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Towards an integration information infrastructure in coal mining asset management application

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TOWARDS AN INTEGRATED INFORMATION INFRASTRUCTURE IN COAL MINING ASSET MANAGEMENT APPLICATION

Jorge Jemel Boneu[1], Leone Dunn[1], Peter Gibson[1]

ABSTRACT: Maintenance is recognised as the largest controllable cost among direct mining costs (Lewis and Steinberg 2001). Ironically, the ideal architecture for information systems and technologies for optimising maintenance functions has not been extensively studied. While many maintenance management approaches recognise the importance of understanding equipment functionality and performance monitoring, based in an integral range of information, extensive study to attain proper organisation of the information have not been undertaken. Degradation detection and prediction applications found in recent literature are generally for specific applications rather than generic (Lee *et al* 2006)

The current study is intended to address Longwall mining equipment integrated data infrastructure. The expected outcome of this study is to come up with a centralised information architecture that will utilise all the relevant information in the organisation to optimise asset management functions in a results based framework.

INTRODUCTION

Even though in practice it is generally considered a non value generating activity, asset management (Bignell 1997), can have a larger impact in the organisation than other central activities. On average maintenance costs represent 40 percent of total operating costs for the business. Downtime for longwall mining machines is recognized as one of the highest in the industry, reaching around 35 percent (Bongers, 2004). Considering that average longwall production is valued at $100,000 per hour; required efforts to improve machine downtime seem evident. Moreover there is a group of costs associated with physical asset management that are difficult to be perceived, difficulties that have resulted in certain costs not being considered. Just to mention some, decrease in productivity or product quality due to asset malfunction are difficult to perceive, usually the equipment fault is made evident only when the equipment stops functioning. The study presented in this paper is one that aims for a measurable improvement in longwall production, by decreasing equipment downtime and proposing an information management framework designed to achieve a higher utilization of the installed capacity by measuring an operational performance.

Longwall asset management function is generally judged in terms of equipment availability, and operations uptime, but rarely is it assessed in terms of the throughput or productivity of the equipment the function is responsible for. This fact alone generates several misunderstandings and lost opportunities for improvement given the lack of awareness. It is recommended through the presented framework to consider the importance of throughput, rather than the availability itself, in longwall sites and other mining sites this recommendation will prove beneficial since the metrics based in this premise will be aligned towards the real goal of the organization, increase profitability.

INFORMATION AND ARCHITECTURE

Why look at information and architecture?

Perceiving and being aware of what is happening with mine throughput and mine assets performance is needed and is needed on time, in order to encourage a proactive frame of mind. Management of information is of vital importance for achieving this. Information may be the only source of evidence of an operations performance.

The right management and the required awareness to obtain it will be achieved only if the importance of information management is perceived; thereby the information infrastructure should be planned and managed. The right information should be in the right hands at the right time.

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Some organisations that do not manage information can't even explain the cause of the asset faults or loss. Events are not related to outcomes, and faults are not related to information that could evidence possible causes for such faults. And the paradox is that generally the information is available, but is not organised and/or utilised. If is not organised then basically it doesn't exist. As an example imagine having the phone number of a friend in an agenda written 10 years ago without alphabetical order; or even worse not knowing in which agenda or book the number is written. Getting to use this information would involve some kind of random coincidence. In fact this is how the IT landscape looks like as this paper is being written, even if it is not accepted by most IT experts; this happens in mining and in many other industries. There are seas of information and we have to mine (datamine) it as if it was as difficult to obtain as gold is. The main reason is the abundance of Silos that exist operationally and technically. The information landscape is conformed by several information systems and devices generating information.

The study being performed demonstrates that the data generated in operations process is underutilised. The real potential of data is not known on most of the mine sites. The excess of information available has been rather a disappointing factor when initiatives to analyse the information appeared. The time required to perform such analysis has been a major turn down. What will be the benefit if the results are obtained even days after the fault presented itself? Barely triggering corrective measures.

This paper is a claim to weight the benefits that managing integrated information accordingly would signify to longwall mining operations and highlights the importance of finding the right vision of how systems are desired to be designed. The systems should be architected.

