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NATURAL STONE EXPLOITATION MANAGEMENT BASED ON PROJECT MANAGEMENT TOOLS AND GIS

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Abstract

An exploitation of natural stone influences social and economic image of a region, so exploitation technology should be accompanied by the development of the management system so as to minimise impact on social, economic, ecological and biological systems. This paper discusses influence factors during the exploitation of natural stone, especially ecological and economic ones. The intention of the presented research is to balance the influence factors thus making the management support system acceptable both economically and ecologically. The proposed methodology combines project management tools, Life Cycle Assessment, Life Cycle Cost as well as Work Breakdown Structure. In order to enhance the management system and bearing in mind that quarry management takes into account lot of spatial data, a GIS-based Management Information System is also proposed. GIS could be used as an excellent data source thus being a basis for a decision making process related to investments and other business issues.

Keywords: quarry management, LCA, LCC, WBS, GIS,

1 INTRODUCTION

A sustainable development concept urges the development of various regulations and tools that are focused on constant improvement of production processes. These regulations and tools are standards of processes. Such group of standards is ISO 14000 standard which implements environmental management paradigm (EM).
A very intense interaction of a quarry with an environment leads to the need of implementation of such standards in the quarry management. A state of the art technology of exploitation of natural stone produces huge amount of the waste-rock, up to the 60 to 90 percent of excavated stone. This is the main problem regarding production, as well as protection of the environment, particularly regarding deterioration of the landscape. Additional negative side effects are: utilisation of vast amount of water, emission of dust and noise.
Because of existing technological limitations related to the vast amount of the waste-rock, it should be treated as secondary raw material. Management of secondary raw material in parallel with an exploitation of natural stone is often neglected although it could reduce a number of openings of technical stone quarries. An optimisation of the

exploitation process is usually preformed through optimisation of quarry development regarding geological as well as other conditions that are variable and should be monitored permanently.
This paper proposes monitoring system through decomposition of a production process into subsystems. Input and output data of such subsystems make a basis for a quarry information system which includes waste-rock subsystem. Integration of databases of a range of quarries enables efficient waste-rock management at different decision levels. Changes of quarry purposes, after its closure, as well as quarry reactivation that are difficult in practice because of either long exploitation life of quarry or possibility to better survey stone reserves face the same problems.
All mentioned obstacles should not burden the company that exploits mineral resources and should not influence its competitiveness on the market. The main idea is to present quarry as a project with complete life-cycle. An application of whole life costing method in the phase of investment decision for planned quarries, or as early as possible for quarries in operation, should enable both recovery and monitoring cost assessment during exploitation and closure procedure. Nature of geo-referenced exploitation objects and necessity to integrate quarry into the environment leads to the application of geographical information systems.
The approach presented in this paper starts with an assumption that quarry management improvement can be achieved by applying sustainable development concept and defining measuring parameters that should be monitored throughout project lifetime.

2 METHODOLOGY

The methodology is based on a combination of project management tools: Life Cycle Assessment (LCA), Life Cycle Cost (LCC) and Work Breakdown Structure (WBS). The procedure follows LCA methodology phases. This is the basis that enables full implementation of LCC economic dimension. WBS structure serves for the definition and monitoring of both LCC and LCA parameters, as well as their integration into relational data base within GIS.
Although each quarry is specific, production process fits into a certain framework. Quarry production process could be presented by sequence of work packages. Decomposition of production process into smaller, manageable pieces, known as Work Breakdown Structure, essentially is a project management tool. Herein, used for decomposition of production system, WBS helps to efficiently determine sub-systems, system borders and system performance. WBS is usually used for systemic recognition and definition of various kinds of tasks (activities, operations, processes) within the project. Even though it does not defines tasks dependencies and durations it defines the structure of the project. Besides planning, WBS structure supports control of activities, resource, responsibilities and helps reporting about system characteristics.
Besides using WBS as an input to another project management tool such as network planning the researches uses it as a framework for control process. Jung and Woo (2004) propose a flexible work breakdown structure for integrated cost and schedule control. They argue that concept of flexible WBS can greatly alleviate problem of increased management efforts required to manipulate detailed data by reducing the number of control accounts.

