

IMPLEMENTATION OF A CUSTOMIZED GIS-BASED TOOL FOR TUNNEL CONSTRUCTION SITES MANAGEMENT (TUNNEL CS TOOL)

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KEY WORDS: Geographical information science, Object-oriented data model, Computer Vision, Spatio-temporal modelling, Decision Support, Desktop Techniques, Tracking System, Construction Sites

ABSTRACT:

The geographic information system (GIS) approach has been extensively used for spatial modeling in a variety of application areas in different engineering and non engineering fields. GIS' graphical environment and simulation models have been successfully used in monitoring, scheduling and estimating tunneling jobs. Also, simulation models have been developed to forecast project completion time, taking into account the dynamic and uncertain variables in the project environment during construction phases. Thus, GIS based management for tunnel projects determines essentially the requirement of resources at various phases of the project and also the cycle time for each of the tunneling activities. Besides the already implemented GIS tools, functions and extensions provide a basis for mathematical modeling. Despite the efforts to build modeling functions into GIS directly and the suitability of specific GIS packages, it is likely that most numerical models, especially those requiring exhaustive calibration, will need to parallel, rather than to work within, the GIS. The Visual Basic programming environment running under GIS helps the programmer to develop and implement his own functions and tools. Focusing on the developed concept of tunnel construction sites management (Nejatbakhsh, Saler, Baumeister 2008), this paper presents the main outlines of processing a time based database, basic entities of forming a data integration system and necessary characteristics of information prototypes required for a Tunnel Management System is studied and discussed in detail. Time dependent functions such as project progress tools and profiling functions are implemented in a user friendly graphical interface.

1. INTRODUCTION

A tunnel project from starting point to the end point can be performed in three main phases, planning phase, performance phase and management phase. The project gets started with the planning phase in the engineer office. After the engineers sketch the first plan in a CAD environment, they feed it to the site data to find out either the plan will be performable. Later, laser scanning data from the construction site should be transformed to match to the site data; it means through a translation process, huge amount of laser scanning data must be translated into an object format like point or a coverage format like points cloud to make it understandable for the computer and end to easier data integration. The result of this transformation procedure might appear as table or directly tunnel objects. In the case study of this paper, points are retrieved from laser scanning data. These two main sources of data will be automated in g_l_survey system; a newly developed extension by company "Arc-Berlin". Office planning data such as curves adjustment, optimized profile structure and etc will integrate to the digitalized tunnel. Kilometre stations will be produced as control target points of the project. After the plan is proved and the construction is firmly started, simultaneously the management phase will run to track either the performance gets executed in its scheduled plan. This management procedure will integrate project database with desktop solutions under the implemented GIS system. Figure 1 presents the implemented concept for these procedures (Nejatbakhsh, Saler, Baumeister 2008). The quality of the user interface (UI) has a great bearing on the utility of a GIS. Thus, the UI is one of the strong points of GIS. To increase the efficiency of GIS the UI must provide a simple conceptual model of what is happening to the database (Collins et al. 1983). It must be easy to learn, appear natural,

and independent of implementation complexities such as data structures and algorithms.

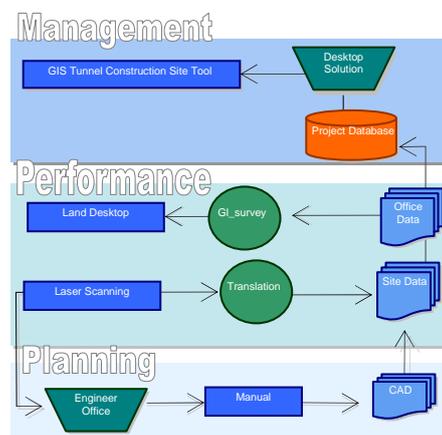


Figure 1. Concept of tunnel construction sites management

In order to do this, one should program the UI to appear as a system for its users, and not as various collections of data (Driver & Liles 1983). GIS software and application program designers can benefit from graphical representations as well as non-programming users. Programmers can interact with GUI representations of their data structures to gain better understanding of the algorithmic processing of their data (Myers 1983; Boecker & Nieper 1985; Boecker, Fisher & Nieper 1986). Such interfaces help both beginning and expert programmers to visualize what a program does and how it

works. This supports code writing, testing, and debugging. GUI representations of the algorithms applied to these data structures are also of great use. Data flow diagrams are one way of communicating the flow of control through computer programs. These have been automated and animated within GUIs to display the inner workings of programs and are useful as both a software design tool and a documentation device (David P. Lanter, 1991).

