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THE DEVELOPMENT OF SPATIO-TEMPORAL DATA MODEL FOR DYNAMIC VISUALIZATION OF VIRTUAL GEOGRAPHICAL INFORMATION SYSTEM

(PEMBANGUNAN SPATIO TEMPORAL DATA MODEL UNTUK VISUALISASI DINAMIK BAGI SISTEM MAKLUMAT GEOGRAFI VIRTUAL)

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ABSTRACT

(Keywords: Volumetric and 3D, Spatiotemporal Data Model, Database, TIN, VGIS)

Virtual Geographical Information Systems (VGIS) is known to be one of the technologies used to improve the presentation of geographic visualization. Developing an efficient spatiotemporal data model is very important in contributing to the functionality improvement of the VGIS. Thus in this research, we focused on the data management aspect and has developed a suitable spatiotemporal data model for storing and retrieving volumetric geographic movement information. Volumetric is one type of spatial object in the VGIS, which is used to visualize 3D information. In order to develop real processes in VGIS, we have integrated the time element as an important factor to 3D objects. Time has been integrated with the data model, and temporal versions of volumetric surface data can be stored by using the model. This research also uses linear interpolating model techniques to visualize the movement changes. This application was implemented by developing a prototype visualization system using a Triangulation Irregular Network (TIN) with integrated time in the TIN structure. Result shows that the proposed data model is able to perform well with a visualization algorithm using linear interpolation and an improved TIN structure. This research contributed a suitable Spatiotemporal Data Model for managing continuous volume and 3D geographic movement data in VGIS and also a prototype of Spatiotemporal Database System which is can be implemented in GIS software. This can be particularly useful in applications such as geographic historical management data application, morphology of the terrain data, mobile movement, and Global Positioning System (GPS) application.

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ABSTRAK

VGIS merupakan satu bidang teknologi yang mampu memperbaiki mutu persembahan sesuatu visualisasi geografi. Pembinaan data model spatiotemporal yang efisyen memainkan peranan yang penting dalam memastikan penambahbaikan VGIS yang bermutu. Justeru, dalam kajian ini, aspek pengurusan data telah diberikan fokus yang utama dalam menghasilkan data model spatiotemporal, bagi tujuan pengstoran dan pengambilan semula data pergerakan volumetrik geografi. Volumetrik ialah satu jenis data spatial dalam VGIS, di mana ia digunakan untuk mengvisualisasi informasi dalam bentuk 3D. Bagi membina proses sebenar dalam VGIS, kami telah mengintegrasikan elemen penting iaitu masa bersama dengan objek-objek 3D. Elemen masa telah diintegrasikan bersama dengan data model, dan versi temporal bagi data permukaan volumetrik boleh disimpan dengan menggunakan model ini. Kajian ini juga menggunakan model interpolasi linear untuk mengvisualisasikan perubahan bagi pergerakan. Aplikasi ini telah diimplementasikan melalui pembinaan sistem prototaip visualisasi menggunakan Triangular Irregular Network (TIN) dengan pengintegrasian masa dalam struktur TIN. Implementasi yang dijalankan telah menunjukkan bahawa data model ini dapat memberikan persembahan yang baik dengan penggunaan algoritma visualisasi interploasi linear dan juga memperbaiki struktur TIN. Oleh, sumbangan utama kajian ini merupakan penghasilan data model spatiotemporal untuk pengurusan data bagi pergerakan volumetrik geografi secara berterusan dalam VGIS dan juga satu sistem prototaip untuk diimplementasikan dalam perisian GIS. Ia boleh digunakan dalam beberapa aplikasi seperti pengurusan data sejarah geografi, *morphology* bagi data *terrain* (permukaan bumi), pergerakan *mobile* dan juga aplikasi global positioning system (GPS).

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CHAPTER 1

INTRODUCTION

1.1. Introduction

Geography is a science of universe which describes phenomena, activity and time of an event occurring in the world. (Narciso, 1999). It can be classified into three major, namely: physical geography, human geography, and regional geography (Yattaw, 1997). Physical geography deals with the natural phenomena for example Geomorphology, Climatology, Biogeography, Hydrology, Soil Geography and Environmental Management. Human geography takes care of the human activities, for example developing city, managing resources, preserving and promoting significant cultural and historical values, and stabilizing the economy. Regional Geography compounds the issues related to the management of area for example Jabatan Ukur dan Pemetaan Malaysia (JUPEM) activity.

However, it cannot be denied that all aspects of geography involve the factor of 'time'. This is the single most important element for determining the moments for the occurrence of a specific phenomenon. For describing a phenomenon it has been observed that there are three important questions i.e. 'What', 'Where' and 'When'. The 'What' question is generally extended for the introduction of the phenomena, the 'Where' question often deals with the geographical location of the phenomena in question and the 'When' question reveals the time factor of that specific phenomena. It may be noted that, this factor brings to the surface period and duration of certain activities. Besides, it also unfolds a variety of important historical information. Figure 1.1 shows a Triadic Model describing the relationship among these three fundamental questions.

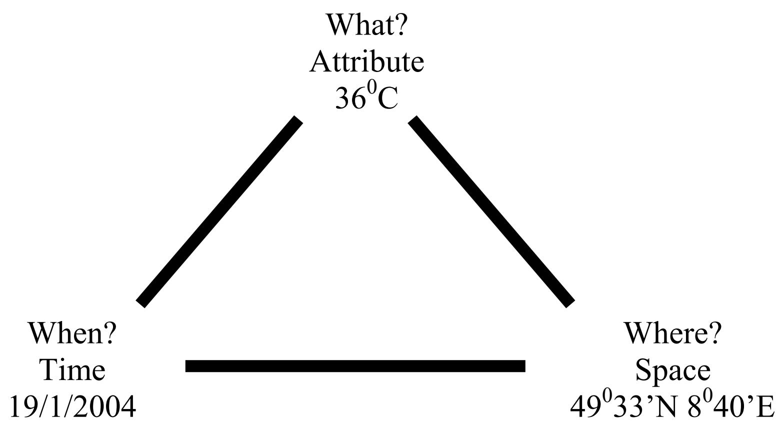


Figure 1.1: Triadic models of space, time and attribute

Geographic movement refers to change of geographic information. These changes take place in various forms. Some changes affect spatial data, some affect attribute data and some changes affect all of the data. It may be noted that change is a continuous process. Therefore, it cannot be ruled out that some times, new features and information may be observed due to this 'change' phenomenon. These changes are always described in the light of single most important factor, i.e. 'time'. Due to the enormous importance of geographic movement, it has been classified into twelve categories (Nassima *et al.,* 2002).

Most of the GIS uses managed data without thoroughly looking into movement or time in the application and software. However, Arcview software (Hogeweg, 2000; Gil and David, 2004; Jonathan *et al.,* 2003) carries an additional tool for handling 'time' factor. Additionally, Spatial Temporal Geographical Information System (STEMGis) is software possesses the capability for managing geographic movement data. However, this software still has some serious shortcomings since it fails in dealing with the complete set of classification of the geographic movement data.

Besides, we also look into other commercial GIS software such as GeoMedia, Mike 11 and ArcView. All these software has difference architecture and different data model to manage GIS data. In order to support geographic movement application, supplementary software and other development tools are still needed. Despite all these developments, a comprehensive examination of these application software comfortably confirms that generally, the current application does not fully support geographic movement analysis. Moreover, there is growing tendency of working with high dimensional data and at present there is no system which can manage 3D and volume data under an integrated environment.

This research focuses on the data management aspect which a suitable data needs model for storing and retrieving geographic movement information for some principal objectives like: analysis, manipulation, presentation and visualization. The importance of spatiotemporal data model to GIS cannot be underestimated. In spite of its tremendous importance, it does not cater specifically on the geographic movement.

1.2. Problem Background

It is a well established fact that data management plays an important role in the application or software development. Data management deals with the data storing and data retrieval process. The reliable performance of this component will cause an effect on other component such as analysis and manipulation; representation and visualization in system or software. Therefore, to achieve a good data management, good data model is a definite pre-requisite.

This research deals with the development of spatiotemporal data model for geographic movement application. There are twelve important classes of geographic movement (Yattaw, 1997). These classes are divided into three basic categories of changes type like cyclical, intermittent, and continuous movement. The four types of space data has been classified into three categories of changes type, like: point, line, area and volume data. There are lot of important issues regarding spatiotemporal data modeling (Sellis, 1999; Yattaw, 1997; Narciso, 1999; Langran, 1992; Glenn and Hanan, 2000; Hatayama, 2002; Li *et al.,* 2002b; John *et al.,* 2004). These issues must be tackled in order to meet the requirement of dynamic phenomena in the world. Through an extensive survey, it has been concluded that there are six properties of spatiotemporal data which needs to be considered while modeling spatiotemporal information in GIS. These properties include: space, time, space-time, scale, non-spatial data and historical.

Majority of the existing software support spatiotemporal data for point, line and area. This means diversion of a lot of focus on 2D data. Relational database model were used in these software and tools. The visualization is done in an animated map (D'Onofrio and Pourabbas, 2003; Hogeweg, 2000; Moris *et al.,* 2000). Despite all this development, these systems lack decision making ability mainly because of the unsystematic integration of the data (Geoffrey *et al.,* 2004; John *et al.,* 2004). This confirms that, semantic relationship and ontology among the data can not be obtained clearly and comfortably.

Regarding ArcView, GeoMedia, Mike 11 and the STEMGis, lack of managing geographic movement data is their major shortcoming. Although these software are undeniably powerful in certain functions, for example ArcView which has a great functionality for visualization of the data, Mike 11 which is a powerful analysis in hydrological and time series data, and the high capability of STEMGis in handling temporal data, yet these application software need significant enhancement for dealing with diversity in GIS. This is essential as geographic movement involves spatiotemporal data which requires the integration of space and time with their own attributes for establishing a detailed analysis.

In ArcView data is stored in the different file format. In term of spatiotemporal it need two shape file or more and follows by attribute also in the same number. Figure 1.2 shows that example of the spatiotemporal data in the ArcView. However, spatiotemporal data is not only on the two set of data but the datasets can vary depending on the changes or the movement. Simple movement or changes can be shown in one shape file and the location of the movement can be stored as attribute in the attribute file. GeoMedia software also uses the same concept of the ArcView.

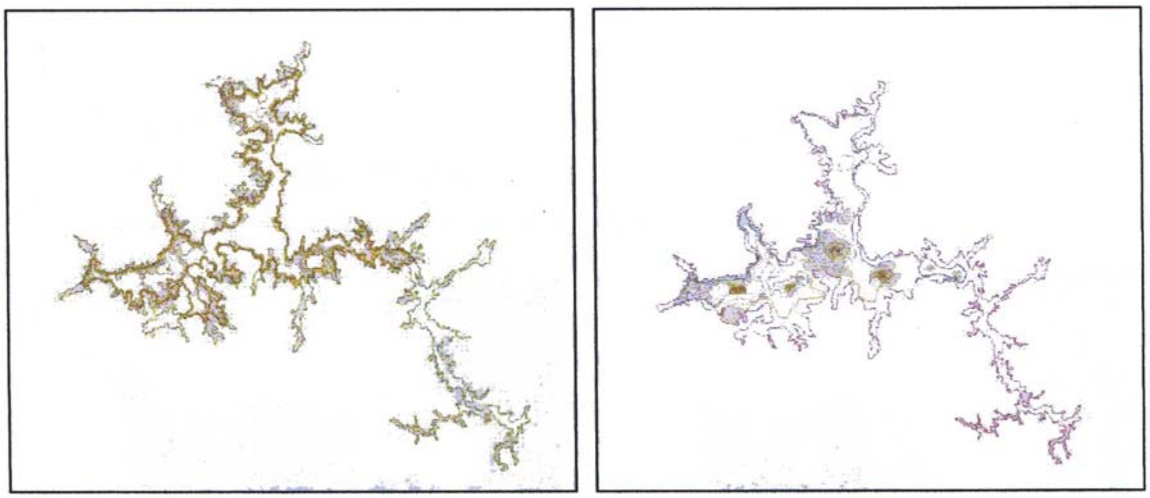


Figure 1.2 Simple Geographic Movements in The ArcView.

Mike 11 has a powerful analysis in the temporal or time series data. Also, the spatial changes can be store in the file system but it needs other software for representation and visualizing of the data. Figure 1.3 show the process has been done to create the spatiotemporal visualization from the Mike 11 data.

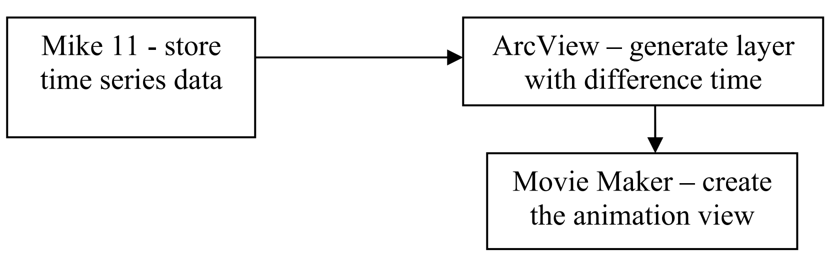


Figure 1.3: Process Flow involve in order visualizing flood data

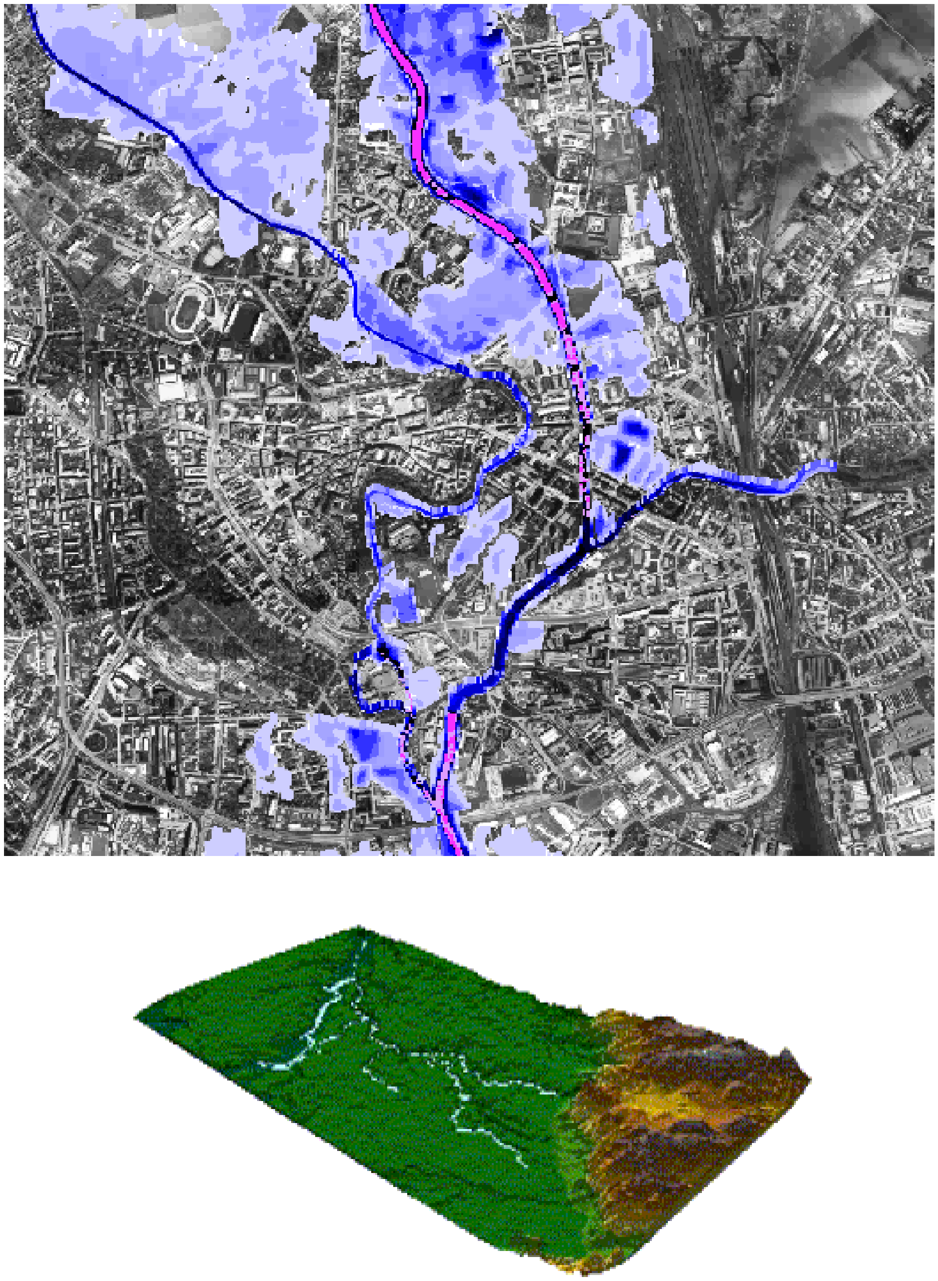


Figure 1.4: Flood Simulation Running in Movie Application

In STEMGis, spatiotemporal visualization can be done by their own database system. Spatial and attribute data is stored in the same integrated database system. However, the system still has some limitations and all type of spatial data is not supported by STEMGis. Figure 1.4 shows the example of analysis done by the STEMGis software.

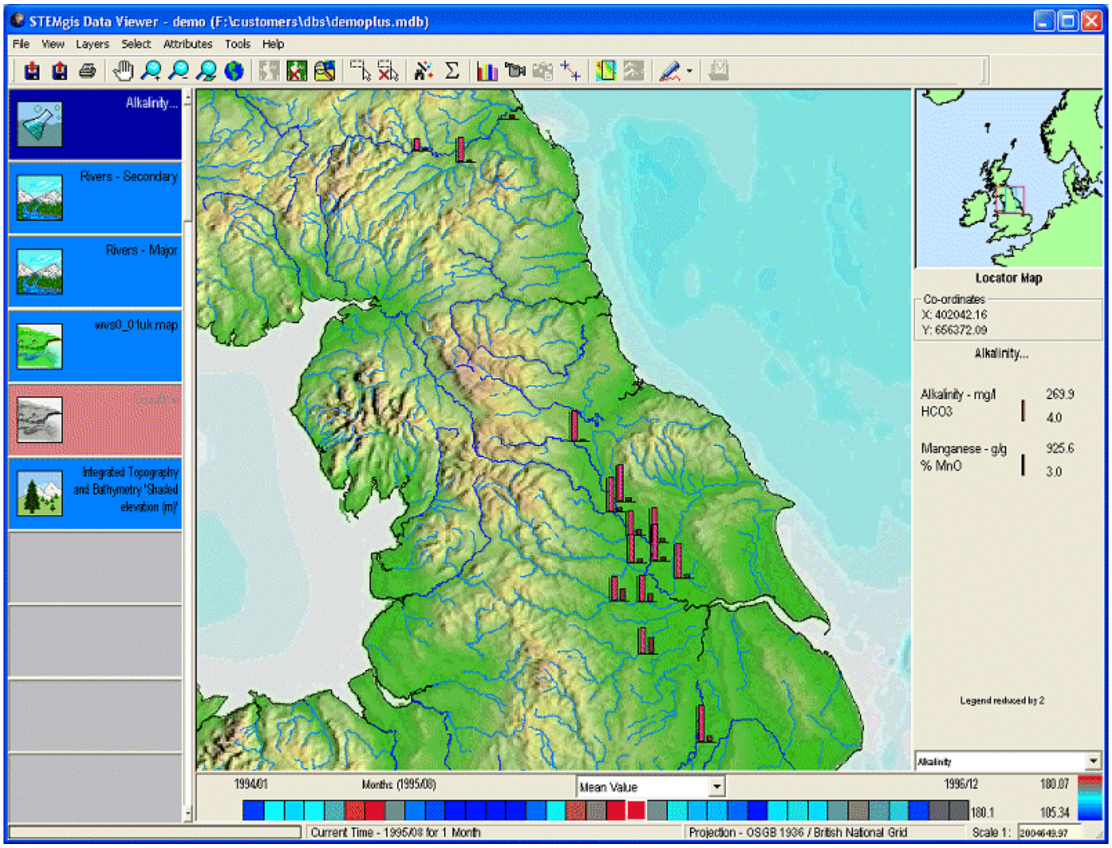


Figure 1.5: Example of Spatiotemporal Analysis in STEMGis.

The above discussion takes us to the conclusion that the most current software does not comprehensively cater geographic movement application. This is because no framework of the geographic movement has been used in the process of developing the software. Besides, no general spatiotemporal data model has been used in the software. Only spatial data model has been used which is based on the layer model and snapshot model. In order to support geographic movement, current data model needs to be improved to accommodate spatiotemporal data model.

A detailed survey of the filed reveals the presence of nine spatiotemporal data models, which includes:

(i) General Purpose Spatiotemporal GIS (GEN-STGIS) Data Model
(ii) A Spatiotemporal Data Model For Zoning
(iii) Cell Tuple Based Spatiotemporal Data Model

(iv) Object Oriented Spatial Temporal Data Model
(v) Cube Data Model
(vi) Object Based Data Model
(vii) A Multigranular Spatiotemporal Data Model
(viii) Activity Based Spatiotemporal Data Model
(ix) Feature-Based Temporal Data Model

The description over each of these data models is presented in Chapter 2. Every member of this data model family has its own advantages and disadvantages. Hence in the real world the space data is multidimensional. Therefore, a lot of emphasis has been given for the consideration of 3D data in the data management component (Narciso, 1999; Commossi *et al.,* 2003; Bonan and Guoray, 2002; Adnan, 2005; Bonan and Guoray, 2002; McBride *et al.,* 2003). The classification of the geographic movement confirms the importance of 3D data and volume data as well.

Other issues in data management includes the extraction of spatiotemporal information from the databases, managing historical information and minimizing storage usage (Narciso, 1999; Commosi *et al.,* 2003; Bonan and Guoray, 2002; Adnan, 2005; Bonan and Guoray, 2002; McBride *et al.,* 2003; Nikos *et al.,* 2002; Taher *et al.,* 2004; Xiaobau, 2003). Extraction approach is very important for the interpretation of semantic and correct information. Presently, extraction information is based on the interpolation model on the spatial data. Attribute and temporal information needs to be extracted together for having a complete set of information. Historical information too needs an efficient and optimized management. There is no standard pattern for maintaining the historical data. Therefore, in some systems it is stored in the same database and in other systems it is kept in an entirely different database. The major challenging issues in this domain are: how to increase the storage capacity and how to bring efficiency in the system.

It may be noted that the existing models do not support specific type of movement, and they are bending more towards discrete model such as snapshot model (Michinori, 2002; Narciso, 1999; Commossi *et al.,* 2003; Bonan and Guoray, 2002; Adnan, 2005; Bonan and Guoray, 2002; McBride *et al.,* 2003). The root cause of this issue is the lack of complete understanding of the real phenomena. And this view point is further confirmed in a number of research publications (Hogoweg, 2001; Michinori, 2002; Nadi and Delavar, 2003; Pfoser and Tryfona, 1998; Narciso, 1999; Robert, 2001; Bonan and Guoray, 2002; Donggen and Tao, 2001; Geoffrey *et al.,* 2004; Jan, 2002; Christine *et al.,* 1999; Li *et al.,* 2002b; Kate, 2003; John *et al.,* 2004). Secondly, most of the data model do not properly covers the type of movement. It focuses certain cases in the type of movement. However, it is a unanimously accepted view that in the case of all type of the movement the model can not support their needs. Therefore, to make a workable data model, the three types of the geographic movement i.e. continuous, cyclical and intermittent must be considered. Besides, theoretical issues regarding managing changes in data and semantic and their mutual relationship can be solved when the model considers various types of geographic movement behavior in the data model.

In addition to the above discussion, other issues revolve around the technical aspect after implementing the data model, which includes the redundancy of data, and also managing temporal and spatiotemporal data which increases from time to time. The models listed above also discuss the issue of data redundancy. This issue arises when we want to store changes and the changed data. In attribute data, this is not a major issue but in the spatiotemporal data this is very critical topic for discussion because in this case data is normally taken by snapshots. This problem can be fixed by storing only the changes without any loss of the information and data. The question is how the structure of the model should be built which guarantees the maximum possible control over the redundancy.

Temporal or spatiotemporal data models are also affected with the issues of redundancy. Data is continuously growing. The question is how to manage this data?

Historical storage is need of the hour. In the list of the data models, there are no allocations for managing historical information. With the passage of time the data keeps on multiplying. It is needed to sort out some possibility for storing and maintaining all the data along with the guarantee of the maximum possible efficiency of the system.
In order to design an efficient retrieval process, indexing spatiotemporal data holds the primary importance. Since the model is not tested rigorously, therefore, it lacks the efficiency factor. Second important crippling factor is conduction of test on prototype but not on real model. Of course the prototyping approach is deficient with the management of large amount of data which involves numerous changes. So, it can be safely argued that for introducing the reliability and efficiency of the model, it has to be tested with real world problem.

In short it can be said that the design of the model should be robust. It must be able to handle the complexity of the data and it should have the capacity to technically manage the geographic movement data. Only these two basic features will facilitate us for quick retrieval of the historical data and it will enable us to exercise a controlled usage of memory and this feature, consequently, enhances the processing speed. Therefore, the model should be designed after a lot of deliberation and after reading between the lines all the technical shortcomings of the existing models.

Finally, understanding of real world phenomena contributes significantly in managing spatiotemporal data. Additionally, the database technology has improved a lot and novel database models are also introduced. Usage of relational database model technique and object oriented database model are the glowing features of the new models. These new models can be employed for settling the issues of memory management, efficiency and reliability of the model.

1.3. Problem Statement

Current GIS software and application does not have a general model to support geographic movement. The issue can be solved by using spatiotemporal data model in the GIS software. Previously, there do exists spatiotemporal data models but these models lacks the quality for managing surface movement data on the volumetric object. Hence there is a strong need for designing a robust data model which can show a reliable and predictable behavior while dealing the complex data, memory management issues and efficiency of the model.

1. How to formalize surface reconstruction characteristic with the temporal element for developing spatiotemporal data model?

2. How to design conceptual and physical spatiotemporal data model which can support management of surface movement data on the volumetric object?

3. How to develop database system which is having capability to manage and visualize surface movement data on the volumetric object?

1.4. Motivations

Change is inevitable. Almost all object in the world change with the passage of time. It happens either by natural phenomena or due to human activity. It is because of this, time occupies a very important aspect in our life.

Since, GIS plays an important role in the solution of the real world problem, it is almost impossible to find GIS that do not have the time component as important part of them. However, it can be argued that the lack of efficient management of time is an issue that needs an immediate attention. Currently, most of the applications do not cater all type of the geographic movement in the system.

This research attempts to provide suitable spatiotemporal data model which can support and manage surface movement data on the volumetric object. It is believed that suitable model will provide suitable application for managing geographic movement information which is reliable for the managing surface movement data. The importance of this research is as a guideline for managing and visualizing geographic movement application for helping in decision making process. The proposed application include: geographic historical management data application, morphology of the terrain data, mobile movement, and Global Positioning System (GPS) application.

1.5. Goal

Provide spatiotemporal data model for managing and visualizing surface movement data on the volume object to support Virtual GIS.

1.6. Objectives

Following are the objectives of this research.

1. To formalize the surface movement reconstruction with the temporal element to handle surface movement data on the volumetric object.

2. To develop spatiotemporal data model based on the introduce formalization of spatiotemporal surface movement to support managing and visualizing surface movement data on the volumetric object.

3. To develop a prototype database system and visualization tools for testing and evaluation of proposed data model.

1.7. Scope

Scope of the research includes:

1. In order to develop the data model, we need to understand the real world process and understand the way the data can be representing in the digital form. In the Virtual GIS, all of the object represent in the three dimensional or in the volumetric form. Surface reconstruction is a fundamental aspect in this research. We have study the surface reconstruction based on the how point created the surface on the object. For the purpose of managing movement in the surface, we have integrated the surface reconstruction with the temporal to come out with formalization. This formalization just only takes account of the geometric data and integrated with the temporal. We assume that all the data sources will be digitize from the data source to become a geometric data.

2. For developing the data model, we use the formalization has been introduce by first objective of the research. We assume that formalization is an important aspect to formalize the real world to the digital form. In this case, we just only focus on surface only without takes account of the object in the surface. For that purpose, we focus on the digital terrain model which is can be consider as volumetric object but we only consider the movement on the surface of the object only. The data model has been design by using the relational data model and not been tested with other database model.
3. In the testing and evaluation phase, we need to develop the develop database system, data loading algorithm, data retrieval algorithm, data format and visualization algorithm. Database has been develop based on the propose model because to test and evaluate the model. The database is developing is based on

the relational database model. The loading algorithm is to develop the loading system with reducing the redundancy of the object. The algorithm just only focuses on loading digital terrain data from the TIN data has been created by the ArcGIS. The retrieval algorithm is based on the database structure and prepares data for load into data format for purpose of visualization. Visualization algorithm is based on the deformable object by using parametric equation which is having capability to simulate the deformable object. The algorithm is developing for the purpose of read the data format and visualize the data based only the data in the data format.

1.8. Report Structure

The thesis is organized in seven chapters. This chapter generally discussed the workflow of developing the Volumetric Surface Movement Spatiotemporal Data Model and their implementation with testing and evaluation process. The aim, objectives and the scope of the research have been clarified. The basic concept of the studies and research will be reviewed in the next chapter.

