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The Application of OLAP Technology in Monitoring Construction Cost

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Abstract
On-line Analytical Processing (OLAP) is a category of software technology that allows users to gain insight into data, through a variety of possible reports and queries. Information is transformed from raw data to portray the real dimensionality of either a project or an enterprise as understood by the user. Key benefits of the use of this technology are: faster query performance, more powerful data analysis than traditional reporting tools and the ability to provide a multidimensional conceptual view of data. This paper presents an approach to monitoring construction cost with OLAP technology. Practical examples are derived from the monitoring and controlling systems that are applied in the construction of the Egnatia Motorway, one of the most significant infrastructure projects currently under construction in Europe, with a total length of 680 km and a total cost of works of 5 € bn.

Keywords
OLAP, Construction Cost, Project Controls, Motorways, Data Warehousing.

1. OLAP Technology

1.1 Introduction
The term On-Line Analytical Processing (OLAP) dates back to 1993 when it was introduced by E.F. Codd, the father of relational databases. Since then, many new acronyms have been used for specific applications such as ROLAP (Relational OLAP), MOLAP (Multidimensional OLAP) and HOLAP (Hybrid OLAP). On-line Analytical Processing is a way to organize large corporations' data in order to analyze and manage it with less time and effort and to create improved reports. OLAP analysis has several applications in areas such as sales analysis and marketing, data consolidation and decision support systems.

Originally 12 OLAP rules were defined to characterize this technology which are as follows: 1. Multidimensional model, 2. Transparency of the server, 3. Accessibility, 4. Stable access performance, 5. Client server architecture, 6. Generic dimensionality, 7. Management of data sparsity, 8. Multi-user support, 9. Unrestricted cross-dimensional operations, 10. Intuitive data manipulation, 11. Flexible Reporting, and 12. Multiple dimensions and aggregation levels. However, another definition was first used in 1995 which is much simpler and describes OLAP as Fast Analysis of Shared Multidimensional Information – or FASMI (Pendse, 2004).

FAST means that the system can deliver answers to most questions within 5 seconds, with the simplest analysis taking no more than one second and very few taking more than 20 seconds. *ANALYSIS* means that the system can cope with any business logic and statistical analysis that is relevant for the application and the user and keep it easy enough for the target user. Thus, all the required analysis functionality must be provided in an intuitive manner for the target users. This could include specific features like time series analysis, cost allocations, currency translation, goal seeking, ad hoc multidimensional structural changes, non-procedural modeling, exception alerting, data mining and other application dependent features. *SHARED* means that the system implements all the requirements for confidentiality and data security in a multi-user and multiple-update environment. *MULTIDIMENSIONAL* means that the system provides a multidimensional conceptual view of the data that includes full support for hierarchies and multiple hierarchies, which is the best way to analyze projects and organizations. *INFORMATION* refers to all the primary and derived data that is needed.

1.2 OLAP Functionalities

Of all the characteristics of OLAP technology the most important feature is multi-dimensional data analysis and all the functionalities that stem from it. When analyzing data, it is possible to find some properties that are called measures, which define a property that can be summarized. Each measure can have one to several million values, all values being of the same data type. When analyzing construction cost the most intrinsic measures are quantities or cost of utilized resources. A dimension is a list of data that is of the similar type in the user's perception and it may contain from two to a maximum of several thousand positions and have several sets of levels. The most commonly used dimension is time and its levels can be year, quarter, month and day. Data that are modeled with dimension properties and measures are called multi-dimensional data. The generalization of tabulated data from a two dimensional table into n–dimensions is called a n-dimensional cube or hypercube and for this reason OLAP databases are very commonly called cubes because they combine several dimensions such as time, geography and product properties. For a cube with n-dimensions there are 2_n groupings of the stored data. OLAP tools that are applied on multi-dimensional data can assist managers and analysts in seeing data in different ways, thus gaining better insight into the organization or a project through a series of functionalities: *Roll-up* being the movement from a detailed view to more summarized view whereas *drill-down* being the movement from a summarized view to a more detailed view. *Slicing* being the procedure of creating a subset of the multi-dimensional data by keeping many values of dimensions of the cube constant. Usually, cubes are sliced to provide a two dimensional view to the end-user. Finally, *Rotation* being the process of changing rows and columns of a report. This can be done by moving one of the row dimensions to the column dimension and vise-versa or by substituting the rows or columns with a dimension that is not in the report (Silberschatz et al, 2002).

2. The Egnatia Motorway and its Monitoring Scope

The Egnatia Motorway is a 680 km long motorway, located on the northern part of Greece, stretching form the eastern border of Greece with Turkey to the western gateway port of Igoumentista to Italy. It is part of the Trans-European Transport Network and is one of the fourteen priority projects of the European Union. It acts as a collector route of the Pan European Corridors IV (Vienna – Thessaloniki), IX (Helsinki – Alexandroupolis) and X (Berlin – Thessaloniki). Financing is secured by national and community resources, i.e. the European Regional Development Fund, the Cohesion Fund, the European Investment Bank and the Community Budget of the Trans-European Transport Network.