Life Cycle Assessment (LCA) methodology treats the whole system lifecycle whose phases vary in needs for resources and levels of efforts. LCA consists of the following phases:

- Definition of objectives and working tasks
- Definition of a system, sub-systems, system boundaries, that is definition of functional system units
- Definition of both input and output parameters for sub-systems/functional units as well as for a whole system
- Collection of data about input and output flows [LCI – Life Cycle Inventory]
- Finalisation of modelling process and data analysis [LCIA - Life Cycle Inventory Analysis]

Control of these phases is the basis for quarry management model. LCA analyses material and energy parameters for the purposes of system management which was introduced for profit gaining. Many authors use LCA for estimation of efficiency and environmental impact of different systems. Pehnt (2005) investigates a dynamic approach towards the LCA of renewable energy technologies and proves that for all renewable energy chains, the inputs of finite energy resources and emissions of greenhouse gases are extremely low compared with the conventional system. Emery et al. (2006) uses a life cycle assessment (LCA) computer model for comparison of the environmental impacts of a number of waste management scenarios. An interactive Microsoft excel spreadsheet model was also developed to examine the costs, employment and recovery rates achieved using various waste recovery methods including kerbside recycling and incineration. Treloar et al. (2004) propose a hybrid LCA method that uses input-output data to improve conventional LCA inventories. They demonstrated developed hybrid LCA method on a life-cycle energy study of eight different road designs, including vehicle manufacture, maintenance, replacement, and operation.

It is necessary to introduce economic parameters, as well. That is why proposed methodology implements Life Cycle Cost (LCC) and combines it with WBS and LCA methods. LCC methodology is based on net present value (NPV) method that enables discounting of all investments, costs and revenue during project lifecycle to the beginning of the project. Considering selection of alternative solutions of quarry lifecycle flows, LCC method, by implementing NPV, represents a powerful tool for solving such problem. The alternative that shows the highest value of NPV is considered as the most convenient. There are efforts to use LCC for environmentally influential systems. Glucha and Baumannb (2004) discuss theoretical assumptions and the practical usefulness of the LCC approach in making environmentally responsible investment decisions. They argue about ability of LCC to handle irreversible decisions and to support decision making under uncertainty. Reich (2005) proposes methodology that consists of a financial LCC used in parallel with an LCA as well as an environmental LCC for municipal waste management systems. The financial LCC covers all the costs incurred by the extended waste management system, as though the LCA system was a single economic actor. By the combination of LCA and LCC methods all relevant input and output parameters of the system are comprised.

3 QUARRY MANAGEMENT MODEL

Management is a process based on decision making aiming at fulfilling objectives. Decisions-making environment ranges from extremely structured to unstructured problems. One of the tools that could help decision making process at all management levels is Management Information System (MIS). It is formal computerised system that integrates data from different sources in order to promptly provide information for decision making to a manager (Turban, 1993). As decision levels rise MIS become more inappropriate, but it could transform into other tool for top decision levels such as Executive Information System (EIS).

Dynamism of the quarry system as well as its environment requires constant monitoring and improvement of both system itself and posed objectives. Diagrammatic presentation of a quarry monitoring system as well as its interaction with the environment throughout its lifecycle phases is showed on Figure 1.

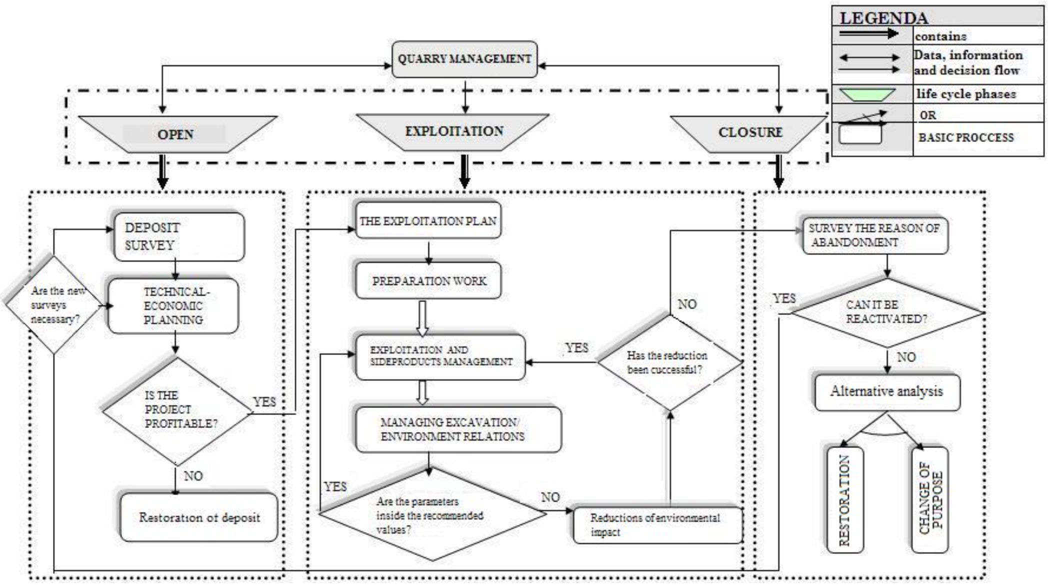

Figure 1: Diagrammatic presentation of a quarry management model in different phases of lifecycle

Presented schemata could be interpreted as a fractal structure, i.e. as cyclic processes at different time scale and values of spatial locations, because all such processes have been repeated during the lifecycle of the quarry. In such way it is possible to test monitoring and rehabilitation methods and to aquatint knowledge in order to improve long-term management.