In Chapter 2, detail descriptions of the study background are discussed. This chapter explains on the background of the idea of spatiotemporal data model and nine data model has been review to understanding the research problem with the solution. This chapter also explains on the comparison with the model and summaries the issues has been occur from their research.

Methodology of the research study is discussed in chapter 3. The discussion includes discusses the methodology used through out the research study, the framework of the research study and other contributing factors in the research study.

Chapter 4 describes the formalization of the surface movement on the volumetric object and the concept of the VSMST Data Model. This chapter also discuss how the model can me use to minimize the redundancy of the data storage and the abstraction of the data model will be implemented. The last of the chapter we discuss the conceptual testing to prove that our formalization and the model can be use to manage volumetric surface movement.

Discusses in Chapter 5 are the methods of implementations of the research study. Phases in the implementation are explained in this chapter. This chapter describe the VSMST Data Model will be design in the conceptual model, logical model and physical model. After that the model will be use to develop the database system. This chapter also describe the loading algorithm, retrieval algorithm, data format and the visualization algorithm.

The results of the experiments are examines and discusses in Chapter 6. In the early part of this discussion is about data processing from the Ariel photos has been digitizing to use into the testing phase. The next discussion is about the result of data loading, data retrieval and visualization. This chapter also discuss capability of the data management by using VSMST Data Model and its visualization. We also discuss comparison of the result with the ArcGIS software to clarify the contribution of the research.

Chapter 7 concludes the thesis. This chapter describes the research contributions of the study. Furthermore, suggestions on future works are also discussed to wrap up the thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

GIS occupies backbone position for analyzing various phenomenons of the earth. Due to its fundamental importance the system is gaining a lot of attention. Among various other important factors, the factor of ‘time’ plays a significant role in the constitution of an effective system. Consequently, this factor cannot be separated from the geographic data. Besides, the system holds a very strong relationship between space and time. The principal objective of this research is to create spatiotemporal data model, suitable for managing geographic movement data specifically on the volume and 3D data. For achieving this objective, previously available spatiotemporal data model were thoroughly discussed.

2.2 Geographic Movement

Movement is an important part of geography. Almost every attribute in the world involves the phenomenon of movement. Movement means the changes that occur within an attribute from one state to another. On earth, movement is considered to be a natural process. All geographical features of the earth move from time to time. Movements of geographical features bring changes to their characteristics and as a result, affect the environment. Movement requires changes in both temporal and the spatial dimensions. The changes involving the spatial data cause changes in shape, geometry, location and topological information. The changes in the non-spatial data provide new information regarding the features. In order to gain a clear understanding on either the phenomena or event or changes regarding geographic movement, there are six important questions that need an immediate attention. The questions are 'who', 'what', 'where', 'when', 'why', and 'how' (Yattaw, 1997). 'Who?' and 'what' are questions of a human and nonhuman phenomenon's identity, respectively. 'What?' typically deals with semantics matters. 'Who' are special cases of 'what' and 'how' questions; they could either be disguised 'what' questions or hidden 'how' questions.

Question of the phenomena occurrence are questions concerning time, past and future event (i.e. Where and When). In all geographic analysis of phenomena involving movement, one fundamental line of inquiry is to ask where the spatial change is occurring. Sometimes knowing the exact location is a necessary part in the examination and interpretation of the phenomenon. For example, in many human migration studies, an important aspect in understanding the movement knows where people moved from and to what location they have moved. The important element in examining a movement does not necessarily know absolute geographic locations, but rather understands the relative spatial structures of the movement such as distance affected or characteristics of the landscape.

'Why' questions can be divided into two categories: authentic 'why' questions and 'how' questions disguised as 'why' questions. Physical geographic processes, movement or spatial change may occur due to human interference, such as the redirecting a river's flow. This is quite possible that this redirection may be caused by natural processes or presences such as the wind or platonic. 'How' questions are often considered the most significant questions asked because they lead to explanation. 'How?' may be a question of existence, process, utility, or policy. When asked about processes themselves, 'how' questions treat sequences of events as a single event and are focused on the relationships between events rather than on the events themselves. Asking ‘how?’ about a movement can extend to include questions about the structure of spatially dynamic geographic phenomena. The basic spatial dimensions of movements are displayed in sharp relief to one another and interpreted in this fashion; different kinds of moves can be seen as basically identical in their spatial structure. Such framework is important for the description and understanding of how things move across three-dimensional space. However, explaining why things move in the human world is to refer to the ideas of spatial interaction.

Spatial change or movement across space requires change or passage of time. Despite the inherent nature of time and space in geographical movement, examination of time has not been given the same significance as the significance given to space. This may be largely due to the method for measuring time. While spatial change can be defined in both absolute and relative terms of distance and direction, non-spatial change measurements are usually based on relative terms only. Time-geography accepts the notion that space and time are universally and inseparably tied together and that examinations of human organization of the earth’s surface, human ecology and landscape evolution cannot separate the two dimensions.

Explanation of geographic phenomena often involves the description of change. A phenomenon may change with respect to its non-spatial attributes, its spatial attributes or in both attributes. Dynamic geographic phenomena, then, are spatial phenomena that change in attribute or non-spatial phenomena that change location over time. It is important to know that both are ‘geographic phenomena’ (involving location) even though the phenomena themselves may be either spatial or non-spatial. All these questions specify the geographic movement. They explain the properties of geographic movement (i.e. Space, Time and Scale). In order to model a geographic movement in GIS, all aspect of the question must be considered for a particular real process.

2.2.1 Geographic Movement in Geographical Information System (GIS)

A geographic information system (GIS) is a computer-based tool for mapping and analyzing things that exist and events that happen on Earth. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies. Map making and geographic analysis are not new, but a GIS performs these tasks better and faster than do the old manual methods. And, before GIS technology, only a few people had the skills necessary to use geographic information to help with decision making and problem solving. Geomedia, MIKE-11, Arcview and STEMgis are tangible GIS examples. These software are discussed in the following section.

2.2.2 GIS Functionality for Geographic Movement

Geomedia is capable of merging two or more adjacent grids into one grid based on user input and it can also create one grid from two or more adjacent grids based on user input. It can combine the first selected grid with grids selected from the file dialog to create a grid of unique values, extracts a new grid by clipping to the inside or outside of an overlaying graphic object and alters the resolution of a grid by performing aggregation calculations on groups of cells with the same value. Geomedia can also takes a grid or set of grids that were created from a true colour image and converts them into a BSQ, BIL, BIP, JPG or TIFF image. It is able to run Majority Filter request on active grid theme and can also create a region for every contiguous group of cells with the same value.

Geomedia have a function to execute grid Extract By Attribute request on active grid theme, it uses a mask grid to replace No Data cell values of the active grid (input grid) with the values of the nearest neighbouring cell. It cleans (smoothes) transition areas between grid zones using expand and shrink methods, shrinks linear features in active grid to one pixel which changes the resolution of the active grid by interpolating values using a chosen re-sampling method (nearest-neighbour, bilinear, or cubic). GeoMedia, enables the users to create a random grid, analysis variable in the VTAB of the grid. It facilitates the users to create a table containing various geometric calculations for each zone in the active grid and produces chart profiles of line features (streams, roads, trails, etc.) using a line theme and an elevation grid theme. Besides, Geomedia can also create elevation profiles of selected lines and selected point features, creates Warp start points, Warp desired points, deletes one or many links from the current link table and rotates the active grid in a clockwise motion around the lower left-hand corner.

MIKE–11 presents dynamic navigation tree that can give a complete overview of model while hiding irrelevant items. The logical dynamic dialogs allow concentrating on the required data, since sub-dialogs contain only relevant parameters. Top-down/Left-right model design leads through the model development in a natural manner. It also runs multiple models from the same data set and update data and all models automatically. Moreover, it executes rapid sensitivity analyses on model domain, grid spacing, layer specifications, etc. it has an easily link local-scale models to regional-scale models, or multiple regional models.

ArcView is a tool which enables the users to see images and maps. It has a zooming facility that allows user to magnify a portion of the map by either (1) clicking directly on the item that user want to see more closely, or (2) drawing a box around an area of the map that user want to magnify. It also has a capability to find information about map features from the attribute table which contains the data used to draw the map.

STEMgis is an editing and visualization software. It can view or edit the header of a grid, concatenate the frames from two grid layer, specify areas indicating no data areas, re-project a raster layer, extract frames, combine tiles, clip or erase data from a raster grid. It can evaluate the difference between time slices, and can also calculate statistics from multi-temporal raster data. This is able to perform raster layer mathematics, calculate volume and area from raster data. It can create contours from raster grid, calculate the slope and aspect from a raster layer, calculate the distance to feature in a raster grid, smooth the filter applied to raster layer, generalize lines, aggregate point data using clump radius, aggregate point attribute data into polygons, perform tracking analysis with curfew and restriction zones, create raster data from a vector layer and extract attribute values from raster data to vector data.

In short it is multifunctional editing and visualization software, which takes care of fundamental and the advance features of GIS. Generally, the functions of these software are based on the concept of snapshot model and layer based model. The GIS software uses animation as an approach to represent and visualize temporal and spatiotemporal information. For that purpose, users need to create animation tool for presenting spatiotemporal and temporal data. For example Marten Hogeweg, (2000) created animation tool for the ArcView to present temporal data. In the STEMGis only, the animation tools are ready to use. MIKE 11 does not have a complete tool to visualize and present temporal and spatiotemporal data. So, to present the spatiotemporal information, they need to use ArcView to create layering data for every period of time and use animation tool (i.e. movie maker) to create presentation (Lawal, 2004). As a conclusion in this discussion, current tool has a basic function to create analysis and presenting tool is meant for the spatiotemporal and temporal data analysis. However, there is a need for having a tool need to modify and to support spatiotemporal analysis and presentation.

2.2.3 Discussion

Managing geographic movement data is not a new idea in GIS software. Traditionally data management system in the software can store and manage temporal information. Discussion in previous section show time series, temporal and spatiotemporal information can be managed in the current software. Most of the GIS software has capability and function to manage time series and temporal information. However, in the spatiotemporal information the software can not support all type of data. According to the classification of geographic movement (Yattaw, 1997) most of the software do not support the comprehensive requirements of GIS. Generally, the software can manage until two dimensional spatiotemporal data. On the contrary, the STEMGis software has a lot of capability (Yattaw, 1997), but this software too failed in dealing more than a two dimensional data.

Generally, GIS software architecture needs a dual database system (Shafry, 2004) where one is for spatial data in file format and the other is for attribute data using commercial database system. This structure gives rise to the issues of synchronization during analysis and integration of the data. This leads us to the point that changes of the data occuring in the spatial do not effect information in the attribute data. The dual database architecture is not beneficial in the case of spatiotemporal information in which data subject keeps on changing. Therefore, it is recommended to use single architecture in which all of the information is under one database system.

Therefore, it can be concluded that a lot of improvement is required in the current GIS software to support real phenomenon. Besides, in the existing GIS software, there are no specific guidelines for the geographic movement application and no general model to handle volume data in geographic movement.

2.3 Spatiotemporal Data Management

Data management is very important component in any application including GIS. Functionality of the data management component is to make sure that data involve in GIS is in proper order. In spatiotemporal data management, user requirement refers to the capability for managing spatial and non-spatial data changes over the time. According to Tryfona (1999) the five requirements for spatiotemporal include:

(i) Represent objects with position in space and existence time.
(ii) Capture changes of position in space over the time, (1) continuous (2) discrete
(iii) Definition of attribute of space and organization in layer
(iv) Capture attribute of the object changes over the time
(v) Represent the relationships among the object in time
(vi) Represent the relationship among the attribute among the time
(vii) Consider spatiotemporal analysis

According to Yattaw (1997) various classes of geographic movement are related to spatiotemporal data which include four type of the spatial data i.e. point, line, area, and volume data. Indeed this data fulfils the above listed requirements. It is prerequisite to understand spatiotemporal data because it will provide a good data model for developing data management system in geographic movement. Presently, there are nine different spatiotemporal data models. These models were extensively studied for developing a most suitable model for geographic movement application.

2.3.1 Spatiotemporal Data

Spatiotemporal data is in fact spatial data which changes over the time. It also has a temporal element. Figure 2.1 shows description of spatiotemporal data.

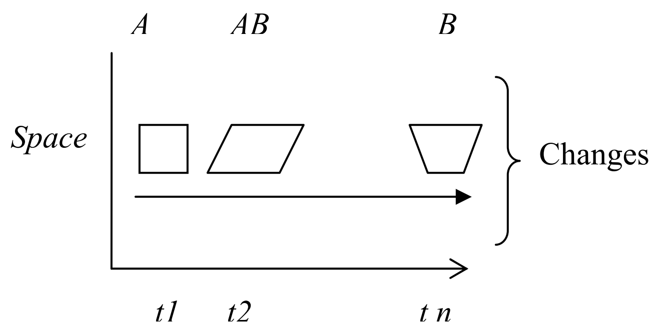


Figure 2.1 Descriptions of Spatiotemporal Data

From figure 2.1, it can be seen that object *A* in the time *t1* changes to object *AB* in the time *t2*, object *AB* changes again to become object *B* in time *tn*. Objects keeps on changing depending upon the situation and the scenario. Spatiotemporal data is series of spatial data was change. Changes will happen until *n* time (end of the changes process).

Spatiotemporal data is part of the geographic movement. Geographic information contains space information, attribute information, and time information. Space describes location, and shape. Attribute describes type of feature, name and other related information. 'Time' describes behaviour of changing, and to know whether change is continuous, cyclical or intermittent. However, time is always changing. So, it is related to all components in the geographic movement. It means space and attribute is related to time.

Since Geographic movement is related to changes. Therefore, it can be described by the collection of changes that happen in the geographic information. In mathematical definition, we can describe as below:

$$\frac{df(gi)}{dt} = \left(\frac{dtf(space)}{dt}\right) + \left(\frac{dtf(attribute)}{dt}\right) + \left(\frac{dt}{dt}\right)$$

$$f(gm) = \left(\frac{f(gi)}{dt}\right)_1 + \left(\frac{df\,(gi)}{dt}\right)_2 + \left(\frac{df\,(gi)}{dt}\right)_3 + \ldots\ldots + \left(\frac{df\,(gi)}{dt}\right)_n$$

2.3.2 Properties in Geographic Movement

The above discussion takes us to the conclusion that spatiotemporal data with the geographic movement behaviour has its own properties. These properties should be there in the data model. Table 2.1 shows, the summaries of the spatiotemporal properties. These properties hold fundamental position in the development of spatiotemporal data model.

Table 2.1: Properties of the Spatiotemporal Data that needs to be considered in Information Modelling

Properties	**Contains**
Space	Shape – Point, Line, Area, Volume Location Place
Time	Real World Time Transaction Time Database Time
Space-Time	Continuous

	Cyclical Intermittence
Scale	Duration Period
Non-spatial Data	Time Series Data Information will explain data
Historical	Time data was change

2.4 Spatiotemporal Data Model

In GIS, data model is the abstract of the database and representative of the real world phenomena according to a formalized, conceptual scheme, which is usually, implemented using the geographical primitive points, lines, and polygons or discredited continuous fields (Nadi *et al.,* 2003). Data model should define as a data types, relationship, operations, and rules to maintain database integrity (Nadi *et al.,* 2003). Spatiotemporal databases deal with geometry changes over the time (Wang *et al.,* 2000). It must consider how to store the changes of spatial data. Traditional relational database technology is not suitable for managing spatiotemporal data, which are multidimensional with complex structure and behaviour (Wang *et al.,* 2000). 'Time' occupies a very important position in spatiotemporal data model. Its significant aspects include (Hogeweg, 2001):

(i) The moment for which a value has been determined (world time)
(ii) The moment the value is stored (database time)
(iii)The moment the value was retrieved from database.

Relational Database Model is being used in majority of the current GIS. Some Spatiotemporal GIS also use this model (Sellis, 1999). Issues regarding storage difficulty (Michinori, 2002; Sellis, 1999; Koji, 2001) and data redundancy have been addressed

(Sellis, 1999; Narciso, 1999; Thomas *et al.,* 2001). It supports the relationship within the object (Sellis, 1999; Narciso, 1999; Thomas *et al.,* 2001). Object Oriented Database Model is also used in GIS (Wang *et al.,* 2000; Sellis, 1999)**.** But Object Oriented Database Model do not fully support relationship of the object (Wang *et al.,* 2000; Stojanovic *et al.,* 2001) but it works with the complex object like 3D. Currently, focus has been shifted to design database model using Object Relational Database Model. Oracle 9i and Informix Database support this type of database model (Shafry *et al.,* 2004; Daut *et al.,* 2001).

Approaches to design data model play an important role for successful Spatiotemporal GIS. The integration of the database model and approaches will give a guide line to an abstraction of the data model. Besides, it is easy to implement and develop database system. There are two approaches that have been found in our literature study. There are Snapshot View Model and Space Time Approach Model (Michinori, 2002).

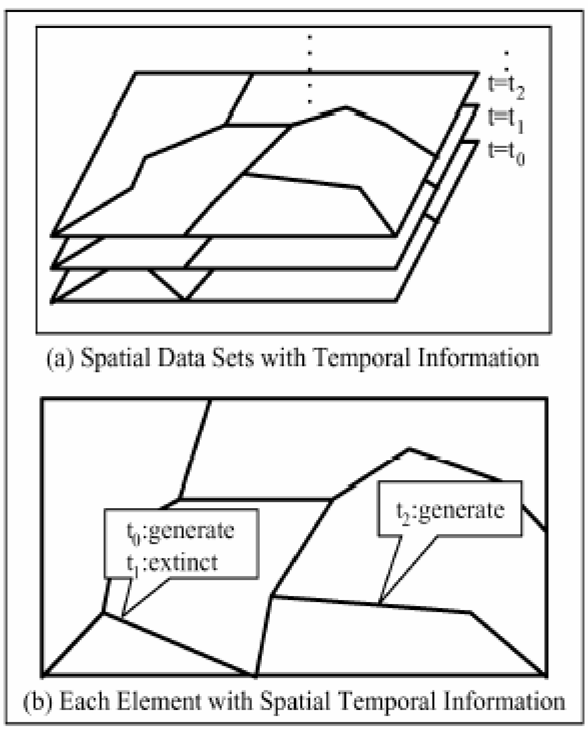


Figure 2.2 Snapshot View Model and Space Time Approach Model (Michinori, 2002)

These two models have taken time element in the model. GIS software discussed in previous section is based on the type of the model. Based on two models, some researcher has develop own data model using Space Time Approach which is including explicit and implicit description. The issues were arising implementing this data model is redundancy of the data and suitable indexing technique for supporting large amount of data.

In GIS, there are four models canned been considered to create data model. These are Field Based Approach, Object Based Approach, Direction Based Approach, Feature Based Approach (Shafry *et al.,* 2004; Daut *et al.,* 2001). Some model has been extended to add time element in the approach. Double Cube Data Model is one of the examples that had been implemented using Cube Data Model and Enhancement of Feature Based Approach by adding time element. However, we want to highlight these four approaches that can be added time element to create data model for spatiotemporal data. These are the challenges for the researcher to explore and find out the suitable model for the managing geographic movement data.

Discussion of the data model will be extended below by looking into several data model has been developed to support spatiotemporal data. There are nine (9) data models that have been discovered throughout 1999 to 2004. The models are:

(i) General Purpose Spatiotemporal GIS (GEN-STGIS) Data Model
(ii) A Spatiotemporal Data Model For Zoning
(iii) Cell Tuple Based Spatiotemporal Data Model
(iv) Object Oriented Spatial Temporal Data Model
(v) Cube Data Model
(vi) Object Based Data Model
(vii) A Multigranular Spatiotemporal Data Model
(viii) Activity Based Spatiotemporal Data Model
(ix) Feature-Based Temporal Data Model

These models were developed based on the different approach to support different application. They have their own advantages and disadvantages. However, a lot of issues were arising in these data model which can be classified into technical issues and fundamental or theory issues. This will discuss detail in the section 2.4.4. Before that we can go detail about the entire model to clearly know purpose of the model and how it was design.

2.4.1 General Purpose Spatiotemporal GIS (GEN-STGIS) Data Model

GEN-STGIS is modelled using 2-dimensional, or plane, Cartesian (x , y) coordinate system and is based upon Euclidean geometry, which is concerned with the study of points, lines and other geometric figures that can be formed with them (i.e., polygons, polylines and arcs) a plane with the described characteristics is called an Euclidean plane. To specify the representation of geographic feature in time, the GEN-STGIS data model uses the two temporal dimensions, valid time and transaction time, which are orthogonal, independent and semantically different so they can be manipulated separately. The GEN-STGIS data model is based on the linear model of time, where time is measured as a discrete variable. This decision has been made based on current temporal data base research that adopts the discrete model for representing valid and transaction time.

The need to solve correctly real world problems in the geographic domain leads to state the reason of using GEN-STGIS. The first reason is to determine if existing spatiotemporal data models can be extended, modified or combined to obtain a good temporal representation for the geographic features of geographic phenomena. The second one involves the design of a suitable spatiotemporal GIS data model for representation, storing and manipulating geographic features that change over time and the relations among them. The principal aim of this data model is to capture the attribute, geographic and temporal characteristics of geographic feature to overcome some of the problems presented in the current spatiotemporal GIS data models.

The design of an object-oriented data model generally involves two basic steps. First, structural modelling, which describes the structure of similar objects in term of classes, their similarities and differences, the association or connection among these classes and the structural constrains. The seconds step corresponds to the behavioural modelling, which describes the behaviour of the different classes in term of operations and relationship.

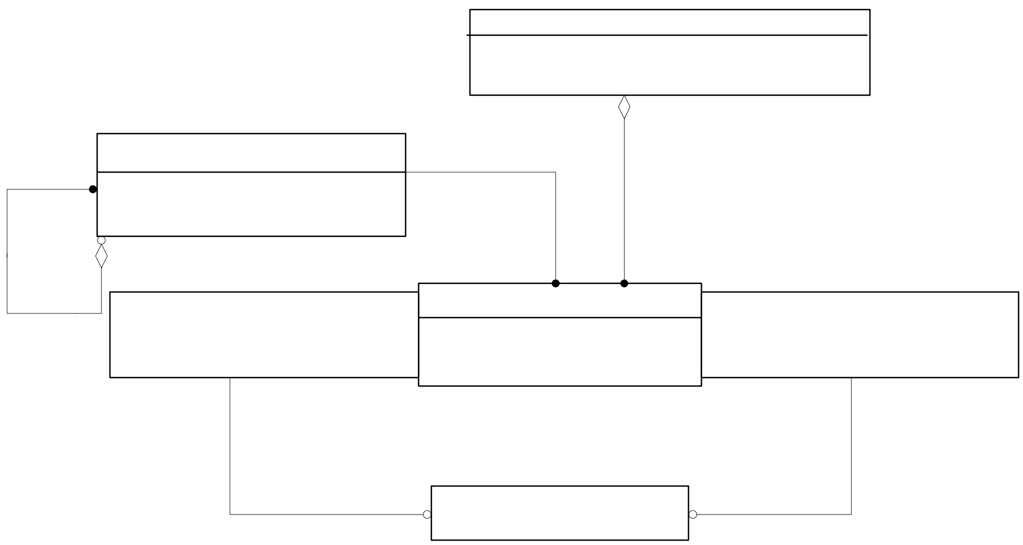


Figure 2.3 Structure Model: Class diagram for geographic phenomena, geographic categories and geographic feature

The evaluation of this data is performed in five parts. The first part is related modelling process and consists of a description of how the GEN-STGIS data model satisfies the eight design criteria for the modelling of spatial data types for database system. The second part is a discussion of those characteristics of the existing spatiotemporal GIS data models that are improved by the GEN-STGIS data model. The third part is presents an evaluation of the functional aspects of this data model in terms of the different ways for querying the data model. In order to evaluate the structural aspects of the data model, the forth part will be performed to illustrate the process of geo-temporal data modelling. The last part will be performed to data model where it could be implemented as object-oriented database.

This new Gen-STGIS data model satisfies the two principal requirements of spatiotemporal GIS application. First, it provides a significant advance in the field of TGIS by providing a reasonable 2D spatial and 2D temporal representation of geographic features and seconds, it allows the retrieval of the corresponding spatiotemporal GIS data. It would be unrealistic to suggest that the proposed GEN-STGIS data model provides a final solution to spatiotemporal GIS development. Much research needs to be done to deal with the complexities of TGIS before any complete version will be available and accept by the GIS community. Some problems, like the requirement of sophisticated hardware and software due to the storage requirement and the manipulation of immense amount of data, need to be solved.

GEN-STGIS provides an important step towards addressing this problem through the decision to store only data changes, which was made in order to minimize the problem of the huge volume of data. The GEN-STGIS data model offers a framework to describe 2D spatiotemporal GIS data. The further capacity to manipulate this kind of data in 3D would be the most immediate extension of this work. It would interest to introduce the management of cyclical time or to consider branching time which would allow the study of several future options and the comparison of different scenarios. Since the data model is defined in terms of temporal discrete variables, future important research should further explore the use of temporal continuous variables.

2.4.2 A Spatiotemporal Data Model For Zoning

Zoning is a legal method for a city to control development. Zoning defines specific areas in a city where land use and building specification are controlled by law according to what is deemed appropriate for that area. For example, an area zoned for residential use would have land use and building restriction that would prohibit uses within that area.

Healthy, safety, sanitation and economic equity, city beauty, humane and available housing; these are all obvious concerns and goals of citizen and their civic leaders. It is possible for civic leader to achieve these goals without any direct control over land use and building in their city. But there are other issues supporting the need for zoning. Health issues are related to varying land uses. Long-term exposure to some industrial process can be hazardous. No one wants to live next to a toxic waste dump or any other property whose emissions are harmful or detract from the quality of life.

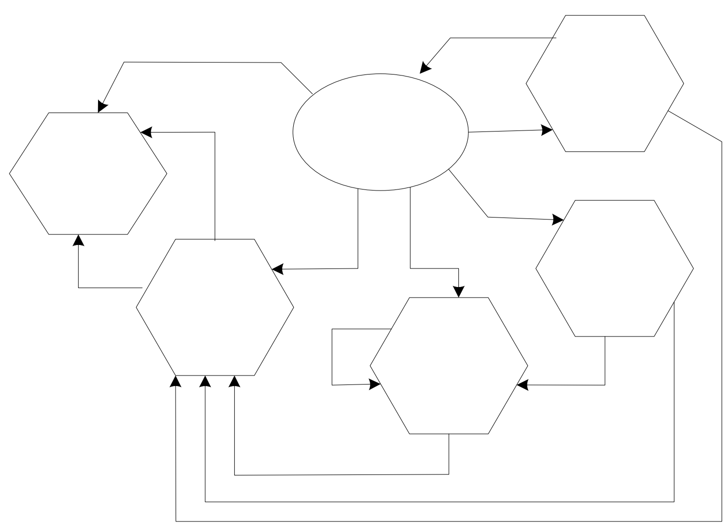
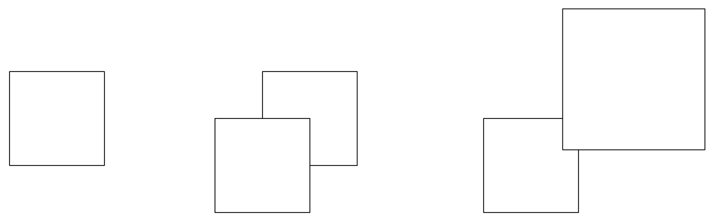


Figure 2.4: The Entity-relationship diagram

The diagram simply shows how one real world entity is related to another real-world entity. The centre hub of this model is the Ordinance event. Ordinances are laws created by city governments. They are not restricted to only planning issues; they can apply to any aspects of city government and business.



In 1978 a city annexes an area & gives it a zone designation

In 1985 a new zone is created which overlaps the original zone

In 1997 zone C is created and overlaps A completely. A is no longer valid, except historically

Figure 2.5: The true nature of zones

In this research, this data model has been implemented using ERSI Arcmap software and Microsoft Access as a database. This model has been test with the Riverbottoms neighbourhood in Provo was selected as the test area. It was chosen because it is an area that has undergo a large number and variety of zoning changes in the last 20 – 30 years. Class of queries has been tested were three classes of basic queries and four modes of spatial analysis to run on spatiotemporal database. The three classes are:

(i) The query deals with changes in the feature (movement, change in shape);
(ii) The query deals with changes in the distribution of features;
(iii) The query deals with the temporal relationships among multiple geographic features.

The four modes of inquiry for spatial analysis are Exploration, Explanation, Prediction and Planning. Basic zoning queries has been running are:

(i) This is a basic query designed to fulfil the need within planning departments for parcel-based zoning histories. These queries can improve both the efficiency and accuracy of planning decisions. The intend is to determine current and past zoning as well as allowed land uses for the property in question.

(ii) To produce the correct cartographic result, the strategy is to achieve the real-world overlapping of zones. By drawing more recent zones on top of earlier ones, the map falls into place visually.