From the very beginning of the project, the management realized the importance of establishing sophisticated project monitoring systems in order to facilitate the best possible control of the project. These systems have covered several business operations such as Scheduling and Cost Control, Document Control, Geographical Information Systems, Contract Funding, Accounting Systems and Human Resource Management.

In particular, monitoring and controlling time and cost overruns on a project like the Egnatia Motorway is a very challenging task primarily because of the huge amount of data that needs to be managed and the geographical dispersion of works. The total budget of the construction works amounts to 5 € bn (with VAT) and is realized by approximately 150 contractors, which are located over an area of 680 km, making data integration very challenging. Furthermore, monitoring is even more complicated by the fact that in some cases multiple specialized contractors realize work in the same areas.

For several reasons it has been decided that the majority of construction contracts will be tendered based on bill of quantities as opposed to lump sum. For this reason, a detailed descriptive price list has been prepared containing over 900 items. This price list makes it possible to apply a common pricing policy on all contracts and to define a reference point so that all designers pre-measure works in the same manner. On average, every large construction contract uses approximately 200-300 items from this list. Taking into account the scale of the project it becomes apparent that a very large allocation exercise needs to be undertaken under which price list items are assigned to activities. Following the initial estimations, quantity allocations need to be reassessed according to the physical progress of works and contractual changes that may arise from unforeseen conditions such as adverse geotechnical conditions, landslides, archaeological findings, force majeure etc. Finally, a key challenge is to implement a unified - monitoring system that collects data from the lowest level, that of the work item, and rolls it up through several management levels i.e. quantity surveyors, construction supervisors, the Managing Service, the Superior Authority and finally the Board of Directors (Maravas et al, 2004).

3. OLAP Applications

The application of OLAP Technology in monitoring construction cost can be implemented either at the project level, the enterprise level or in cooperation with a data warehouse.

3.1 Applying OLAP at the Project Level

Due to the complexity of tracking cost data on such a large project it is interesting to apply OLAP technology at the project level. Cost analysis on the Egnatia Motorway is conducted by breaking down each project into activities through the application of a uniform Work Breakdown Structure (WBS). Resource Assignments is the process of allocating price list items (resources) to activities which represent scopes of work that are organized by the WBS. The whole project of the construction of the 680 km is realized by a series of smaller projects. Thus, an average single project of the Motorway which refers to approximately 20 km may cost 100 mil. €. At a two-dimensional level, the resource assignment spreadsheet could consist of a table with 250 rows (resources) and up to 400 columns (scopes of work). However, since a project may last 4 to 5 years there is also a time dimension. Thus, for a period of 60 months we have a data cube with 250 x 400 x 60 = 6 million cells! The potential number of cells are not all filled since some dimensions are sparse and others are dense, but still even at three dimensions the vast enormity of the cube indicates the complexity of cost and time management.

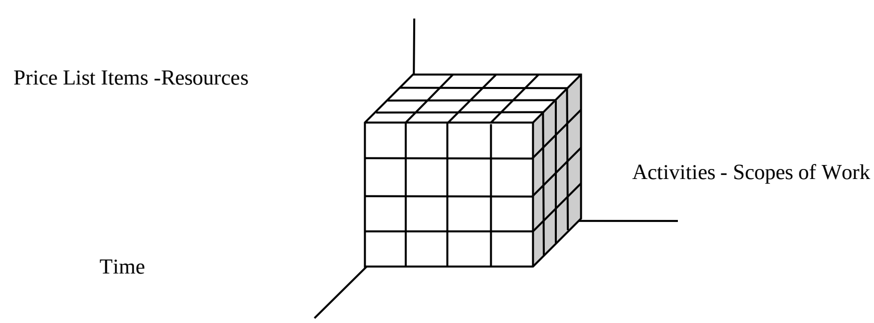

Figure 1. An OLAP cube

In the data cube presented in Figure 1 the positions of the time dimension might be months, days, periods or years. Thus, quantities and costs can be analyzed at several hierarchies of the time dimension. Resources also have several hierarchical levels which may be referred to as the Resource Breakdown Structure (RBS). In the Egnatia Motorway these are Earthworks, Structures, Pavement, Asphalts, Signage, Electromechanical Works and Greenworks. The hierarchies of the scopes of work Dimension are essentially the WBS levels. On the Egnatia Motorway a multilevel WBS is used with the following characteristics: *Geographical Areas* (a horizontal segmentation of the main axis into 70 distinct areas of monitoring significance), *Construction Units* (the division of a geographical area into Motorway Sections, Junctions and Secondary Road Networks), *Construction Entities* (the division of Construction Units into Roadworks, Tunnels and Bridges) and *Technical Scopes of Work* (the most fundamental level of analysis of an entity i.e. bridge foundations, piers, superstructure, tunnel excavation, lighting, ventilation etc.).

