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CONSTRUCTION MANAGEMENT INFORMATION SYSTEMS FOR LINEAR PROJECTS – APPLICATION IN THE GREEK RAILWAY CONSTRUCTION MANAGEMENT COMPANY

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ABSTRACT
ERGOSE S.A., the Greek railway construction management company, implementing a huge program of 5,040 MEURO, is developing an integrated system assisting in the planning, scheduling, monitoring and reporting functions of all non-construction (preparation of designs, procurement and expropriations) and construction (performed by external contractors) activities. The system integrates a commercial package's database with ERGOSE's procedures, other databases and graphical data (maps, photographs etc) in order to produce a multiplicity of graphical and text reports that relate physical constructed objects (e.g. bridges, tunnels etc) to location, time, cost, quality and procedure. It is argued that the delivered system, once completed, will assist drastically ERGOSE in realizing its ambitious program of upgrading and modernizing the Greek railway network for the 21st century.

KEYWORDS
Construction Management, Linear Projects, Railway Construction, MIS, Greece

1. INTRODUCTION

Construction management is an intensive data (information) driven exercise. The entire process or the project management life cycle as described in the Body of Knowledge prepared by the Project Management Institute is based on the accurate and timely gathering and sharing of information. Information is therefore a crucial resource needed to manage other resources (people, materials and equipment). The increased complexity of projects have necessitated the need for the proper dissemination of information at various levels of management. The development and use of management information systems (MIS) is concerned with the perception, recording, processing, transmission, storage, retrieval, presentation and use of appropriate information that will lead to better planning, better decision making and therefore to better results. MIS is one of the top priorities for every organization managing projects (Loo, 2002). A method for the quantification of the benefits from the use of a MIS has been presented by Back and Moreau (2000).

In this paper, we will discuss the development of construction management information systems for linear projects. A "linear project" can be defined as the project in which the majority of activities it entails are "linear". "Linear activities" are those activities that are completed as they progress along a path (Harmelink and Rowings, 1998). Examples of linear projects are the construction of roads, railways, tunnels and pipelines. Linear projects have their own specific information requirements, and characteristics that affect the development of the MIS. Although specific methodologies for the management of linear projects have been developed since the 1940's, the dominance of the Critical Path Method (CPM) in the early 1970s led most managers to select the mainstream CPM (Mattila and

Abraham, 1998). The situation is reversing in recent years, as management methodologies for linear projects are revived in both research and practice (Suhail and Neale, 1994, Arditi and Psarros, 1987, Arditi, 1998, Harmelink and Rowings, 1998, Eldin and Senouci, 2000, Arditi et al 2001, Harmelink, 2001, Yamin and Harmelink, 2001). These "linear methodologies" relate location to some management parameter (e.g. time) to create a graphical representation of the project. Today interactive Geographical Information Systems (GIS) allow the organization and analysis of data that can be referenced spatially and, furthermore, allow the interaction with this data by selecting features and performing actions (e.g. queries). GIS have found their way to construction engineering applications (Miles and Ho, 1999).

Clearly there seems to be an interesting opportunity to combine "linear methodologies" with GIS and modern computer technology (powerful computers, commercial project management software, databases, reporting tools etc) in order to develop a construction management information system. In addition, to this opportunity, there was a real-world requirement to produce a construction MIS for ERGOSE S.A., the Greek railway construction management company, who is responsible for the construction and upgrade of the Greek railway network. This is the stimulus for this work; and this stimulus has led to the formulation of a construction management information system proposal which is the subject of this paper.

2. BACKGROUND

Greece is a European country participating fully in the European Union (EU) and the European Monetary Union. ERGA OSE S.A. (ERGOSE for short) is the company formed in 1997 to take over the management of the Greek Railways Investment Programme, and in particular to manage the projects co-funded by European Union's funds. ERGOSE is affiliated to the Greek Railway Organisation (OSE in Greek) in that the latter is the sole share holder of the former.

The aims of the Greek Railways Investment Programme are fully in line with the European Union transport policy as expressed in the White Bible for transport issued by the EU in 1993 in which the development of the European Railways is given high priority. All the projects of the Programme will become part of the trans-European networks of high speed railways, combined transports and conventional trains.

