structured Query Language (SQL), as a database access language.

In the GISAP Analytical System, the Windows Open Database Connectivity (ODBC) standard was used to communicate between the ArcView GIS project in spatial database and Access in monitoring databases, allowing the GISAP Analytical System to treat data in Access as tables in ArcView GIS. The ODBC is a widely accepted Application Programming Interface (API) for database access, which utilises Structured Query Language (SQL), as a database access language. ODBC allows maximum interoperability allowing a single application access to various DBMSs that share the same source code (Anon, 2007). To achieve data flow in the GISAP Analytical System (Figure 5) the system automatically links data from the monitoring database with the appropriate theme in the ArcView GIS. This feature is critical to the integration of the spatial and monitoring data in the GISAP analytical system as it allows users to associate the location of specific monitoring sites on the ArcView theme with the corresponding records in the Access monitoring database. Thus the ArcView GIS software provides the capability to link to spatially referenced data stored within a relational database of the software.

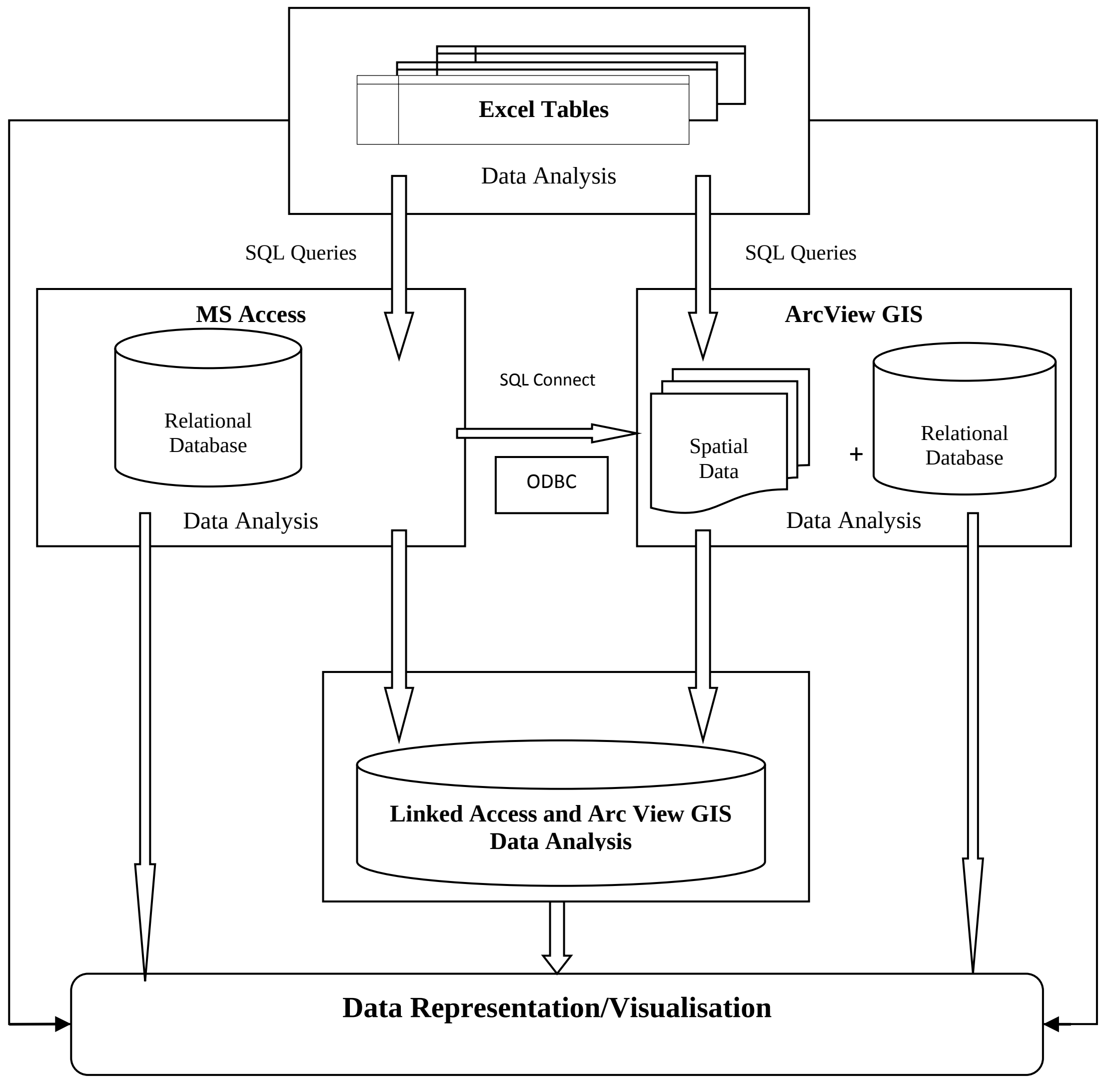


FIG 5: GISAP Analytical System Architecture

The GISAP analytical system's spatial data and monitoring data are linked through the SQL-connectivity. Data can be imported into any ArcView GIS project using Arc View GIS's Structured Query Language (SQL) connection feature as illustrated in Figure 6. This feature allows users to query a database or spreadsheet using SQL and to store the returned records in an ArcView table. As a result, any data stored within a relational database (Microsoft Access) or spreadsheet (Excel) can be made available to the Arc View GIS very easily or as required.