The characteristics of an actual zone were identified and found to be very similar to a basic GIS feature: a non-topological polygon. The problem was greatly simplified by using a feature that can exist essentially independent of any other feature. Zones never move, zones never change shape and zones do not die. The master plan regions can also be stored in the same manner as zoning. Having this data in the database can create more queries that focus on analytical and predictive questions rather than the day-to-day queries.

2.4.3 Cell Tuple Based Spatiotemporal Data Model

A cell tuple T is an (n+1) tuple of cells $\{c_0,c_1,c_2,\ldots, c_n\}$, where any *i*-cell is incident with a (i + 1) cell. The proposed model preserves the spatial, temporal and spatiotemporal topology at any given time.

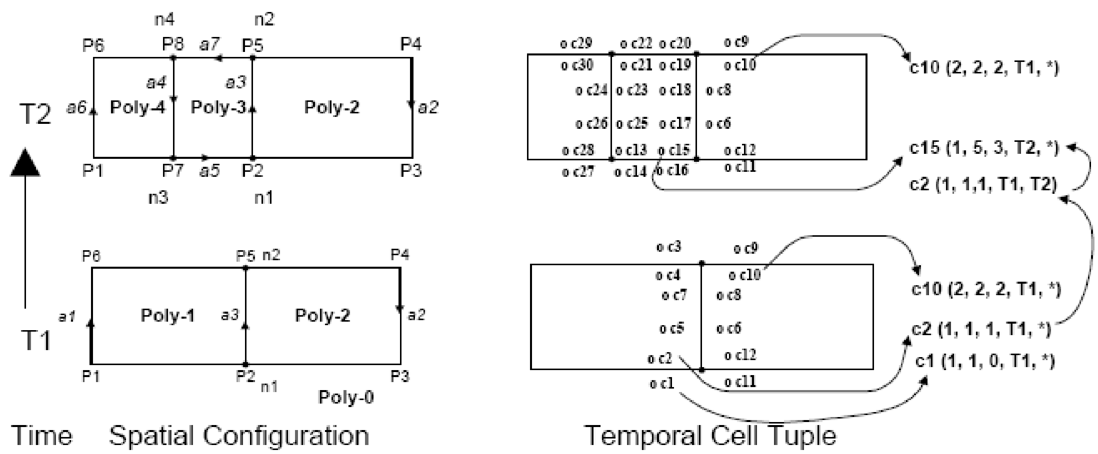


Figure 2.6: Cell Tuple Based Concept

In the temporal cell complex, intra cell complex relations, i.e. relations between the cells in the cell complex can be describe using boundary and co-boundary relations. The boundary of an n-cell are its (n-1) faces at time t. the co-boundary relations capture two types of topological relationships i.e. adjacency and containment. Relations between spatial objects can be found based on boundary / co-boundary relations between cells. The boundary and co-boundary relations are encapsulated in a simple temporal cell tuple structure.

Each 0-tcell of 1-tcell is assign two tuples. At base state (T!) there were 12 temporal cell tuples. At time T1, the tuplesc1 has the following configuration c1= (1,1,0,T1,*), where the first cell "1" is the 0-tcellid , the second cell "1" is the 1-tcellid, the third cell "0" is the 2-tcellid. Due to the spatial change at T2, the configuration of the tuples are changed and new tuples (c13, c14, …, c30) are created; some old tuples cease to exist (c1,c2,c3,c4,c5,c7) and other remain the same (c6,c8,c9,c10,c11,c12).

One of the problems in adopting the proposed models is that they are based on an existing commercial GIS. Most of the commercial systems are closed system, which can not be extended or modified. The second problem in this data model is about the system response time. Because of the adoption result is in voluminous data, the system response may be increase.

One of the great advantages of this model is that spatiotemporal topology is stored all the time in an implicit manner and spatial-objects are treated uniformly. The model is dimension independent. Therefore, the approach can be extended to higher spatial dimensional objects and singularities of cells can be incorporated. The cell tuple structure may generate a large number of tuples, but it is expected that it would not affect the system performance because of its simple structure.

2.4.4 Object Oriented Spatial Temporal Data Model

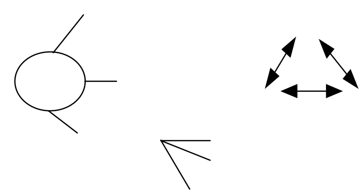


Figure 2.7: Superclass structure of the model

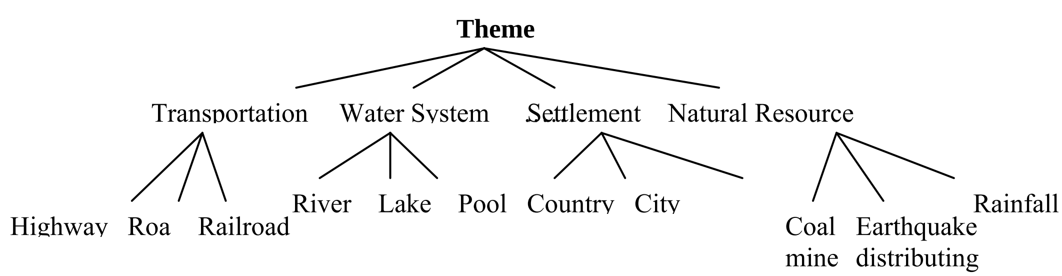


Figure 2.8: Theme classification hierarchy

There are three kinds of behaviours in this model has been consider. There are spatial change of the object, spatial relationship with other objects, and temporal relationship with other objects. Spatial change includes: 1) stay-in; 2) Transform-between; 3) Appear/disappear: 4) Increase/decrease 5) Splitting: 6) Moving.

Concept of the object oriented modelling is involved generalization, specialization and aggregation. Generalization extracts similar properties of different classes into a super-class, while specialization extends a class to some sub-class. In Figure 2.7 transportation is a super-class, which can be specialized into highway, road, railroad, etc. Association can also be called grouping which enables some objects of same type to form an object of higher-level type. Aggregation is a construct that enables different objects to be amalgamated into a higher-level object. The super class mentioned above defines basic void attribute and behaviours of a spatial temporal object. This super class can be specialized into sub-class. Each sub class can also have its own sub-class. With this class hierarchy and the aggregation and association of different classes, multi semantic space and time can be expressed.

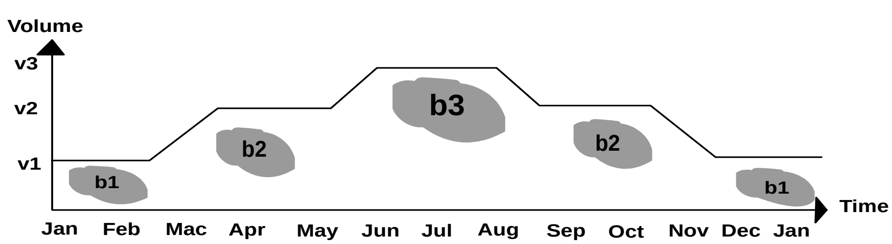


Figure 2.9: Volume and border change of the lake

There exist various spatial temporal phenomena such as “stay-in”, “transform-between”, ‘appear/disappear’, “splitting”, etc. As shown in figure 2.9, the lake stays in volume v1 and border b1 from the beginning of January to the end of February. From the beginning March to the beginning of April, the lake transform from v1 to v2, b1 to b2. Supposing every year, the river has same changes. During one year, the change of the river border and volume is linear, while in many years change is cyclic.

One problem with previous data model is that spatial and temporal aspects of databases are modelled separately. Spatial database focused on supporting geometries while temporal databases focus on the past state. But in many circumstances, spatial and temporal attributes should be connected together. Application-driven is another problem. Many database systems concentrate on the definition of a particular spatial temporal model that is related to certain application. Each model focuses on a specific set of spatial temporal features. When encountering other features and applications, that model doesn't work. The third challenge for spatial temporal modelling is on the discrete representation of continues phenomena. Many temporal systems can only capture discrete snapshot of real world but many temporal phenomena in nature are continuous, such as clouds, rains etc. The fourth problem is representation of data should be natural to human. The structures of space and time are identified as essential for the realization of cognitive systems. Human knowledge of the dynamic geographical world comprises of three different subsystem that handle "what", "where" and "when aspect of object properties. Theme-based model, location-based model and time-based model separately describe one subsystem.

Based on human cognition, the model linked together theme, space and time through common object references. This model is built up from the basic attributes and behaviours of spatial temporal objects. Based on object oriented strategy, it's extensible to any applications by generalization, specialization, association, and aggregation. Thus, this model can completely support the multiple semantics of space and time. This model has the same efficiency no matter querying time or querying space. Each time table, each space table and each theme table has an object ID as the index.

2.4.5 Cube Data Model

The WIS database design is best described in two parts, firstly the logical database design and secondly the physical database design. The logical database design provides a simple conceptual model that helps users and developers to visualize how their data are stored. It allows the user to record the history of any object, or feature as it moves through space and time. Descriptions of features and the events observed at them are recorded in terms of properties or attributes. Thus, to store river water quality data, an individual monitoring site might be classified as a feature and the variables which describe or are observed at the site, such as its position, the site name, a unique reference number, river flow, pH values and so on, would be its attributes. Other examples of features could include a river network, land use map, and satellite images. WIS supports a wide range of spatial and non-spatial data types allowing the user to record most types of variables. Both features and attributes are decided and defined by the users and their system and user definitions are stored in data dictionaries

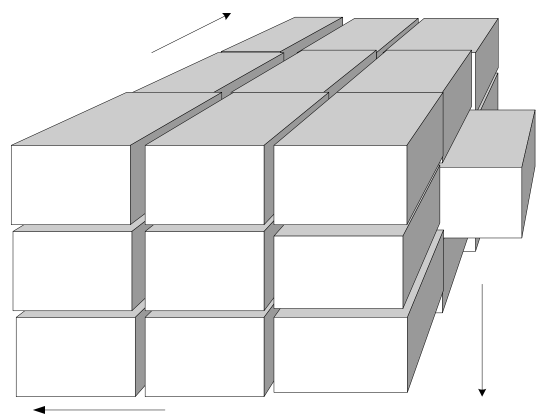


Figure 2.10: Cube Data Model

The three axes of the cube represent features attributes and time. Each cell contains a value of an attribute describing a feature at some moment in time. There are no constrains on the number of features, attributes or occasions that can be stored by the cube other than imposed by the physical limits of the hardware. List below are the key properties of the WIS cube: 1) any attribute may be observes at any feature; 2) a feature may have any number of attributes; 3) any number of values may be recorded for an attribute over time at a feature; 4) the values may be recorded at fixed or random time intervals; 5) the data model does not distinguished between spatial and temporal data; 6) the cube is infinite in all directions.

The WIS cube was implements in Microsoft Access. The underlying tables contain three different types of data: data tables; list tables and reference data. The data table shares a common basic design and varies only in that different data types need different columns to hold the value. Each row in a data table contains a value from a cell in the cube. A list contains a set of feature identifiers, attribute identifiers or date/time range that pick out a set of feature of interest. Reference data provide supporting information such as units of measurement, periods, field and structure definitions, feature type definitions and attribute information.

Traditional geographical information systems employ a two dimension or at best 2.5 dimensional frameworks, suitable for many applications. However, mapping the environment introduces certain problems not easily managed within existing systems. The natural environment is constantly changing and this requires a more dynamic way of handling such data. Environmental media, such as the ocean and the atmosphere, complicate matters further as processes that occur within them vary through three-dimensional space and through time.

Using WIS data model, all attributes or properties are assumed to be potently tem variant. Even positional properties may form a time series. All point and line features are time stamped, so change is expressed by storing multiple occurrences of a feature. WIS data model also provides a completely generic data independent structure around which to build equally generic tools for data visualization, analysis, retrieval and data loading. It also can be implemented in virtually any relational database management system.

2.4.6 Object Based Data Model

The relative view treats space-time as relationships between objects, phenomenology that is intuitively suited to epidemiological queries, Which seek information regarding associations between health events. Whereas current GIS data models store information regarding *what* and *where* events occur, the Space-Time Information Systems data model is designed to store *what*, *where* and *when*.

The approach to constructing space-time information systems: the data structures; including the object-based data model; movement and attributed change models; space-time indexing; and queries possible within a STIS. The space-time object model is being used to represent an individual, as might be required to model exposure and disease status at the individual level. This approach applies equally to other possible objects, whenever a space-time object representation is appropriate.

Object-based Data Model is a TimeSpaceObject has the following characteristics: start location, spatial extent, movement vector (for an object that changes shape during the observation interval, the movement vector describes the movement of each vertex), start time, stop time (optional), pointers to the previous and next objects in the *object chain* (described below) and the label of the parent chain. A complete set of objects composes the object chain that represents the individual's movement through time. This model extends the triad (what, where) used in conventional GIS to the triad (what, where, when) necessary for spatiotemporal modelling. Each SpaceTimeObject identifies a modelled entity. The space time coordinate is a spatiotemporal location that may be a space-time point or a more complex object such as a space-time polygon. The movement model function defines how the object moves through space as a function of time, the simplest non-static movement model being a vector and velocity defining linear movement at a constant speed.

In addition, morphing can occur when the shape of a complex object, such as a polygon, changes through time. Morphing can be gradual, in which case the change in the object's boundary occurs over a defined time interval; or it can be abrupt. Morphing is a ready mechanism for handling changes in cadastral systems such as realignment of administrative and political boundaries. Attributes are observations on variables describing the modelled entity and its environment and the change models describing how those attributes change through time. These change models support the rapid visualization of space-time change in, for example, disease rates as well as the health status of individuals as demonstrated in the "STIS-Influenza" application presented in the Results section. The attributes are defined at the application level by extending these object definitions through inheritance. This provides a powerful mechanism for designing custom objects that retain full functionality defined by the SpaceTimeObject data model. Object Chains Object chains represent individuals moving through time and space as chains of sub-objects.

These object chains can describe people, raccoons, mosquitoes, trees, or structures. Object chains can have time-dependent attributes such as weight, height, disease status, size, etc. These attributes, however, are fixed in the duration of a subobject. Mark, Egenhofer et al (2000) describe geospatial lifelines for representing an individual's movements and exposure throughout a defined time period, and is an example of an object chain representation made specific to modelling exposure at the individual level. While observations on chains occur at a finite number of time points or time intervals, these observations do not have to happen at the same time for all individuals under scrutiny.

Object chains have certain features. They are single strands that do not break spatially, do not split to create two sub-objects at one point, nor do they join. Pregnancy would be handled by having two entities occupy the same location from conception until birth, but at birth their paths diverge. Terminating the dividing cell at the moment of division would represent cellular division. At division, two daughter cell chains begin. The spatial extent of sub-objects can be points, lines, multilines, and polygons. Object chains can be modelled in two ways—as snapshots in time or as continuous objects. For snapshot-type methods, object chains are represented as a linked list of time point data, with no projections of movement between time points

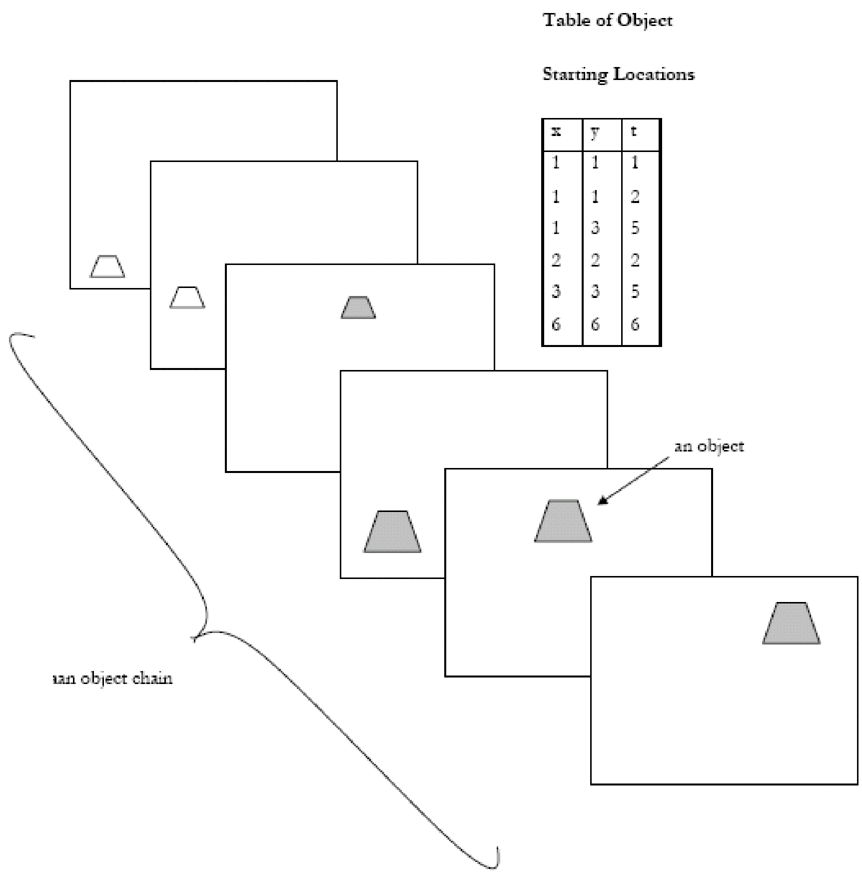


Figure 2.11: Abstraction of Spatiotemporal Data Storage in Database

This method restricts analyses of the object to the time points or time intervals recorded. Essentially, the object will disappear between records. Alternatively, object chains can be modelled as continuous objects.

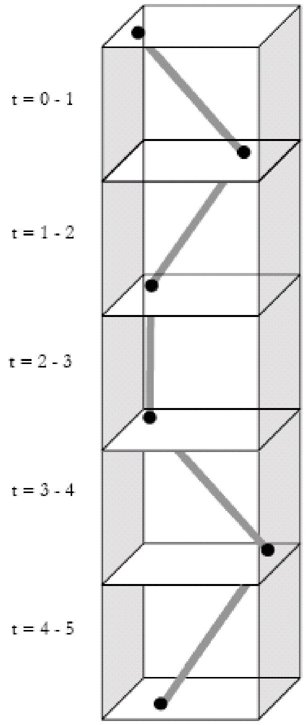


Table of Object

Starting Locations

x	y	t
2	2	0
5	4	1
2	4	2
2	5	3
6	5	4
3	2	5

Figure 2.12: Movement Management in Database

This is achieved by creating sub-objects with start times equal to the end time of the previous sub-object. Movement Models Movement models dictate how object location is determined between the start and end times, the simplest movement model being linear interpolation at a constant speed. The constraint of linear movement is relaxed by defining families of movement functions. These functions can be non-linear, or they may constrain to adhere to networks such as rivers, roads and corridors. Logical and agent-based operations can define changes in trajectory upon collisions with other objects and features. The research has been limited to linear motion, but the movement functions obviously can be defined to describe many physical and biological systems. Attribute change models in this data model assume observations occur at discrete times at which the attributes of an object are quantified. Attribute change models describe how the values of attributes change between observations times. The simplest attribute change model is a step function that updates an attribute's value when a new observation is made on that attribute. More complex change functions which "borrow strength" from nearby locations can be used to interpolate values through space and time for both categorical and continuous data. These include techniques from the field of geo-statistics, which provides a probabilistic framework for space-time interpolation by building on the joint spatial and temporal dependence between observations. This methods overview has touched on several of the important questions and potential solutions that provide the framework of Space-Time Information Systems.

2.4.7 A Multigranular Spatiotemporal Data Model

A Multigranular Spatiotemporal Data Model has been proposed for representing both spatiotemporal data supporting multiple granularity management for spatial and temporal dimensions. This data model are modelled in modelling situations in which the position of moving entities must be related to geographic areas represented by maps. Both moving entities and map data can be specified at different levels of detail, the notion of spatial granularity partitions the space by taking into account the specific application domain considered. Therefore, this notion is application domain dependent.

To compare spatial data expressed at different granularities, this data model refer to map generalization operators specifically those used in model oriented generalization. Particularly, the operators supported by this model will guarantee topological consistency. The framework for this model presents an extension of the ODMG model, by taking into account the work done in a previous temporal extension. This multigranular framework can be considered as a basis for developing an object oriented spatiotemporal model with an expressive query language, as extension of OQL and the temporal path expression language, for performing the analysis of spatiotemporal data expressed at multiple spatial and temporal granularities.

The spatiotemporal data model manages uniformly both spatial and temporal information. This data model have extended the ODMG (Stojanovic *et al.*, 2001) type system with specific types for representing spatial data by means of vector features, and with parametric constructors for specifying spatial, temporal and spatiotemporal information at multiple granularities.

The model has been designed for handling moving entities and temporal maps uniformly. The model allows for the definition of data at different spatial and temporal granularities, at different levels of detail with respect to spatial and temporal dimensions. In particular, data representing moving entities or maps that have spatiotemporal characteristics can be specified with respect to both different spatial and temporal granularities.

The object attributes for this model can be spatial, temporal, spatiotemporal or conventional attributes, that is, attributes without any spatiotemporal characteristics. Temporal and spatial multirepresentations of object attributes are orthogonal characteristics of the model. They are obtained by taking into account temporal and spatial granularities sets separately, and scaling a temporal/spatial value to a different granularity.

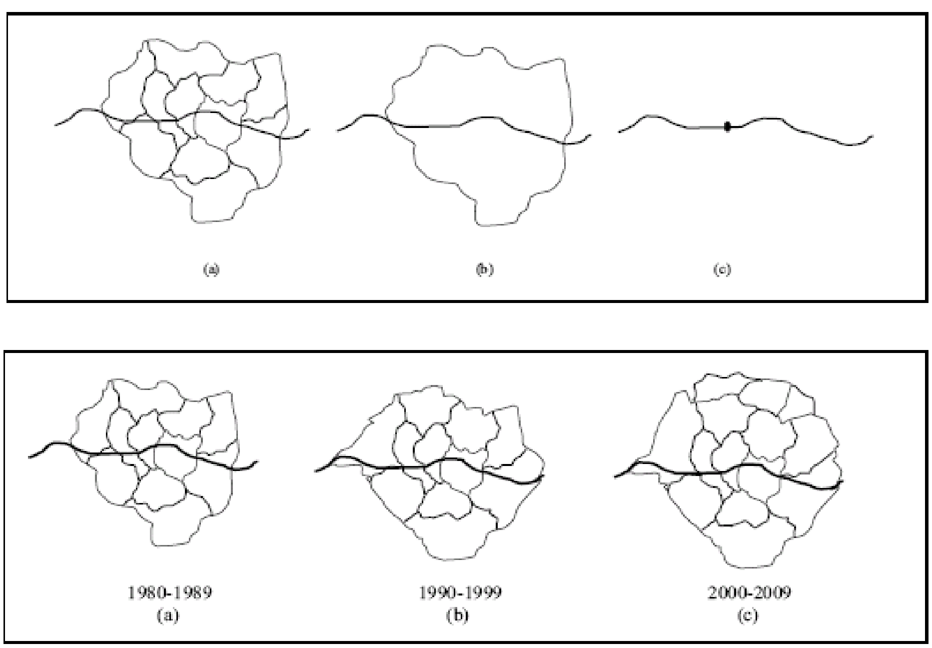


Figure 2.13: Multigranular Concept in the Model

A framework for the specification of a spatiotemporal extension of ODMG data model with support for multiple spatial and temporal granularities has been presented. By designing a database model including both spatial and attribute data, this data model adopts an integrated approach that uniformly handles all data and differentiates itself from traditional GIS systems.

Although the specification discussed is not complete, this data model does present some interesting aspects. First of all, this data model give uniform specifications for both multigranular spatial and temporal types that can be easily combined to define multigranular spatiotemporal types. It also specifies the model query language by extending OQL with spatiotemporal path expressions. This data model also considers an integration of the query language with map overlay operations.

The data definition language have been extended to allow for the explicit storage of topological relationships of spatial data represented in temporal maps, that is a critical issue for speeding up queries. Moreover, this data model can combine the static conversion specification in the database schema with a more flexible on-demand specification system, by extending the query language with ad-hoc conversion specifications.

The data model are planned to implement and test the spatiotemporal model and its query language. In particular, they are interested in developing a GUI for visualizing spatiotemporal representations of query results. Plus, this data model will also develop to optimizing performance by maintaining materialized views of different levels of representation of spatiotemporal data.

2.4.8 Activity Based Spatiotemporal Data Model

This data model has been developing with the aim to representing, analyzing and predicting changes of spatial information over time. A lot of models have been proposed. All the models are intended for addressing and modelling the dynamic behaviours of natural phenomena, which is normally related to changes in spatial extent. These model are however, not tailored to the need of activity-based research. This is because the dynamic of activity and travel behaviour are related to changes in locations of human subjects. Spatiotemporal data models for activity-based transport demand modelling have been created to overcome these problems. In this mode, the behaviour of activities is represented as a sequence of two states-staying at and travelling between activity locations. The proposed model can support analysis and queries of activities from multiple perspectives. The activity based approach has resulted in a wider range of issues that need to be addressed. It includes:

(i) Demand for activity participation
(ii) Activity scheduling in time and space
(iii) Spatiotemporal, interpersonal and other constrains
(iv) Interactions in travel decision over time
(v) Interactions among individuals
(vi) Household structure and roles

Since most activity data are location specific, a GIS is particularly useful for activity-based modelling. It is likely that GIS will be used increasingly as a spatial decision support tool for activity modelling. In general, GIS has great potential to support activity-based modelling in data collection, data management, data manipulation, data output and visualization. Specifically, activity-based travel demand modelling will benefit from GIS in the following respects:

(i) Support for data collection
(ii) Provide cross-classification of activity by type, time, location and socio-demographic characteristics of individuals

(iii) Define an individual's spatial and temporal opportunity set for conducting activities

(iv) Represent the space-time prism

Based on the changing characteristics of the spatial attributes of objects, such as location, boundary or shape, three types of spatiotemporal behaviours can be differentiated.

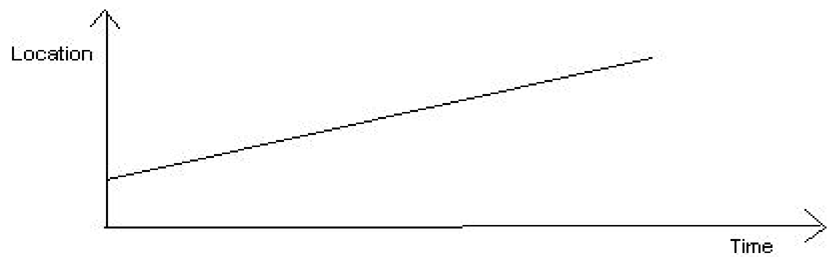


Figure 2.14: Continuous Change

A continuous change: objects of this type are always considered to be in a changing state.

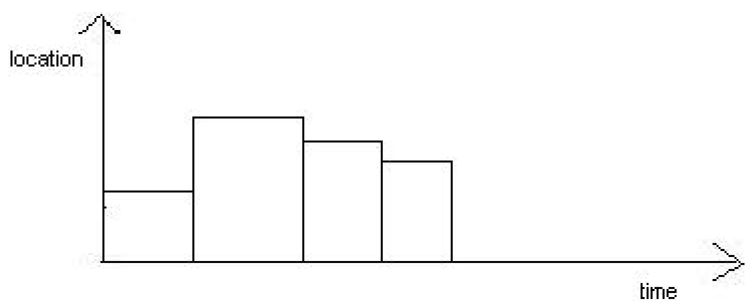


Figure 2.15: Discrete Change

A *discrete* change: objects of this type are always in static states but change instantaneously by events.

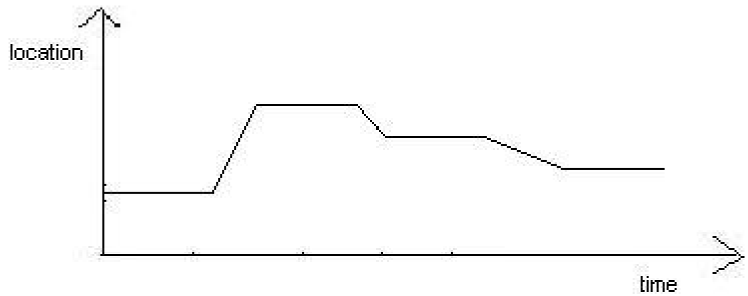


Figure 2.16: Stepwise Change

A *stepwise* change: objects of this type are sometimes static and sometimes changes. The database used for this data model is only included the major information. The information included activity type, travel mode, activity partner and time in the transport system.

This data model supports queries from time-based, person based, activity-based and location based perspectives. This data model is powerful in organizing, managing and manipulating data for activity based modelling. The prototype of this model will be extended to support activity schedules and policy change evaluation, by providing functions to find out activity schedule and to identify impacts on activity patterns of changes in opening hours and level of service of the transport system.

In the future, this data model should be able to manage large amount of activity data, although the search time might increase if the data size is very large. The proposed data should also be able to handle Global Position System (GPS) derived data and easily establish links with the data types included in the model. This data model hoped can be applied to represent and model the dynamical behaviour of objects with step wise changes in general.

2.4.9 Feature-Based Temporal Data Model

The feature-based temporal representation has three components, space, time, and theme, but these three components are not considered as three separate dimensions as in a space-time cube. Instead, the time dimension is incorporated into the feature and its other two components. Therefore, a feature is a temporal feature, and it may have multiple temporal spaces and multiple temporal themes during its lifespan. In other words, a feature and its space and theme are all functions of time (equations 2.6, 2.7 and 2.8).