2. METHODOLOGY

Programming support in ArcGIS is built on an open structure based upon the DLL technology. With this open structure, one can add his own format support into ArcGIS by creating a customized DLL and plugging it into ArcGIS. When creating a DLL file it will be possible to pass an object from the DLL to ArcMap. To create a custom command in a DLL, an implementation code needs to be written. The developed DLL files within this paper are written in a way to interact directly with ArcGIS. Literally, the author divides the developed tools as control tools and graphical tools.

2.1 Control Tools

Control tools consist of the tools which deal with the application project and the document of an MXD file. Shape file creation and customization, reporting, join or relationship definition and projections are among them.

2.1.1 Define Kilometre Stations: Glsurvey as an ArcGIS based system for tunnel planning can provide wider access to the visualized data via the graphic environment and allow greater integration of datasets developed over the course of the project. However due to this fact that glsurvey is newly developed some of its functionalities are weak to operate; among them, point series selection in integration with ArcGIS. It causes the author to develop the tools in an alternative way meaning to develop a framework that suites the immediate results of the point feature export of the glsurvey and provides a base for an optimum adaptation to ArcGIS. Figure 2 shows the interface of this implemented tool.



Figure 2: Implemented UI for Kilometre Stations

As the figure shows there are two main data types to start the project with. First is to work with shape files, if exist, through the button “Add Layer”. This button has a multi use purpose and can be used to load shapefiles as well as raster dataset and CAD features. Once after loading a shapefile, manager defines the shapefile as tunnel axis points (kilometer stations); he will be provided with a function to create tunnel axis line out of the

points and save the lines in a new shapefile as line feature class. It is because glsurvey does not support line feature class and the manager has to define the tunnel axis through the commands. As mentioned above, it is not yet possible to transfer or access defined series of points through GIS integration of glsurvey. It means GIS integration of glsurvey can either transfer all of the point features departing from their type and concept, or just manually selected features. Although this is possible to select point series but not yet implemented to take just the selection into GIS integration. The author does not find transferring all of the points in one layer a scientific solution. Because the foundation of ArcGIS is based on layers; differences in data sets and data concepts is the main reason of layering the data in ArcGIS. That is why the author prefers to transfer the data via exporting tables. If this concept would be invoked later on in development steps of the glsurvey system, it will be possible to use “Add Layer” button as an integrated functionality between GIS and glsurvey. If the shapefile does not exist, the user can load point tables, these tables are exported from glsurvey. As export tool of glsurvey seems to be in its most complete phase, the export process is done seamless with all the required attributes. The coordinates of the points are the attributes which enable the user to create point features out of the table and ensures possibility of creating a 3D model of the tunnel later on. In contribution to glsurvey, this tool uses the same definition for tunnel kilometer station visualization as glsurvey.

2.1.2 Set Relationships: Association between tables in ArcGIS can be made if the tables share a field that contains common values. It is rarely possible in a tunnel project to save all the attributes in one table. Different data from different sources but always are sharing a common field. For example soil prototype table as a polygon dataset can be joined to kilometer stations table as a point dataset to define the soil properties at each kilometer stations. One should know which fields from which tables can carry this relationship or joint. Also cardinality of a relationship should be known. Supported cardinalities by ArcGIS are one-to-one, one-to-many and many-to-many. It defines singularity or plurality of the records of primary key from primary layer (source class) and foreign key from foreign layer (destination class) which are appended. If the relationship is one-to-one or many-to-one, the tables should be associated using a “join”. In other cases tables should be appended using a “relate”. Once two datasets are connected to each other, each record will attain in all the operations with its corresponding or associated records. For example reporting at a defined kilometer station will give all the appended attributes and properties as well. This can involve physically moving related features, deleting related objects, or updating an attribute. For example, one could set up a relationship such that whenever you move a utility pole, attached transformers and other equipment move with it. Mentionable that ArcGIS supports the predefined relationships in any database supporting software (e.g., MS-Access) as well. Relationship classes help enforce referential integrity. They facilitate editing, helping managers lower maintenance costs; by providing automatic updates to related objects, a relationship class can save the user from performing additional edit operations. Because relationship classes are stored in the geodatabase, they can be managed with versions. Versions allow multiple users to edit the features or records in a relationship at the same time. As table 1 shows, axis points table “achspunkte-pnt” is related to the timing table through the kilometer stations.