ACTUAL LANDSCAPE OF MINE ASSET MANAGEMENT

According to Lewis and Steinberg (2001) currently the mining industry is slowly evolving from reactive to proactive maintenance philosophies. Undoubtedly implementing one of the current structured maintenance approaches will result in cost reductions and productivity improvements. Hartman (1992) also mentioned how maintenance is gaining a strong emphasis in the mining industry due to awareness that improved equipment availability is the key for obtaining a return on mine investment

It is also important to highlight that Hartman (1992) described the evolution of the equipment with a trend to larger, more costly and complex equipment as time advances. Heavy mobile equipment has been considered costly for many years, but the increase in technologic advances in the last decades is making it even more complex and therefore more costly for materials and the qualified personnel to maintain it.

RELEVANT FACTS OF INFORMATION IN ASSET MANAGEMENT

- An overwhelming amount of data is produced by sensors and systems. According to Lee *et al* (2006) "Many sophisticated sensors and computerized components are capable of delivering data about the machine's status and performance. The problem is that little or no practical use is made of most of this data". In longwall sites massive amounts of information should be recorded if all the sources of raw data were to be stored. That accounts to approximately 4Gb per week. (Bongers, 2004) That makes historical analysis costly since the mentioned growth of information will require a constant increase in data storage.
- Process and Technologic Silos. Although there is communication among different organisational areas, it is difficult to accept that objectives are shared between them and that the work is performed to improve the whole performance. As an example we can cite the relationship between operations, maintenance, quality and engineering. Issues are generally solved individually when the cause of problems come from another area it is difficult to perceive and solve. The same happens with technological efforts. Individual efforts are the most common when developing new systems or buying new equipment. Information is also recorded in stand alone sources for analysis, such as Excel sheets or individual Access databases.

- Information systems lack of flexibility. Evans (2007) found that organizational change usually disrupts the process and how the work is performed in this process, but it will not change the associated computer application and usually no information recording process is changed to mirror the process.
- Information systems are not planned to work interconnected. Devices and systems rarely communicate to each other. As a sole example redundancy of information was found in certain processes on the longwall, manual recording of stoppages and equipment data recorded evidencing stoppages. Bongers showed that both sources of data where rarely congruent (Bongers 2004, p7), which diminish value of having two sources of the same information. Data obtained redundantly from a process will only be useful if reconciliation of the information is performed. A lack of integration of data and process make this task almost impossible to perform continuously.
- Lack of reliability of information. Communication problems cause incompleteness of information. Underground condition cause problems in communication of data, resulting in a large amount of information loss (Bongers, 2004) Bongers in his thesis recommends a framework to deal with this problem as a part of his fault detection and isolation solution.
- The lack of process compliance also results in unreliable information. An interview made by Pancucci (2000) to the Industrial analyst Cambashi suggests that the main barrier for a meaningful computer maintenance management system (CMMS) implementation generally is the lack of adequate data that will allow implementing the practice. One of the main reasons, he explains, is a lack of discipline in process compliance.
- Big software and equipment providers try to push towards unique software provider solution not contributing with system integration.
- Outsourcing and third parties involved in daily process. One of outsourcing practices risks is the fact that diagnostic records may not be analysed in conjunction with plant site management records-critical historical information is lost when this happen; this fact is identified by Evans (2007).

INFORMATION INTEGRATION FOR ASSET MANAGEMENT STATE OF THE ART

The main studies regarding integration between the maintenance function and other areas are explained below.

Artificial intelligence is used to integrate maintenance management system taking into consideration not only equipment condition but also production quality, efficiency and costs, this is discussed by Zhang and Yeung(1997).

Fung (1993) studied the integration of CMMS with quality assurance and energy management. Jonsson (1995) propose the integration among maintenance and production.

Kans (2009 confirms an important fact for this paper, "while other areas of the business were integrated into enterprise wide systems such as Enterprise Resource Planning (ERP) systems and Computer Integrated Manufacturing (CIM) systems, maintenance has not been well represented". Most of the ERP and CIM systems where used but most of these systems doesn't include maintenance modules Nikolopoulos (2003). Pancucci (2000) also reported how the rush to keep production up and running is still impacting the actual integration of maintenance with planning.