As a result, the European funds contribution to the realisation of the Programme is substantial. The programme is funded by the Community Support Framework (CSF), the Cohesion Fund (CF), and the European Regional Development Fund (ERDF)).

A budget of 3,800 MEURO has been approved for the period 2000-2006 by the 3rd Community Support Framework (3rd CSF) and an additional budget of 1,240 MEURO by the 2nd Cohesion Fund (2nd CF) giving a total of 5,040 MEURO. The project, which is the largest in terms of budget single construction project in Greece today, is expected to be completed by 2008. It entails the upgrade of the basic railway network backbone (approx. 700 Km) to achieve speeds of 200 Km/hour and the refurbishment of the secondary lines (approx. 600 Km) to assist urban development. Electrification of the basic backbone and telecommunications and signalling for the greatest part of the network is also envisaged.

From its initial setup of ERGOSE (1997) assisted by an external specialized international consulting firm attempted to achieve effective operation, and the transfer of know-how to the company's personnel. The approach followed was based on critical path methodologies, on well established commercial software products (Primavera, Excel and a suite of specialized construction management programs (e.g. for the preparation of tender documents), and databanks (e.g. legislation)).

Three years later, the above arrangement proved inefficient. A number of problems were identified:

- Information was dispersed within the company in various organizational units (in different formats, and, in some cases, of questionable integrity and accuracy).
- Reports prepared (based on CPM) were too complex to follow, a fact, which led to growing dissatisfaction both internally and externally.
- A lot of manual work was needed for the preparation of non-standard reports requested either internally or externally.
- Decision-making had to be based on incomplete and, thus, error-prone data.

- Problems manifested themselves first and then corrective action was taken; there was limited feed-forward control to envisage problems before they arise.
- Document management was paper based a fact which coupled with the big volume of documents (drawing, contractual documents, correspondence etc) led to ineffective operation.

There was clearly a need to attempt to develop an integrated construction management information system, which coupled with a change in procedures, and standardization of information flows was expected to assist drastically in the prompt realization of the project.

3. METHOD

For the development of the new MIS a task force consisting of the decision makers from all appropriate areas of the company and external experts was assembled. The goal of this task force was to harmonize, integrate and standardize the data collected and the information disseminated both internally and externally. More precisely the goal of the task force was divided into a number of targets:

- To design and implement a company-wide database incorporating and integrating all existing "islands" of data and serving all necessary managerial requirements. The database should address the issues of data ownership, responsibility, access and availability (commercial database software provides the necessary functionality).
- To evaluate, select and standardize the project management methodologies and tools used.
- To model and manage the information flows inside and outside the company.
- To design a set standard reports to be produced by the information system serving the requirements of all possible recipients.
- To develop and manage an information technology strategy for the company in order to secure the investment (Aouad et al., 1999).

It was agreed that work of the task force should entail:

- The comprehension of the problems that should be tackled and the identification of success criteria, assumptions, risks and obstacles.
- The development of a detailed project proposal (including critical assessment of the tools, methodologies, procedures and data currently in use, the reviewing of current technological opportunities (both in software/hardware and systems analysis and design), the change management and the estimation of resources needed)
- The execution of the project proposal (including monitoring and control).
- The evaluation of the work performed, the documentation of the lessons learned and the recommendations for future work.

In order to produce the system, a number of systems analysis and design techniques were used. These, briefly, were:

- <u>For the description of the "logic" of the system</u>. This part is concerned with the analysis of the information needs and the design and documentation of the various logical processes involved in the implementation of the MIS and the way they relate to each other and to the data files of the system. Critical Success Factor (CSF) analysis was used to effectively define the information needs of managers (whose support was crucial for the success of the MIS development) (Rockard, 1979). To design and document the inter-dependencies between processes and data files, Data Flow Diagrams (DFD's) were used. The technique is well known to the industry, simple and justified (Austin et al., 1994, Hassan, 1996, Baldwin at al. 1999). Also to identify loops or iterative tasks the Design Structure Matrix (DSM) (Steward, 1981) was used. To represent the relationship between business functions and data the Integration Effectiveness Matrix (IEM) analysis was adopted (Jung et al., 1999). Finally, to document the reporting requirements of the system the prioritized schedule of construction information needs was followed (Tenah, 1986).
- <u>For the description of the "logic" of the system data</u>. This deals with the entities of the system and the ways they associate to each other. Entity-Relationship modeling (Chen, 1976) was used.
- <u>For the design of the databases of the system</u>, also known as "normalization" the synthetic approach to database design (Yang, 1986) and non-commercial software produced by the author (Pantouvakis, 1990) was used.