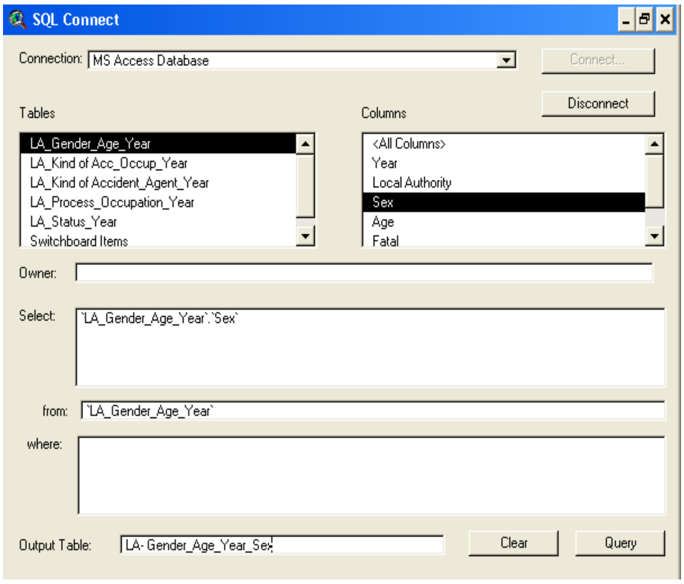


FIG 6: SQL Connect in Arc View and Results of the Query of SQL Connect

The GISAP Analytical system offers data management functions as a component. The functions of the data management component include the inventory, monitoring and statistical analysis. In the inventorying part the GISAP analytical system is a generic extensible inventory that stores spatial and attribute requirements of various types of information. This methodology allows formatted and transformed up-to-date spatial and attribute sources of information to be stored and made available at every stage of the construction process. This capability offers the HSE, access to a large source of data relating to many factors upon which specific analytical procedures for understanding the spatial and attributes relationship of the data. The GISAP analytical system as a central resource of data can produce complete, accurate and up to date data, if the system is updated regularly. The data can also be easily accessible which can save labour time. As a central resource for data it can be easy to access and distribute the information to users. Monitoring in this approach is the process of repeatedly measuring an attribute over time to determine changes in location or condition. Nearly all of the resources or factors traditionally monitored by the HSE can be assessed within the GISAP analytical system. By facilitating the storage, retrieval, and comparison of any attribute data over any time frame, the GISAP analytical system can simplify the process of monitoring, assessing change, and determining trends (thereby identifying causation factors). Furthermore the GISAP analytical system can carry out specific Statistical Analysis Query calculations. Various queries utilising varied formulae and parameters in order to arrive at the sound conclusions. Data analysis through statistical analysis can be performed by looking at and summarising data to extract useful information and make inferences and develop conclusions. This would involve the use of data that is collected, formatted and stored in the databases of the system. Statistical analysis can be very useful in exploratory data analysis and confirmatory data analysis, where emphasis is placed on discovering new features in the data and on confirming or falsifying existing hypotheses respectively (Figure 5).

7. GISAP ANALYTICAL SYSTEM APPLICATION

7.1 Monitoring Database

Querying of non-geographical data is conducted in the Monitoring database of the GISAP Analytical System as illustrated in Figures. The select query utilises SQL in Access to show, for example, accidents that occurred between the years 1999 to 2006 and classified by occupation, severity, age, process, time, month, day and climatic conditions (Figure 7 and Figure 8).