KM_STATION	SEITL_ABS	DH
43071	0,000	---
43061	0,000	---
43051	0,000	---
43041	0,000	---
43031	0,000	---

DATUM	K_TMHUL	KALOTTE
25.02.2003	151	43053
26.02.2003	155	43049
27.02.2003	159	43045
28.02.2003	164	43041
01.03.2003	168	43037

Table 1: Relationship between two tables

2.1.3 Reporting: For managers, reporting tools are among the most common ways of recording, saving, and archiving the necessary formatted information of a project. Portable Document Format (PDF) allows capturing and viewing robust information—from any application, on any computer system—and sharing it with anyone around the world. Furthermore the solid format of a PDF file which makes it not deformable gives a better storing tool. Multiple platform of this format, extensibility, trust and reliability, maintaining information integrity regardless of the application used to create them, high security, Search ability, accessibility, and lots of other advantages of this format makes a PDF file the best archive for reports and information.

2.2 Projection Tools

Map projection utilities are much more robust in ArcGIS than in older ESRI GIS tools. First among these changes is the ability to project layers with different projections into a single projection. There are also better, more intuitive tools that allow the user to find the correct projection, rather than recall the complex array of parameters appropriate to all projections. Defining the projection for a data set is a very important part of working in ArcGIS. Although it is possible to work with data that has an undefined projection, it is not possible to properly overlay data from different projections without first defining a projection. Additionally, certain analysis tools can be inaccurate with data that does not have a projection defined. Because *gl_survey* works under ArcGIS, it applies and uses the supporting coordinate systems of ArcGIS. Therefore, once transferring the data from *gl_survey*, the projection will be carried as well. But still there are some data sources which have no defined projection system; among them CAD files, which are coordinate dependent but not necessarily fitted into a projection system. Some raster datasets don't have projection as well; they will be placed at the principle point of the ArcGIS after loading. The define projection or change projection tools of ArcGIS as well as geocoding or rectifying possibilities assist the user in overlaying the datasets. Once creating a new shape file out of tables or other coverage, it is also essential to define the projection of the new file in such a way that is overlays other data sets. For this purpose one can import the projection from any other corresponding data set or define a projection. Defining a projection is different from projecting data. Defining a projection simply attaches the information ArcGIS needs to properly display and geoprocess the data. Defining a projection for a data set does NOT modify the coordinates of the data.

2.2.1 Not Projected Vector Data: Here the main focus of vector data is on CAD files. Best practices for CAD interoperability can take many forms since the use of CAD and GIS data can be very diverse. When CAD files are added to ArcMap they are not necessarily in the same coordinate space as the rest of the data being used. There are three methods to transform CAD data in ArcMap: Transform By World File; Transform By Coordinates; and Transform By Rotate, Scale, and Translate. It is a fact that it is always better (although not required) to include a coordinate projection file with the CAD drawings to define where on the world the project is. If the CAD file is not having the projection information, a message telling that the data has an unknown spatial reference will appear.