- For the collection of data questionnaires (including tables), structured interviews and informal working meetings were used.

It should be noted that no attempt was made to suggest new fundamental information system frameworks or approaches. More specifically:

- The available product models (such as GARM, PISA, IRMA, ATLAS, RATAS, OPIS, COMBINE, OSCON, STEP, and EPISTLE) have not reached the maturity, acceptance and relevance required to be followed in a real world railway construction project. Further justification can be found in Tolman (1999). The development of a unified information resource was sought in the development of a new common spatial framework. It was recognized from the outset that this approach introduces organizational impacts and requires significant restructuring and rebuilding of existing databases. Top management support and key personnel consensus was secured from the outset.
- Object technologies, although relevant and useful (see for example Karim and Adeli, 1999) required considerable investment in database systems and software tools whereas relational technology was already available and was used by the project management software packages in operation within the company. Also, there is a clear indication that relational technology was selected in addressing real-world problems of this nature (see for example Rasdorf et al, 2000). Furthermore, studies related to current practices and problems faced in similar organizations (White and Fortune, 2002, Wilkinson, 2001) and technologies used (Liberatore et al., 2001) do not contradict with the application of relational principles.

Part of this research was devoted to identify those information system issues present in construction management data that significantly complicate the information system design, development, management and use process. The spatial component of data is a unique and critical integrator for management (see below – system design).

For the purposes of this effort the following MIS description was adopted: MIS is a system using formalized procedures at all levels in all functions with appropriate information based on data from both internal and external sources, to enable managers to make timely and effective decisions for planning, directing and controlling the activities for which they are responsible (Argyris, 1991). A successful MIS must be designed and operated with due regard to organizational and behavioral principles as well as technical factors. Management rarely observe operations directly; they attempt to make decisions, plan and control activities using information which they obtain from formal sources (subordinates and/or MIS) and by informal means (conversations, meetings, telephone calls etc.). MIS, therefore, is an accessible and rapid conveyor belt for appropriate high quality information from its generation to its users. A MIS can be manual or computer-based. When computers are used they can be very useful, they are not, however, essential.

4. SYSTEM ANALYSIS

There are four project management units (groups) within ERGOSE's organizational structure:

- Three of them were formed according to the geographical location of the projects (South, Central and North).
- One was formed according to the function of the project (Athens suburban railway).

Each group is assigned with the task to deliver a number of "lines" of a total length ranging from 300 to 700 Km. For example, there are seven lines assigned to the Southern group. Each line is further sub-divided into "sections" (autonomous parts of the line).

In each of the "sections" work (upgrade or new alignement and construction) along a linear path is needed. Three types of activities should be performed for each and every section:

- Surveys & Design
- Expropriation
- Construction.

In turn, construction entails six types of activities:

- Infrastructure (mainly earthmoving operations, supporting walls, tunnels and bridges) and planting
- Superstructure

- Electrification
- Signaling and communications
- Railway station and facilities construction (e.g. freight complexes, warehouses, container terminals, rolling stock repair and maintenance workshops).
- Upgrade activities of existing railway lines (change of ballast and rails, reinforcement of bridges etc.) and railway stations (upgrade of facilities).

Some of the construction activities follow a hard logic (e.g. superstructure can only be constructed after the completion of infrastructure) whereas others follow a soft logic (e.g. electrification and signalling).

From ERGOSE's viewpoint, designers and construction resources are considered to be in abudance, since the work is performed by external contractors.

Two auxiliary management units (groups) were also created to cater for needs not satisfied by the above organization.

- One group was setup for the procurement of materials (sleepers, turnouts, rails, ballast etc.) for the needs of all the projects.
- One group was setup for "sweeper" projects (i.e. ones working in different geographic locations – usually to complete work left behind (for a number of reasons, e.g. disputes) by other contractors) as they are not going to be used for only one location and, therefore, it would be useful to monitor them individually.