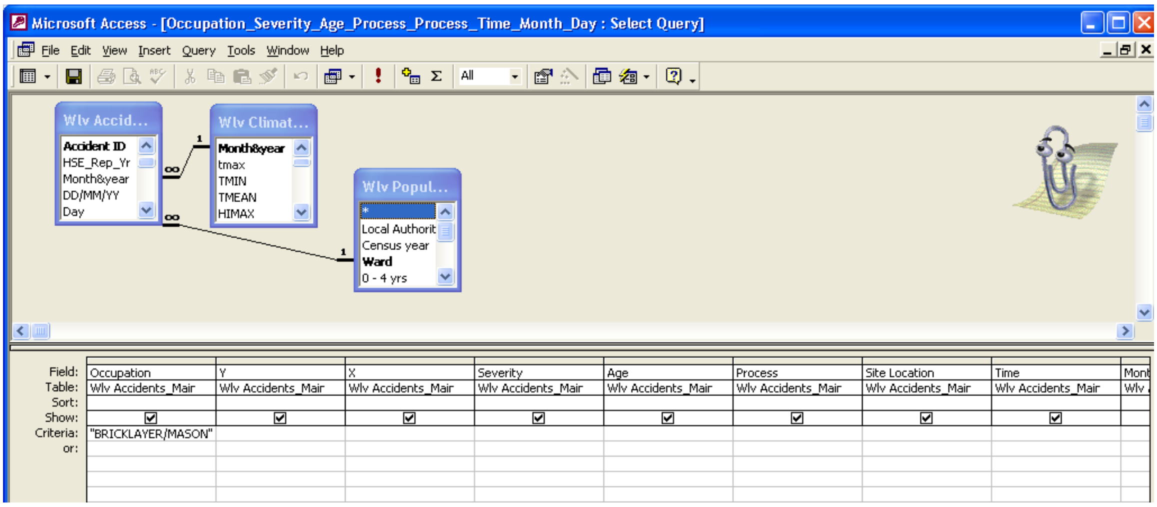


FIG 7: Example - Use of Select Query in MS Access

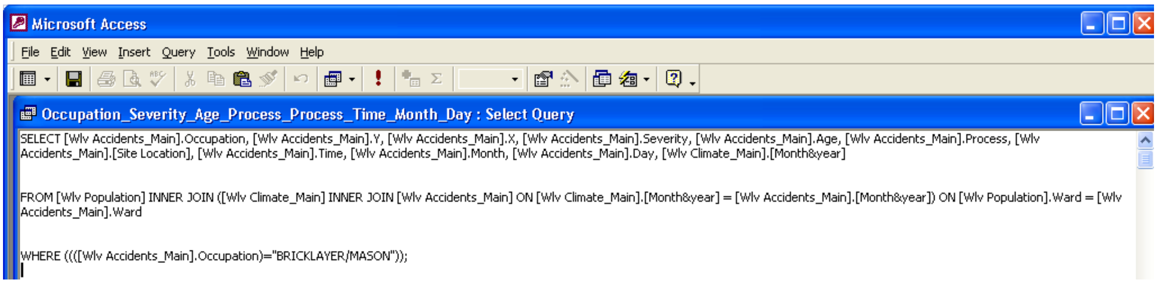
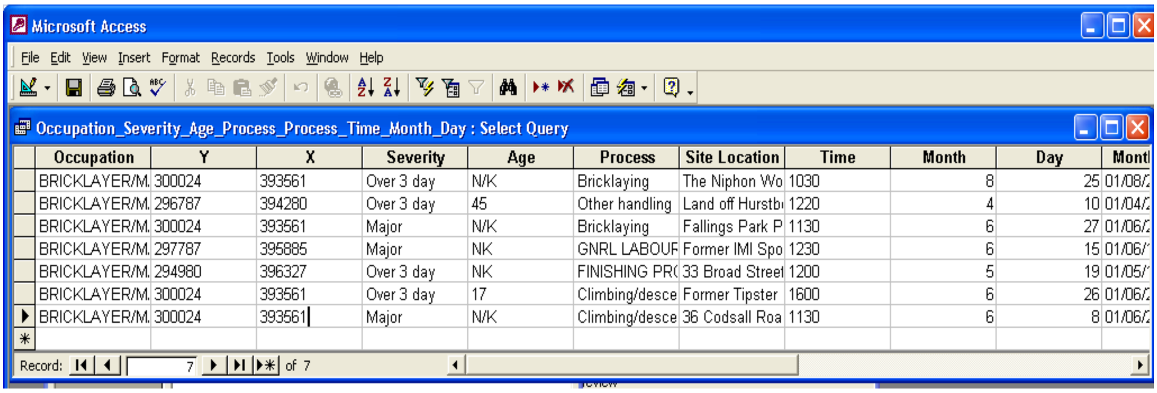


FIG 8: Example - Query in SQL Select

Results of the above query can be given in the forms of table or report. Table and report are as illustrated in the Figure 8.



Occupation	Y	X	Severity	Age	Process	Site Location	Time	Month	Day	Montl
BRICKLAYER/M.	300024	393561	Over 3 day	N/K	Bricklaying	The Niphon Wo	1030	8	25	01/08/:
BRICKLAYER/M.	296787	394280	Over 3 day	45	Other handling	Land off Hurstb	1220	4	10	01/04/:
BRICKLAYER/M.	300024	393561	Major	N/K	Bricklaying	Fallings Park P	1130	6	27	01/06/:
BRICKLAYER/M.	297787	395885	Major	NK	GNRL LABOUF	Former IMI Spo	1230	6	15	01/06/'
BRICKLAYER/M.	294980	396327	Over 3 day	NK	FINISHING PR(	33 Broad Street	1200	5	19	01/05/'
BRICKLAYER/M.	300024	393561	Over 3 day	17	Climbing/desce	Former Tipster	1600	6	26	01/06/:
BRICKLAYER/M.	300024	393561	Major	N/K	Climbing/desce	36 Codsall Roa	1130	6	8	01/06/:

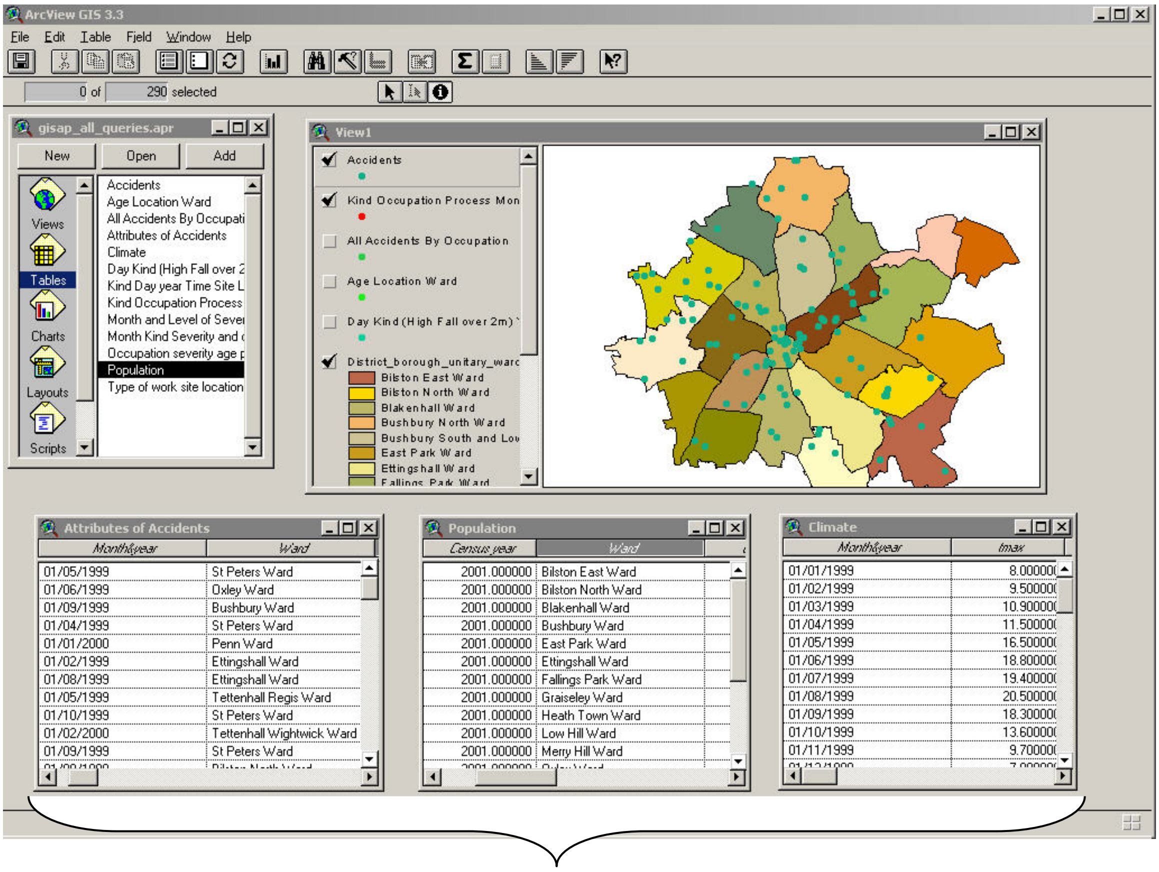
FIG 9: Example - Query Result in the Form of the Table