Besides that ArcGIS won't know what to do with your CAD data if it is added or copied to a map frame with a different coordinate projection. ArcGIS will use the coordinates in the drawing unmodified unless you give it more information about where on the globe the data belongs. Another file that can be included with a CAD drawing to solve this problem is called an ESRI world file. It works as the Transformation tab on the Properties dialog of the layer can be used to add transformation information. This file is an ASCII file of two sets of coordinates that define a coordinate transformation. The file contains two base points and two target points. Target points are base points' corresponding points in the CAD system with local coordinates. If a world file exists in the same directory with the same name as the drawing with a ".wld" file extension, the four points in the world file will be used to calculate new coordinates for the drawing. With these four points there is enough information to define a "MOVE", "SCALE" and "ROTATE" transformation. When data is created in page units or some local coordinate system the world file can be used to push the CAD data into its proper position. If the drawings that are all oriented correctly one to another are drawn in a local coordinate system, using for example an origin coordinate (0, 0) at the corner of some buildings, one can create an ESRI world file that defines the proper geographic location of that building corner (0, 0) and one other point on the map and then include what the proper coordinates should be. By also including a projection file properly named for the CAD files, ArcGIS would have a complete and accurate spatial reference for the data in each CAD file even though the data was drawn in a local coordinate system. Out of creating a world file for the CAD drawings would be to use the CAD program to MOVE, SCALE and ROTATE the drawing contents into the proper coordinates space so that the ESRI world file would not be needed. World files are for people who don't have or know how to use their CAD program. This concept can be implemented also through a line to line transformation. If one line of a CAD file corresponds to a line of the SHP file, there will be two pairs of coordination provided, through which scale, shift and rotation of the CAD file can be computed. In this concept, kilometer stations of a tunnel project or a short section of the tunnel axis may be of the use, shown in figure 3.

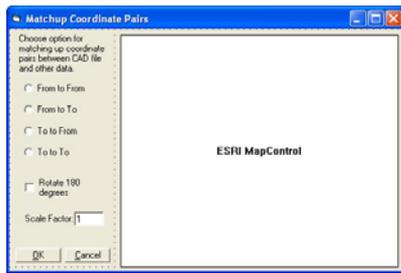


Figure 3: Interface of transformation tool of a CAD layer (source: ESRI Develop Kit)

2.2.2 Not Projected Raster Data: Frequently digital geographic data are acquired by scanning aerial photographs or satellite images. Once the data are input they need to be assigned their proper map coordinates so that they will occupy a real world space. Georeferencing defines the location of a dataset using known map coordinates and assigns it a coordinate system. This allows for the dataset to be viewed, queried, and analyzed with other geographic data. Typically in a GIS environment such as ArcMap, raster datasets (such as images) are georeferenced using a control layer.

This layer contains known coordinates and is used as a point of reference for the georeferencing process. ArcMap allows the user to either georeference an image using ground control points, or to georeference one image to another. There are two main georeferencing methods in ArcMap; transformation (a temporary georeferencing, good only for the current session) and rectification (a permanent georeferencing that creates a new, georeferenced image) to finalize a georeferencing process. In the framework of a tunnel project, the best is to use the concept of the control points. Fix points of a tunnel project which start rout planning of the tunnel are the best control points with the most robust coordinates. These point pairs, in nowadays photogrammetry and remote sensing methods are called ground control points and are supposed to be identifiable in any satellite image clearly. It is enough to create a text file and collect all the Ground Control Points (GCPs) in the text file with their local coordinates on the image and their universal coordinates on the ArcGIS map. It will be then possible in ArcGIS to load the GCP text file for georeferencing purpose. Georeferencing should be finalized afterward to be permanent. For a normal georeferencing, at least two pairs of coordinates are needed; more points will help in higher accuracy and better precision.

Link	X source	Y source	X map	Y map
1 (Fix point)
	(from image)	(from image)	(from coordinates table)	(from coordinates table)
2 (Fix point)
	(from image)	(from image)	(from coordinates table)	(from coordinates table)

Table 2: The structure of a GCP text file

2.3 Graphical Tools

All the tools which deal with the graphical environment of ArcGIS are classified in this set category. Such elements are just for design and view and they don't have any attribute. They are used mostly for visualization purposes. Although they carry their geometry, position, colour and size but they don't have geographic entity. Project status as a graphical band to demonstrate the progress of the project phases up to a defined date (current date as default) and drawing and creating vertical sections of the tunnel in 2D or 3D format are the implemented graphical applications in this research.

2.3.1 Project Progress and Timing: As mentioned before, it is always important for the manager to know which step his project is currently running. In another word, after planning it is necessary to define either if the project is getting performed according to the time plan or not.

Tracking phase after planning informs the manager of delays, lacks, and progressives. The current status as a feed back to the project enables the manager to update the shortcomings and compensate the losses on time. For this purpose a tracking tool has been implemented within this paper which demonstrates the status of the project in different construction phases. The tool applies the date information of the timing table on the tunnel axis and presents the result in a graphical representation. Figure below shows the interface of this tool. Timing table is a table which defines which phases are under construction on each date. The construction phases' status is defined in this table through the kilometre stations.

