Geographic Information Systems support for monitoring environmental impacts caused be deep hard coal mining

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Abstract

Every human activity has impacts on the natural environment, also deep hard coal mining with long-lasting activities and digging huge amounts of hard coal. To detect and minimize effects on anthropological landscape and natural environment, monitoring of specified phenomena takes place. This means large amounts of data and complex analyses that can't be accomplished without using computerised support, especially by GIS. So this paper provides an insight into the concept of monitoring environmental impacts and how GIS can be used to support this.

1. Introduction

Deep hard coal mining in depth up to 1500 metres always leads to changes on the earth surface. Digging hard coal causes underground- and surface-movements which may have significant effects on infrastructure and natural environment on the earth surface.

For specific projects the regulations of the German Federal Mining Act (BBergG) from 1990 demands an Environmental Impact Accessment (EIA) to identify, describe and assess effects on the landscape and natural environment. Deep hard coal

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mining activities in Germany have to perform an EIA until any administrative permission is given. Thus all project information to future emissions, residual materials and effects on humans, flora, fauna, soil, water, air, climate, landscape including the interactions among each other must be defined and analysed before starting any activities. This is a problem for mining projects because of the needed long term planning reliability (up to 15 years) and only roughly known future digging activities. Therefore not all forecasts can be predicted as precise as it should be and as a result, the administrative consent can only be given with additional conditions. Such an additional regulations can be the demand to monitor specified environmental parameters to eliminate, minimize or compensate effects.

2. Concept for monitoring the mining impacts

Monitoring environmental impacts caused by deep hard coal mining (in the following only the short term Monitoring will be used) is a complex task among the authorizing agency, sectoral planing agencies and the mining company as major partners.

An official approval defines Monitoring as a systematic program for observing, controlling and supervising mining activities and their environmental impacts. In this context supervision means to decide how negative effects can be eliminated or minimized.

This paper presents the tasks of the mining company in a Monitoring project, so that the mining activities conform to the actual law. The administrative agency defines precise tasks in close collaboration with the sectoral planing agencies, depending on the planed mining activities and the area under investigation.

Basically the extraction of large quantities of hard coal in the subsurface mostly results in a general cause-and-effect-chain based on surface subsidences. Earth surface subsidences lead to changes of the ground water surface with effects on terrestrial biocoenosis. This leads also to morphological and hydrological changes of rivers and lakes with effects to aquatic and terrestrial biocoenosis.

For the causes and the effected environmental object classes the mining company has to work out the following investigations:

1. capture, analyse and interpret specific environmental parameters,
2. detect, analyse and interpret changes (change detection),
3. analyse effects to find the reason for changes,
4. control effectiveness of adopted actions,
5. validate made forecasts,
6. if necessary revaluate forecast models,
7. compare actual states and changes with defined future aims (long term forecasts from EIA),
8. make proposals to define new actions or modify carried out actions to eliminate, minimize or compensate effects.

3. General requirements for a GIS-support

The use of Geographical Information Systems (GIS) to capture, maintain , analyse and visualize spatial information has been verified in the last years. One topic to support a monitoring as described before is to bring all data together using the spatial and temporal references, creating a monitoring cadastral.

(Worboys, 1995) pointed out, that space in GIS can be conceptualized in two distinct ways, as a set of locations with properties (spatial field view) or as a set of objects with properties where space is only one of these (spatial object view).

Monitoring uses the field view to describe continuous surfaces, like earth surfaces or ground water surfaces, and also the discrete object view, for example to model biotopes or lakes. Most commercial-off-the-shelf GIS offer different data models (object- and field-view) and also plenty of methods to analyse the spatial components of objects, modelling phenomena of the real world.

Temporal concepts in contrast to spatial concepts are neglected in GIS. There are no spatiotemporal data models or analysing methods implemented. But this fact is essential for a monitoring. It must be possible to make queries and analyses like:

- show the states of some predefined objects at a specific point in time,
- show me the predecessor or successor of some predefined objects or
- show me how some objects in a spatial area changed over a time period.

One part of the monitoring where temporal queries and analyses plays a major role is for example the change detection, where GIS can be used to:

- detect and interpret real changes while comparing one state (at time t_x) with former states (at time $t_{x-1..n}$),
- to detect divergences with defined future aims:
  - comparing forecasts of future states,
  - comparing forecasts of future changes,
  - comparing real states with forecasts of future states,
  - comparing real changes with forecasts of future changes,
- to validate forecasts:
  - comparing real states with forecasts of states made in former time for the same time point,
  - comparing real changes with forecasts of changes made in former time for the same time period.

4. Conceptual approaches to integrate time in GIS

This chapter only gives a short introduction to some conceptual approaches of the integration of time into the GIS. Detailed information can be found for example in (Roosmann, 2003).

4.1 Basic terms and definitions

(Langran, 1992) introduces the cartographic-time to integrate time in GIS and harks back to the simple Newtonian conception of non-interacting space and time. In everyday life people understand time as a one dimensional homogenous continuum, complete, linear and infinite, thus isomorphic to the real numbers. Cartographic time can be discretised as a finite set of chronons which are isomorphic to a finite sequence of natural numbers. The sequence of chronons may be thought of as representing a division of the real time line into equal-sized, indivisible segments (Jensen, 1997).