7.2 Spatial Database

Spatial analysis is the process of modelling, visualising, and interpreting results (ESRI, 2000). The geo-processing analyses (Spatial Analysis) in the GISAP analytical system can enable HSE decision makers perform sophisticated spatial analysis on the desktop. The process in the system guides the user through the functions with step-by-step instructions. The instructions in the process ensure easy and accurate execution of the analysis thereby ensuring easy-to perform spatial analyses. Analytical capabilities in the GISAP analytical system spatial Monitoring database include: overlay analysis, buffer/proximity analysis, network analysis, statistical analysis, query extrapolation and locational analysis.

7.2.1 Overlay Analysis

The GISAP analytical system can overlay different pieces of information. This capability helps in decision-making and health and safety research through multi-criteria modelling; for example, understanding the association between prevalence of certain accidents and/or diseases and specific geographic features. In construction environment information analysis, the HSE decision-maker can use these spatial techniques to combine demographic data, such as the number of households, showing the average number of school age children, with the region accident data showing members of the public related accidents. This can be done in order to derive risk factors for the total number of members of the public-related accidents relative to the total number of school age children region thus for members of the public-to-school safety analysis. Alternatively, HSE decision-maker or researcher may try to find out the relationship between the year/month an accident occurred and the population in which the accident occurred and the climatic conditions existing at the time of the accident as illustrated in Figure 10.



Typical attributes (pieces of information) overlayed

FIG 10: Example - Geographical Data in Arc View showing typical overlayed attributes

7.2.2 Proximity Analysis (Buffering)

Proximity analysis is one other type of the GISAP analytical system query capability and a category of spatial analysis that represents the fundamental difference of GIS from all other information systems. In proximity analysis, the GISAP analytical system creates buffer zones around selected features. For example, buffering around a feature which includes finding information about accidents that occurred within a particular feature (such as the railway station (Figure 11), thus the GISAP analytical system selecting all accidents within the specified distance of the feature. Such a selection will enable the user to analyse only select accidents within the specified distance, finding relationships that are apparent in the data or in relation to the features within the specified area.