According to Kans (2009) "having a holistic perspective on maintenance enables predictive-proactive maintenance".

PROPOSED ARCHITECTURE

The author suggests a continuous performance measurement strategy that will involve performance data from both operations and maintenance. This architecture is reliant in a continuous process and not a one time activity, holistic performance measurement and analysis should become an automated task.

The main feature of the presented architecture design recommendations is that it is centred in obtaining value for the business, rather than using the highest technological advances. This ensures using only that what provides beneficial outcomes.

INTEGRATED INFORMATION ARCHITECTURE ROADMAP

For making a broader use of the information it has to be holistic and reliable. The recommended roadmap to achieve this asset management practice is presented bellow. The roadmap of the architecture was kept independent of the technology or processes necessary to support it, since technology and processes change, they are not to be part of an information architecture guideline. The guideline is to be used as a vision to trace the architecture of information systems, considering a broad and complete spectrum.

Measure Performance: monitoring trends in performance and detecting degradation of performance in variables such as:

- Productivity
- Utilization
- Condition
- Maintenance function.

Performance should be continuously monitored and stored. For a practical framework on maintenance performance analysis refer to De Groote (1995), although individual asset performance measurements are not covered.
Key questions: Is the throughput of the mine continuously monitored? Is the throughput of individual sections of the longwall being measured? Is there any procedure to detect performance degradation in equipment other than programmed inspection or the fault made visible? Are there production/energy consumption metrics implemented?

Integrate Information: having a unique repository of information where data could be continuously analysed in a time feasibly way and considering all the involved factors.

- Plan systems ahead for enabling interoperability and standardise. Otherwise build reliable interfaces
- Develop or acquire required information infrastructure
- Business process oriented solutions to enable interoperability

Key questions: Is sensors information being used? How many stand alone devices, PLCs or SCADAs are working in mine operations? What information is recorded and daily analysed from such systems? What benefit is acquired from historical information obtained from such devices and equipment?

Analyse: creating the respective analysis methods and procedures. Data should be used to model optimal operational condition and performance for assets, processes and systems. Organisations usually fail in completing the follow-up analysis as concluded by Campbell and Jardine (2001) and the reporting that is expected to be continuous generally is neither regular nor timely.

- Determine the assets that impact more on the total system output
- Determine the right variables to monitor
- Track performance trends and analyse
- Detect evidence of degradation of performance/condition before the occurrence of a fault.
- Analyse undertaken actions and results

Key questions: Are the reasons for a decrease in mine throughput known? Are those continuously analysed? What is the optimal throughput of each of the critical assets in the Longwall? Is the throughput kept constant?

Execute: Execution of the measures necessary to solve the detected evolving degradation of performance or implementation of a continuous process to eliminate the root of the failure.

- Process compliance
- Manage teams and institute continuous processes
- Knowledge should trigger actions

Key questions: Which is the ratio of reactive maintenance vs. proactive maintenance? Is manual information recorded consistently? Are stoppages and time documented? Are CMMS systems predictive capability used to trigger inspections or maintenance?

If any of the stages in the cycle is not accomplished the cycle is not complete and the whole effort will not generate the desired value.

The information integrated architecture specific application for Asset Management was named Sensible Maintenance and is explained in the following sections with an illustrative case for longwall mine equipment.

SENSIBLE MAINTENANCE

Sensible maintenance is an asset management practice only enabled by the use of integrated information with the purpose of detecting degradation in asset performance and/or condition. Based in holistic information from operations and business and obtained from the system and equipment data. The concept aims at determining the relationship between equipment degradation and the degradation of performance and using this analysis for early detection of asset degradation and prevention of fault. Sensible maintenance model is shown in Figure 1.