Temporal feature = f (t) ………………………………….. 2.6

Temporal space = g (t) ………………………………….. .2.7

Temporal theme$_i$ = h_i (t) ………………………………….. 2.8

In equation 2.8, theme$_i$ is the one of the themes belonging to the feature. In this study, time and spatiotemporal changes are simplified as discrete. Therefore, function f(t) can be simplified as below (equation 2.9).

$$f(t) = \begin{cases} f_0 \ldots \ldots \; t \in [t_0, t_1) \\ f_1 \ldots \ldots \; t \in [t_1, t_2) \\ \ldots \\ f_n \ldots \ldots \; t \in [t_n, NOW\;] \end{cases}$$

…………………….2.9

In equation 2.9, f_0, f_1, and f_n are all constants, representing the status of the feature during corresponding interval time [t_0, t_1), [t_1, t_2), and [t_n,NOW] respectively. The word "NOW" means the feature is still valid as status f_n at this time. Similar to f(t), functions g(t) and h(t) can be simplified as equation 2.9. From this all equation, figure

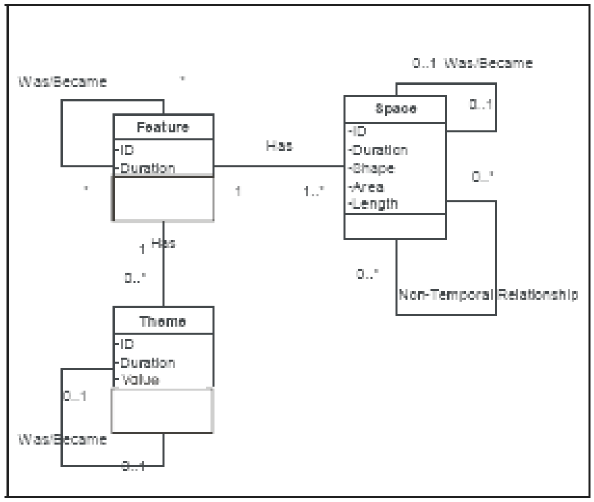


Figure 2.17 Conceptual Model of Feature Based Model

In the UML conceptual framework of the feature-based temporal model a temporal feature may have one or many temporal spaces and one or many temporal themes; there exist temporal relationships, “Was/Became”, between temporal features, between temporal spaces, and between temporal themes. The difference is temporal relationships between temporal features are m-n, while those between temporal spaces and between temporal themes are 1-1. Temporal themes related with temporal space, such as area and length, are treated as attributes of temporal space, while others are modelled as temporal themes belonging to temporal features.

Besides the temporal relationships, there also exist two other kinds of non-temporal relationships. First, there are spatial topological relationships between the temporal spaces, which co-exist at certain time-period. Second, there are other non-temporal relationships such as ‘Connects To’ and ‘Flows To’. This approach is reasonable for object-based data, because a feature is the basic element in the object-view. It represents time in temporal feature using its status rather than the change. In order to get the spatiotemporal changes, temporal spaces have to be compared for differences.

Object-oriented database management system (OODBMS) fit the spatiotemporal data model best to store the database. OODBMS takes the advantages of OO programming into database management. However, OODBMS is not successful in commercial database marketplace for certain reasons. One of the shortcomings of OODBMS is not good at backwards compatibility to RDBMS, which is used by almost all of the databases on the world. ORDBMS implement the OO features in relational database, so ORDBMS has good backwards compatibility to RDBMS and supports OO features as OODBMS does. It provides OO features including abstract data type and inheritance, and is more mature than OODBMS. The feature-based temporal representation can take advantage of these features, especially nested table, collection, and reference. The 1-m "has" relationships between a temporal feature and its temporal spaces or temporal themes can be well represented using nested table, and the m-n temporal relationships between temporal features can be modeled using collection data type. Therefore, the object-relational schema is efficient in storing and querying spatiotemporal data modelled in the feature-based temporal representation.

The temporal representation be best implemented in OR schema, which supports ADT and fits the feature-based temporal data model very well. In order to visualize spatiotemporal data organized in OR tables, it is need to develop a new temporal GIS rather than extending an existing one, because the existing GIS environment overall limits the advantages of OR schema. However, there is lots of work to develop a new system.

Most existing GIS are layer based, and each layer has fixed spatial type--point, line, or polygon. While in ORDBMS, spatial type of a feature is not specified at table level, but at record level. Therefore, one type of feature can be represented as multiple spatial types, and this can benefit the spatial representation of base geographic data. For example, in base geographic data, building should be represented as point or polygon according to its size. In existing GIS, the other data model can not define such a building feature class. However, it is possible for this data model. An original small house changed to a big building can be represented from a point to a polygon in OR schema and visualized as such in this data model. In this study, the temporal GIS developed is very crude. The next step is to add data editing, feature defining, and more visualization programs to the temporal GIS. Further, real world feature data, such as census boundary and transportation should be put into the feature tables for better experiments.

2.5 Discussion

The process of building data model is to know what exactly the need to archive and what the scenario. The model can be flexible, dynamic, extendable and able to implement. In this situation, goal of the entire spatiotemporal data model is able to store and manage spatiotemporal data. However, the database can be store and manage various types of spatiotemporal data. Research has been done until 1999. Table 2.5 was adopted from (Narciso, 1999) which the result of the study regarding issues are related with spatiotemporal data model.

Table 2.2: Research Issues and Models (Narciso, 1999)

Problem	Models
Individual geographic feature	Space-time cube
Not stored topology	Space-time cube, Triad
Large amount of data	Space-time cube, snapshot (vector, raster), space-time composite, Triad
Complex algorithms to recover topology	Space-time cube, update snapshot (vector, raster)
Complex temporal queries	Space-time cube, snapshot (vector, raster), update snapshot (vector, raster), 3D/4D
Data redundancy	Space-time cube, snapshot (vector, raster), space-time composite, Triad, relational
Data inconsistency	Snapshot (vector, raster)
Difficult to detect change	Snapshot (vector, raster), space-time composite
Poor temporal resolution	Snapshot (vector, raster), update snapshot (vector, raster), space-time composite
Complex model	Space-time composite, 3D/4D, Triad
Difficult to represent geographic data	Relational
Time is not included in the model	Snapshot (vector, raster), update snapshot (vector, raster)
Not implemented	Space-time cube, Space-time composite, 3D/4D, Triad, object-oriented

In Table 2.2 are the issue was arising and will be solve by current research. However not all issues will be solve. During our study it still have the same issues was arise in the current spatiotemporal data model. Here we were mention that nine (9) a new model has been developing during 1999 until 2004. The entire model was implemented in the prototype version. There are no complete data model was been tested currently accept WIS cube has been use to develop STEMGis. In other GIS software, the data model was extending from the spatial data model to support time in the model. Time just as additional attribute was use in the software. It will contribute difficulty to full analyst data based on time. Time is not only an attribute, but it will give more information. That is why in the ArcView GIS software, researcher need to create additional tool for specific application.

Many issues in the spatiotemporal data model need to solve. Current spatiotemporal data model still does not comply with the current requirement. Most of the models only support point, line and area in the data model. In the real phenomena, data was in the 3D. The data models need to consider 3D data which to follow enhancement of the computer graphic technology. Most of the models also just consider discrete data movement. However there are models was consider in the data modelling. If refer to classification of geographic movement, all of the model lack of consider continuous, cyclical and intermittent behaviour of the geographic movement.

Technical issues are also important in developing spatiotemporal data model. It will provide efficiency in data management in order to support all requirement of the spatiotemporal analysis especially in the geographic movement. Technical issues always arise are redundancy of data, managing increasing of data every period, and integration of the information to provide comprehensive information to a user. Table 2.3 shows, several issues was arise from the nine model has been studied.

Table 2.3: Research Issues in Spatiotemporal Data Model

Data Model	Extend / New	Note	Issues
GEN-STGIS Data Model (1999)	New	• Object Oriented Databases	• Suitable GUI to represent STGIS Visualization. • Improve temporal and spatiotemporal query performance • Future can support 3D, research focus on 2D. • Do not support on continuous, cyclical and intermittent variable and process. • Support spatiotemporal analysis and decision making • Data redundancy
Cell Tuple Based Spatio-Temporal Data Model: An Object Oriented Approach (1999)	Extent	• Using generic model • Use object oriented concept and mathematical theory	• The spatiotemporal topology is stored all the time in an implicit manner and spatial-objects are treated uniformly. • This model is dimension independent • It may generate a large number of tuples, but it is also expected that it would not affect the system performance because of its

			simple structure.
Object Oriented Spatial Temporal Data Model (2002),	Extent	• Model was extending from the Triad Structure Model. • Implement using Object Oriented Databases Model	• Inefficient on testing with query space and integration with in time, space and theme. • Redundancy of the data • Only 2D Spatiotemporal
Cube Data Model (1999)	New	• Using generic data model. • Capable of holding many types of data even if they are non environmentally related	• All attributes are assumed to be potentially time variant. • All point and line feature are time stamped. • Provide a completely generic data-independent structure around which to built equally generic tools for data visualization, analysis, retrieval and data loading.
Object Based Data Model (2000)	Extent	• Using GEN-STGIS Model • Use Object Relational Databases Model	• In the testing phase. • Need to minimize redundancy of data • Enhanced into 3D data
Multigranular Spatiotemporal Data Model (2003)	Extent	• This model was extend from ODMG model by adding temporal element	• Going to develop model in the Object Relational Model. • Using XML for the data model which will be more

		• Using Object Oriented Databases for Implementation	generic. • Cannot support topological issue in the spatiotemporal data • Suitable GUI for visualize spatiotemporal data. • Only 2D Spatiotemporal
Activity Based Data Model (2000)	Extent	• Using mobility-oriented spatiotemporal data model. • The prototype support queries from time-based, person-based, activity-based and location-based.	• This model was able to manage large amount of activity data. • It was also be able handle GPS (Global Position System). • It can be applied to represent and model the dynamical behaviour of objects with step-wise changes in general.
Featured-Based Temporal Data Model (2004)	New	• Object-oriented database management system (OODBMS) fit the spatiotemporal data model best to store the database • Simplifies time and spatiotemporal changes in base geographic data as	• Will add data editing, feature defining, and more visualization programs to the temporal GIS. • Most existing GIS are layered based and each layer has fixed spatial type-point, line or polygon while in this data model, spatial type of feature is not specified at table level, but at record level.

		discrete, then proposed to represent to\time-based on temporal feature.	
Data Model for Zoning (2001)	Extent	• Modelling valid time in the zoning data model • Design specifically to facilitate the querying of historical zoning information.	• Zoning portion would likely take a year to create. • The master plan regions are stored in the same manner as zoning.

Movement is a natural process in the world. GIS must have a capability to manage geographic movement data for the purpose of providing more useful functionality. Now a day, people are not only requiring static process as in the current GIS software. Is better to use GIS to analysis and to know phenomena will happen by prediction and forecasting process. Based on the study on the four GIS software and application, in order to support geographic movement a lot of enhancement in all components in GIS needs to be done.

To do the enhancement of the GIS for support geographic movement, the general understanding of the geographic movement is require. In our opinion, classification of geographic movement by Yattaw in his doctoral research on 1997 is very useful. From that, research can be continued to provide general frame work to extent GIS for support geographic movement application.

In the GIS, data management is very important. Data management component is start from the good data model which is fulfilling requirement. For support geographic movement, spatiotemporal data model is requires. Spatiotemporal data model can be replacing current database model in the GIS software or application to develop geographic movement application in the GIS. However, to replace the data model is not too simple. It needs research to make sure that spatiotemporal data model has been choosing meet the requirement application. It is because no general model has been developing to support geographic movement. However, there are one model has been meet which is can be use as a general data model but not is tested well. This research has been complete in year 1999, but more research in the implementation in various application part need to be done to make sure that model are surely general. The lacking of this model is does not cater all categories of geographic movement behaviour as mention in classification of geographic movement and does not support volumetric data. Not only on this model, all of model has been studied face the same of issue.

To support volumetric data is very important. It is because by revolution of computer hardware and computer graphic technology, GIS can be done more that 2D data. Besides, by using volumetric data, GIS be more realistic process and realistic presentation. It can provide more understanding with the user especially civilians people.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This research aims to create the capability in GIS to manage volumetric surface movement data. The findings from the literature review take us to the two major conclusions: firstly, spatiotemporal data model is the most suitable option for meeting the objectives of this research. However, it may be noted that the proposed spatiotemporal data model must be able to handle volumetric surface movement data. Secondly, the existing spatiotemporal models do bear some technical deficiencies. Therefore, a efforts were made to enhance the current capability of spatiotemporal data model to store and manage volumetric surface movement data.

The ultimate objective of this research is to provide a spatiotemporal data model for volumetric surface movement data which can support continuous geographic movement behavior. The objectives established include: (1) to formalize volumetric surface movement data behavior and its characteristics to create a spatiotemporal data model, (2) to develop a spatiotemporal data model which is extendable to any application related to surface movement, (3) to develop a prototype of database system and visualization tool to evaluate and validate the generality of the spatiotemporal data model. In this chapter, we will outline the methodology used in this research to achieve the objectives mentioned.

3.2 Research Framework

Process of developing data model for GIS database system is based on the understanding the real world process. From the real world process, we need to create the conceptual idea to represent the phenomena. Besides, we also require to understand current data gathering for the propose application. In this phase, we are requiring to identify the geographic feature, and element of the data. Based on the conceptual understanding, data model will be developed. In the data model, definition of the object types, relationships, operations, and rules will be presented. After that, from the model the structure of the database will be created with consideration of the logical and physical aspect. Figure 3.1 shows the process which refers to Yattaw et. al 1999.

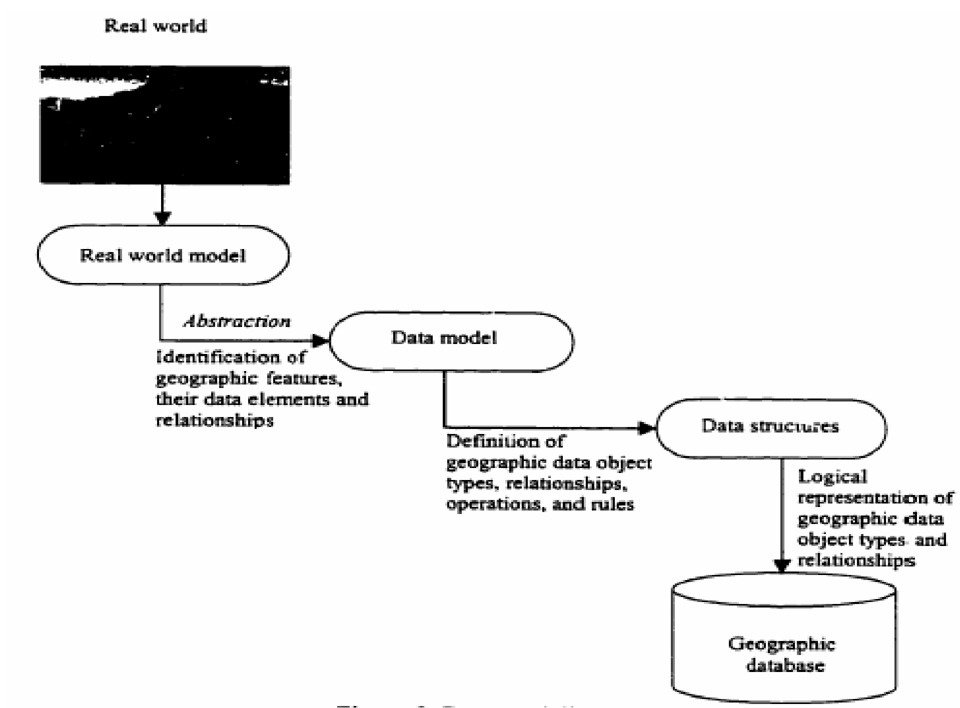


Figure 3.1: Process of Developing Database

In this research, the research activities will be arranged according the standard process are given in figure 3.1. Research will be carryout by review all aspect of developing spatiotemporal data model and identified current data model which are available for managing spatiotemporal data. From the review, research will identified the issues are related in the spatiotemporal data model and identify research problem. In this research issue has been address is developing spatiotemporal data model for managing and visualizing surface movement on the volumetric object.

According to figure 3.1, in order to understand the real world process we need to develop the formalization of the surface movement on the volumetric object reconstruction. In this phase, current definition of surface reconstruction will be integrated with the temporal aspect. From the formalization we will develop the proposed data model which is can use to manage and visualize the surface movement data on the volumetric object.

After that, data model will be implemented by using current approach of database development for developing the database system. In the database development system database structure, data loading approach and retrieval approach will be developing based on the requirement for evaluation and validation. Besides, we also require developing the visualization tool for visualize and simulate the surface movement.

For the testing and evaluation aspect, we have used the Arial photo data and digitize the data to create Digital Terrain Model data. These Arial photos have a series of data in the same area which is with the difference time. This data will be load into the database. For the evaluation we conclude the results and compare with the ArcGIS. Figure 3.2 shows the research framework for this research

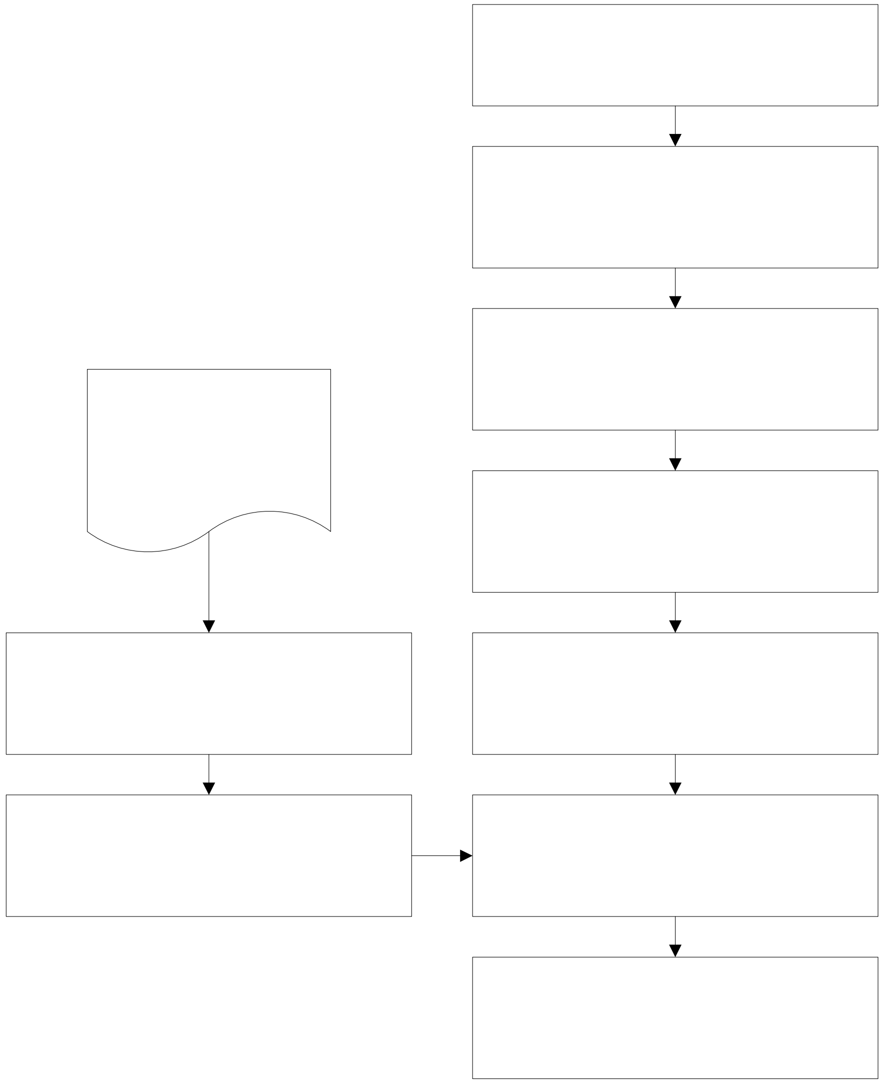


Figure 3.2: Research Framework

3.3 Process of Volumetric Surface Movement in Formalization

Spatiotemporal is a term for spatial data with the temporal element. Spatiotemporal data can represent the changes or movements are happen in a spatial data properties. In this research, spatial data will be focus on the data which created the surface with the temporal element. Currently, there are not definition has been done to define the surface with temporal aspect. According to Allan Watt (2000) in his book fundamental of the computer graphics, he was defining the surface reconstruction without the temporal element. In a real world, terrain data will be changes time to time. So, the surface on the object is move accordingly when the terrain has been changes. In this case, for modeling the surface movement information we need to consider temporal element in the surface properties. This is a basic information which is require to do simulation in the Virtual GIS for modeling the information as same as in the real world.

For that purpose, in the first step we need to formalize the real world phenomena to give a way to modeling the information. In this case, current surface reconstruction has been defined from previous researcher such as Allan Watt (2000) will be integrating with the temporal aspect. In the way of integration process, we need to understand process of surfaces is move from the previous state to the current state. In the movement process, actually points are changes accordingly during the process. So, the point its self must be integrating with the temporal element. However, in order to identify which surface are moves, temporal element also need to integrate in the surface reconstruction level.

The next step is to identify the redundancy issues in the database management. For this case, we need to store all the information of the surface movement together in the single storage. When all the information are storing in the single storage we assume that we can reduce the redundancy by store only the changes point.

All the properties are identified will be formalize and define from the basic surface movement reconstruction until management level. In this case, we assume that all the data has been integrated and have a same number of points in the surface reconstruction and ignore the uncertainty data. For all our definition, surface reconstruction is based on the geometric definition.

3.4 Spatiotemporal Data Model Development

Idea of developing spatiotemporal data is based on the formalization has been done. For the developing the data model, we need to translate from the formalization to the conceptual, logical and physical model. Currently, based on the data model has been review, there are no data model for the surface movement. In this case, we will extend idea of the current model has been review by enhancing for managing and visualization aspect of the surface movement. The data model also need to be consider the support of the current database software in the managing the data. For that purpose, we use the relational database model as a guide to develop the model.

Most of the data model has considered point, line and polygon in the data model. In the proposed model we need to enhance the model for the surface data with the temporal aspect. We assume that, in the logical model temporal element are require in the surface data in the high level and point in the low level. The model also will be design to consider the redundancy issues. For this purpose, all the surface will be integrated into the single data model with consider the managing series of data. So, we assume that every point may have the series of point if the points are moves. In this case, temporal data indexing are very important. So, the data will be load based on the same identification with the previous but it will be index as difference data in the database.

3.5 Data Management System and Visualization Tools Development

For testing and evaluating the data model, data model need to be implemented by developing database system. From the conceptual and physical model, database will be developing in the relational database system. The development of the database will be develop in the SQL Server which is open sources and not involve any cost.

After database has been develop, for loading process we need to develop loading algorithm. Loading algorithm followed the formalization which defines the ways of loading data into the database. In this loading algorithm, we assume that all the data in the geometric format which have the point, line, polygon and surface structure. In the attribute, point and surface have their temporal element. Other properties we assume that, the structure do not changes and maintain the same topological aspect. By doing this we assume that temporal point can be easy loading and manage.

For the retrieval aspect, we need to design the algorithm which is retrieving data based on the requirement to simulate the data. For this case, the algorithm will retrieve the based data. After that follow by point are involve with the movement. Important inputs for this process are time and surface identification for the specific area. Data has been retrieve will be sort into the data format which uses to load data into the visualization tools. The data format structure is containing point coordinate for the surface, surface reconstruction properties, follow by the number of movement has been retrieve based on the input information, and point which is series of the point are involve with the movement.

In the visualization tools, we use the morphing technique which always uses to deform from one object into another object with the same number of point. To perform this process, we use a parametric equation which always used to operate the morphing of the object. In this case, the algorithm need to modify based on our data structure which more dynamic.

The development of the visualization tool also use the basic of the TIN structure to generate the surface and integrated with the temporal by using the parametric equation which is mention above. Visualization tool has developed by using Visual C++ and graphics library which call OpenGL.

3.6 Testing and Evaluation

To testing and evaluate the data model, series of Ariel photos are use. This data need to be digitizing to create the TIN structure. In the digitizing process, we use the ArcGIS to digitize the data and created the TIN structure. This TIN data will be load into the database to evaluate the capability of data model handle the data. From the loading we will evaluate the number of data has been reduce from the original data with out lost the data.

After testing and evaluate the data loading, we test how efficient the data retrieval process to support the visualization process. The data will be retrieving based on the surface identification with their temporal aspect. This data will be put into the data format for visualizing.

After all the sample are loading and retrieve we will make a conclusion regarding the result. In this case we assume the result is the proposed model can support the managing of surface movement data on the volumetric object. To prove the result, we make a comparison the result with the data source (Ariel photos).

Evaluation of the result will be done by comparing the result with the current ArcGIS software. In this case, ArcGIS can visualize the Digital Terrain Model with the difference data set in the difference scene. In this evaluation, we aspect that some improvement can be shows from the result to prove the contribution of this result.

3.7 Summary

In this chapter, a description of the volumetric research methodology was given. The discussion has started with the general process of developing data model in GIS and follow by the research frame work from the problem definition until the evaluation process. The discussion was focus on the formalization process has been deriving; developing of data model, database system development with the visualization tool and testing and evaluation process will be carryout. We hope that by doing all the process our proposed model is enough to prove that the model can be use to manage surface movement data on the volumetric object.

CHAPTER 4

VOLUMETRIC SURFACE MOVEMENT SPATIOTEMPORAL DATA MODEL

4.1. Introduction

Data model is an abstraction of database structure and management. From data model, the capabilities of a database system can be measured. Therefore, a proper data model design is very crucial in determining the efficiency of data management.

In this chapter, we will discuss all aspect of data model development for storing and managing volumetric surface movement data including its visualization aspect. As it is already known, the development of a database system starts with an understanding of the real world. Based on the requirements and events gathered from the understanding, only then a good data model can be developed. In this research, the purpose of the data model developed is to handle volumetric surface movement data in an efficient way which includes the support of visualization process. In addition, the data model developed also considers several issues such as data storage capacity and data redundancy, in which solutions will be provided to tackle these issues.

We will start this chapter with a discussion on the formalization of volumetric surface movement, and will be followed by a description of the proposed data model and its conceptual testing in order to simulate the usability of data model.

4.2. Formalization of Volumetric Surface Movement

Whenever a volumetric object changes in its physical aspect, automatically its surface also changes. These changes involve points that form the object's surface, which it should be recorded for reference. Here, time is the most important factor as a reference tool for data query. Figure 4.1 shows the change process that occurs on a surface of a volumetric object.

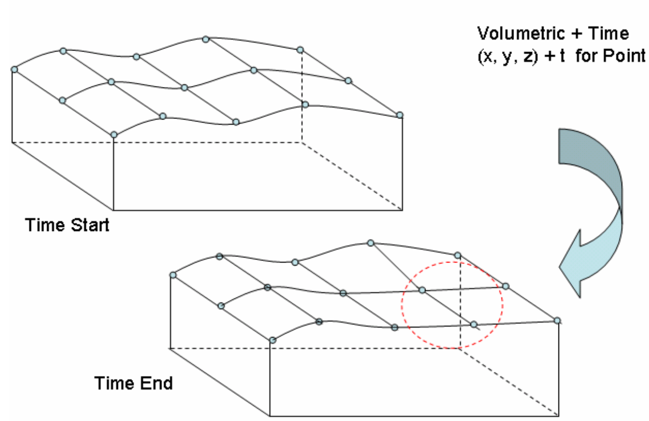


Figure 4.1: Volumetric Surface Movement

4.2.1. Volumetric Surface and Movement

Based on the definition of changes in a volumetric object, time is defined as the attribute that acts as a reference of the changes. Hence, the volumetric surface movements have two important parameters, object and time. This can be described as:

Definition 1: A Volumetric Surface Movement (*mv*) consists of two parameters which are volumetric object (*v*), and time (*t*)

1. Volumetric surface object (*v*) is a set of geometric object created by the surface → triangle → line → point
2. Time (*t*) represents the period of changes and duration of changes.

Corollary: Real world objects are in volumetric form where only its surfaces are visible. Each change that occurs can only be seen on the objects' surface. Thus, the surface became an important component in presenting a volumetric object. An object surface is constructed by the combination of points that create lines, and lines that were joined together to build a surface. A change is defined as a movement from one state to another where time is the main reference. For example, an object *(v)* that goes through a change will move from one state to another. Figure 4.2 shows the movement that occurs on object (*v*) at 3 states of time, start time (t_1), intermediate time (t_2), end time (t_3).