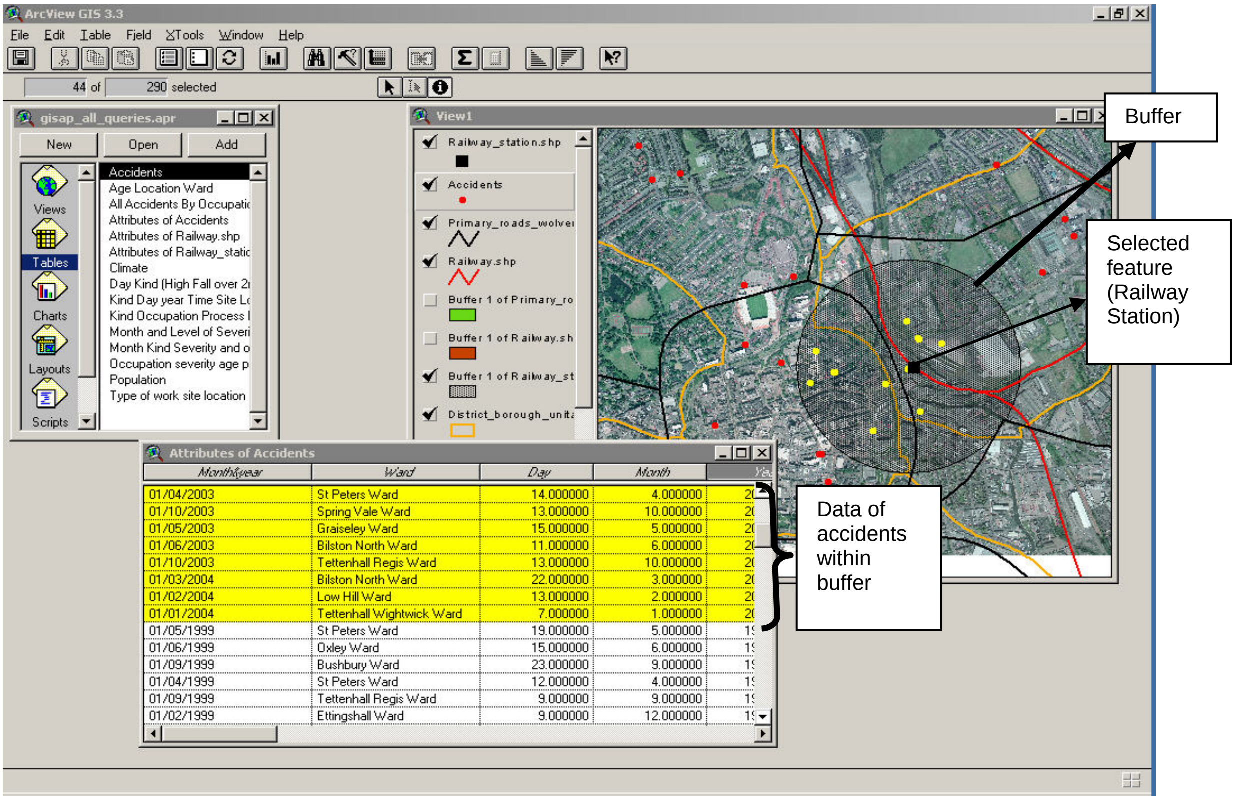


FIG 11: Example - Buffer around a Specific Feature

Buffering is a means of performing this practical spatial query to determine the proximity of neighbouring features. Therefore, buffering can locate all features within a prescribed distance from a point, line, or area, such as determining the number of accidents that occurred within 800 m of a location, or locating accidents that occurred within a certain distance and time (e.g., 400 m and 30 min) of other accident events. Another example would involve the creation of buffer zones around the construction inputs and combining them with land cover information derived from aerial or satellite images. This analysis would help in defining the residential (members of the public) exposure to accident occurrence. Targeted areas of exposure (based on cutting-off distance from construction affected areas to residential areas) can be used for further scrutiny with regard to temporal changes in accident concentration. Proximity analysis can also be used to measure the extent and type of problem within a certain distance around a particular location. The distance can be anything that one wants to use as a radius around a particular location. For example, a radius of 1 km around a construction site and then combine this information with accident (disease/hazard incidence) data to determine how many hazards fall within the buffer. Proximity analysis can be used to map the impact zones of hazardous sites, where control activities need to be strengthened.

In the event that the user would like to have information about accidents that occurred in relation to all construction work conducted from a specific distance from, say, the railway line, the GISAP analytical system can be used to select all such accidents by buffering the railway line to a set distance, providing all the information about those accidents very easily and quickly (Figure 12)

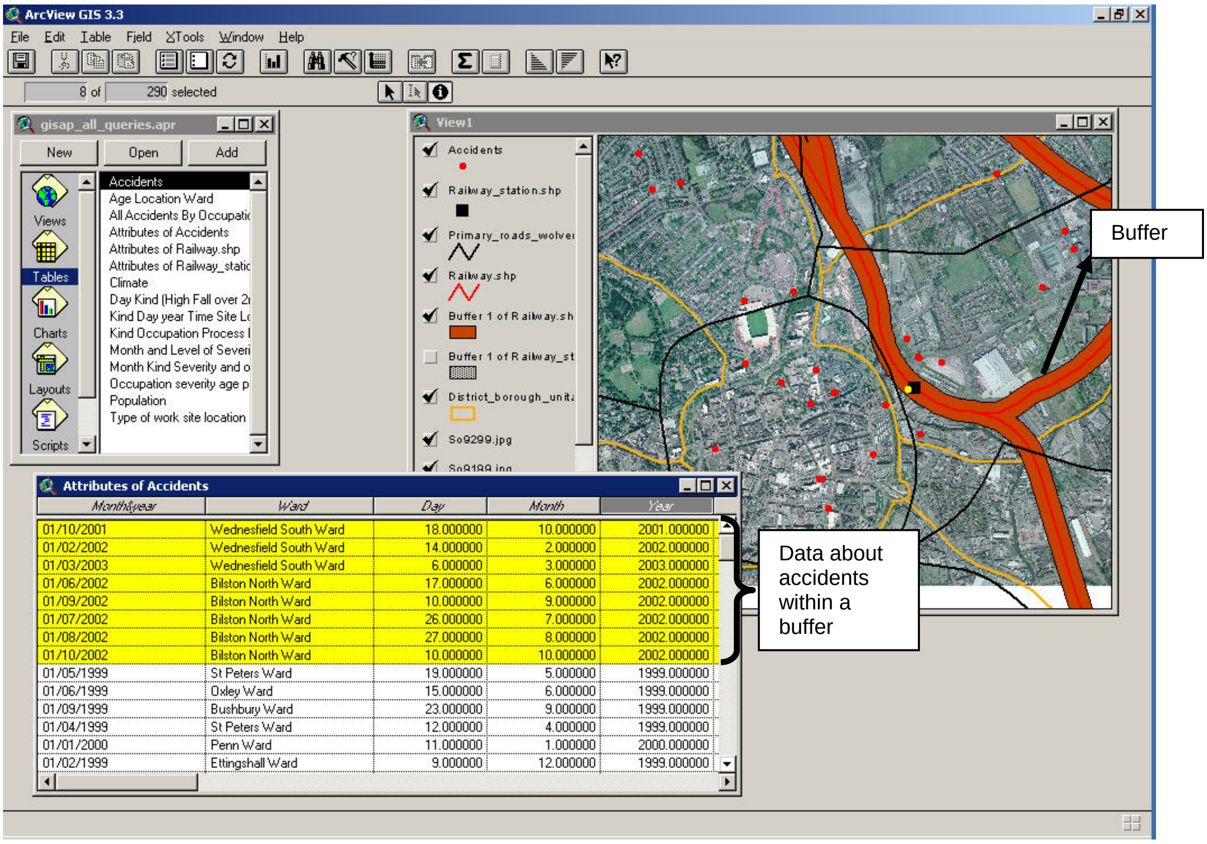


FIG 12: Example - Buffer along the Railway

The table view of the dataset shows a rectangular array with objects organised as rows and the attributes arranged as columns. This allows the user to see the attributes associated with objects at a glance, in a convenient form. These kinds of analyses are capable of revealing aspects that are not apparent or immediately visible or obvious. From the foregoing GISAP analytical system application procedures, it is clear that diverse “what if” scenarios can be forwarded to the system. Various factors in the construction environment can be filtered out for further analysis or related to other factors to see if any correlate.