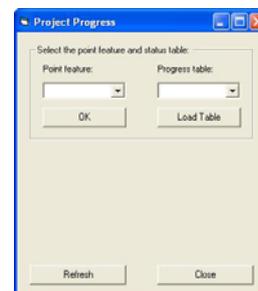


Figure 4: Implemented UI for visualising the project progress

The application will find the records which belong to the dates before today and will read in the latest kilometre stations. Then the kilometre stations less than this will be added to a collection of points. This collection will build the polyline of the progress. The visualization will set the color, thickness and position of the progress line. Figure 5 shows the flow diagram of this algorithm.

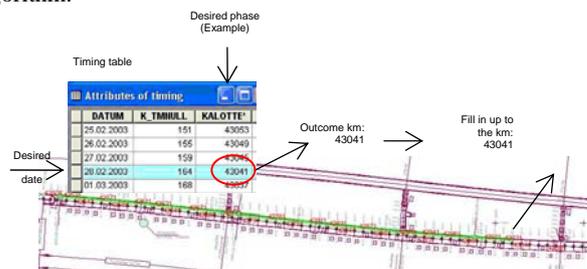


Figure 5: Application of the Project Progress Visualization

Figure 6 shows the application of this interface, providing transparent colors for a better view, an informative legend and the last update of the progress table.

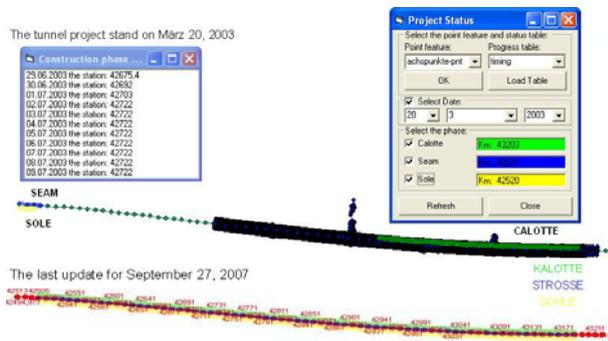


Figure 6: Application of project progress tool for a date during the construction and for an actual stand

2.3.2 Profiling: Profiling a tunnel in different phases gives a check and control on cutting, filling, concreting operations, digging and sabotage. So that always the manager can re-operate the phases in a proper way.

2D and 3D profiling provides a multi dimensional prospect to the construction. As drawing the profile for the whole structure will provide extra information which disturbs optimum data derivation from the profile, the author finds profiling between kilometre-stations a good solution to prevent any interruption or ambiguity and to avoid confusion in such a way that the developed tool applies the selection of the user for profiling and draws the profile just between the selected kilometre-stations with a 3D view. If the manager would like to have the vertical section of the tunnel just at a certain kilometre-station, he will get a 2D view of the profile.

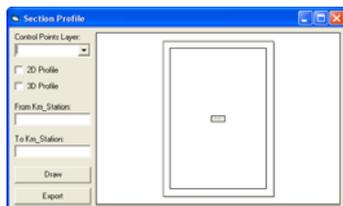


Figure 7: Implemented user interface for profiling

Profiling can be divided into two main types of profiling: 2D and 3D. The system recognizes itself which one to perform. If the manager chooses a line to observe the tunnel profile along the line, the system performs a 3D profiling, and in the case that the manager selects a kilometer station to check the profiling at that station, the system provides a 2D view. Profiling mainly is based on concreting observation points. Otherwise, the information would not be demonstrated in detail and the manager won't be informed about the problems. Gl_survey has also profiling option but as explained, profiling of the gl_survey demonstrates 5 or 6 main points which are not rational enough for a decision making. Figure 8 shows the profiling in gl_survey and compares the graphics with the enhanced and developed profiling function of the Tunnel Construction Site Tools in figure 9. Figure 9-a and 9-b demonstrate 2D and 3D representations of the tunnel at or along the kilometer stations. As it is comparable in the figures 9 and 10, the produced

profiles of the Tunnel Construction Sites Tool (TCST) is much detailed and better visualized. Still it is not yet programmed to have a base profile to compare the current situation.