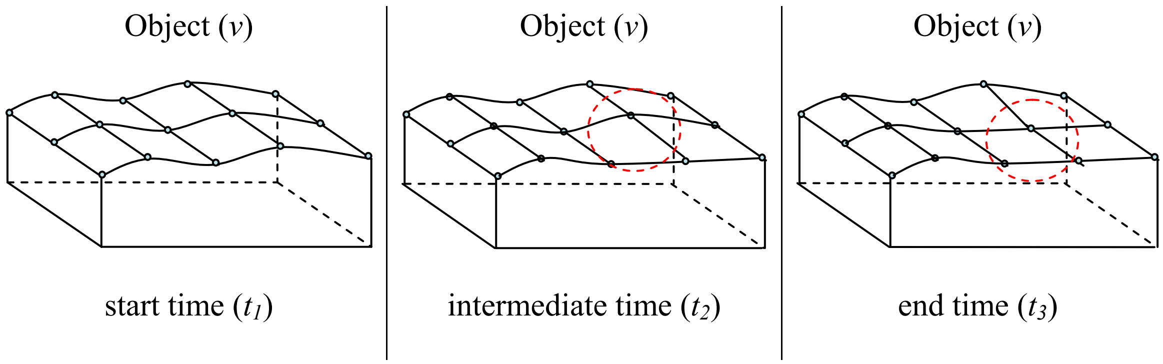


Figure 4.2: Movement Process on Volumetric Surface

4.2.2. Time Characteristic

Figure 4.2 shows time as one of the entity that represents changes or movements on the surface of a volumetric object. The changes occur from a starting point to an ending point. Time is used as a reference in determining the duration of the change and can also be used as a parameter to classify the state of a surface.

Definition 2: Time (t) is a measurement tool for the movement process. All movement process has a start time (t_s) and end time (t_e) and each movement recorded must have time (t) as a milestone of the process. The difference between start time (t_s) and end time (t_e) will provide the duration (Δt) of movement.

Corollary: In general, all things that exist in this world have its initial starting point and ending point. Likewise, each movement that occurs on a volumetric surface also has its starting point and ending point. From there, we can determine the duration of an occurring event, its starting point as well as its ending point. As shown in Figure 4.2, the change that occurs on the surface of object (*v*) is recorded at state t_1, t_2, and t_3. Thus, its starting point can be defined as start time (t_1) and the ending point as end time (t_3).

Based on the Figure 2:

Start (t_s) = t_1, End (t_e) = t_3;

Duration of Movement (Δt) = Start (t_s) - End (t_e)

4.2.3. Time as Entity for Point

Definition 1 and 2 shows that time and object is linked together semantically. This relationship is a natural association that is tightly bonded and inseparable. A movement or changes on an object is actually caused by changes that occur on the points that form its surface. Thus, we have to carefully determine and identify at which points these changes occur. Therefore, time belongs to an object, or more specifically, the points that form the surface of an object. This can be defined as follows:

Definition 3: A change or movement refers to point (*p*) which forms the surface along with time (*t*) as its attribute. Thus, a point (*p*) can be defined as (*x*, *y*, *z*, *t*).

Corollary: A surface of a volumetric object (*v*) is created by sets of triangle containing points p_1 (x_1, y_1, z_1), p_2 (x_2, y_2, z_2) and p_3 (x_3, y_3, z_3) at a certain time (*t*). Therefore, a volumetric surface (*v*) can be defined as:

$$Surface\ (v) = \{\ p_1\ (x_1, y_1, z_1), p_2\ (x_2, y_2, z_2), p_3\ (x_3, y_3, z_3)\ \}$$

Surface (v) at time (t);

$$Surface\ (v_t) = \{\ p_1\ (x_1, y_1, z_1)\ at\ t\ ,\ p_2\ (x_2, y_2, z_2)\ at\ t,\ p_3\ (x_3, y_3, z_3)\ at\ t\ \}$$

$$= \{\ p_1\ (x_1, y_1, z_1, t)\ ,\ p_2\ (x_2, y_2, z_2, t),\ p_3\ (x_3, y_3, z_3\ t)\ \}$$

4.2.4. Movement Behavior

From the definitions (1)-(3), we can say that a movement on the surface happens during which a new point is created on the volumetric surface. As it is precisely shown in Figure 4.3, movement will change the location of a point and generate a new line which contributes to changes on the volumetric surface.

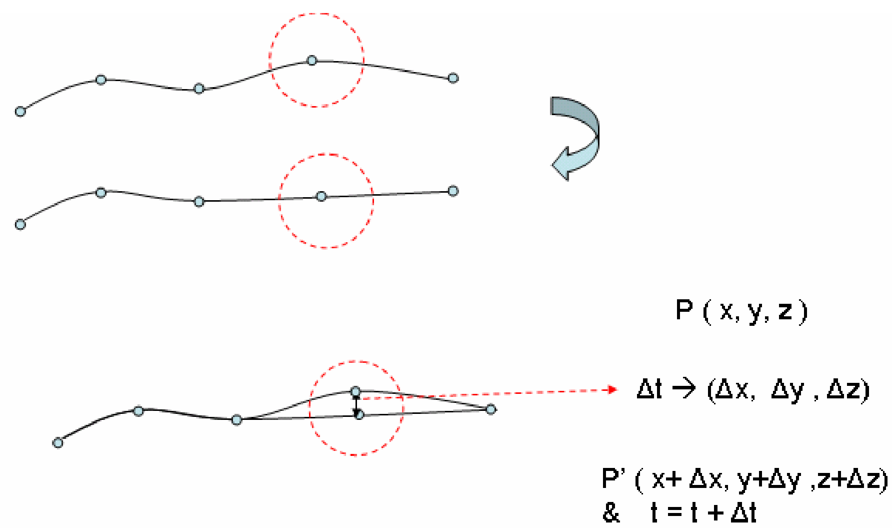


Figure 4.3: Transformation of point at time (*t*)

The movement process can be described as follows:

$\Delta t = t' - t$, representing time duration of the change

$\Delta x = x' - x$, representing changes along the *x* axis

$\Delta y = y' - y$, representing changes along the *y* axis

$\Delta z = z' - z$, representing changes along the *z* axis

Direction of the movement can be defined based on the modules value of the axis of *x, y,* and *z*. Table 4.1 shows these directions of movements.

Table 4.1: Description of Transformation Point in Volumetric Surface Movement.

No	State of Point Movement	Direction of Movement
1	$(\|\Delta x\| \ \& \ \|\Delta y\| \ \& \ \|\Delta z\|) = 0$	-
2	$(\|\Delta x\| > 0) \ \& \ (\|\Delta y\| \ \& \ \|\Delta z\|) = 0$	x axis
3	$(\|\Delta x\| \ \& \ \|\Delta z\|) = 0 \ \& \ \|\Delta y\|) > 0$	y axis
4	$(\|\Delta x\| \ \& \ \|\Delta y\|) = 0 \& \ (\|\Delta z\|) > 0$	z axis
5	$(\|\Delta x\| \ \& \ \|\Delta y\|) > 0 \ \& \ \|\Delta z\|) = 0$	x & y axis
6	$(\|\Delta x\| \ \& \ \|\Delta z\|) > 0 \ \& \ \|\Delta y\|) = 0$	x & z axis
7	$(\|\Delta y\| \ \& \ \|\Delta z\|) > 0 \ \& \ \|\Delta x\|) = 0$	y & z axis
8	$(\|\Delta x\| \ \& \ \|\Delta y\| \ \& \ \|\Delta z\|) > 0$	x & y & z axis

Movements can be presented simply by using the linear interpolation model. Figure 4.4 shows the process of this interpolation.

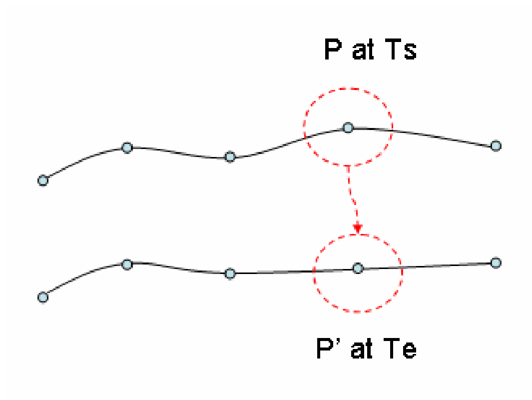


Figure 4.4: Linear Interpolation Process for Simulating Movement

Based on Figure 4.4, let *P(x, y, z)* at start time, *Ts* and moves into *P'(x',y',z')* at end time, *Te*. Thus, the movement process that changes within the three axes are $\Delta x = x' - x$, $\Delta y = y' - y$, $\Delta z = z' - z$ and $\Delta t = Te - Ts$. The next point *P'*, is the previous point *P*, added with differences within the axis. The next point can be calculate as $x' = x + \Delta x$, $y' = y + \Delta y$, $z' = z + \Delta z$, and $Te = Ts + \Delta t$.

4.2.5. Data Reconstruction

Usually, data are collected discretely even though the event that changes a surface occurs continuously. As defined, a Volumetric Surface Movement is a combination of data sets where the changes were recorded under one object. For example, a change or movement occurs on a surface of an object thus the data of the event were recorded. Therefore, there will be a set of points and lines that will form the surface where each of it has the element time representing the change that occurred. The situation can be defined as the fourth definition as below:

Definition 4: Assume that the version of spatial data are f(v) at time $f(t_1)$, $f(t_2)$., $f(t_m)$.

Object at time 1:

$f(v, t_1) \rightarrow \{ <x_1,y_1,z_1, t_1>, <x_2,y_2,z_2, t_1>, \ldots <x_n,y_n,z_n, t_1>, \}$

Object at time 2:

$f(v, t_2) \rightarrow \{ <x_1,y_1,z_1, t_2>, <x_2,y_2,z_2, t_2>, \ldots <x_n,y_n,z_n, t_2>, \}$

....

Object at time m:

$f(v, t_m) \rightarrow \{ <x_1,y_1,z_1, t_m>, <x_2,y_2,z_2, t_m>, \ldots <x_n,y_n,z_n, t_m>, \}$

Let *f(mv)* be defined as volumetric surface movement process. Thus, the set of Volumetric Movement data is a union of all set of version data.

$f(mv)t_1, t_2,\ldots, t_m \rightarrow f(v, t_1)\ U f(v, t_2)\ U\ldots\ U\ f(v, t_m)$

$f(mv)t_1, t_2,\ldots, t_m \rightarrow [\{ <x_1,y_1,z_1, t_1>, <x_2,y_2,z_2, t_1>, \ldots <x_n,y_n,z_n, t_1>, \}\ U$
$\{ <x_1,y_1,z_1, t_2>, <x_2,y_2,z_2, t_2>, \ldots <x_n,y_n,z_n, t_2>, \}\ U \ldots U\ \{ <x_1,y_1,z_1, t_m>, <x_2,y_2,z_2, t_m>, \ldots <x_n,y_n,z_n, t_m>, \}]$

Corollary: Let the surface of object *v* has 5 points,

$f(v) \rightarrow \{ <x_1,y_1,z_1>, <x_2,y_2,z_2>, <x_3,y_3,z_3>, <x_4,y_4,z_4>, <x_5,y_5,z_5>\}$

The surface of object *v* has gone through 3 states of changes and each is recorded based on time t_1, t_2, and t_3. Therefore the surface of the object has three sets of movement data based on the three 3 state changes.

$f(v, t_1) \rightarrow \{ <x_1,y_1,z_1, t_1>, <x_2,y_2,z_2, t_1>, <x_3,y_3,z_3, t_1>, <x_4,y_4,z_4, t_1>, <x_5,y_5,z_5, t_1>\}$

$f(v, t_2) \rightarrow \{ <x_1,y_1,z_1, t_2>, <x_2,y_2,z_2, t_2>, <x_3,y_3,z_3, t_2>, <x_4,y_4,z_4, t_2>, <x_5,y_5,z_5, t_2>\}$

$f(v, t_3) \rightarrow \{ <x_1,y_1,z_1, t_3>, <x_2,y_2,z_2, t_3>, <x_3,y_3,z_3, t_3>, <x_4,y_4,z_4, t_3>, <x_5,y_5,z_5, t_3>\}$

For the purpose of presenting Volumetric Surface Movement (*mv*), *f*(*mv*) is a union of all points based on the time that forms the object

$$f(mv)t_1, t_2, t_3 \rightarrow f(v, t_1)\ U\, f(v, t_2)\ U\, f(v, t_3)$$

4.3. Data Model

Based on the volumetric surface movement formalization, we can see that conceptually, the data that were used to define the surface of a volumetric object are actually the points with the value of *x, y,* and *z.* This refers to the location and the coordinate of the points. As we have discussed earlier, whenever there are changes on the surface, these points also changes accordingly. Therefore, time is the utmost important component in efficiently managing the points that forms the surface.

In order to develop an efficient data model all the factors must be taken into account. In a research done by Yattaw on 1997, several issues were brought into attention. For this research, the main focus is how to resolve the needs of definition 1, 2, 3 and 4 where data can be stored and extracted efficiently. Furthermore, solutions to reduce redundancy in the data model will be given an important focus in this research.

Based on definition 4, the following shows that all the data that form the surface will be stored and extracted using in the equation of $f(mv)t_1, t_2, \ldots, t_m$ where it is a combination of the surface set. This combination is classified as a volumetric surface movement object. It will be the base in building a data model that manages surface movements data. It will also be the foundation in managing volumetric surface movement object in the real world.

$$f(mv)t_1, t_2,\ldots, t_m \rightarrow f(v, t_1) \cup f(v, t_2) \cup \ldots \cup f(v, t_m)$$

$$f(mv)t_1, t_2,\ldots, t_m \rightarrow [\, \{ <x_1,y_1,z_1, t_1>, <x_2,y_2,z_2, t_1>, \ldots <x_n,y_n,z_n, t_1>, \} \cup \{ <x_1,y_1,z_1, t_2>, <x_2,y_2,z_2, t_2>, \ldots <x_n,y_n,z_n, t_2>, \} \cup \ldots \cup \{ <x_1,y_1,z_1, t_m>, <x_2,y_2,z_2, t_m>, \ldots <x_n,y_n,z_n, t_m>, \} \,]$$

In real process, not all of the points on the volumetric surface moves or changes. This raises the question as whether it is necessary to store all of the points, which will increase the storage usage in the implementation. Therefore, in order to avoid data redundancy, the data model must be able to identify which point that has changed. To identify these changes, data model must have the capability to check every point among version of data and capture the changing point. To perform this task, the formalism that was defined earlier will be used. The conceptual identification is as follows:

If $<x_1,y_1,z_1,t_n> - <x_1,y_1,z_1,t_{n+1}> = 0$*, data at* t_{n+1} *equal to data at* t_n *,*
else If $<x_1,y_1,z_1,t_n> - <x_1,y_1,z_1,t_{n+1}> \neq 0$ *, data for* t_{n+1} *is* $<x_1,y_1,z_1,t_{n+1}>$

Visually, the data model has been proposed to manage volumetric surface movement can be translated in table form where it can give a clearer view. The following table describes the proposed data model.

Table 4.2: Volumetric Surface Movement Data Model

v / t	**P_1**	**P_2**	**P_3**
t_n	(x_1,y_1,z_1)	(x_2,y_2,z_2)	(x_3,y_3,z_3)
t_{n+1}	$(x_1,y_1,z_1) \parallel (x_1,y_1,z_1)'$	$(x_1,y_1,z_1) \parallel (x_1,y_1,z_1)'$	$(x_1,y_1,z_1) \parallel (x_1,y_1,z_1)'$
.	.	.	.
.	.	.	.
t_{n+m}	$(x_1,y_1,z_1)'' \parallel (x_1,y_1,z_1)'''$	$(x_1,y_1,z_1)'' \parallel (x_1,y_1,z_1)'''$	$(x_1,y_1,z_1)'' \parallel (x_1,y_1,z_1)'''$

If there is a change that occurs at time *t*, not all of the points that form the surface changes. Therefore to store data at time *t*, a comparison will be done to determine which points that actually changes. In this case, process identification as stated in the algorithm above is used. Thus, the process is as follows:

P1 (x_1,y_1,z_1,t_n) move → P1' (x_1,y_1,z_1,t_{n+1}) move → .... → P1' (x_1,y_1,z_1,t_{n+m})

If $(x_1,y_1,z_1,t_{n+1}) - (x_1,y_1,z_1,t_n) = 0$

$(x_1,y_1,z_1,t_{n+1}) = (x_1,y_1,z_1,t_n)$

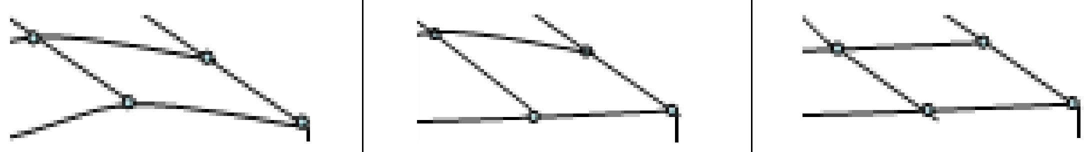
Else if $((x_1,y_1,z_1,t_{n+1}) - (x_1,y_1,z_1,t_n) > 0) \| ((x_1,y_1,z_1,t_{n+1}) - (x_1,y_1,z_1,t_n) < 0)$

$(x_1,y_1,z_1,t_{n+1}) = (x_1,y_1,z_1,t_{n+1})$

Therefore, the next point will be stored in the storage for every point after movement occurs from t_n until t_{n+1} ➔ $(x_1,y_1,z_1) \| (x_1,y_1,z_1)'$.By executing this process, movement data can be stored more easily and each change doesn't have to be repeated. Therefore, the data model developed will be less redundant and can manage changes on a volumetric surface more efficiently.

4.4. Proof of Hypothesis

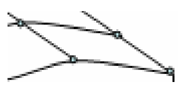
Several tests were made to evaluate the idea of the proposed data model. Here, the tested data model will sample a polygon which has several points that change at a certain time. For this conceptual testing, it is assumed that a volumetric surface has been changed caused by a certain event. The polygon that represents the volumetric surface that changes is sampled. It is assumed that only one polygon changes and that it have four coordinates. These coordinates moves or changes into a new shape in three states of time. Figure 4.5 below shows the data for the capability simulation of the data model.



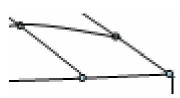
$f(v,t_1)$	$f(v,t_2)$	$f(v,t_3)$

Figure 4.5 Samples of the Data in the Volumetric Surface Movement for Conceptual Testing

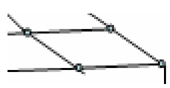
In this test, data were constructed based on definition 1, 2 and 3. It is assumed that $f(v,t_1)$, $f(v,t_2)$ and $f(v,t_3)$ all have the same number of points. Therefore, each object can be defined as below:



$$f(v,t_1) \rightarrow \{ (x_1,y_1,z_1, t_1), (x_2,y_2,z_2, t_1), (x_3,y_3,z_3, t_1), (x_4,y_4,z_4, t_1)\}$$



$$f(v,t_2) \rightarrow \{ (x_1,y_1,z_1, t_2), \underline{(x_2,y_2,z_2, t_2)', (x_3,y_3,z_3, t_2)'}, (x_4,y_4,z_4, t_2)\}$$



$$f(v,t_3) \rightarrow \{ \underline{(x_1,y_1,z_1, t_3)', (x_2,y_2,z_2, t_3)'', (x_3,y_3,z_3, t_3)'', (x_4,y_4,z_4, t_3)'}\}$$

Figure 4.6 Object Definition

The underlined points in the definition above show the points that change in the original state to second and third state. In second state, two points have been moved from start time to second time, and four points have been moved in the third state. Thus, based on definition 3, a volumetric surface movement object is a union of all of the object states.

$$\begin{aligned} f(mv)t_1, t_2, t_3 \rightarrow [&\{ (x_1,y_1,z_1, t_1), (x_2,y_2,z_2, t_1), (x_3,y_3,z_3, t_1), (x_4,y_4,z_4, t_1)\} \cup \\ &\{ (x_1,y_1,z_1, t_2), (x_2,y_2,z_2, t_2)', (x_3,y_3,z_3, t_2)', (x_4,y_4,z_4, t_2)\} \cup \\ &\{ (x_1,y_1,z_1, t_3)', (x_2,y_2,z_2, t_3)'', (x_3,y_3,z_3, t_3)'', (x_4,y_4,z_4, t_3)'\}] \end{aligned}$$

Following the union process, we can see the redundancy of the points clearly. As we mentioned earlier, each movement or changes does not involve all points on the surface. In Figure 4.6, it is shown that only the underlined points were changed from the first state to the current state. Thus, before storing into the database, this set of data needs to be checked for redundancy. The identification process is shown in Figure 4.7 below.

$$f(mv)t_1\ ,\ t_2\ ,\ t_3 \rightarrow [\{ (x_1,y_1,z_1,\ t_1),\ (x_2,y_2,z_2,\ t_1),\ (x_3,y_3,z_3,\ t_1),\ (x_4,y_4,z_4,\ t_1)\}\ U$$
$$\{ (x_1,y_1,z_1,\ t_2),\ (x_2,y_2,z_2,\ t_2)',\ (x_3,y_3,z_3,\ t_2)',\ (x_4,y_4,z_4,\ t_2)\}\ U$$
$$\{ (x_1,y_1,z_1,\ t_3)',\ (x_2,y_2,z_2,\ t_3)'',\ (x_3,y_3,z_3,\ t_3)'',\ (x_4,y_4,z_4,\ t_3)'\}\ ]$$

$$\downarrow$$

If $(x_1,y_1,z_1,t_{n+1}) - (x_1,y_1,z_1,t_n) = 0$

$$(x_1,y_1,z_1,t_{n+1}) = (x_1,y_1,z_1,t_n)$$

Else if

$$(\ (x_1,y_1,z_1,t_{n+1}) - (x_1,y_1,z_1,t_n) > 0\ )\ ||\ (\ (x_1,y_1,z_1,t_{n+1}) - (x_1,y_1,z_1,t_n) < 0\ )$$
$$(x_1,y_1,z_1,t_{n+1}) = (x_1,y_1,z_1,t_{n+1})$$

Figure 4.7 Process of Reducing Data Redundancy before Loading in the Storage

After this verification process, conceptually the system will load the data into the data storage by following the coordinates (*x, y, z*) along with the attribute time. Here, time is used as the indexing of the data for the purpose of query processing. The illustration of the data storage is shown on Figure 4.8 below where data that wasn't involved in the movement or changes will not be stored. The figure also shows that the coordinates in the highlighted boxes actually represents the new points that is stored after the changes occurred.

v / t	P_1	P_2	P_3	P_4
t_1	(x_1,y_1,z_1)	(x_2,y_2,z_2)	(x_3,y_3,z_3)	(x_4,y_4,z_4)
t_2		$(x_2,y_2,z_2)'$	$(x_3,y_3,z_3)'$	
t_3	$(x_1,y_1,z_1)'$	$(x_2,y_2,z_2)''$	$(x_3,y_3,z_3)''$	$(x_4,y_4,z_4)''$

Figure 4.8 Illustration of the data storage in the Data storage

For our research, we assume that every object have the same number of points whenever movement process happens. Each object must have a basic object which complete as a base data. This is to retrieve data based on user requirement which is time and area. After any movements, points involved will be identified from the base data and will be stored in the storage. This process will be repeated each time a movement happens on the surface.

For data retrieval process, the two parameters required are location and time. The parameter location is to identify which area is needed for simulation along with the parameter time that signifies when the changes happen and its duration period. Basically, to produce a set of data for simulation and visualization, definition regarding data construction is required. Based on this definition, query will be check the data storage and create the based map for the simulation start time which will be sent to the data representation tool for visualization. This process will be detailed out in the following chapter of data management and visualization.

4.5. Summary

In this chapter, a description of the volumetric surface movement spatiotemporal data model was given. Data model were developed based on the formalization of the volumetric surface movement process. The formalization includes definition of volumetric surface object, time, and movement behavior. From the definition given, a description of the volumetric surface movement construction has been defined to be used for the development of the data model. Furthermore, in this chapter we have described several theoretical proofs in confirming the usability of our proposed model. From these verifications, it is proven that our data model is able to manage volumetric surface movement data with minimum redundancy.

CHAPTER 5

DATA MANAGEMENT AND VISUALIZATION

5.1 Database Development

In the purpose Volumetric Surface Movement Spatiotemporal Data Model (VSMST), surface on the volumetric object are represent on the 3D space with temporal element which is represent the changes or movement. To specify their position in space, this data model use Cartesian frame of reference. The reason for choosing this frame based on the successful of developing database system in the GEN-STGIS by Narciso (1999). More specifically, VSMST Data Model use 3 dimensional Cartesian (x,y,z) coordinate system and it based on the upon Euclidean geometry, which is concerned with the study of points, lines, polygon and other geometric figures that can be formed with them (i.e. polygons, polylines, and arcs) (Narciso ,1999). Worboys (1995) was defining as a Euclidean plane. The WSMST Data Model is based on the linear model of time, where time measure as a discrete variable. This is based on the definition has been define in the previous section which define behavior of time and related with the surface movement. In the reality, we do not have the equipment to measure time as continuously. By doing this time can be recoded in the data model. The relational approach has been use to design and implement the VSMST Data Model ensure that it is flexible enough so that this model can implement in various database systems in the market. In this section, we focus on the development of database in order to manage and visualize surface movement data in the volumetric surface.

5.1.1 Logical Model

From definition which has been defined in the previous section, volumetric surface movement is constructing with the set surface with the temporal dimension. In other word, for the volumetric surface movement they have the set of surface based on the time. For every time (t), every surface has been constructed from the polygon. Polygon will be constructing from the line and line has been constructing from the point. For the series of surface in the many time (t), every surface has been construct based on the polygon, line and points. Based on the definition a lot of redundancy will be happen in the database.

In order to reduce the redundancy, we have defined the definition which in the model, every point which has not involved with the movement do not store in the database. We know that, actually movements in the surface happen in the point level. So, that before loading into the database, all set of data will be check with redundancy of data. Only point which involve with the movement will stored in the database. Figure 5.1 shows that the conceptual model of the data model when its will be implemented.

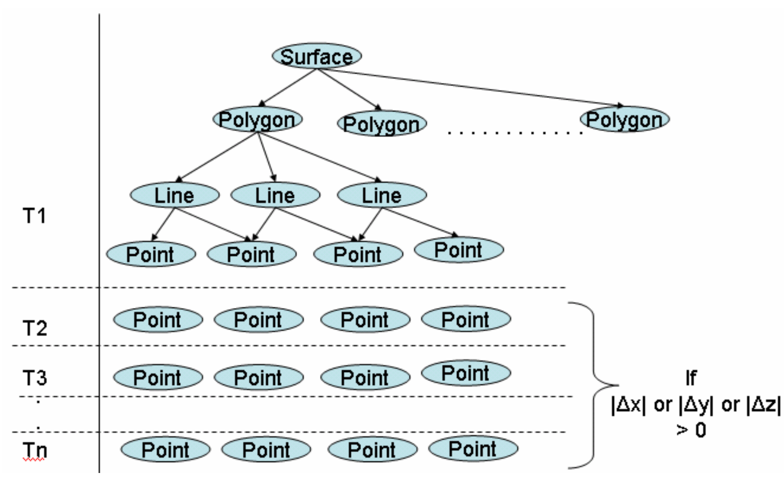


Figure 5.1 Logical Model of the VMST Data Model

From the figure 5.1, we can see that for T1 is representing the basic of the surface which must be store in the database. T2, T3 until Tn is refer to only point which involve with the movement will be store into the database. So, for doing that the conditional which represent on the figure 5.1 is very important to loading data. This conditional has been defined in the previous chapter. From the conceptual and the definition has been derive in previous chapter, we need to transform into the logical model in order to develop physical model and database. For that purpose, we need to identify the entities which have in the model and their attribute including relationship. Temporal element is very important aspect; this will contribute the major factor in the logical model. Figure 5.1 show the entity and their attribute must be in the logical view.

Table 5.1: Entities, Attributes and Relationship before Normalization Process

Entity	Attribute	Relationship
Surface (*s*)	Set of Polygon , Time, General Information	Surface *has many* set of polygons and also have the other information which explain about the area Surface *have* time represent movement
Polygon (*p*)	Set of line	Polygon may *have many* set of lines
Line (*l*)	Start Point , End Point	Line *have two* set of point
Point (*v*)	X axis, Y axis, Z axis, Time	Point is *contribute to change* the shape of the surface Point also *have* Time which can represent actual point involve with changes

Entities, attributes and relationships will be going to normalize for providing logical model. This normalization process which assigning entities with attribute and creating identifying proper relationship. Normalizations process has 3 level which is first level, second level and third level. First level is just identifying the entity and attribute with relationship to come out with second number form. Second level is to identifying dependency of the attribute with the entity. In this case, a new attribute will be created if require. Third level is to identify recursive attribute in the entity and come out with minimum redundancy of the attribute.

In this case, first level is come out with four entities which are surface, polygon, line and point. In this level, we assume that time must be in the surface and point. Others entities have the attribute as mention in table 5.1. The entity in the first level is show bellow:

Surface (id_surface, general information, series of polygon in the surface, time)
Polygon (id_polygon, series of line in the polygon)
Line (id_line, start_point, end_point)
Point (id_point, x, y, z, time)

Result of the first level is entities and attribute will ready for the second level process. From the result we identify that, series of polygon and series of line in the Surface and Polygon entities is very difficult to create. The relation with surface and polygon is one surface has many polygons and the polygon has many lines. So that, every set of polygon must have the identification of the surface. By doing this, polygon entity is add new attribute in the entity which is id_surface. So that, we know which polygon is belong to which surface. In the polygon entity, the same case was happen with surface and polygon. Now, we add new attribute which is id_polygon into line entity, so that we which line is belong to which polygon. The result of the second level show that the entire attribute locates at the correct entity. The entity in the second level is show bellow:

Surface (id_surface, general information, time)
Polygon (id_polygon, id_surface)
Line (id_line, start_point, end_point, id_polygon)
Point (id_point, x, y, z, time)

In the third level, we need to identify the attribute which repeat inconsistently. In this case, temporal element (time) management are very important to organize which its can represent a movement without any redundancy issue. For purpose of managing the surface movement we need to create a new entity which is surface movement. Surface movement entity will cater surface and time in the spatiotemporal data management. Besides, point entity also has an issue if time including in the entity as an attribute. For this purpose, point entity has change to temporal point entity which contains point data with temporal element. In both entities we created index as identification in the entity. In this level, we come out with the suitable logical data model which represent in the Entity Relationship Diagram in Figure 5.2.