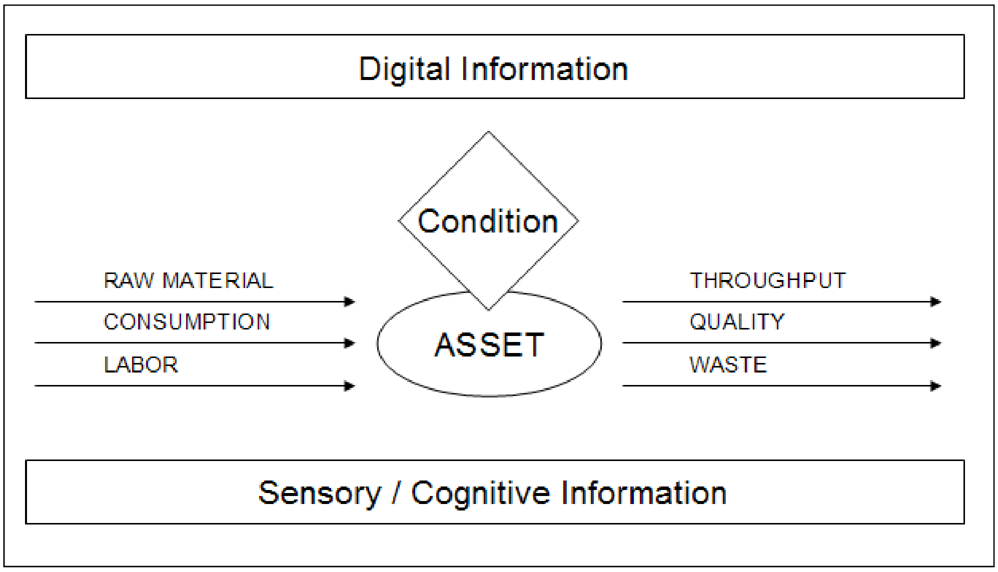

Figure 1 - Sensible Maintenance Model

CASE STUDY INTEGRATED INFORMATION ARCHITECTURE APPLIED IN ASSET PERFORMANCE DEGRADATION DETECTION. (SENSIBLE MAINTENANCE)

In order to illustrate sensible maintenance, the concept obtained from applying an integrated information architecture for Asset Management purposes, a single application in longwall coal mining was selected.

Longwall shearer maintenance related literature, and performance information will be utilized to create a model for monitoring the performance and condition of this type of equipment. The recommended framework is based on the possible encountered failures in the equipment, its components and subcomponents, although this study scope only covers the range of information that has to be monitored to detect the failure and encourages further study of the relationship of actual equipment condition with equipment performance.

A complete classification of shearer failures in terms of the root of the failure and component of the system where the fault is explained and organized as a fault tree by Gupta, Ramkrishna and Bhattacharya (2006). Only the section specifying the causes of failure of cutting-drums will be used for this case, which is presented in Figure 2.

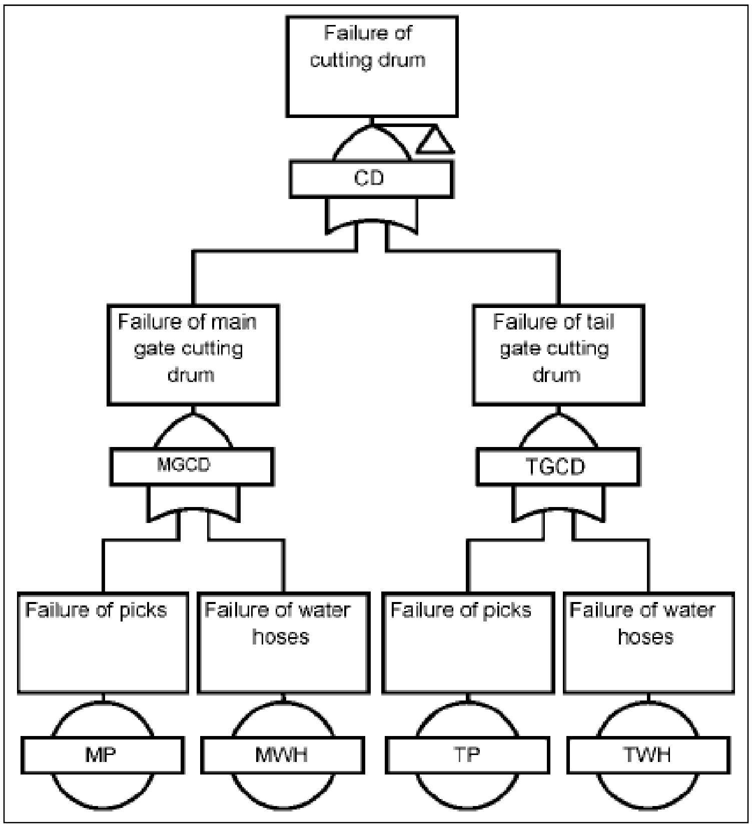

Figure 2 - Cutting-drum fault tree (Source Gupta, Ramkrishna and Bhattacharya 2006)