The time-point is an interval whose duration is less than the resolution of the time scale. The time-interval is equivalent to a curve in space and represents the extent of time. The time-interval is bounded through two time points (beginning and end time point) and has a duration (equal the temporal distance between the time points bounding the time interval) that is greater than the resolution of the time scale. To aggregate sets of temporal geometrical primitives the temporal geometrical complexes can be used. The so-called time-aggregate is similar to the spaghetti-model known from spatial concepts. Time-composite behaves as a temporal topological simplicial complex.

To describe states of entities at a given time on the one hand and the changes that occurred, are occurring or will occur, Langran [8] asserts that there are at least three types of spatiotemporal data in GIS on the other hand which are: state, event and evidence. Others differentiate further between events and episodes.

State is an aggregate of conditions of an object that describes an entity. States have duration and are therefore represented by time intervals. State of an object is changed by an event. Events can be understood as snap-shot and thus represent a time point. Changes may occur over a longer duration and are then referred to as episodes represented by a time interval. As an evidence the datum describing the source of state and event data may serve (Wachowicz, 1999).

4.2 Different views of time

Referring to (Frank, 1998), different types of time exist. Not in the physical space, but in the conceptual models for the time people use in common. These views can be found in computer applications dealing with time.

Field View vs. Object View

Just like space the time can be conceptualised in the same way:

- as a set of time points with properties (field view or absolute time) and
- as a set of objects with properties and maybe even temporal properties (object view or relative time).

Scales of Time

Time may be measured with different types of scales. If the states of objects are in the foreground, like in historical information systems, time is measured only as a time point on an ordinal scale (static view). If the occuring changes are relevant time is measured on an interval scale (dynamic view).

Discrete vs. Continuous time

Discrete time is used when time is measured at certain time points or time intervals and the variation is discontinuous between them.

Continuous time may be required to describe processes. Time may be measured at some time points and a theory to interpolate a value for every time point on the continuous time axis exists.

Structures of time

Time can be modelled as

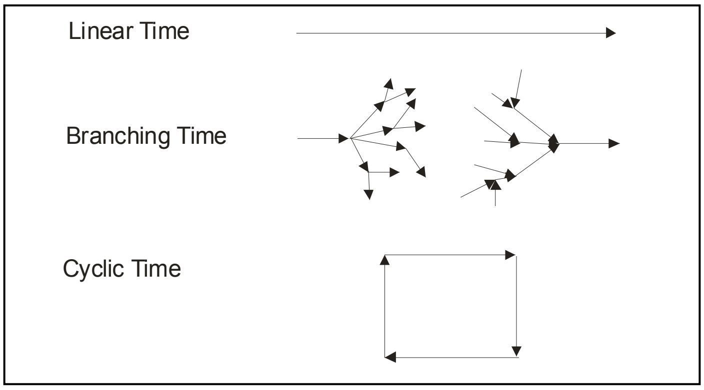

Figure 1: Structures of time

Modelling time as linear means that events occur one after another. An object can not exist more than once at the same time. This constraint does not exist when time is modelled as branching time. Branching time permits multiple alternative futures, presents and pasts. The cyclic time can be used to describe things that occur periodically.

4.3 Approaches to integrate time in GIS

In the following only some approaches shall be presented. (Langran, 1992) must be regarded as a great pioneer. In 1992 she presented the following data models to integrate time in GIS:

- The space-time cube

  Three coordinate axis define a three-dimensional coordinate system, where space is two-dimensional and time one-dimensional. The coordinate axes are orthogonal to each other. Every object is modelled as solid in this space-time cube representing spatial attributes at different times.

- Sequent snapshots
  This is of course the simplest way to implement time in GIS. The complete area under investigation must be brought into the GIS at every time point.
  The advantage is the quick and easy analyses of the states. The disadvantage is that a great amount of data has to be stored redundantly. Furthermore the changes between the stored states have to be calculated every time they were needed.
- Base state with amendments
  This approach uses the algebraic topology to describe state and change. The state for the initial time point is stored. For later time-points only the changes are tracked, leading to a refinement of the initial state.

Next to this approaches you can find many others extending these approaches or define new ones, like the:

- Spatio-bitemporal approach from (Worboys,),
- ER-models for temporal objects from (Kaiser, 2000),
- Object-oriented approach from (Ramachandran, 1994).

5. Extending commercial of the shelf GIS

In the last years commercial-off-the-shelf GIS were enhanced a lot. These GIS are no longer monolithic systems using proprietary data models and programming languages. Today’s GIS use standardized data types and modern programming languages.

Regrettably no temporal or spatiotemporal data model is integrated in common GIS until now. But this is essential for a Monitoring.

In the following some basic points shall be presented that must be kept in mind when creating a GIS solution using time as a further dimension.