The main objective of the quarry exploiting natural stone for architectural constructions is to optimise stone blocks of the commercial dimensions. Besides the flow of the blocks through whole system, it is necessary to monitor the flow of the side-products, mainly fragments which are irregular and sub-regular blocks, as well as shapeless smaller blocks. Proposed conceptual model of the quarry system management is showed on the Figure 2. All products and side-products are deposited on the depot, temporary ($t>0$, Figure 2), or permanently ($t \rightarrow \infty$), otherwise they could be sent directly to the market without being deposited ($t=0$).

Most countries introduced taxis for the deposited materials, thus motivate companies to plan management of the secondary raw material emerged from the exploitation. At the same time a long-term planning of the openings of technical quarries are being stimulated. By separation of the fractions manipulation of the depots are easier so the cost are lower. Moreover, by removing of the fractions the manipulation on the depot as well as outside the facility site is easier and less costly. This leads to the need for the depot management system for the both blocks and side-products of the exploitation. Quarries are water consuming production plants, so the possibility for water reuse should be considered as well.

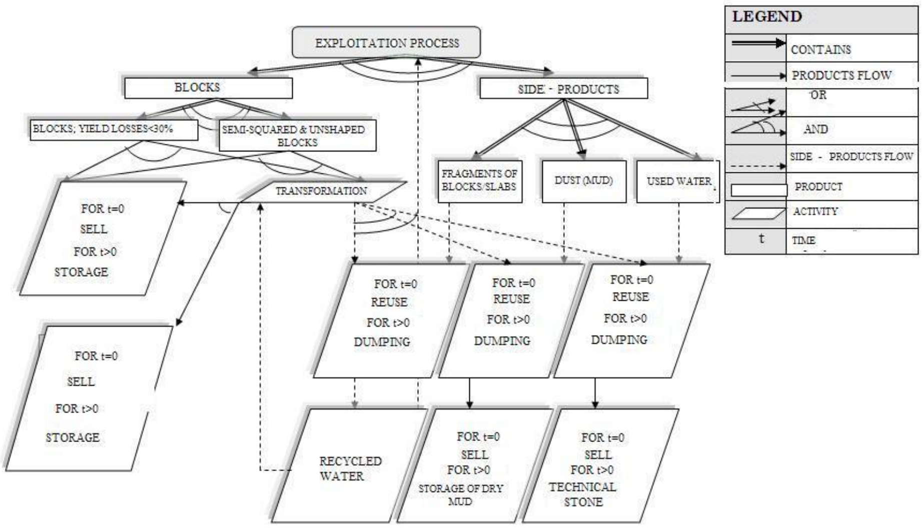

Figure 2: Quarry products during exploitation, processing and rehabilitation

Functioning of the proposed model is possible only by continuous system monitoring. First and very important step is to implement Management Information System based on relational data base.

MIS is organised according to the scheme showed on Figure 3. The data base structure is based on the sustainable management concept that will satisfy both economic and ecological criteria. This could be fulfilled by application of LCA, LCC and WBS tools each of which covers a part of the concept as it is shown on Figure 2.

The proposed system considers following functional parts:

- Data collection
- GIS layers
- Data editing and analysis

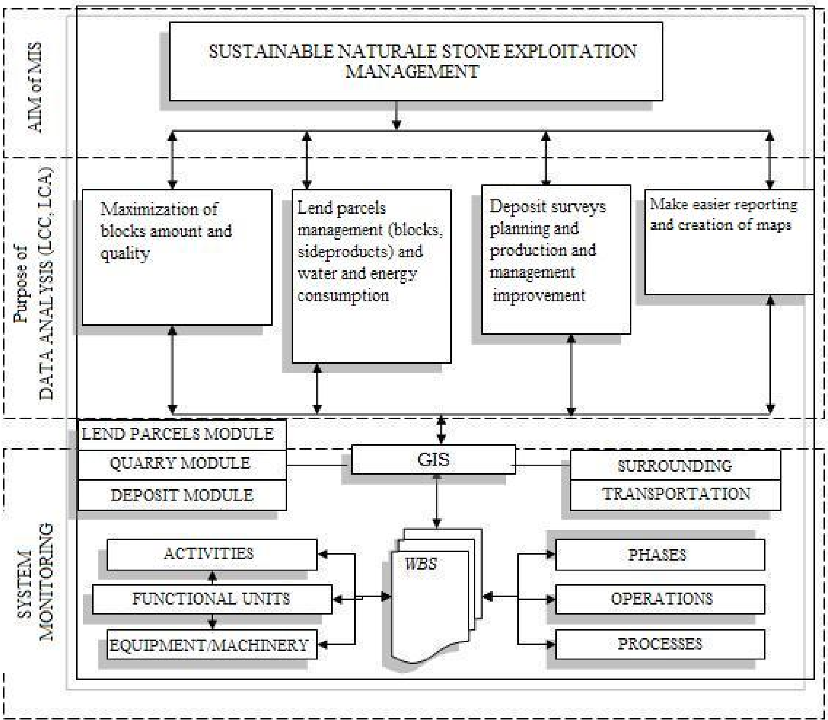

Figure 3: Structure of the Management Information System of the project

The main objective of the system is an exploitation process support. The Figure 3 shows functional parts. Arrows determine information flows through the system. Two-ended arrows should emphasise the fact that data could become management information.
Designing of the management information system is based on modelling of real system so it should follow its rules: data entering the system, sate of the data base is changed via code for updating, and via software for reporting (Plastić, 2006). General architecture of the information systems consists of process model and data model. Process (function) model is a structured set of the processes which change the system state and processes which from output of the system. Processes driven modelling is based on detailed analysis and decomposition of processes (Plastić, 2006) that is implemented by WBS structure. WBS structure is a base framework of the both proposed exploitation management model and data base. Data model is a basic concept for data base system development, because it implements data structure into a certain data base model. Data base model of the proposed information system is realised as a relational data base and implemented into MS Office Access 2003. Central entities and relationships of WBS based data base are shown on Figure 4. The main role of WBS is production decomposition, but regarding data analysis WBS has integration role and it unites all production phases into unique process. It is a backbone of MIS and data base that enables structural process control.

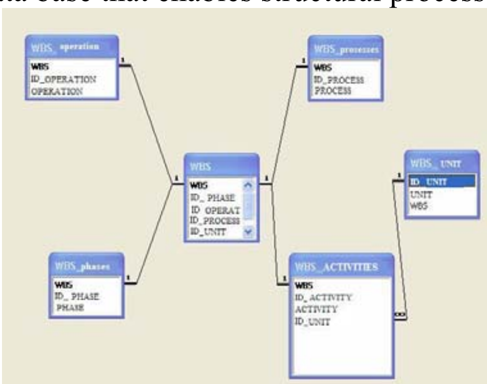

Figure 4: Relationships between basic data base entities

3.1 System monitoring

For the data that describe operations, activities, equipment a WBS structure is used. WBS structure is defined through five levels: phases, operations, processes, activities and basic functional units. Phases of the WBS structure are the phases of the quarry life cycle from the idea, design, production i.e. exploitation to closure and rehabilitation. Logically and organisationally they can be defined differently, but in the most cases the main criterion is successiveness of the phases. In the practice there could be exemptions regarding available staff and mode of the organisation, but in such case operations which are constitutive parts could be defined differently. The main objectives of the WBS are:

- Planning and monitoring of the all sort of costs;
- Planning and controlling of the production system
- Controlling of the quantity and composition of stone waste, air emissions, water as well as depot cost
- Creating and analysing of the environmentally sound alternative solutions
- Definition of the input into information system of the project (company)

WBS can serve for another activities such as planning and control of:

- Duration of tasks and activities
- Efficiency of equipment and plants/facilities, and avoidance of idle status
- Equipment maintenance costs, transportation equipment and plants, administration and management
- Efficiency of labour
- Assignment and control of tasks and responsibilities
- Eventual profit from side products
- Material and energetic input and output data according to the life cycle phases of the project, functional units or other parameters

Functional units are defined in a combination i.e. as processes or plants/facilities or equipment depending on system needs. They are components of WBS but also of LCIA. Each functional unit is described by its technical and economic characteristics. The main objective is responsible environmental management by mutual application of LCA and LCC analysis. A sustainable management concept tries to find a compromise between these two approaches.

LCA method enables choice of both types and quantities of materials, quantities as well as environmentally sound technologies. LCC lifecycle outputs relevant economic parameters that should not be in conflict with previously mentioned demands. LCC analysis gives both total and types of costs for each phase, process or functional unit, as well as for a whole lifecycle.