Detecting relevant variables to monitor

Based in a hierarchical organisation; relevant information that can evidence degradation in the functionality of the system or its components can be selected. If we examine specifically the cutting drum component we will find that the basic sub-components that may fail are the picks and the water hoses and therefore the degradation can be evidenced by monitoring those components.

Selected Component: Shearer Picks

Asset Function: The main function of the picks is to cut the coal out of the coal bed.

Environment variables: Include variables that are not controlled and affect the accomplishment of the asset function as coal hardness or flatness of the coal bed.

Controlled variables: Include variables that are controlled by the operator or configured previously that relate with the accomplishment of asset function as cutting motor power of the leading drum, cutting depth, current rotation speed of the leading drum, shearer travelling speed.

Internal uncontrolled variables: are the variables that are measured from the components as condition monitored for example cutting drum motor temperature, components oil state, cutting drums vibration and ranging arms vibration.

Output variables: Are basically variables that are uncontrolled and are a result of the system operation as in this case metric tons of material per hour, electric consumption, dust in the environment, coal size and coal quality.

Timely detection of degradation of the condition and/or performance of any of the sub components may prove to be useful, since it increases the time available before the total failure of the shearer system takes place.

In fact it was detected with this analysis, that there are some system components from which no condition monitoring is being made, and in those components we found that a related performance measurement could still be made. This fact opens the possibility to monitor certain variables related to the piece of equipment for evidencing degradation in equipment from which it was obviously impossible to monitor its condition.

Designing the system of correlation of information

The main premise to design the system is:

The right correlation of parameters acquired from inputs and the environment should have a predictable outcome.

There by: the capacity of the system and asset should be predictable.

In practice the right system of correlation of information can only be obtained with real data, recorded when the equipment is achieving its expected performance under the operational context. But for the study case a model will be generated considering a possible correlation of variables.

Studied input parameters will be classified in environment variables, controlled input variables and condition variables:

- Environment variables such as coal hardness, composition of the strata, thickness of the coal bed, flatness of the coal bed, geological obstacles.
- Controlled input variables such as cutting motor power of the leading drum, cutting depth, height of leading drum, current rotation speed of the leading drum, shearer travelling speed.
- Condition variables such as cutting drum motor temperature, components oil state, components age, cutting drums vibration, ranging arms vibration.
- Performance variables such as metric tons per hour, electric consumption, dust in the environment, coal size, coal quality.

The relationship between these variables will be stored as numerical data. A combination of certain environmental conditions and intended controlled input should result theoretically in a throughput ranging between A and B, that is somehow predictable, after gathering data of operations utilising optimal equipment.

After gathering enough information about each variable mentioned in a holistic and correlated manner, we will have a notion of what can be considered a *standard behaviour*, and if performance is as expected then we have a numerical evidence of what can be considered an *optimal behaviour*.

Consequently the system analysis will lead to an understanding that if all the input variables stay constant then there should be no reason for an abnormal output. And that if a decrease in the metric tons per hour is detected and the current rotation speed of the leading drum and the shearer travelling speed remain constant and all the variables controlled remain constant probably there is a decrease of performance in some component that is related with the final output or the equipment is not being manipulated properly.

So for exemplifying the above stated, the example of the picks condition will be used:

If all the input variables stay constant, including the current rotation speed of the leading drum (measurement that is obtained by a rotation sensor or rotameter), cutting depth and shearer speed, the average metric tons per hour is supposed to be predictable in certain degree. But if data measurements prove that average production has decreased under specified expected outcome (value that will be obtained from historical analysis of the system) it leads to the conclusion that degradation of the picks has taken place, because the last component before the studied component, the leading cutting drum, is working under expected rates of performance. Then the probability of needing maintenance of the picks is high, when any other possible causing factor hasn't been identified. It has been explained by Tiryaki (2004) that actual problems related to clearance ring picks in longwall equipment cause excessive wear to the backplate, excessive vibrations of the machine and increases the amount of respirable dust and fines. Most of these are indicators that can be monitored and were placed among the variables to be considered since a relationship between those variables and the condition of the equipment is likely to exist and provide help in the early detection of equipment degradation.