Other examples of proximity analysis applications of the GISAP analytical system include spot/intersection analysis, and cluster analysis.

a) **The spot/intersection analysis:** can be used to evaluate accidents at a user-designated point or intersection for a given search radius. The spot or intersection of interest can be selected by clicking on the map using the mouse or by entering the intersecting street names. The end result of this analysis is a report that lists the number of accidents, fatalities, injuries, costs, etc., (as defined by the user) and a graphic representation that can be an output such as a hardcopy map depicting the spot, search radius, and selected accidents (Figure 13).

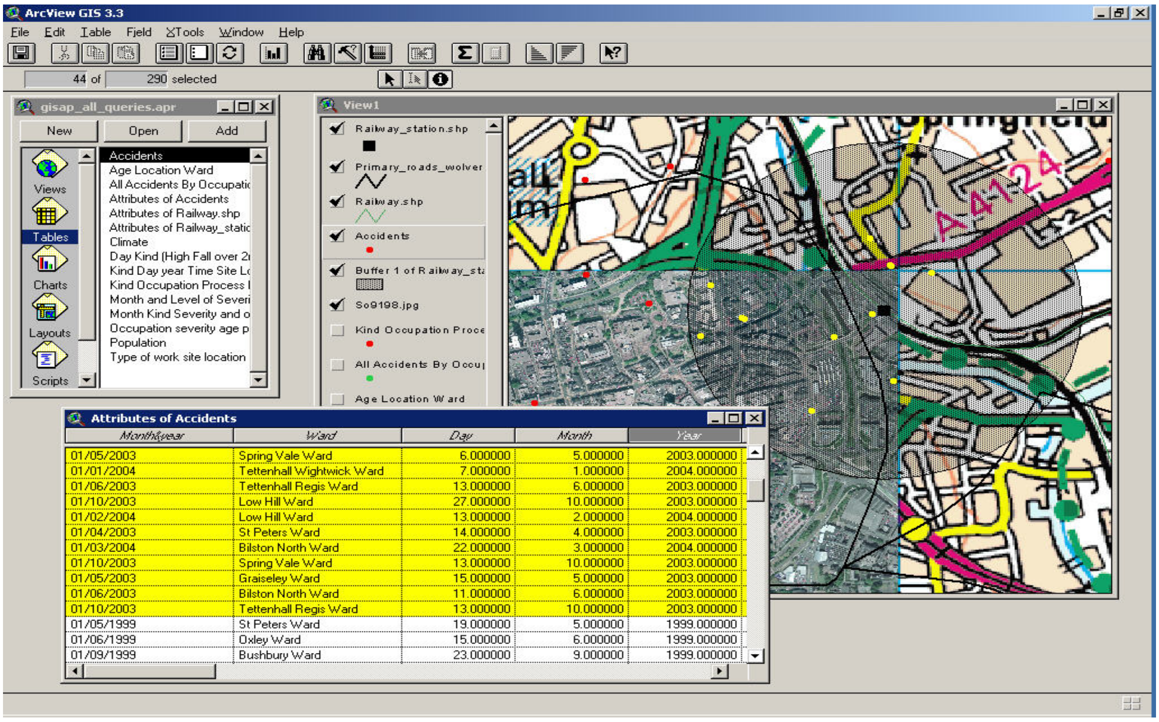


FIG 13: Example - Spot Intersection Analysis

b) **Compare locations of hotspots across time**: Accident hotspots that have been identified over several months can be displayed at the same time. This can allow for the identification of areas with chronic problems and indicates the direction in which particular accidents or disease may be shifting. This information is then represented on maps. These types of maps can be used to solicit resources for an area from other public and/or private agencies.

c) **Compare hotspots of different accident types**: Hotspots of different health and safety offence or accident types can be displayed on a map to identify where they overlap. For instance, non-compliance of a particular regulation can be displayed along with an accident hotspot to discover where they overlap. A more detailed analysis of these intersecting areas can then be performed.

d) **The Cluster analysis**: can be used to study accidents clustered around a specific feature, such as a bridge or railroad crossing. Cluster analysis can identify areas that contain dense clusters of events (hotspots) and fall within a given distance from a particular feature. These high concentration areas would demand special attention. Again, the output is a report that lists various summary statistics selected by the user and a map depicting the high accidents locations. Hotspots of fatal accidents, major accidents, residential accidents, commercial accidents, auto accidents, etc., can be calculated for each in every local authority area.

7.3 Network analysis

Subject to the population of the databases with relevant transportation data and maps, construction materials delivered on construction sites can be scheduled in a more efficient manner by analysing transportation factors and street patterns, and by recommending the most efficient safe route. The GISAP analytical system has the potential through this analysis to provide accurate and timely information about where health services, public buildings, schools are located and instructions and maps on how to get there.

Unlike proximity analysis that searches in all directions from a point, line, or area, network analysis is restricted to searching along a line, such as a route, or throughout a network of linear features, such as the road network.

Network analysis can be used to define or identify route corridors and determine travel paths, travel distances, and response times. The GISAP analytical system networking capabilities thus has the potential to be used for the selection of optimal safe paths or routes. The user inputs the origin and destination, and the proposed system produces a map and walking directions for the preferred route, which is based on the level of hazard associated with the various roadway and traffic elements. To improve the network model and provide the capability of automated route selection, the road network thus can be developed to include turning points, avoid improper turns onto one-way streets, represent posted traffic control restrictions, and include impedance factors to travel (such as mean travel speeds, number of travel lanes, and traffic volumes) to enhance the network analysis.

7.4 Spatial Statistical Analysis and Query

The GISAP analytical system can carry out specific calculations. For example, proportion of population falling within a certain radius of a construction site. It can also calculate distances and areas, for example, distance of a community/construction site to a health centre, and area covered by a particular health and safety programme.