3.2 Applying OLAP at the Organizational Level

As mentioned before, the project is realized through approximately 150 subprojects – contracts. Thus, when viewing the data at the organization level there are more dimensions and hierarchies of the data than those presented previously. The most important of these are Enterprise levels, the Organizational Breakdown Structure, Project Funding, Project Contractors and Project Phase. Due to the geographical dispersion of the project there are several organization levels based on geographical and functional properties. The Enterprise Project Structure on the Egnatia Motorway has three levels: Level 1 - Superior Authority (West, Central and East Region), Level 2 - Managing Service (a set of 5 regional offices), Level 3 - Construction Supervisors. The Organizational Breakdown Structure shows the hierarchy of authority in the project from the Board of Directors to the General Manager, Technical Director, Regional Superintendent, Regional Office Manager, and Construction Supervisors. Since the motorway has multiple funding sources every project has a funding code assigned to it. Thus, it is possible to study the progress of each project and compare its performance in relation to its funding. Since some specialized contractors may be working in different areas of the motorway, it is also feasible to analyze the amounts of work that they are required to perform at several time periods and different locations. Finally, the cost of projects may be grouped according to project phase which is Design – Tender – Construction. This example has illustrated the complexity of the data on a very large project in which the combined analysis of project and enterprise data can produce a multi–dimensional OLAP cube.

3.3 Data warehousing and OLAP

During the construction of the Egnatia Motorway there are offices in many locations that create large amounts of data which is sometimes stored in different corporate databases and schemas. Since decision makers need information from all sources the need for data warehousing often arises. A data warehouse is a warehouse of information that is collected from many heterogeneous sources and is stored under one unified schema in one location. Information stored in data warehouses can be analyzed by OLAP technology enabling users to leverage the stored data for sophisticated data analysis (Chaudhuri and Dayal , 1997).

Up to now, examples have been derived from the Egnatia Motorway cost and time project control monitoring system. Data from this system has shown that although tunnels and bridges comprise 12% of the motorway length they consume 55% of the total cost. Hence, for this and other reasons specialized databases have been developed to study bridges and tunnels in greater detail. The Egnatia Tunnel Information Analysis System (TIAS) and Bridge Management Database are separate databases containing relevant technical data.

TIAS (Tunnel Information Analysis System).

The Egnatia motorway Tunnel Database commonly referred to as TIAS (Tunnel Information Analysis System) has been developed by the cooperation of Egnatia Odos A.E. and The National Technical University of Athens. The development started in Feb. 2004 with a total duration of 2,5 years. The main goal is to conduct research into the reasons affecting tunnel cost by the investigation of the behavior of geo-materials under different conditions and in finding the correlation of tunnel cost with Geotechnical – Geological Conditions and tunnel constructions methods. An example of data stored in the database is tunnel geometric data, geological data, geotechnical data, tunnel excavation methods, fundamental design parameters, temporary support measures, final lining, tunnel portals, rockmass properties (GSI, RMR, Q), drilling data – lab results and measurements from special instruments. As in the Project control database the data stored in the TIAS database can be structured by dimensions.

Egnatia Motorway Bridge Management Database

The Egnatia Motorway Bridge Database has been developed under a research program in conjunction the Hellenic General Secretariat of Research. The main purpose of this program is to study the seismic protection of bridges. To this purpose a database has been developed with data related to bridges and bridge inspections. The main data structures are bridge type, location, structural characteristics (materials – construction method), geometric data (length – width), seismic data, bridge inspections and bridge repairs. The bridge and tunnel databases contain technical data that are not included in the project controls database. With OLAP technology and Data Warehousing, correlations can be made between surveyed construction quantities and bridge and tunnel technical characteristics that hold an intrinsic multi-dimensionality. Reports can be generated giving average costs per bridge type across the motorway such as balanced cantilever, pre-cast pre-stressed beams and traditional scaffolding. Similarly, cost reports can be generated for different tunnel construction methods and rock mass properties. Most importantly, an environment can be created in which the end-user can create ad-hoc queries with great ease and simplicity.

4. Conclusions

The shear volume of data that has to be dealt with during the construction of a mega-project requires the application of sophisticated information technology systems. At the project level OLAP technology provides a robust platform for viewing and analyzing construction cost. At the organizational level OLAP technology provides an unprecedented ability to organize and view data in ways that where not possibly seen before. The application of OLAP is maximized when used in combination with data warehousing, in which cost data from the Project Control Database is analyzed with that from specific technical databases such as Bridges' and Tunnels'. An investment in OLAP technology can reduce report production time, deliver improved accuracy and create reports that where not possible before. Overall, the cooperation of highly skilled Information Technology Experts, Project Control Engineers, Design and Project Managers can yield impressive results and insight into project cost data.

5. References

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