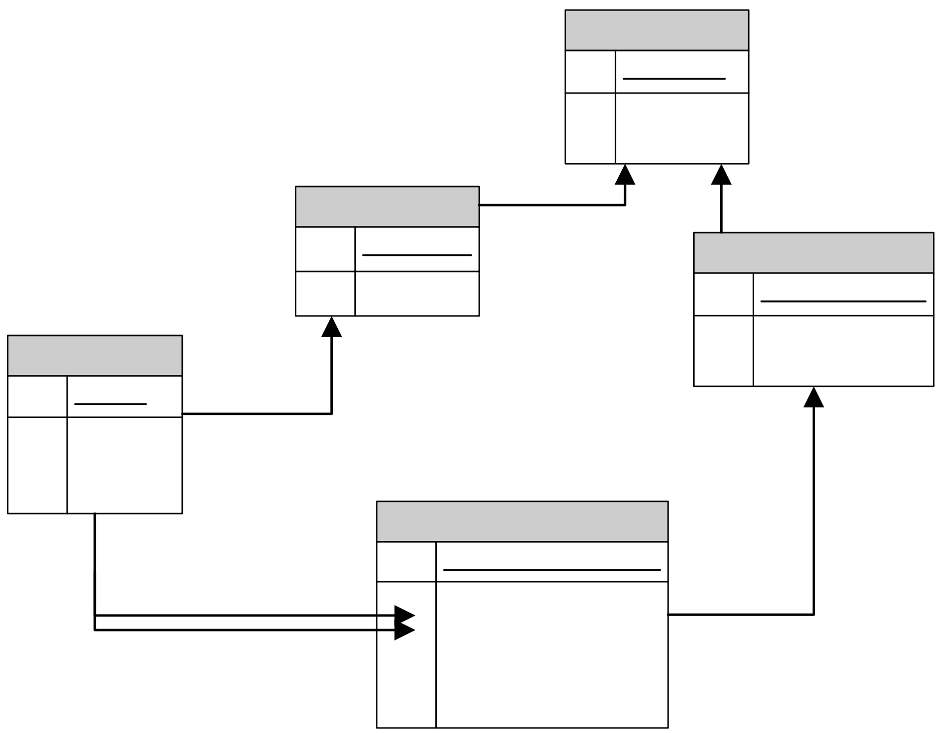


Figure 5.2: Entity Relationship Diagram (ERD) for Volumetric Surface Movement Spatiotemporal (VSMST) Data Model

In the ERD for VSMST shown in Figure 5.2, there are five entities need to be created in the database to store and manage volumetric surface movement data. There are Surface_Movement, Surface, Polygon, Line and Temporal_Point. Every entity has their relationship with related attribute. Table 5.2 show the attribute with the entire entities in Figure 5.2. Table 5.3 show the relationship entities with related entity.

Table 5.2: Description of the Entities in the Logical Model

Entity	Description
Surface_Movement	Surface_Movement entities contain information about set of surface which involve with movement. Attribute will be store in this entities are, Movement_Index which is an indexing of the surface movement object, Id_surface which is surface involve with movement and time which is time of the surface involve with movement
Surface	Surface is an entity store about the surface information. This is the place which this model can be extended with other information. In this entity we have Id_surface which is index of surface, General_Info and History which is an additional attribute which based on requirement
Polygon	Polygon is an entity will store the information about the polygon in which surface. So, in this entity we have an Id_polygon and Id_surface.
Line	Line is entity stored information about construction of line and the line is belonging to which surface. Attribute will be in the entity are Id_line, id_point (start point), id_point (end point) and Id_polygon.
Temporal_Point	Temporal_Point basicly containing information about data which created the surface movement. So the attribute must be a coordinate (x,y,z) and the temporal. Temporal elemant is same as time involve in the surface movement, so that we just including the Movement_Index as one of the entity. However, we have temporal_point_index to index the data which involve with the movement in the specific surface.

Table 5.3: Description of the Relationship in the ERD

Entity	Relatioship	Entity
Surface_Movement	Has	Surface
Polygon	Member of	Surface
Line	Member of	Polygon
Line	Construct by	Temporal_Point
Temporal_Point	Movement	Surface_Movement

5.1.2 Physical Model

A physical model must be created after the logical model is complete. The Physical Database Design consists of implementing the logical data model schema within the database system. This entails physically creating all of the features designed in the Logical Model. This is the final step before the migration of existing data to the database system as shown on Table 5.4.

- Name tables and columns how they will appear in the database.
- Remove redundancy of attributes by creating new tables if necessary.
- Include foreign key relationships.

Table 5.4: Physical View of the VSMST Data Model for Developing Database

Entity	Attribute	Data Type
Surface_Movement	Movement_Index	Number
	Time	Date / Time
	Id_surface	String
Surface	Id_surface	String
	General_Info	String
	History	String
Polygon	Id_polygon	String
	Id_surface	String
Line	Id_line	String
	Id_point	String
	Id_point	String
	Id_polygon	String
Temporal_Point	Temporal_point_index	Number
	Id_point	String
	X	Number
	Y	Number
	Z	Number
	Movement_index	Number

5.1.3 Database Model

Based on the logical and physical model, database will be developing using Sequel Query Language (SQL). There are five table need to be develop in the database and the SQL for developing the table in the database.

Surface_Movement		
Movement_Index	Time	Id_surface

```
CREATE TABLE `surface_movement` (
  `movement_index` bigint(10) NOT NULL auto_increment,
  `time` double NOT NULL,
  `id_surface` bigint(10) NOT NULL,
  PRIMARY KEY  (`movement_index`)
);
```

Surface		
Id_Surface	General_Info	History

```
CREATE TABLE `surface` (
  `id_surface` bigint(10) NOT NULL auto_increment,
  `general_info` text NOT NULL,
  `history` text NOT NULL,
  PRIMARY KEY  (`id_surface`)
);
```

Polygon	
Id_polygon	Id_surface

```
CREATE TABLE `polygon` (
  `id_polygon` bigint(10) NOT NULL auto_increment,
  `id_surface` bigint(10) NOT NULL,
  PRIMARY KEY  (`id_polygon`)
);
```

Line			
Id_line	Id_point	Id_point	Id_polygon

```
CREATE TABLE `line` (
  `id_line` bigint(10) NOT NULL auto_increment,
  `id_point_s` bigint(10) NOT NULL,
  `id_point_e` bigint(10) NOT NULL,
  `id_polygon` bigint(10) NOT NULL,
  PRIMARY KEY  (`id_line`)
);
```

Temporal_point					
Temporal_point_index	Id_point	X	y	z	Movement_Index

```
CREATE TABLE `temporal _point` (
  `temporal_point_index` bigint(10) NOT NULL auto_increment,
  `id_point` bigint(10) NOT NULL,
  `x` double NOT NULL,
  `y` double NOT NULL,
  `z` double NOT NULL,
  `movement_index` bigint(10) NOT NULL,
  PRIMARY KEY  (`temporal_point_index`)
);
```

5.2 System Architecture

Figure 5.3 show the architecture of the prototype system. It consist *Data Storage*, *Spatiotemporal Data Loader Processor*, *Spatiotemporal Data Retrieval Processor*, *Volumetric Surface Movement Simulator*.

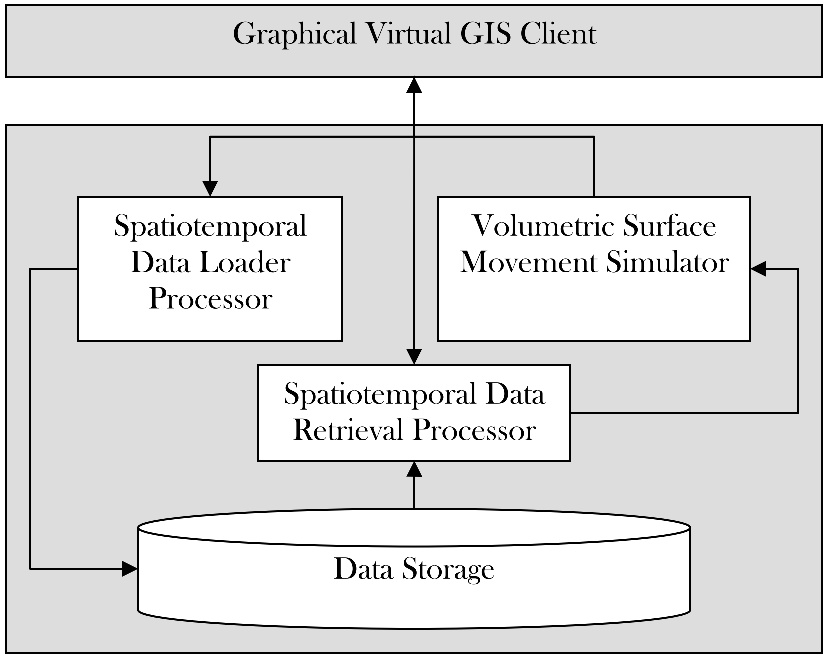


Figure 5.3 Architecture of the System

Data Storage stores the volumetric surface movement object according to database scheme. The database use in this system is MySQL which is open source.

Spatiotemporal Data Loader Processor provides the ways of loading data into the database. This processor will be checking the data redundancy in the database and store only the point which has involve with movement.

Spatiotemporal Data Retrieval Processor will retrieve the data for the database based on the user require. In this case, user needs to give area and duration of data. Data has been retrieve will be post into our own file format.

Volumetric Surface Movement Simulator read the data set has been retrieve from the database system and simulate the volumetric surface movement object.

Graphical GIS Client accepts the user's queries, sends it to the Spatiotemporal Data Retrieval Processor, receives the results and shows them to the user in graphical presentation.

5.3 Data Management

In the system architecture of the prototype system based on the propose data model, we have two component which Spatiotemporal Data Loader Processor and Spatiotemporal Data Retrieval Processor. As mention above, the function is to load data into the database and retrieve data fro displaying based on the query. In this section, we will discuss the algorithm to perform the process.

5.3.1 Data Loading Algorithm

Basically, the data will be load into the database system is data that has been digitizing from the data sources. Most of data has been collected in the digital image data format which using aerial photo data or satellite data. From this data sources, we can created the terrain data by using Triangulation Irregular Network (TIN) data format which have all point or vertex created surface for the object. This data have time which is represent time of data has been collected. By using this information, data has been load into the database. This data will be given an identification to load into the database. When the data have a series of changes in the same area with the same number of vertices, this data will be check into the database if they have already a based data, the data loader processor will be store the vertices which has involve with the changes only. However, if data does not into the database, we need to create the based data refer to the first data set. Figure 5.4 show the process flow to perform the process of loading data into the database.

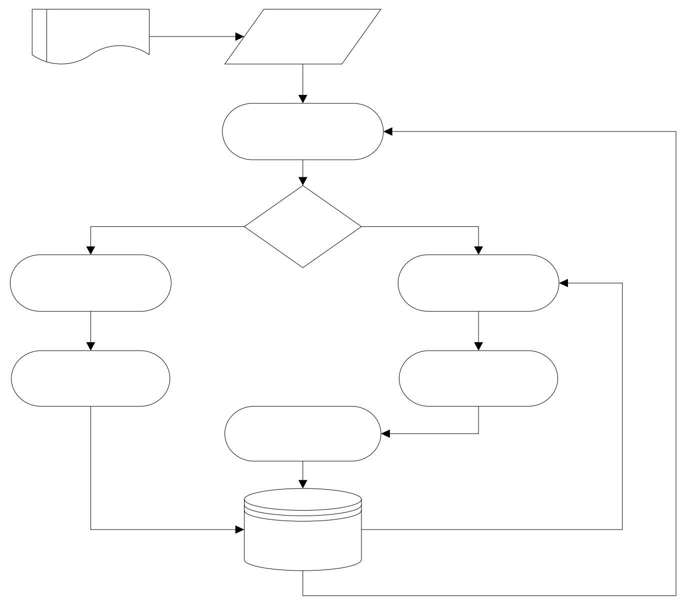


Figure 5.4 Spatiotemporal Data Loader Processor

Data will be stored into the database need to be checking with which is the data have in the database or not. The first process need to be done is get the data from the database and check with input data. The process will be performing as algorithm bellow:

1. *Initial Record Set, Get Identification form new data set (Id_Surface_input)*
2. *Record Set [ ] = "SELECT Id_surface , FROM Surface"*
3. *While not end of record*
4. *If Id_Surface_input = Record Set []*
5. *Data in the database*
6. *Load changes data into database*
7. *Else*
8. *New Record*
9. *Data not in database, created new based data and load the data*
10. *End If*
11. *End While*

Result from the algorithm will be a set of data need to be store in the database or create a new data set. If the was data in the database, which means this has data in the previous time. For this data set we need to checking the point and id it have any changes a new point need to be store in the temporal point table. The algorithm to perform this process will be show bellow.

1. *Get the point from new data set (new_point) and Initial a Temporal_point for specific area*
2. *Temporal_point = "SELECT Id_point, x,y,z FROM Temporal_point WHERE Movement_Index = SELECT Movement_index FROM Surface_Movement WHERE Id_surface = Id_Surface_Input"*
3. *While not end of file input*
4. *If new_point ! = Temporal_point*
5. *Data Involve with changes*
6. *Load data into the database*
7. *Else*
8. *Data not involve with changes*
9. *do not load in database*
10. *End If*
11. *End While*

If are not in the database, based data will be created and load all data with database scheme in the table. To create based data, need to assign a new Id_durface, and Movement_temporal Index. After that store data into the Surface_Movement, Surface, Polygon, Line and Temporal_Point table in the database by assigning the entire primary key.

5.3.2 Data Retrieval Process

The purpose of retrieve data from the database is to simulate the surface movement on the volumetric object based on the user requirement. Inputs on the process are area (Id_Surface) and period of time (Start Time and End Time) which need to be simulated. Algorithm for data retrieval process to prepared data for simulates movement is bellow.

1. *Get input from user; Area of the surface (Id_Surface), Start Time (Ts) and End Time (Te)*
2. *Select Surface required based on the Id_Surface and Time in between Ts and Te.*
3. *Select Point based on the coordinate of area Id_Surface and Time in between Ts and Te.*
4. *Create surface based on the Time Start (Ts).*
5. *Calculate number of changes involve in the movement process*
6. *Identify list of vertex involve with changes based on time between Ts and Te.*

Result of this process will be a set of data which can be simulate by using our propose Spatiotemporal Data Visualization Simulator. This data will be store in to the propose data file format before load into the Spatiotemporal Data Visualization Simulator. The purpose of data file format is to reduce loading time from the database into simulator. With that, user can be navigated the visualization in the suitable time.

5.3.3 Data Format

From the data retrieval process, data has been retrieved will be transfer into our propose data format before load into the Volumetric Surface Movement Visualization Simulator. For that purpose, we are using the Triangulate Irregular Network (TIN) file format with including temporal element. The concepts of the file format are started with the created based data for the visualization based on the user requirement. In the based data we follow the TIN structure which stores the point and the triangle which represent surface creation. After the based data has been arranged, the file will be continuing with the changes information in the based data. The changes will be started with the number of changes or movement will involve on the require surface. After that, data will be arrange by the changes with point involve with changes. In the every change we state that number of point which involve in the changes. Arrangements of the data in propose format show in the Figure 5.5.

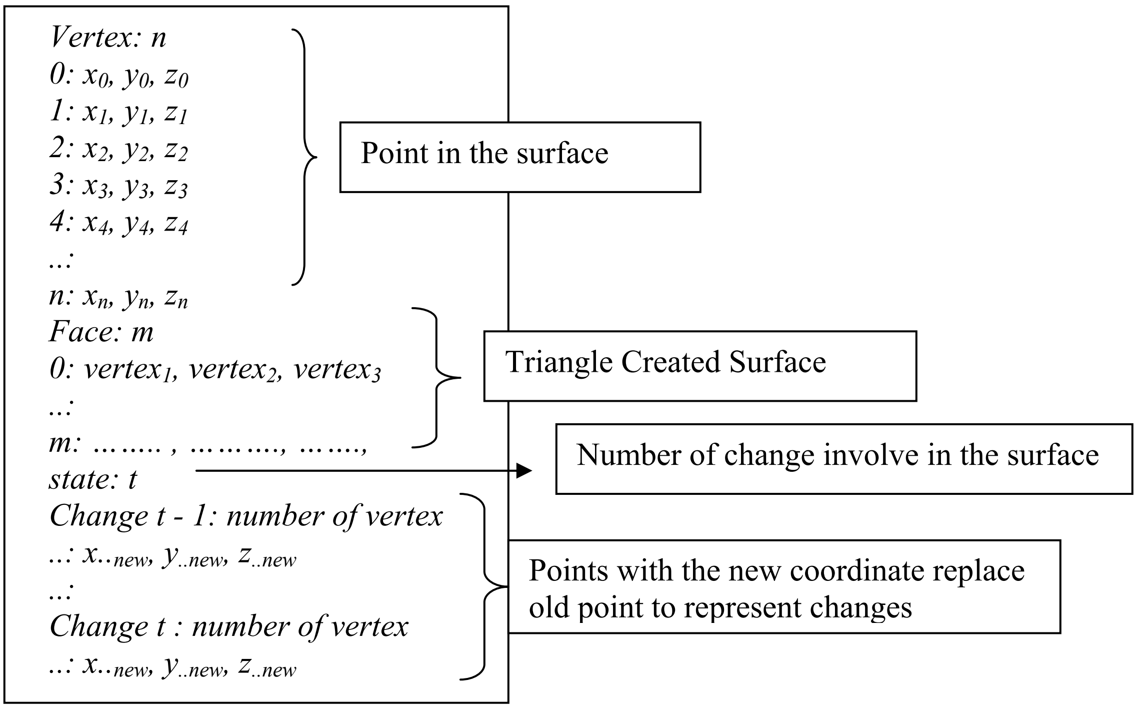


Figure 5.5: Data Format for Volumetric Surface Movement Visualization

5.4 Data Visualization Algorithm

For the data visualization algorithm, parametric equation has been use to visualize the movement from the one stage to other stage. As we know the parametric equation is use to show the value within two values based on range has been given. For example we have two value of q which is (q_1 and q_2) and we want to know value within range has given. So, intermediate can be define by value of $q_2 - q_1$ and multiply with range of value μ in the range (0 until 1). So, the equation is:

$$q_{intermidiate} = q_1 + \mu\,(q_2 - q_1) \qquad (5.1)$$

Which is $\mu = \{0 \text{ until } 1\}$

This equation has been applied with all point in three axis x, y and z. to get the suitable coordinate for the within the two set of point from the start point until end point. This process will be repeated based on the number point involve with the movement process and the hole process will be repeated from the start time until end time based on the number of changes in the user query. Figure 5.6 shows the process which applies into the visualization algorithm.

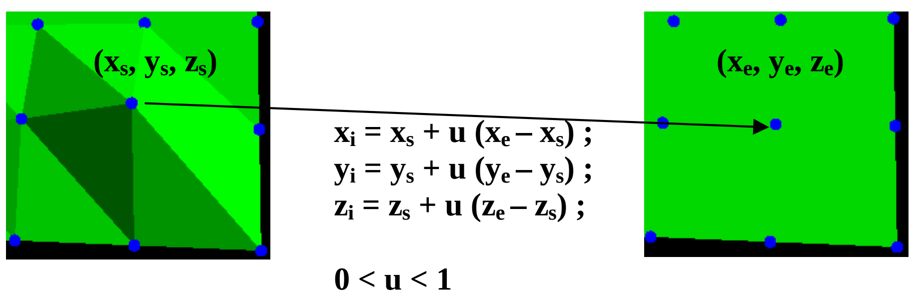


Figure 5.6 : Use of the parametric equation in the surface movement

The visualization algorithm is show bellow:

1. *Read data set*
2. *Draw the surface for the starts time*
3. *Get the number of change (n)*
4. *for (i=1, i=< n, i++);*
5.   *Get the number of point change (m)*
6.   *Get the point has been change on the state n*
7.   *for (j=1, i=<m , i++);*
8.   *for (u=0, u=<1, u=u+0.1);*
9.   *xintermidiate = xstart + u * (xend – xstart);*
10.   *yintermidiate = ystart + u * (yend - ystart);*

*11. zintermidiate = z start + u * (zend - zstart);*

12. Redraw the surface by replace current point with new value;

13. end for

14. end for

15. end for

5.5 Conceptual Data Testing

For the conceptual testing, data has been use is 16 number of point was created the surface in the difference state of time. Table 5.5 shown three set of data which is in the same area but in difference time.

Table 5.5: Conceptual Data for the Conceptual Testing

Point Id	State 1(x,y,z)	State 2(x,y,z)	State 3(x,y,z)
0	0.75,0.75,0	0.75,0.75,0	0.75,0.75,0
1	-0.25,0.75,0	-0.25,0.75,0	-0.25,0.75,0
2	0.25,0.75,0	0.25,0.75,0	0.25,0.75,0
3	0.75,0.75,0	0.75,0.75,0	0.75,0.75,0
4	-0.75,0.25,0	-0.75,0.25,0	-0.75,0.25,0
5	-0.25,0.25,0	-0.25,0.25,0	-0.25,0.25,0
6	0.25,0.25,0	0.25,0.25,0	0.25,0.25,0
7	0.75,0.25,0	0.75,0.25,0	0.75,0.25,0
8	-0.75,-0.25,0.25	-0.75,-0.25,0.25	-0.75,-0.25,0.25
9	**-0.25,-0.25,0.15**	**-0.25,-0.25,0.35**	-0.25,-0.25,0.35
10	**0.25,-0.25,0.0**	**0.25,-0.25,0.15**	**0.25,-0.25,0.5**
11	0.75,-0.25,0.25	0.75,-0.25,0.25	0.75,-0.25,0.25
12	-0.75,-0.75,0	-0.75,-0.75,0	-0.75,-0.75,0

13	-0.25,-0.75,0	-0.25,-0.75,0	-0.25,-0.75,0
14	0.25,-0.75,0	0.25,-0.75,0	0.25,-0.75,0
15	0.75,-0.75,0	0.75,-0.75,0	0.75,-0.75,0

Data on the table 5.5 will be load into the database system as discuss in the previous section. After loading data into the database, all the point which is redundant will not be store. We just store the new point which is having difference value within previous data. We can se a result in the temporal point which after all set of data has been store into the database. This result was query from the table *temporal_point* by perform the SQL statement (*SELECT * FROM temporal_point*). Table 5.6 shows the result after loading the data.

Table 5.6 Point after Loading Data into the database.

Temp point Index	Id point	X	Y	Z	movement index
1	0	0.75	0.75	0	1
2	1	-0.25	0.75	0	1
3	2	0.25	0.75	0	1
4	3	0.75	0.75	0	1
5	4	-0.75	0.25	0	1
6	5	-0.25	0.25	0	1
7	6	0.25	0.25	0	1
8	7	0.75	0.25	0	1
9	8	-0.75	-0.25	0.25	1
10	9	-0.25	-0.25	0.15	1
11	10	0.25	-0.25	0	1
12	11	0.75	-0.25	0.25	1
13	12	-0.75	-0.75	0	1
14	13	-0.25	-0.75	0	1
15	14	0.25	-0.75	0	1
16	15	0.75	-0.75	0	1
17	9	-0.25	-0.25	0.35	2
18	10	0.25	-0.25	0.15	2
19	10	0.25	-0.25	0.5	3

In the Table 5.6, *movement_index* represent the time of the movement was happen. The time for the changes can be known from the table *surface_movement* which store all the record of the movement for the surface. This result was query from the table *surface_movement* by perform the SQL statement (*SELECT * FROM surface_movement*). Table 5.7 shows the result.

Table 5.7: Movement Information in the Surface

Movement Index	Time	Id Surface
1	Date 1	1
2	Date 2	1
3	Date 3	1

For retrieving data from the database to load into the visualization tool, we need to perform the retrieval process and arrange data into the data format has been proposed. Firstly, system need to create the based data with all the topological created the surface. After that, system will identify how many changes was happen within the time and system will retrieve all the point which involve in the changes to load into the file format.

In this conceptual testing, number of vertex involve in the surface is 16, number of polygon (triangle) is 18 and they have three changes in the surface. The number of point which involve with movement are two point in the second changes and one point in the third changes. Figure 5.7 shown arrangements of the data in the data format will be load into the visualization tool.

```
Vertex:16
0:-0.75,0,0.75
1:-0.25,0,0.75
2:0.25,0,0.75
3:0.75,0,0.75
4:-0.75,0,0.25
5:-0.25,0,0.25
6:0.25,0,0.25
7:0.75,0,0.25
8:-0.75,0.25,-0.25
9:-0.25,0.35,-0.25
10:0.25,0.5,-0.25
11:0.75,0.25,-0.25
12:-0.75,0,-0.75
13:-0.25,0,-0.75
14:0.25,0,-0.75
15:0.75,0,-0.75
Face:18
0:0,4,5
1:0,5,1
2:1,5,6
3:1,6,2
4:2,6,7
5:2,7,3
6:4,8,9
7:4,9,5
8:5,9,10
9:5,10,6
10:6,10,11
11:6,11,7
12:8,12,13
13:8,13,9
14:9,13,14
15:9,14,10
16:10,14,15
17:10,15,11
State:2
Change:2
9:-0.25,0.15,-0.25
10:0.25,0.15,-0.25
Change:1
10:0.25,0.0,-0.25
```

Figure 5.7 Data Arrangements in the Data Format

This file format will be load into the visualization tool to get the visualization result. Based the conceptual testing, data has been used which is 16 points with two sets of movement with 12.5% data involved with movement. In this case, before loading the numbers of points are 48 point. After loading the data, number of data in the database is 20 points. So, we were reducing data by 58.3% of redundancy of data. Figure 5.8 shows the simulation of data from the start time (t_s) and end time (t_s).

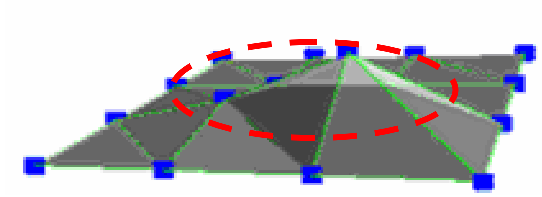
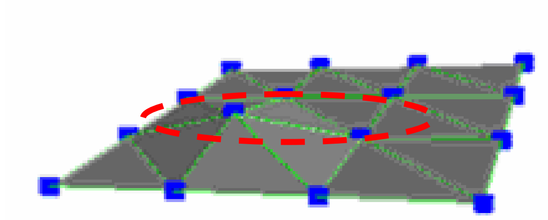
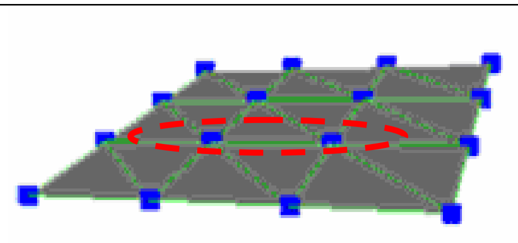
	Start (t_s)
	Intermediate (t_i)
	End (t_s)

Figure 5.8: Simulation of the Surface form Start Time (t_s) to End Time (t_e)

5.6 Summary

In this chapter, the implementation, and conceptual testing of the Volumetric Surface Movement Spatiotemporal Data Model has been discuss. Database has been design and developed using relational database model based on the formalization and definition in the chapter 4. From the result, we have come out with logical design and physical design for developing database. For testing and evaluation, we have developed data management system and visualization tool in the prototype version. For that purpose, we have come out with data loading algorithm, data retrieval algorithm, visualization tool and data format with modification for the TIN to add time component which to make sure that our visualization tool can be read and display the result. In the end of the chapter 5, we have test the prototype system with conceptual data and result shows that the model is suitable for managing volumetric surface movement data.

CHAPTER 6

DATA MODEL TESTING AND EVALUATION

6.1 Introduction

Volumetric Surface Movement Spatiotemporal Data Model (VSMST) can manage the surface movement in the volumetric object. The conceptual testing in the chapter four has been proven that the model can be work by using the relational database model. In this chapter, VSMST Data Model will be testing using aerial photos data which is from the real application. In generally, requirement for the testing the data model is a series of the data set in the same area which involve with the movement on the surface at the terrain. For that purpose, we have received two set of data from government agency which in 1983 and 2004 in the same area. The problem with the data is aerial photos not in the same scale and difference kind of color. This data has been process to make it in the same and creating the mesh for generating surface by using Triangular Irregulars Network (TIN). The data has been digitized will be load into database system, and retrieve to creating data format for load into visualization tool for simulate the changes in the surface movement data. According to ( ), the next generation of GIS is must have capability to manage aerial photo in the spatiotemporal database. In this chapter, we will discuss our experience do this process from aerial photo to our VSMST Data Model. Besides, this chapter also discuss all result has been archive in the testing phase to evaluate capability of VSMST Data Model.