The GISAP analytical system allows interactive queries for extracting information contained within the map, table or graph. It can answer queries of location, condition, trends, spatial patterns and modelling. The GISAP analytical system contains various ways to query and analyse data. CDM duty holders can run the easy-to-use geo-processing processes or define their own analysis procedures and yield powerful results (Figure 14). Answers can be found according to location, content, proximity, and intersection. As data is added to maps, CDM duty holders can be able to find the geographic factors and attribute factors that drive health and safety trends and distributions. Furthermore, an addition of different data layers, CDM duty holders could be able to determine locations where particular characteristics coincide and identify the places where most accidents occur enabling thorough accident mitigation procedures to be put in place.

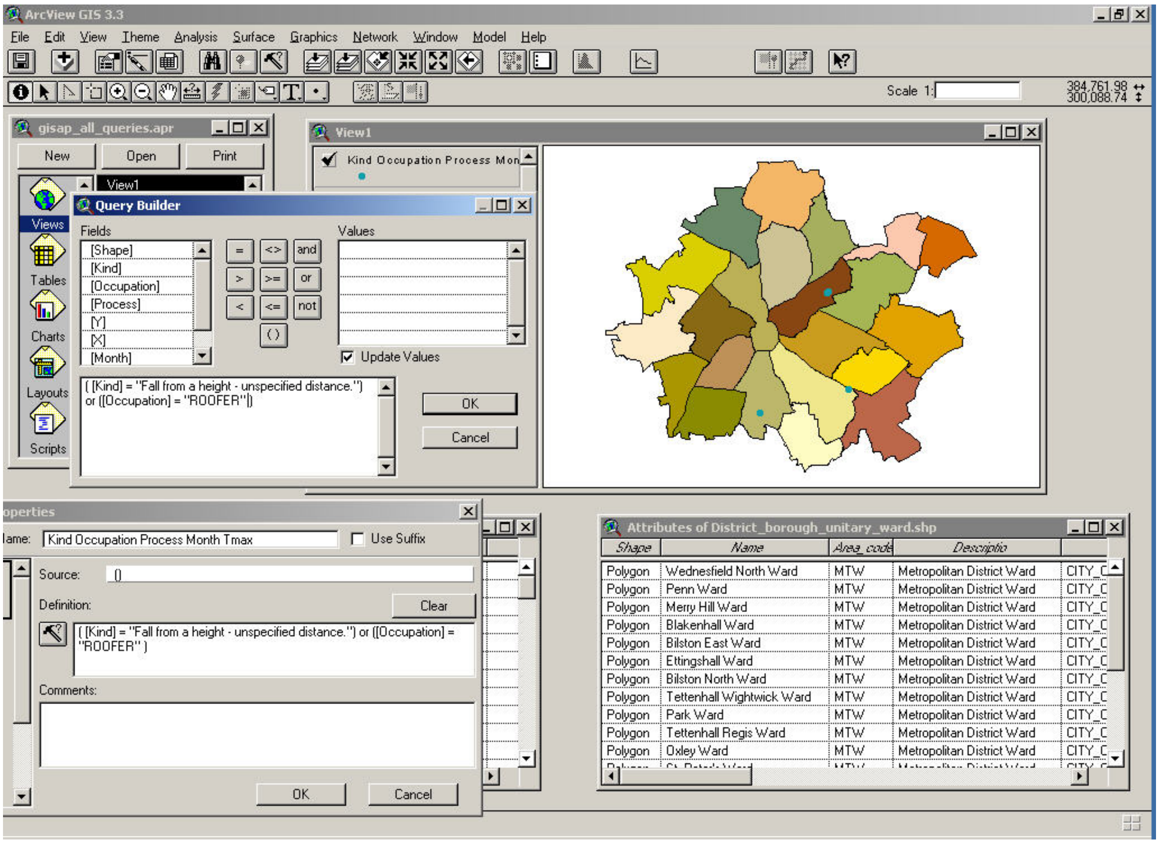


FIG 14: Example - Results and Graphical Visualisation of the Query in Arc View GIS

The GISAP analytical system would be able to aggregate varied data in the system database geographically by summarising it based on areas such as census tracts, local authorities, or country. This will enable the commencement of the comprehension and visualisation analyses in a new light. Furthermore, the output from one analysis can be used as the input for the next analysis, enabling user to refine their analysis for better results.

Maps are the pictures the GISAP analytical system uses to communicate complex spatial relationships that the human eye and mind are capable of understanding. The computer makes this possible, but still, it is the GISAP analytical system user that determines what data and spatial relationships will be analysed and portrayed, or how the data will be thematically presented to its intended audience. Using the database capabilities of GISAP analytical system, the user can query the database and have the results graphically displayed. This query analysis takes on the form of a "show me" question, such as *"Can you show me all accidents that resulted in a fatality?"* (Figure 14) Query analysis capabilities in the proposed GISAP analytical system can also be exploited for other purposes, such as database automation, which can be used for error checking and quality control of coded data. The use of imagery in GISAP analytical system in conjunction with terrain modelling can provide a virtual reality display for construction safety analysis, giving the user a more realistic view of the landscape. The potential of using GISAP analytical system to store, query, and analyse accidents as well as their potential root causes is cardinal. Asking questions such as "*What is there*?", "*Why are they there*?", "What will happen if?", "*What might happen if*?" of the data to simulate different scenarios and help strategists when planning. This aids users in the analysis of the best options of use of information and provide a sound basis for effective decision making.

8. GISAP ANALYTICAL SYSTEM ATTRIBUTES

8.1 Spatial Representation

The GISAP analytical system offers powerful tools to present spatial information to the level of individual occurrence. It determines geographical distribution and variation of accidents/diseases, and their prevalence and incidence. For example, in studying the surveillance of fall from height, it is important to find out which type of fall from height is occurring in which parts of the country, as this has important implications for the accident eradication strategy employed. GISAP analytical system can help in generating thematic maps - ranged colour maps or proportional symbol maps to denote the intensity of the accident. In comparison with tables and charts, maps developed using GISAP analytical system can be extremely an effective means for communicating messages clearly even to those who are not familiar with the technology. It would allow policy makers to easily understand and visualise the problems in relation to the resources, and effectively target resources to those communities in need. Simple maps that display the locations where accidents or concentrations of accidents have occurred can be used to help direct surveys or patrols to places they are most needed. Policy makers in the might use more complex maps to observe trends in accident activity, and maps may prove invaluable in solving accident cases. GISAP analytical system permits dynamic link between databases and maps so that data updates are automatically reflected on the maps.