3.2 Architecture of the Geographic Information System

Data obtained in accordance to the initial MIS structure (Figure 3) are being classified aiming at obtaining an organised structure of GIS, thus making easier updating procedures. Choosing GIS as a main information system can be very useful for distance analysis of the markets, transportation costs, as well as for the remote monitoring of quarries and depots with GPS devices.

The management approach presented in this paper is possible to apply to the middle and top decision and management levels, as a support for tactical and strategic decisions. It can serve as a support for both short and long term planning of management of natural resources as well as support for local authorities.

Possible application is in coordination of economic parameters and responsible environmental management by systemically applying LCA and LCC analysis.

4 PILOT PROJECT -QUARRY „MILOVICA“ ON THE ISLAND OF BRAC

Production of the quarry Milovica is 2000 m^3 blocks per year. Considering priorities and side-products of the exploitation, following production alternatives are defined:

1. Disposal of the side-products on the different depots that are created by revision of unique depot during the exploitation phase, there is possibility for reuse and influence on a closure of the quarry.
2. Disposal of the side-products on the different depots that are designed at the beginning of the exploitation phase, there is possibility for reuse and influence on a closure of the quarry.

3. Disposal of the side-products on a one common depot that are designed at the beginning of the exploitation phase, there is possibility for reuse and influence on a closure of the quarry. This alternative describes how quarry works now.

Rehabilitation costs are defined according to the depot costs of 3€/m^3 of deposited material. The costs are distributed throughout production phase. The existing scenario, the third alternative, has not got such kind of costs because, at the moment, it is not part of the quarry management and it is not part of the legislation.

4.1 LCA analysis of the alternatives

By monitoring process the parameters about percentage of blocks' categories obtain in total production as well as non-block mass are obtained. Non-blocked mass is the same because the same technology is used in all alternatives. Only difference is in non-blocked mass management. Besides a register of produced blocks sorted by the categories which is very important for exploitation efficacy, information about the quantity of the side-products is also important.

The amount of the material in the quarry of the second alternative is lesser than in the other alternatives. The part which is left serves for construction of approaching roads to the quarry levels and other similar purposes.

4.2 LCC analysis of the alternatives

Economic analysis of the main scenario as well as of the proposed alternative solutions was performed by modified software P2/FINANCE. The concept of the analysis is to compare the alternative solutions with main scenario. The basic assumption was that there no differences in blocks' prices. The amount of waste-rock is also the same, but it is treated differently for each alternative. The basic scenario is compared to the situation in which quarry does not exist. Beginning of restoration payments here is in 15th year of project life cycle.

Despite of 18 % higher payments for the fuel, the total amount of the item Energy/Water/Fuel is the lowest for the second alternative because almost 90% of the water is saved, that is very important for the karst region as Island of Brač. Although it has 82% higher capital investments, even 142% higher payments for salaries and investment in same kind of "environment portfolio", which does not exist in the basic scenario, the second alternative shows the best net present value (63.964.416 kn) according to the first alternative (31.190.211 kn) and basic scenario (34.578.805 kn) for the period of 15 years. Internal rate of return is also the best for the second alternative (41%), if compared to the first alternative (23%) and the basic scenario (29%) for the same period. The values for net present value and internal rate of return also show that the second alternative guarantees the shortest payback period of 3,6 years comparing to the first alternative (5,5 years) and the basic scenario (4,5 years).

Those results are achieved by management of average amount of 12.500 m^3 by-products per year: unformatted (18%) and unshaped (22%) blocks convenient for strips, tiles and slabs; stone fragments (39%) convenient for aggregates; soil (14%) for restoration; and water decanted from mud (8%).

5 CONCLUSION

During the quarry lifetime there are many limitations starting from geological to spatial, time, law, market, social and others. Inside of them system have to be maximal develop and used. Quarry development should be monitored as well as optimise throughout its life-cycle regarding spatial, time, legislative, market, social and many other constraints. The paper proposes an application of the “whole life costing” approach as early as possible, namely, in the phase of an investment decision-making process so as to include both rehabilitation and monitoring costs, during the exploitation and also after closure of the quarry. The proposed combination of the project management tools, such as Life Cycle Assessment, Life Cycle Cost as well as Work Breakdown Structure in the unique GIS-based Management Information System could make both functional and sustainable management of quarries more efficient. The methodology was applied to the case study of quarry of island of Brac. Application proved that it could be very helpful in both strategic and short-term planning of natural stone, for either architectural or technical purposes, as one of non-renewable resources.

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