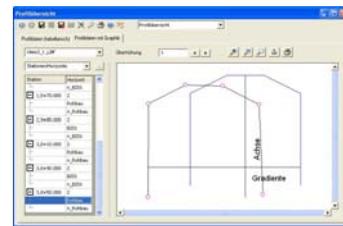


Figure 8: Profiling tool of the gl_survey

Due to this fact that a profile in gl_survey is drawn through its main 5 or 6 points, the visualization is not matching to the reality and the numerical compare will be performable at defined edge points and no detailed information are visualized. A combination of the numerical advantages of gl_survey profiling tool and TCSM tool will give the best solution for this purpose which is under development in future works. The programmed export procedure will give one this possibility to export the existing layout to keep or archive the file.

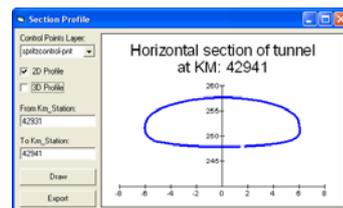


Figure 9-a: Application of profiling tool of the tunnel project, 2D

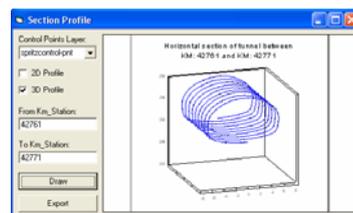


Figure 9-b: Application of profiling tool of the tunnel project, 3D

Finally, the programmed export procedure will give one this possibility to export the existing layout to keep or archive the file.

3. CONCLUSION

3.1 Conclusion

As mentioned before, current attentions to decision making assessment in the construction area has focused on the use of "Desktop methods" which function for individual phenomena. Tunnel Construction Site Tool is a task-based decision support system, which operates as a tempo-spatial analysis tool to aid the managers in management process. Pointing at the fact that

most of the construction sites are remote from home office and different construction phases are planned in various offices which cause non-continuity and data divergence, Tunnel Construction Site Tool's benefiting the data integrity of ArcGIS provides a linking net among the different data types. The integration between CAD platforms and GIS shape files was successful in performing the optimization in decision making process: Overall, the integrated system managed to benefit from the planning capabilities of gl_survey and at the same time utilize the powerful graphical capabilities of both GIS and CAD systems. The suggested solution for performing the dynamic construction site management overcomes the shortcomings; as temporal visualization currently draws upon the animation technology of multiple snap shots recorded in sequence and replayed to create an impression of motion, graphical and animation and visual tools of Tunnel Construction Site Tool benefiting the recent advances in GIS's capability to develop and implement dynamic models offers an opportunity for formulating a GIS representation of tunnel and progress of the project in a manner that was not feasible using the geo-relational data model. Thus, Tunnel CS Tool can be satisfactorily used to solve the tunnel construction site management problem: When tested with an actual case study the graphical environment helped an optimum decision making. Run times are feasible and reasonable compared to other decision support tools taking into account the iterative dynamic optimization approach used.

3.2 Future Studies

1. Complete the under running system with more functionalities and more integration:

Assigning features and time based operation solely neglects other secondary objectives such as transportation & relocation around the site. Thus, a comprehensive multi-objective functionality should be formulated that takes all influencing factors into consideration according to their relative importance.

2. Provide the system with a higher temporal identification module:

This module will apply the changes inside the project simultaneously and wont need importing the additional data. This application will be based on gl_survey project related data and will consider the changes of the gl_survey data in the ArcMap project. It provides the system with an online update once the system data base of gl_survey updates and avoids importing and exporting each time the project extend changes.

3. Enhance, generalize and extend the existing system to a management system for any construction site is one of the goals in future researches.

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GEODATA Gesellschaft mbH, *Kronos: Tunnel Information System*, GEODATA, Leoben, Republic of Austria:
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ACKNOWLEDGEMENTS

I am indebted to my supervisor Prof. Dr. Heinz Saler my main supervisor, not only for his generous and insightful advises, help and supervision during this research, but also for the guidance through his lectures. Besides, many thanks are due to "Angermeier Ingenieure" company, for supporting and providing the data and information necessary for this research and its case study.