There are five types of time and cost reports:

- Master Report (per group)
- Line Report (per section of line)
- Work Package Report (per work package)
- Phase Report (per phase)
- Detailed Report (including summary and detailed activities)

ERGOSE, as the management authority of the project is expected to report on a monthly basis to the Greek Government (Prime Minister's Office, Ministry of National Economy and the Ministry of Transport), the Greek Railway Organisation (OSE) as the sole share-holder (in order to allow OSE to schedule the procurement of the neccessary rolling stock and other materials necessary for the commercial use of the network), and the responsible European bodies (which co-fund the project and supervise the physical and monetary progress). At the same time, ERGOSE should co-ordinate a number of external organisations (designers, contractors, suppliers) and liaise with public organizations (electricity board, water supply board, archaelogy, public funds for the realization of expropriations etc). Finally, ERGOSE should record and transmit information from about sixty geographically dispersed construction sites, disseminiate internally this information to the various managerial levels and be able to mobilize its resources fast to address problems as they arise.

Efficient project management, therefore, should focus on minimizing this variance, an objective which can only be achieved by implementing active and efficient time & cost control, comprising basically of the following elements:

- Collecting and processing available time & cost data to produce a realistic and accurate project schedules so as to substantially decrease the possibility of time and cost variance, which is crucial to the project.
- Monitoring constantly project progress to identify immediately any variance, to analyze it in relation to the project critical path and to initiate corrective measures if possible.
- Preparing time and cost reports for various recipients (ERGOSE, OSE, Ministries, European Union etc.).

The nature of ERGOSE's work is such that "time" must be considered and dealt with in the information management system and in particular in its spatial component. The physical layout of the network ranges from a single line connecting two locations (before the design phase), to a detailed alignment incorporating physical objects (bridges, tunnels etc) (after the design phase). Temporal data therefore is a consideration in the information system design.

In examining time, the project life cycle should be considered. The life cycle of a project in ERGOSE is a four-step process:

Step 1: The Greek Railway Organization (OSE) decides that a particular section (or sections) should be upgraded or constructed. The project is handed over to ERGOSE for construction.

Step 2: ERGOSE describes the technical requirements of the project, schedules and budgets it and applies to the appropriate (Greek and/or European) authorities for funding.

Step 3: Following the acceptance of the proposal by the appropriate authorities, ERGOSE proceeds with the necessary actions to execute the project (i.e. designs, expropriations, material procurement and construction). At frequent intervals ERGOSE is obliged to report to the supervising bodies and authorities to ensure that the work is performed as intended and, in case of difficulties that all necessary actions are taken.

Step 4: The completed project is delivered to OSE for revenue service.

This project life cycle is closely related to the core procedures of the quality system (ISO 9001). More precisely:

- Step 1 is related to 3 core procedures.
- Step 2 is related to 4 core procedures.
- Step 3 is related to 29 core procedures (9 for designs, 4 for material procurement, 12 for construction and 4 for land acquisition)
- Step 4 is related to 2 core procedures.

The above procedures (38 in total) contain forms that document the various stages and describe the necessary workflows.

Finally, an examination of methods revealed that project management units (or groups) used CPM (activity-on-the-node) to report to the company, however, they used type II (time-scaled for planning and monitoring) Gantt charts and "horse blankets" (Barrie and Paulson, 1992) for their internal management purposes. It was decided to produce a mapping between the current CPM system and the simpler graphical methods used by the groups. Also milestone reports (to portray graphically time slippages in different reporting dates) were adopted. This mapping provides also the necessary links between activities and the product model (see next paragraph).

5. SYSTEM DESIGN AND IMPLEMENTATION

The conceptual model of the MIS consists of three inter-related entities (Angelides, 1999): an organization model, a product model and a process model.