6.2 Testing with Arial Photo Data

For the purpose of testing and evaluation, we have a two set of data in 1983 and 2004. This area is limestone area which involve with human activity to getting all the stone for the purpose of development. This area is in the longitude 178d21’08.17”W until 178d19’52.27”W and latitude 4d33’30.19”N until 4d33’33.06”N. Image in the figure 6.1 (a) show the area at the 1983 and figure 6.1 (b) show the image at the 2004. The differences of the image, we can see a lot of changes were happen from year 1983 until year 2004. From this area we decide to sample three samples for test VSMST Data Model and its visualization tool. From this image we get the point to load into the database and generating file for loading into the visualization tool. However this data will be process to get the point which can generate surface of the terrain in the earth surface.

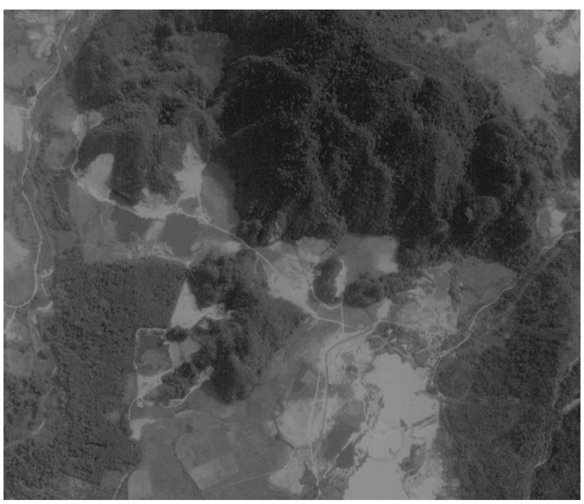


Figure 6.1(a): Arial Photos year for 1983

Figure 6.1 (b): Arial Photos for year 2004

6.2.1 Data Processing

Ariel photos in the figure 6.1(a) and 6.1(b) are in the difference scale and difference color. We can see that image on figure 6.1(a) is in the gray scale color and image on the figure 6.1(b) in the RGB color. Before selected the samples for the testing, both of images need to be to unify the geo-reference and rescaling to get the same resolution. After that, the images will be process to creating the Digital Terrain Model to get the coordinate. Figure 6.2 bellow show the process has been done to get the image before sampling the data for testing.

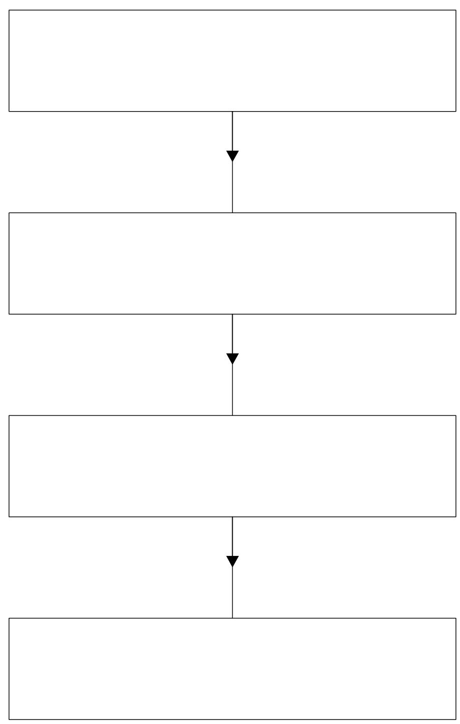


Figure 6.2: Process of Getting Data for Testing

According to figure 6.2, Unify Geo-references has been done using Geomatica software. The purpose of the process is to make a geometric correction. In this task, we identify the geo-references based on the image on 2004. It is because the images have a geo-reference. The software done the correction and result show that image in the same size and resolution with the correct geo-references.

After that, both of the images will be load in to ArcGIS software to generating the Digital Terrain Model (DTM). Before generating the DTM, both of the image need to be digitizes to get the all point to generate the surface. In this process we generate point of the image 1983 based on the DTM on 1991. From the 1991 DTM data selected area are not involve with a changes. Reason of using 1991 DTM are the data does not have the reference and also difficult to extract the high information. Figure 6.3 (a) show the result of the sample area after digitizing the area. For the 2004 image, from the image we are creating the contour as a reference to digitize the data. From the contour has been generating in the ArcGIS software, we changes the high value to a true values. Figure 6.3 (b) shows the sample data for the image in 2004.

After we get data from the both images, we generate the DTM for creating TIN data. This data can be created the 3D model in the ArcGIS Software by using Arc Scene function. From a both process we get the point for reconstructing the surface. This data will be use to load into the database for generating the data to simulate the changes.

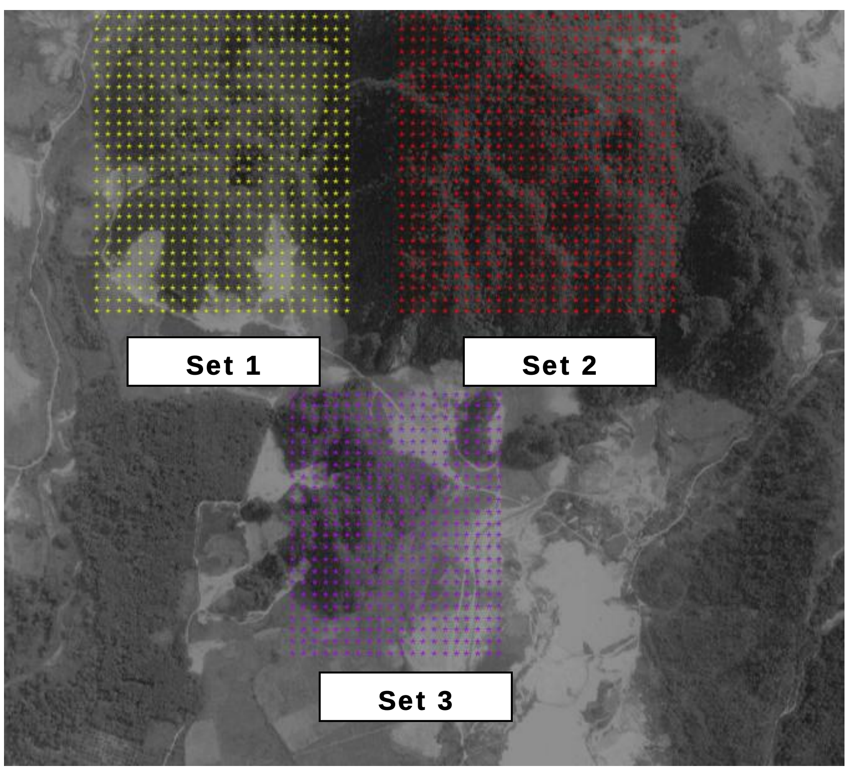


Figure 6.3 (a): Sampling Data from the 1983 Ariel Photo

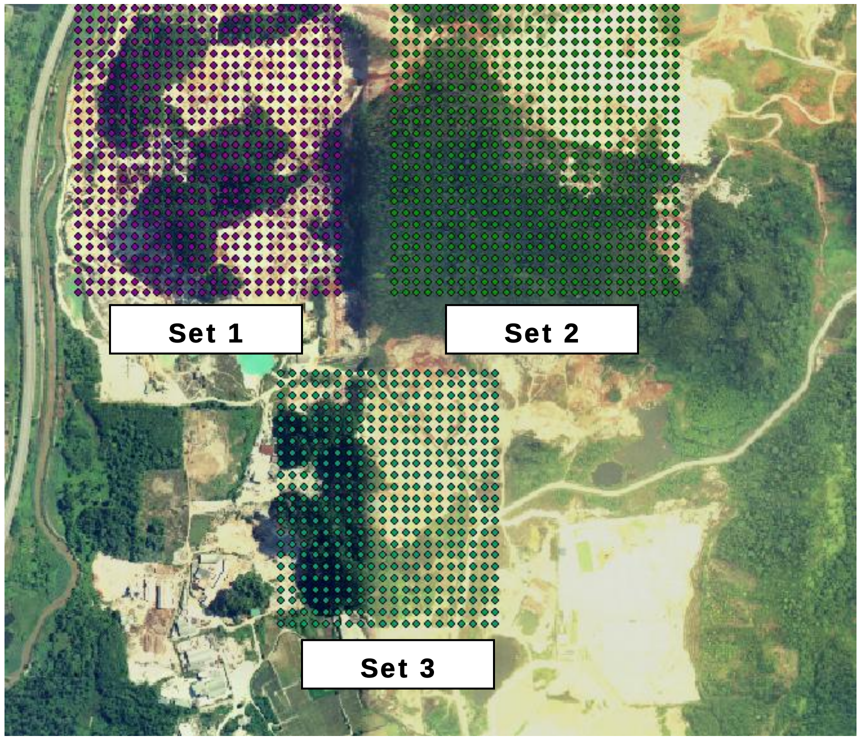


Figure 6.3 (b): Sampling Data from the 2004 Ariel Photo

6.3 Result of Testing Sample

For the first sample, we can see the comparison with the data in the 1983 and 2004. Table 6.1, 6.2 and 6.3 show the comparison with the data has been sample. This data will be load into databases system. Firstly, we load the data in 1983 into the database system. After that the data, data in 2004 will be loaded into the database system.

Table 6.1: Sample Data for Set 1

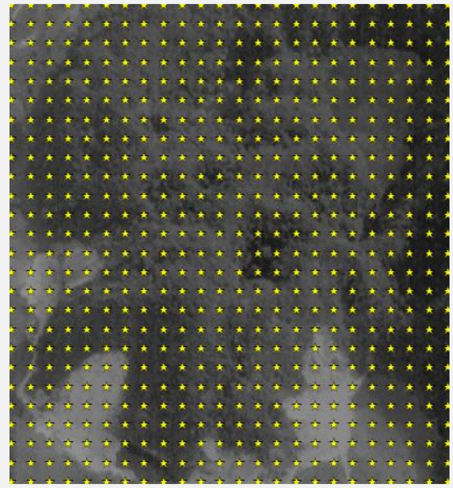
Year	Image	Point Generated
1983		
2004		

Table 6.2: Sample Data for Set 2

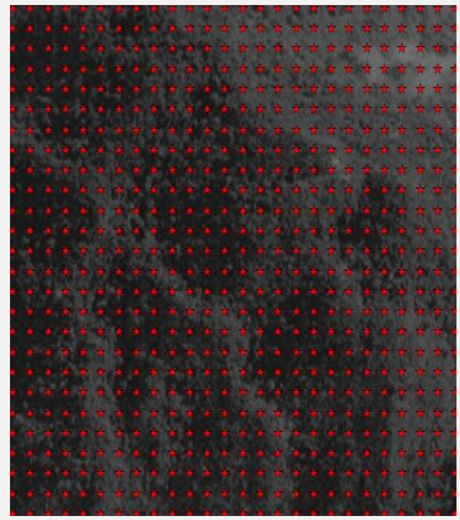
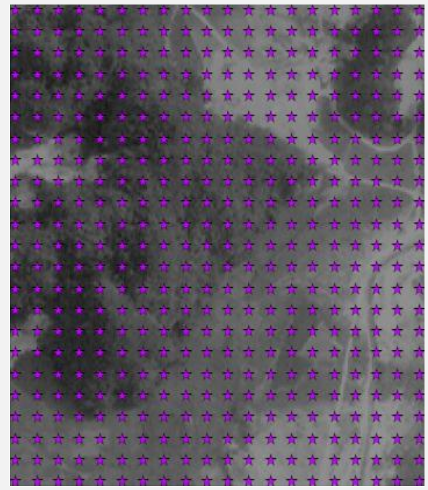
Year	Image	Point Generated
1983		
2004		

Table 6.3: Sample Data for Set 3

Year	Image	Point Generated
1983		
2004		

For the data loading process in every sample, all the points which not involve with the changes were not being store into the database. It is because the points which not involve with movement do not change.

Table 6.4: Result of Loading Data into Database System

Sample	Task	No Point		Total Point	Loading Time (s)
		1983	2004		
1	Before Load	624	624	1248	0.016
	After Load	624	297	921	
2	Before Load	676	676	1352	0.017
	After Load	676	255	931	
3	Before Load	460	460	920	0.013
	After Load	460	202	662	

Data in the database will be allocated in the *temporal_point* table. All the point in for the related surface will be in the table including the changes point. Figure 6.4 show the some of the data with the changes in every sample. Figure 6.4 (a) is for sample 1, figure 6.4 (b) is for sample 2 and figure for the 6.4 (c) is for the sample 3. We can see that, the point have same identification but have two value which is mean that the point involve with movement. Then we can see the when the data was changes.

temporal_point_index	id_point	x	y	z	movement_index
16	16	350700	504060	88.8419	83
640	16	350700	504060	73.8419	2004
17	17	350730	504060	94.845	83
641	17	350730	504060	79.845	2004
18	18	350760	504060	99.3275	83
642	18	350760	504060	84.3275	2004
19	19	350790	504060	92.6093	83
20	20	350820	504060	88.272	83
21	21	350850	504060	88.985	83
22	22	350880	504060	77.661	83
23	23	350910	504060	85.427	83
24	24	350940	504060	85.7357	83
25	25	350250	504030	54.4515	83
26	26	350280	504030	54.2272	83
643	27	350310	504030	37.9437	2004
27	27	350310	504030	52.9437	83
28	28	350340	504030	53.3263	83

Movement changes

Movement change

Figure 6.4 (a): Point in Database for sample 1

temporal_point_index	id_point	x	y	z	movement_index
1	1	351090	504060	172.3675	83
677	1	351090	504060	157.3675	2004
2	2	351120	504060	205.7958	83
3	3	351150	504060	229.5032	83
4	4	351180	504060	247.4567	83
5	5	351210	504060	265.0904	83
6	6	351240	504060	277.4453	83
7	7	351270	504060	280.972	83
8	8	351300	504060	287.6832	83
9	9	351330	504060	291.9066	83
678	10	351360	504060	267.7829	2004
10	10	351360	504060	282.7829	83
11	11	351390	504060	265.8094	83
679	11	351390	504060	250.8094	2004
12	12	351420	504060	240.9716	83
680	12	351420	504060	225.9716	2004
681	13	351450	504060	210.3194	2004
13	13	351450	504060	225.3194	83
682	14	351480	504060	194.048	2004
14	14	351480	504060	209.048	83
15	15	351510	504060	196.2495	83

Movement change

Movement changes

Figure 6.4 (b): Point in Database for sample 2

temporal_point_index	id_point	x	y	z	movement_index
1	1	350790	503100	56.4381	83
461	1	350790	503100	36.4381	2004
2	2	350820	503100	57.116	83
462	2	350820	503100	37.116	2004
3	3	350850	503100	56.9169	83
463	3	350850	503100	36.9169	2004
4	4	350880	503100	56.927	83
5	5	350910	503100	58.3296	83
464	6	350940	503100	38.4014	2004
6	6	350940	503100	58.4014	83
465	7	350970	503100	40.8953	2004
7	7	350970	503100	60.8953	83
466	8	351000	503100	42.6783	2004
8	8	351000	503100	62.6783	83
467	9	351030	503100	46.2598	2004

Movement changes

Movement changes

Figure 6.4 (c): Point in Database for sample 3

After data was load into the database, data can be retrieve to load into data format for the purpose of visualize the data in visualization tool. Table 6.5 show the query in the data retrieval process for every sample. From the table we can see that query was execute to get the base data, calculating the number point involve, number of changes, number of point and point involve with change.

Table 6.5: Query of Retrieve the data for load into data format

Type of Query	Query
Calculate No of point for Based Data	SELECT COUNT(id_point) FROM temporal_point WHERE movement_index='Year of Based Data'
Retrieve point for the Based Data	SELECT id_point, x, y, z FROM temporal_point WHERE movement_index='Year of Based Data'
Calculate no of triangle	SELECT COUNT(id_polygon)/3 FROM line
Retrieve face reconstruction	SELECT id_point_s, id_point_e, id_polygon FROM line
Calculate no of change	SELECT COUNT(id_point) FROM temporal_point WHERE movement_index = 'Year of Next Changes'
Retrieve point involve with changes	SELECT id_point, x, y, z FROM temporal_point WHERE movement_index = 'Year of Next Changes'

From the query has been execute for every sample, we can get a result of all information and data to load into the data format. The result has been summaries in the table 6.6 below. Speed of time for data retrieval in every sample has been summaries in table 6.7 bellow.

Table 6.6: Contain of data in the File Format for Load into Visualization Tool

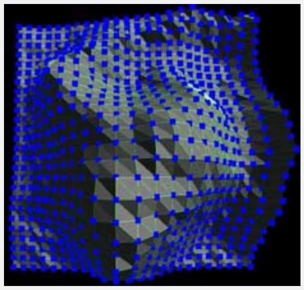
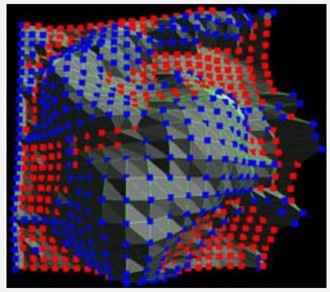
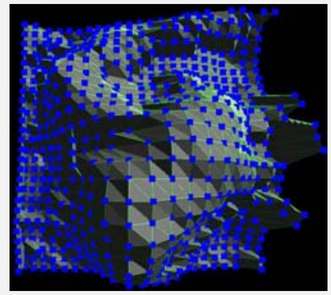
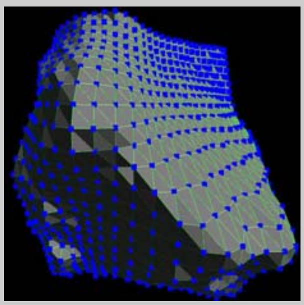
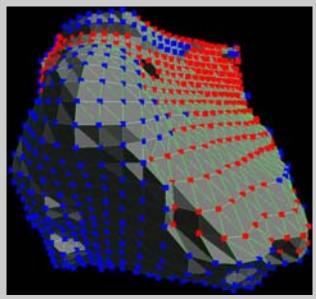
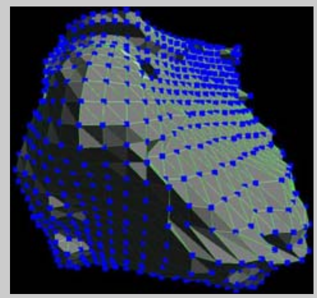
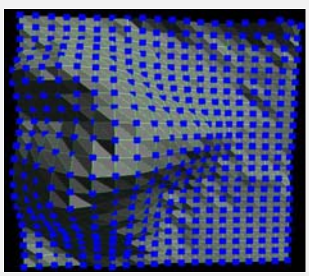
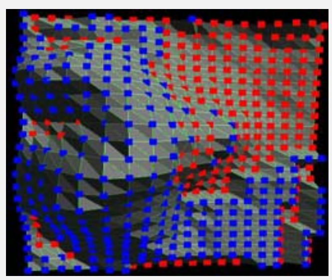
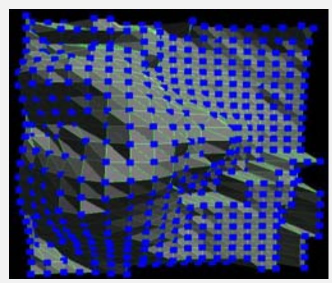
Sample	Based Point	Face	Changes	Changes Point
1	624	1150	1	297
2	676	1250	1	255
3	460	836	1	662

Table 6.7: Result of Retrieve Data from Database System

Sample	No of Point	Retrieval Time (s)
1	921	0.0013
2	931	0.0015
3	662	0.0011

Data has in data set will be load into the visualization tool to simulate the result. Results of the three set of the sample data are shown in the table 6.8. From the table 6.8, we can see that the result of the visualization in the start time at 1983, intermediate visualization data and the end of the time at 2004.

Table 6.8: Result of Visualization Sample Data

Sample	1983	Intermediate	2004
1			
2			
3			

In the table 6.8 also we can see the changes of the point is represent in the red color and the point in the blue color is represent the point which is not involve with the changes within the period of time. From the result we can compare with the image has been capture to demonstrate the changes was show in the visualization is true. Figure 6.5 (a), (b), (c) show the comparison within the result of the visualization and the image has been sampled.

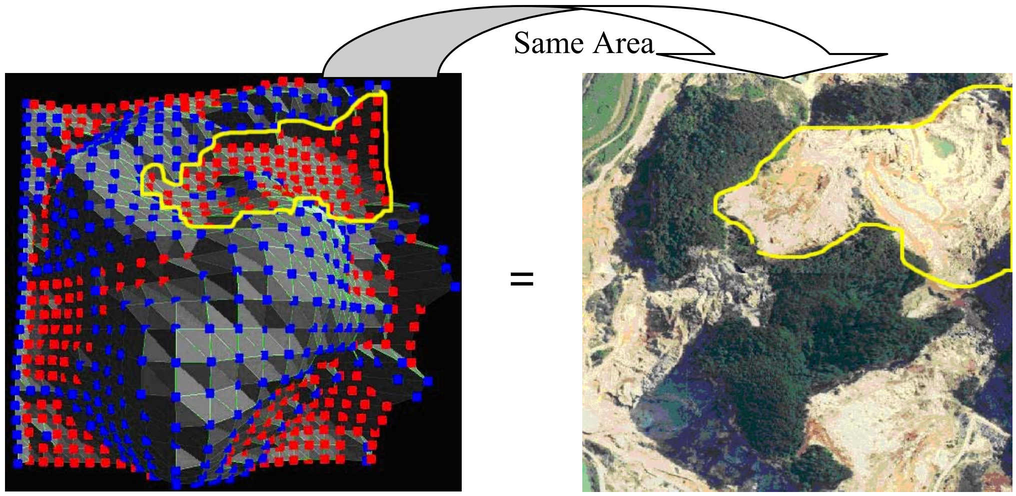


Figure 6.5 (a): Comparison the changes of sample 1 with the image

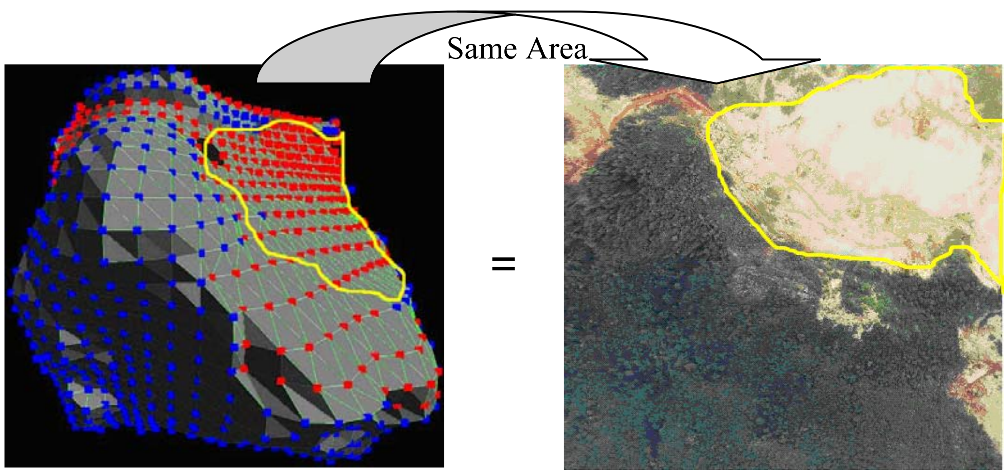


Figure 6.5 (b): Comparison the changes of sample 2 with the image

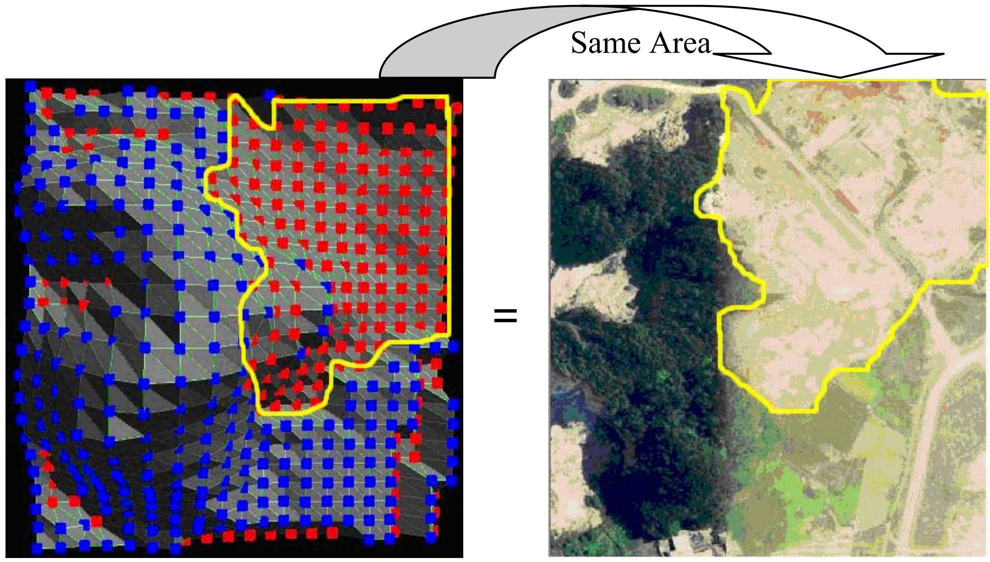


Figure 6.5 (c): Comparison the changes of sample 3 with the image

6.4 Capability of Managing Volumetric Surface Movement Data and Visualization

6.4.1 Managing Surface Movement Data

The Volumetric Surface Movement Spatiotemporal (VSMST) Data Model is capable to manage surface movement data efficiently. The efficiency is refer to data model can store surface movement data, data storage has been reduce their redundancy; and time data processing for loading and retrieving is acceptable.

Data model has been implemented for the testing are using relational database model. All the point which involve with the data storage was store into the single database design. For the storage, we store all the information about surface reconstruction with the topological aspect. In this data model, for the first time to store area are not in the database, we need to load all the geometric structure of the surface which point, line, polygon, surface and the other information are require with the time of surface in the real world. Which means if the data was collected on 1983, so value of time was recorded is 1983. In our case, this process is a creating based data for the data not in the database. For the purpose of managing surface movement data, we were created *temporal_point* entity to store all the point together with the changes. Besides that, we also created *surface_movement* entity which are use to mange the series of surface have involve with a change. Every set of data will be store together with the movement_index which become primary key of the table *surface_movement* table. *Movement_index* is to manage the changes in every surface. We know that, every surface have an identification but for the managing the movement on the surface *movement_index* are require to show the relationship of the surface movement with the point are changes in every surface. For the next series of data, other movement index will be created in every surface has been store. In the next series of point, we assume that the number of point in the surface not is change and topological entity also not being changes. So, number of polygon and number of line are not being change. For other series of surface will be used the same topology. The next series of point will be store in the database just involve with the *temporal_point* table and *surface_movement* table only. So, *movement_index* will be come a relationship for every point has been store in the database. Point for the next series of surface will be store in the *temporal_point* table by using the *movement_index*, with the point identification and the value of point. However, not all point in the surface has involved with a changes. In this case, the process of loading data will be checking the identification of every point with value of x, y, z value. If the value of point is difference between current data and data in the database, we assume this has been move and need to store in the table *temporal_point*. If data in the same value, means data not involve with a changes and new point not to be store. This operation will be benefit of reducing the number of redundancy in the database. Figure 6.6 show the data in the table *surface_movement* and *temporal_point* represent the managing of the changes data in the database.

temporal_point_index	id_point	x	y	z	movement_index
1	1	350790	503100	56.4381	83
2	2	350820	503100	57.116	83
3	3	350850	503100	56.9169	83
4	4	350880	503100	56.927	83
5	5	350910	503100	58.3296	83
6	6	350940	503100	58.4014	83
7	7	350970	503100	60.8953	83
8	8	351000	503100	62.6783	83
9	9	351030	503100	66.2598	83
10	10	351060	503100	64.6836	83

movement_index	time	id_surface
1	83	1
2	2004	1
3	83	2
4	2004	2
5	83	3
6	2004	3

Figure 6.6: Managing of surface movement data in the VSMST Data Model.

In the proposed data model, the interesting of the model is reducing the number of point. The reducing of data has been done by remove point does not involve with a movement. Means that, database only store the point have difference value of (x, y, z). The reducing process will be process after the based data has load into the database. In the database, this data has been organized by creating the *index_temporal_point* which is representing a primary key for the temporal point table. The purpose of creating the *index_temporal_point* is to give *id_point* can be store in many time regarding the number of changes. So, for this case, *id_point* can be redundancy if point have involve with a movement. By doing this, surface movement can be managing easily and besides its benefit to reduce the redundancies together reduce storage usage in the system.

Figure 6.6 above show how point has been store in the table to manage the movement of point in the surface.

From the testing result, we can see that from the three sample of the data set, comparison of the number of point in the surface before load data into the database and after load into database. Sample 1 was reducing 28.2 %, sample 2 was reducing 31.1% and sample 3 was reducing 28 %.