5.1 Data capturing

The identity is one major point when states of objects and their changes over time shall be analysed. Many philosophical discussions have been started to the question: when does the identity of an object change. We don’t want to join in this discussion. In our opinion the answer to this question follows from the actual task.

If any change analysis shall take place, we have to check the existence of identic objects (objects with the same identity) in other epochs. If a new captured object has a predecessor and / or successor, the identity of the predecessor / successor has to be assigned to this object.

To assign objects from different epochs the same identity, different procedures can take place:

- fully manual: The user has to find objects having predecessors / successors, getting the predecessor identity and assigning the same identity to the corresponding object of the actual epoch.
- fully automated: Based on defined rules the predecessors / successors are detected automatically. These rules can use the shape (area / perimeter) and / or alphanumeric attributes controlling equality or even similarity using specified deviations. Objects with predecessor / successor inherit the object identity, others get a new unique identity.
- partly automated: The same rules as described for "fully automated" were used. But in this case the user has to decide which object identity shall be assigned (only in critical cases).

When modelling continuous changes, not only the state for one point in time has to be defined but also an interpolation method between the measured or calculated states.

In contrary to the time management the user has to assign the duration of validity to every object (or maybe to all objects of one discrete time point):

- Rollback-Databases using transaction time (database time),
- Historical-Databases using valid time (real time) or
- Bitemporal Databases using at least transaction-time and valid-time (and maybe other user-defined definitions of time).

5.2 Data management

In our research work the ESRI Geodatabase in combination with Oracle9i is a basis for the data management. ESRIs Geodatabase offers options to integrate database-time using versions. We extended the ESRI systems- and meta-tables so that we can create a bitemporal database, with space and time modelled as discrete snapshots using linear and branching time.

With the developed concepts we are able to assign time to:

1. the whole geodatabase by extending versions with valid time,
2. groups of time synchronic classes. This concept enables an arrangement of classes whose states change at the same point of time,
3. single classes: used to assign a duration of validity to single classes using valid time,
4. groups of time synchronic attributes. This concept enables an arrangement of attributes whose values changes at the same time.
5. single class attributes,
6. single objects.

To every new state an event causing the change is stored. Because only objects states are stored, changes must be calculated every time they are needed.
ArcSDE and ADO.Net is used to insert, update and delete objects or classes.

5.3 Analyses

(Ott, 2000) defined four groups of analysing types that could be part of a spatiotemporal GIS:

1. Location analysis: Functions based on the spatial properties of an object, like spatial queries, statistical functions, overlay or geometric-topological operations.
2. Attribute analyses: Functions based on the alphanumeric attributes of an object, like alphanumeric queries or statistical analyses.
3. Time series analyses: Procedures to document and to investigate changes of spatial and thematic attributes, like temporal queries or interpolation.
4. Process analyses: Operation to model spatial and thematic states and changes of an object in the past, present or in the future, like process analysis and simulation.

Commercial-off-the-shelf GIS offers a broad range of location and attribute analysis tools, which can be used for to investigate temporal processes.
Time series analyses must integrate temporal queries based on temporal topology to compare time points or intervals, like (Wachowicz, 1994):

Spatial operators	**Temporal operators**
disjoint	before / after
meets	meets
equals	equals
contains	during
covers	starts / finishes
overlaps	overlaps
intersects	intersects

For this reason it is possible to search for objects within a specified time interval. It is not necessary to store state and change because change can be calculated if at least two states are available. To calculate change, operations for location and / or attribute analysis can be used.
(Piquet, 2000) pointed out, that there must be a conceptual link between events as causes and the effects. The aim is to create a dynamic concatenation of operators acting on objects and affect their states and maybe activate other operations. At the end a real world system can be modelled and influences of planned activities can be simulated. The process analysis is not part of our research work so far.

5.4 Presentation

One thing is to store and analyse spatiotemporal objects and maybe processes. Another thing is to visualize spatiotemporal objects, so that this voluminous and – for some people – encrypted information can be used as a basis, maybe for decision-makers or the GIS-expert.

For this multimedia applications and especially animated visualizations can be used. It is possible to define a kind of screenplay where the user defines a spatial path on which he can specify viewpoints where time can be changed. The user can walk through space and on specified viewpoints he can see changes of a defined area through time, too.

Of course we can only visualize states and changes through time for the time points where the states are measured or it is possible to calculate intermediate states.

To calculate intermediate states interpolation methods must be known, describing the changes mathematically.

6. Conclusion

Time is implemented in some commercial-off-the-shelf GIS, like in ESRIs Geodatabase. But in this case only the transaction time (database time) is integrated as a basic for a rollback database. To satisfy the requirements to support monitoring environmental impacts caused by deep hard coal mining the data model has to be extended.

Many spatial and alphanumeric analyses are implemented in common GIS that can be used to analyse spatiotemporal features (time-series and process analysis). To support time-series analyses temporal topological operators must be implemented.

Because of the GIS-enhancements of the last years, it is possible to extend common GIS easily to specific requirements. In this case we had to extend the geodatabase data model and develop some analysing tools.

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