- The *organization model* addresses the project organization and controls, such as regulations, contracts and budgets.
- The *product model* uses a linear referencing method (LRM - Scarponcini, 2001) and railway alignment data to relate physical constructed objects (bridges, tunnels, supporting walls, railway stations etc.) to location. For each physical object the bill quantities (taken from the contractual documents) are linked in a similar fashion to business data (or events) links to an LRM. Each bill quantity is further subdivided to resource quantities (e.g. materials) and attached to the model. In this manner events (in our case point (e.g. intersections) or linear type (e.g. tunnels) physical objects) are located using an LRM that is mapped onto a cartographic map (by using a GIS), which is in turn automatically mapped onto "linear diagrams" (offering the same functionality as the X-axis of "horse blankets").
- The *process model* incorporates all the activities (both non-construction (design, expropriation and procurement) and construction) needed to produce the product and all the associated documents. Each activity is linked to the LRM so that questions like "how many sections have completed more that 50% of their design phase" can be answered. In a similar manner, documents are linked to the LRM by using document templates (see Hajjar and AbouRizk, 2000 for further information). In this way questions like "show me all documents related to a particular section" can be addressed.

To implement the conceptual model described above, a number of modules were necessary:

- A cartographic model with the railway alignment implemented on a GIS
- A conversion module, which uses the cartographic model to produce linear diagrams.These linear diagrams consist of different standardized CAD layers depending on the kind of the physical objects depicted.
- A database holding data on the LRM, physical objects, activities (description, dependencies, method of execution, responsibility), quantities, time, cost, procedure, regulations and standards.
- A document management system linked to the database through document templates.

The development of these modules was performed both in-house (collection of data, database design, document templates) and outsourced (GIS, LRM, conversion module). Also, standard commercial packages were used to facilitate development. Although development work is still underway, concrete outcomes have been produced. As an example, a sample report produced by the system is shown as Figure 1.

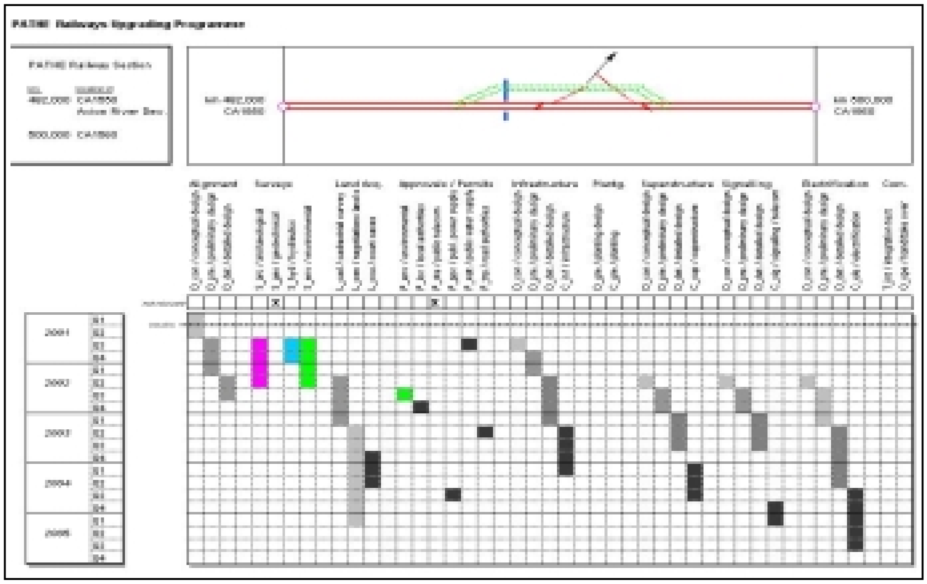

Figure 1: A Sample Time Report for a Section

6. CONCLUSIONS

Construction management information systems play a profound role in the prompt realization of mega projects such as the railway construction and upgrade project described in this paper. The development of such a system, however, is a difficult task that requires considerable effort and investment by the company undertaking the task.

The major difficulty is that of data integration. Unless a standard product model emerges and is supported by the vendors, this problem will continue to require considerable resources. The work presented herein did not attempt to propose new information system approaches; it confined itself to produce a limited applicability construction management model for railway construction projects based on the well-established relational technology principles.

The fact that all data is related to a linear project was taken into account by providing a common way to describe the topology of the project through an LRM. Also, a set of conversion capabilities was described to support data access and report generation (e.g. automatic production of "linear diagrams"). All other model components (organization and processes) were then linked to that topology. It is expected that the delivered system, once completed, will assist drastically ERGOSE in attaining its ambitious targets.

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