Table 6.9: Percentage of Reduce Redundancy

Sample	Task	No Point		Total Point	Percentage (%)
		1983	2004		
1	Before Load	624	624	1248	28.2
	After Load	624	297	921	
2	Before Load	676	676	1352	31.1
	After Load	676	255	931	
3	Before Load	460	460	920	28
	After Load	460	202	662	

The reducing factor is dependent on the number of changes in the surface at the certain time was recorded. In the first, all the based data which start time data has been store in the database. Number of data after load into the database system is depend on the total amount of data in the based data and plus with summation of the changes of the point in a surface which is involve with the movement. This number of data can be compare with the total amount of data before load and we can get the actual number of point has been reduce based on set of data has been store in the database.

Besides the reduce redundancy, other aspect in managing movement data is to answer user question such as:

1. How much movements have been recorded in the certain area?

SQL Statement:

```
SELECT COUNT (movement_index)
FROM surface_movement
WHERE id_surface = “Input Id_Surface”
```

Result:

Sample	Input	Result
1	Surface Id: 1	1
2	Surface Id: 2	1
3	Surface Id: 3	1

2. How much many point involve with the movement in the surface at the certain time has been recoded?

   SQL Statement:

```
SELECT COUNT(z),  movement_index
FROM temporal_point
WHERE (movement_index= “Input Start Movement Index”) <
(movement_index=“Input End Movement Index”)
    GROUP BY movement_index
```

   Result:

Sample	Input	Result
1	1983 , 2004	297
2	1983 , 2004	255
3	1983 , 2004	202

3. How much differences value of movement in a point in the certain area with a given start time and end time?

SQL Statement:

SELECT temporal_point_id, point_x, point_y, point_z
FROM Temporal_point startChange
WHERE Id_surface = "Given Id_Surface" and time = "Given Start Time"
SELECT temporal_point_id, point_x, point_y, point_z
FROM Temporal_point endChange
WHERE Id_surface = "Given Id_Surface" and time = "Given End Time"
SELECT temporal_point_id, (startChange.point_z – endChange.point_z) as difference FROM startChange LEFT JOIN endChange USING (temporal_point_id).

Result:

Sample 1

2004(c)	**83(v)**	**fid**	**value**
54.1509	55.0397	1	0.8888
52.6183	53.8923	2	1.274
38.9442	51.3096	3	12.3654
37.6183	52.6183	4	15
39.1509	54.1509	5	15
36.6097	55.6097	6	19
43.8620	58.8620	7	15
..	..	..	..
..	..	..	..
43.2693	58.2693	621	15
42.0613	57.0613	623	15
45.3914	60.3914	624	15

Sample 2

2004(c)	83(v)	fid	value
157.3675	172.3675	1	15
267.7829	282.7829	10	15
250.8094	265.8094	11	15
225.9716	240.9716	12	15
210.3194	225.3194	13	15
..	..	..	..
..	..	..	..
399.1850	414.9185	409	15.7335
397.2396	412.2396	432	15
395.6860	410.6860	433	15

Sample 3

2004(c)	83(v)	fid	value
36.4381	56.4381	1	20
37.1160	57.1160	2	20
36.9169	56.9169	3	20
38.4014	58.4014	6	20
40.8953	60.8953	7	20
…	…	..	..
…	…	..	..
37.4733	57.4733	457	20
37.2840	57.2840	459	20
36.9047	56.9047	460	20

4. How much average of movement value in the certain area with the two state of area in the difference time?

   SQL Statement:

   ```
   SELECT AVG (startChange.point_z – endChange.point_z) as value
   FROM startChange LEFT JOIN endChange USING (temporal_point_id).
   ```

Result :

Sample	Output
1	15.111582175227
2	18.753121875
3	16.181818181818

Capability of managing surface movement data has been tested and evaluate. From the result and discussion, Volumetric Surface Movement Spatiotemporal (VSMST) Data Model can be use to manage volumetric surface movement data. Data model can be implemented using any database model, in this research we implemented using relational database model because this model support by many type of database software in the market. Besides that, most of the system developers also have lot of knowledge in the relational database model. So, that the VSMST Data Model can be use and implemented easily.

From the result we can see that, the model contribute to minimize the data storage. This model not be tested and evaluated for the data manipulation, we just focus on the retrieval process to prepare the data for the visualization to looking the process of movement in the surface. For the purpose of the visualization, this model has great capability to prepare the data for the visualization.

In this implementation, we use the TIN structure for simulation and enhance the TIN concept by integrated with the temporal element. From that, we have proposed the data format to improve the managing of the surface movement data. For the visualization approach, we use the parametric equation to simulate the movement. This is common approach for the deformable object in the computer graphics.

6.4.2 Data Visualization

Data visualization is a part of our research activity. The purpose of developing visualization tool is to test a result which is retrieve from the database for simulating the changes. Based on our review has been done during research has been conducted, there are no specific algorithm and visualization tool have capability to visualize and simulate movement in the surface from the TIN structure data. Most of the tool was simulate movement of the surface separately. However, the basic algorithm is based on the TIN structure for simulating the movement in the surface and we have applied parametric equation to simulate or visualize the movement.

In the algorithm has been propose, we have develop by integrate terrain algorithm with the parametric equation. By using the proposed algorithm we can simulate every series of terrain data together in one application. From the testing has been done, the tool is proof that our proposed algorithm can simulate the movement. However, we have initiate a rules which is every series of set data must have same structure of creating the surface with same number of point and together with a same topological structure. Result has show that, the visualization tool can be simulate the data based on the number of set of surface has been store into the database. Result of the testing has been show in the figure 6.7.

From the result, we can compare that all the movement was happen are follow the input data from the Ariel photo image has been digitize and store in the database. From the figure that we can see the data input is from the Ariel photo which we can see the differences from the image before movement was happen and after movement was happen. In the figure 6.7 (a) is a data set from the 1983 and figure 6.7 (b) is a data set for the year 2004. From the two images we can see the differences between the data set. In a result beside of the both image is show the result in the visualization tool which contain series of point in differences state. Both of images are in the same area in the difference time of data collection.

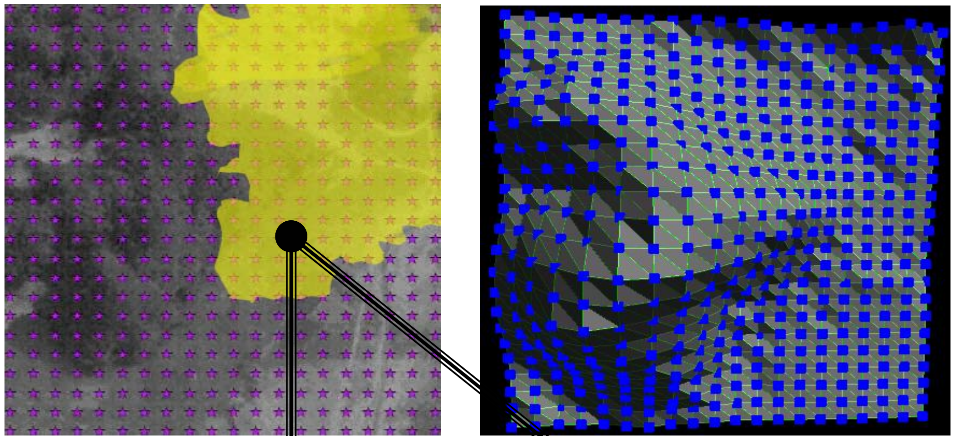


Figure 6.7 (a): Input Images and Visualization Result in Year 1983

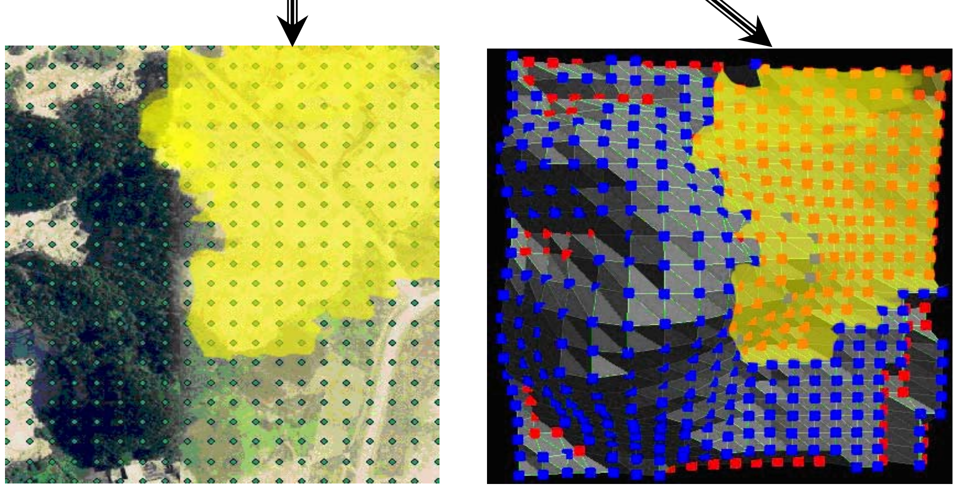
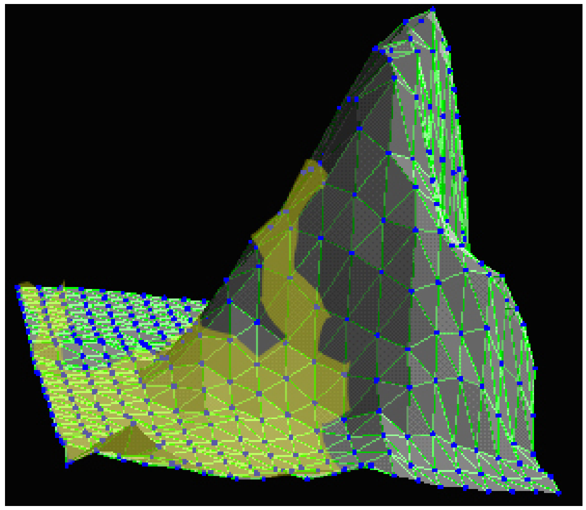
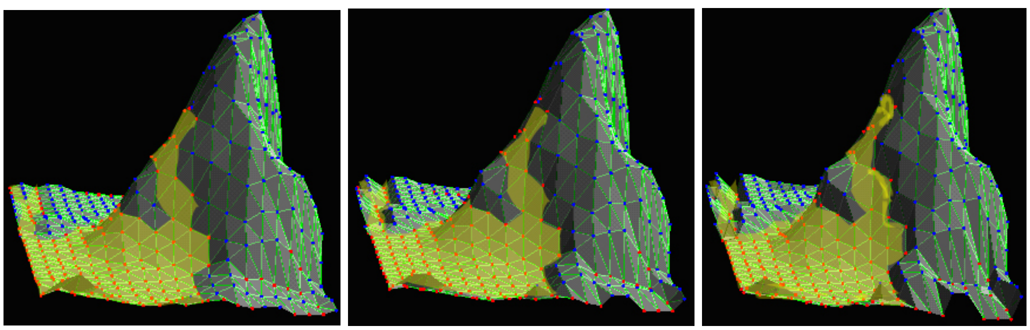


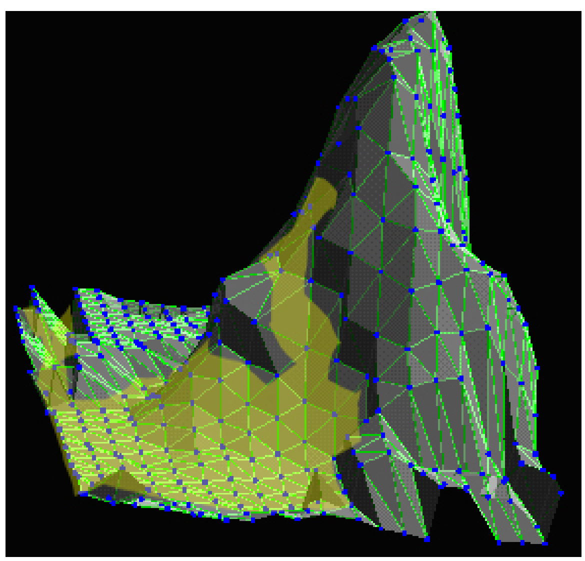
Figure 6.7 (b): Input Images and Visualization Result in Year 2004



Terrain Model of the Start Point



Terrain Model of the Within Movement20



Terrain Model of the End Point

Figure 6.7 (c): Result of Simulating Movement of Digital Terrain Model

Figure 6.7 (c) shows the result of simulate the series of set data which has been load into database and retrieve to simulate the movement. From the figure we can see that data form the start time and end time. This tool also give user to navigate the data with the two set of data. In the figure, the red point is show that point has been changes within the movement.

In order to simulate the Digital Terrain Model with the movement, we have come out with our own data format which is can be read by our visualization tool. In the data format, we have a series of point and series of triangle which is use to creating the surface for the Digital Terrain Model. After that the data format continue with the number of changes are involve in the area and with the number of point which has been involve in the movement process. Idea of proposing the data format is to make sure that time of navigation of the movement data is faster then retrieve from the database in every navigation process. So that, all the point are related for the simulation process has been store into the data format. The difference of data format from the TIN format is our proposed format containing the movement point which together in the single file and easy to load into the visualization tool. Besides, the TIN format also has been modified with adding temporal element to make sure that movement process can be simulated.

As a conclusion, our propose data format and visualization algorithm can be work together to simulate the movement in a series of surface. Capabilities of this algorithm has been prove that simulation of the surface can be done by integrated in the single file with modification in the digital terrain model algorithm by using parametric equation. Proposed algorithm is work based on the input data from the data format to do simulation of the surface movement in the terrain model. It means that, if we have many series of data in the same area in the differences time it can be simulate.

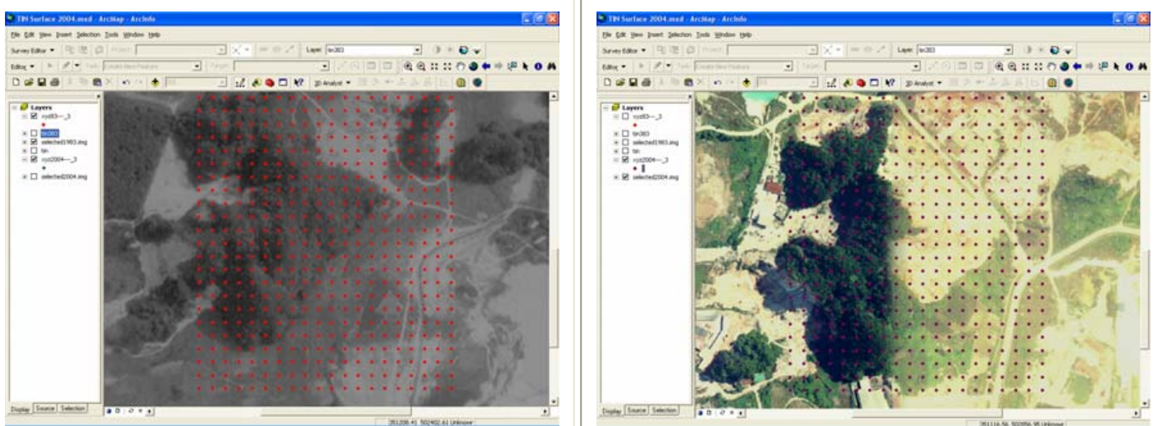
6.5 Comparison with Current GIS Software

Volumetric Surface Movement Spatiotemporal Data Model has been proposed in this research. Generally, the aim of this research is to manage surface movement data on the volumetric object with support visualization of the surface movement in the interactive way. From the previous discussion, we have prove that our propose model can be manage and simulate surface movement on the volumetric object. This model has been test and validates using terrain data which is capture from the Ariel Photo.

In this section, discussion will focus on the comparison study of the result of implementing data model with the current Geographical Information System (GIS) software. The purpose of the comparison is to validate that the propose model have same advantages and added value for the GIS software in the future. The software are selected to be comparing is ArcGIS Software. This software is famous software which always use in the development of the GIS application.

Major differences of ArcGIS with the propose model is in the managing and visualizing temporal data. Currently, ArcGIS are does not have capability to do analysis on the spatiotemporal data and visualize movement data. The basic reason is the way data managing in the ArcGIS is in the separate file for any set of spatial data. For the purpose of the spatiotemporal data, ArcGIS manage the data in the difference set of file system. Besides that, the visualization capability of the spatiotemporal data ArcGIS lack of capability to simulate the movement together in the single visualization tools. However do not deny that ArcGIS have a great capability to analysis spatial data.

In the ArcGIS, data can be display by using layer based model. Every layer they have the difference set of file which is store spatial, attribute and their relationship. In order to manage spatiotemporal data, data can be load into the software by using differences set of data. Means that, all the data in the same area with the difference series of time will be store in the difference file. Figure 6.8 bellow show the result of the set of data has been tested in our model is loaded into the ArcGIS software.



Data in year 1983	Data in year 2004

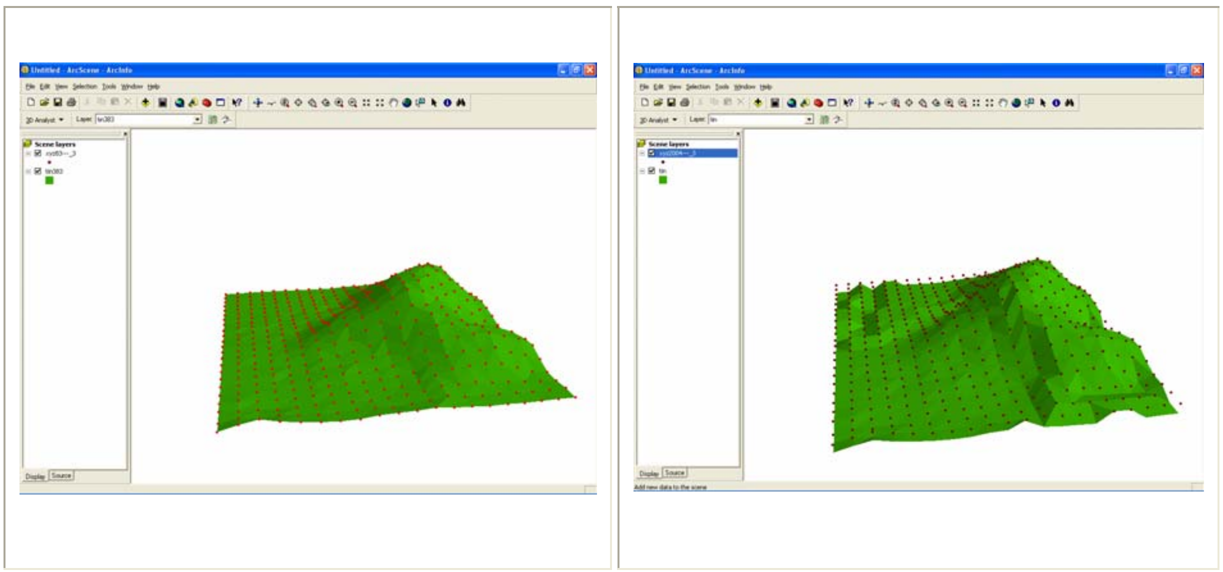
Figure 6.8: Data in year 1983 and 2004 in the ArcGIS Software

In the figure 6.8, dotted point is show the related point to create the surface in every series of the data set. Data set for creating the digital terrain model is in the difference set of file. Every data set in the Figure 6.9 to create 3D model of the surface will be stored in the two set of file followed by its own layer. Affect of this approach is data has been stored in the ArcGIS will be increase by series of data set. Besides, not all the data has involved with a movement and this will contribute the redundancy of the data.

In our propose data model, all of the data will be load into the database by using the single database system. As discuss in the previous section, data will be load by checking the redundancy and reduce the number of point will be load into the database. For the purpose of the spatiotemporal analysis, this model is better then ArcGIS. From our testing with the three sample most of sample has been reduce by 30% in average.

However, the reducing factor is based on the series of data set and number of the point has involved with the movement.

For the purpose of the visualization the digital terrain model to show the movement, ArcGIS can show the model in the difference set of display and does not have the capability to navigate the movement process. Digital Terrain Model can be visualizing the data by using the ArcScene function in the ArcGIS. Figure 6.9 bellow show the result of the visualizing two set of terrain in the ArcScene.



Terrain Model in year 1983	Terrain Model in year 2004

Figure 6.9: Terrain Model in year 1983 and 2004 in the ArcScene

The difference between our propose model with visualization tool development, this data set can be visualize and simulate together in the one display. In the figure 6.9 at the previous section we can see that the same data can be navigate to see the movement process. This another advantages of our proposed model which have integrated all the spatiotemporal data into the single database system, single file system and display with the single visualization tool.

As a conclusion in this section, our proposed model can be use to develop spatiotemporal database with the visualization tool. These have much difference with the current GIS software and it can become solution of the managing spatiotemporal data.

6.6 Summary

In this chapter, the testing, and validation of the Volumetric Surface Movement Spatiotemporal Data Model has been discuss. Testing of the model has been done by using Ariel photo in the difference set of time. This data has been given by JUPEM which in the digital but in the difference resolution. This data has gone through the process to making the data is valid to testing in our system. This data has been digitizing to get the point for creating the surface of the terrain model. This data has been load into the database system with reducing the redundancy which only store the point are related with the movement process. From the result, we have discussed the capability of the model in managing surface movement data with the evaluation of the testing result. Besides, we also discuss the propose visualization approach in visualizing the surface movement data in the object. Comparison with the ArcGIS software has been done to analyze the difference between the proposed model and system. Based on the comparison study, we can conclude that our approach has some advantage in managing the spatiotemporal data.

CHAPTER 7

CONCLUSIONS AND FUTURE WORK

7.1. Introduction

Spatiotemporal data model is important for modeling, managing, manipulating and visualizing spatiotemporal data. Spatiotemporal data model will describe an approach of managing spatiotemporal data in the database system. VGIS require spatiotemporal data model to enhance capability of managing movement data or changes data in the earth surface when developing virtual environment in the certain area. Currently, there are many spatial, temporal and spatiotemporal data model has been developing for GIS. In this research, we have studied and discuss nine related models which are proposed to use in GIS. Generally, all the model can not be use in the VGIS because the model does not support the three dimensional object. Most of the research has been proposed to created spatiotemporal data model which is can manage, manipulate and visualize three dimensional objects with the movement or temporal element.

In this research, we have proposed our own spatiotemporal data model call Volumetric Surface Movement Spatiotemporal (VSMST) Data Model. This model will give the way of manage and visualize spatiotemporal data in three dimensional with the movement on the surface. This model can store and manage surface movement by using the concept of the surface reconstruction. Chapter 4 in this report has been discussed in detail about the surface reconstruction concept and it implementation in the developing and designing the VSMST Data Model. We have formalized the approach by integrating surface reconstruction with a temporal element. Besides, the formalization of the model also considers about the increment of the data in the database storage and optimizes the storage by storing the only changes point in the database. This data model has been implemented by using the relational database model. For the implementation, we have translated the formalization of the VSMST Data Model in to the conceptual design and physical design to developing the database system. For the testing VSMST Data Model, we have developed the spatiotemporal database system with the data loading and retrieval process. In this phase, data loading algorithm and retrieval has been design to perform the process. VSMST Data Model is for the VGIS purpose, so we need to test and evaluate the capability of the model based on the capability of visualizing the three dimensional data with the movement. For that purpose we have develop the visualization tool with the spatiotemporal visualization algorithm by using the parametric equation. This model also focus on the digital terrain model, so the visualization algorithm has been developed based on the TIN structure. In our propose system, data has been retrieve will be store in the data file with our own data format which is enhancing the TIN structure by including temporal aspect. The process of developing application for the testing has been discussed in the chapter 5. The model has been tested using the conceptual data.

Testing and evaluation of the VSMST Data Model has been done by using Ariel photo has been recorded in 1983 and 2004. Before test and evaluate the model using data set, all the data need to be process to get the coordinate on the surface. From the data set, we have sample three sample for test and evaluate the capabilities of the model. All of the three samples are the difference area in the same Ariel photo. We have selected the areas which involve a lot of changes. From that we assume that, we can show the capabilities of the VSMST Data Model in order to managing the surface movement.

Result form the testing and evaluation process, we can see that VSMST Data Model have capability to manage surface movement on the volumetric or three dimensional object. Database system only store the based data and with only the point which is involve with the movement and do not store the point which is not involve with the movement. The retrieval processes also have capability to retrieve the data to prepare the data format for load into the visualization tools. Visualization tool also have capability to visualize the movement data with it can be navigate through the time, so user can look the transformation process from the start time until end time.

7.2. Result and Major Finding

The major contributions of this thesis are:

1. Formalization of Surface Movement on Volumetric Object

   We have develop the formalization of the surface movement on the volumetric object for developing Virtual GIS application which is have capability to handle spatiotemporal data to support visualization and simulation the deformation of the surface. In this formalization, we have integrated the surface reconstruction with the temporal element. This is the new contribution to enhance the surface reconstruction theory which has been use in the most of the computer graphics application such as Virtual GIS, Virtual Environment and Virtual Reality. By enhancing the theory, we have come out with the formalization which gives a new ways to manage the surface movement data. Before this all the data on the surface for animating, simulating and visualizing use a difference set of data for simulate the same object. This formalization can be use to model a database and visualization of the data set not only in Virtual GIS but in various area in scientific application.

2. Spatiotemporal Data Model and Data Management Approach

   Based on the formalization has been develop, other contribution is developing the spatiotemporal data model which is can be use to manage surface movement data in the volumetric object. The data model namely Volumetric Surface Movement

Spatiotemporal Data Model. This data model have capability to handle surface movement data in the given area which minimize the data storage by only store the point has involve with a movement. The data has focus in the data model is volumetric surface which can be digitize from the data source such as Ariel Photos. The difference our data model with others is solves the issue of the capability of spatiotemporal data model to manage the volumetric data or three dimensional data with the temporal element. This model has capability to integrate all the data has been recorded to analyze the movement in the surface. Most of the data model has been review in the chapter 2 has been suggested to improve the spatiotemporal data model for managing the three dimensional and the volumetric data.

3. Triangulated Irregular Network with Temporal Data Format and Its Visualization Tools

We have developed a Triangulated Irregular Network with Temporal Data Format in this research actually to support the visualization of the surface movement data on the volumetric object. The reasons are in the current GIS software currently they do not have the capability to visualize and simulating the surface movement data. We have make a comparison study of result has been got from the research with the facilities with the ArcGIS and prove that the ArcGIS can not do the simulation. The data format actually has a same concept with the TIN structure. Currently, there are no TIN structure can be integrated with the temporal element. So, this research has proposed a new data format which is integrated TIN with the temporal aspect in the structure. In this data format, the unique is the structure of the data format is started by TIN data for the terrain area and follows by temporal element with the only changes data in the specific data. By proposing the TIN temporal data format, we can simulate the movement data in the surface easily. The database will prepare the data based on the request from the user and put the data together in the data format, then data can be read from the visualization tool for simulate the surface movement on the volumetric object. The visualization tool has been developing by using parametric equation which is take account of the temporal aspect.

7.3. Future Work

In this thesis, we have proposed Volumetric Surface Movement Spatiotemporal (VSMST) Data Model and implement by developing database system with the data management system with the visualization tools. During the design and implementation of the VSMST Data Model, a lot of research needs to be done to enhance the capability of managing the surface movement data and visualize the data. The major improvement can be consider to improve is the data model. Currently, the data model has been design to handle the data which is we assume that the surface have same geometry to construct the surface. Our proposed model can have enough capability to manage the data which have same number of point to reconstruction for visualizing the data. For testing and evaluate our model, we have digitize Ariel Photo by using the same scale and using the same number of point in the surface. This will be contributing easy managing the data in the database. The structure of the data is same from the start data and the end data, by doing that we store only the changes data in the database without change the geometric structure. So that, our propose model not consider uncertainty data. For the future work, model can be considered to handle uncertainty data which is the data not always in the same number structure and number of point. In this case, a new interpolation model is require to integrated with the data model to manage uncertainty data. For example, between the set of data may there are some data will be appear and may be a certain point will be lost from the data set. In this case we can consider in the start data set we have three number of point and with the same are we may have two number of point or we have four number of point. This will contribute to manage more realistic data.

Other aspect of improvement the data model is consideration of other geographic object to integrate with the terrain model. Currently we only focus on the surface its self but in the real phenomena a lot of geographic object in the terrain surface. This is a lot of impact if we can integrate the model with the other object. In the Virtual GIS, they just not only simulate the terrain surface but it must be integrated with the other objects.

In the implementation phase, we have developed the database system by using the relational database model. We use the relational database model is because this relational database model most of the database software support this model. We know that, currently we have a new database model such as object oriented database model and object relational database model. These database models have their own benefit. In the future VSMST Data Model implementing using the both model. This will give more impact in the database development system in the future.

In the data management aspect, we know that in the future data has been store into the database will be increase time to time. We have proofs that our model can be reduce the redundancy but increasing of the data will be happen to adding a new data in the database system. This will be arise management of the data issues inter of data loading and data retrieval. It will be come more complex and more difficult to handle. This can be solve by using proper indexing approach. Our suggestion is to improve the current indexing approach by adding the temporal element. A lot of the indexing approach such as B-Tree, Kd-Tree, BSP-Tree and others can be consider to implement with enhancement by adding temporal element.

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