Digital maps are the quickest means of visualising the entire accident scenario. The locations of accident events can be routinely displayed on maps. This provides an easy method of viewing activities in an area rather than searching through a listing of events in the GISAP analytical system. Maps can also be used to convey more than one type of information at a time. Accident locations can be symbolised according to the day of week, type of accident, modus operandi (a particular victims or causers' method of operation when committing an accident) or frequency. Furthermore, maps can be produced at any geographic level (e.g. national, county or local authority) to aid in the analysis of accident patterns. Each response area can be shaded to represent the number of accidents that occurred in that area during a specific time frame. The darker the shade, the more the events that occurred within the area. These thematic maps can also be used to show the change in an area's accident rate. The percent change in the number of accident incidents can be displayed by shading each area according to whether there was an increase, decrease or no change. Furthermore, accidents do not occur uniformly and their occurrence may be due to the number of limitations existing in those areas. These accidents could be studied and analysed to identify some form of patterns through the proposed system. To observe the patterns of accidents, it is necessary to mark the location of accidents in area on the map and thereafter, define the areas in terms of problems and resources. The reason accidents do not occur uniformly could be because, characteristics of construction sites vary significantly. The reason may also be the geography of area, demography of area, funds allocation or combination of these. The analysed information would be useful in adopting improvement measures for finally selected areas.

8.2 Integrate Community Characteristics

Community characteristics (for e.g., markets, schools, colleges, parks, alcohol permit locations, etc.) can be integrated and routinely displayed on maps while analysing accident patterns to interpret relationship between these characteristics and the accident in the GISAP analytical system. Other mapping data such as bus routes and public housing can also be displayed at the same time to analyse relationships between neighbourhood characteristics and accidents.

8.3 Communication

The GISAP analytical system could be an effective tool for public outreach, communication, and education. The GISAP analytical system could be effective because most people understand information more readily when it is portrayed graphically, and one of the principal outputs of GISAP analytical system is a map, combined with other data in graphical form. Construction health and safety analytical issues are often contentious, requiring a good understanding of several variables and their interrelationships, and where impacts and potentials occur within the environment. By graphically showing these interrelationships and locations, GIS-produced maps can improve communication among management personnel and the public, as well as among different stakeholders. Further, the GISAP analytical system can be set up in public meetings to allow immediate exploration of “what-if” scenarios to illustrate potential effects and outcomes of different decisions. For example, if one user group wants to improve road access to a construction site, the GISAP analytical system could be used to show the likely impact on density of people around the site, and effects on roads. This information would be useful for managers to communicate to various stakeholders the potential impacts and tradeoffs of different management alternatives, as well as to improve communication among the different stakeholders.

9. Conclusion

The study provided evidence that utilisation of capabilities in GIS could enhance the analyses of construction environment information and understanding of various factors in the construction industry for the mitigation of accidents. The contribution of integrating varied data set provides a baseline from which future improvements may be measured and gives an insight into the areas where future risk control measures and interventions may be best targeted. Furthermore, the ability of the GISAP analytical system to integrate different and varied datasets to have a broader picture of what is happening geographically around a region creates a solid platform for predicting future accident trends and providing visual identification of potential accident spots, thereby providing a proactive solution to future accident prevention strategies. Integration of varied datasets also provides opportunities that could enhance the better understanding and targeting of construction safety programs, e.g., regional focused efforts, emphasis on hazardous trades, targeting offending companies, through the analysis of varied factors associated with them. The concept advocated in this study provides reasonable and insightful results as they reveal clusters of dangerous locations, identify important relationships based on varied datasets thus, enabling the user to quickly formulate appropriate countermeasures or preventive in at various stages of the construction process. Such steps enable the elimination of the risk of accidents and injuries on construction sites at various stages of the construction process. The GISAP analytical system concept in this study also provides a platform for efficient manipulations of information to gain new insights such as establishing spatial associations between accidents and other factors. The ability to map, monitor, update and query disparate information on statistics enables visual identification of potential problem spots at the various geographic scales that warrant greater study. Furthermore, the GISAP analytical system could also improve knowledge about the occurrence of accidents such as conditions of incident site, and frequency of incidents at any given location in a region. This type of tailor-made graphic information is useful to the HSE in identifying potentially dangerous (accident prone) locations when planning for development of new infrastructure, and also aids designers in choosing among different design alternatives. Finally, the outcome of this research has also enabled a system that captures, analyses and presents information for use in the construction industry and with continued industrial application, the data derived from the system would be useful for development of further research. Such a system can be utilised by the HSE and other similar organisations in generating information that can aid in processes such as:

- **Tactical analytical processes:** that provide information used to assist operations personnel (patrol and investigative officers) in identifying specific and immediate accident trends, patterns, series, sprees and hotspots, providing investigative leads and clearing cases. Analysis includes associating accident, disease or construction activities by method of accident or disease occurrence, time, date, location, victim, vehicle, and other types of information.

- **Strategic analytical process:** is concerned with long-range problems and projections of long-term increases or decreases in accident or diseases (accident/disease trends). Strategic analysis would also include the preparation of accident/disease statistical summaries, resource acquisition, and allocation studies.

- **Administrative analytical process:** is focused on provision of economic, geographic, or social information to administration

The findings in this study have also opened up new grounds in construction health and safety research.

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