The system analysis also lead us to one question, if all the variables in the system are not being considered as a whole in any known longwall site, is productivity degradation being accurately perceived for longwall equipment?

Bongers (2004) work proved that by adequately monitoring the condition of the equipment in a holistic framework it is possible to detect developing failures in longwall systems, even without the inclusion of performance measurements. Developing failures that can be detected with anticipation include: "blockage/overload stoppages, temperature trips and dupline faults" (Guan, Gurgenci and Meehan, 2005). Including performance monitoring to the state of the art of condition monitoring is expected to add value and certainty to actual Failure Detection and Isolation (FDI) practices and with time to maintenance management process itself.

CHALLENGES

Interoperability between information systems is a technical challenge that has not yet been completely managed. Several organizations are working on standards to close this technical gap between systems. The purpose of systems architecture initiative is to trace a vision of the ideal systems architecture oriented towards the purpose of the organisation.

Information systems can have a lack of flexibility. Evans (2007) found that organizational change usually disrupts the process and how the work is performed in this process, but it will not change the associated computer application and usually information recording process isn't changed to mirror the process. This is one of the factors that should not be underestimated when implementing the systems architecture.

CONCLUSIONS

Longwall asset management function is generally judged in terms of equipment availability, and operations uptime, but rarely is it assessed in terms of the throughput or productivity of the equipment the function is responsible for. This fact alone generates several misunderstandings and loss opportunities for improvement given the lack of awareness. It is recommended through the presented framework to consider the importance of throughput, rather than the availability itself. In longwall sites and other mining sites this recommendation will prove beneficial since the metrics based in this premise will be aligned towards the real goal of the organization, increase profitability.

Currently operations and industrial recording processes and practice are not being studied extensively, and the range of possibilities this field offers have not been exploited to the maximum extent possible. Specifically in Longwall mining sites, data that is recorded is rarely used for fault detection and isolation. This could only contribute to a reactive rather than proactive framework of mind.

CMMS are not being implemented widely and its full potential is not being exploited probably because benefits are not recognized. Whenever corrective and scheduled maintenance work are practiced, a new approach will not be accepted unless the gained benefits are not only measurable but easy to perceive. Current proposed initiative creates the possibility to measure the results of every action undertaken by a maintenance function, since the architecture is focused in equipment performance management.

The current paper recommends a simple formula; equipment degradation can be early detected through monitoring process-throughput information and comparing it with the expected condition and performance. Every piece of equipment or component has attributes or behaviours and for each diagnosis methods can be abstracted and used in a simple model for the optimization of maintenance functions. Yet this model requires a certain level of integration and organization of the information. The architecture is the enabler of such integration.

Things are not static, but on the opposite side absolutely dynamic. It was found that information architecture to be successful has to be conceived so it can support any change whether it is in process, structure, information, strategy or purpose.

REFERENCES

Bignell, W, 1997. Maintenance Management Systems in the Coal Mining Industry, Master thesis, Department of Mechanical Engineering, University of Wollongong, Wollongong

Bongers, D, 2004. Development of a Classification Scheme for Fault Detection in Longwall Systems, PhD thesis, Department of Mechanical Engineering, University of Queensland, Brisbane

Campbell, J and Jardine, A, 2001. Maintenance Excellence Optimizing Equipment Life-Cycle Decisions, *CRC Press*

De Groote, P, 1995. *Maintenance* performance analysis: a practical approach, *Journal of quality in maintenance Engineering*, Vol. 1 No.2, 1995. pp. 4-24

Evans, R, 2007. Industrial Maintenance Data Collection and Application: Developing an Information Strategy, PhD thesis, Department of Mechanical Engineering, University of Queensland, Brisbane

Fung, W Y, 1993. Computerized maintenance management system in a railway based building services unit, in *ASHRAE Transactions*, Vol. 99 No. 1, pp. 72-83

Guan, Z, Gurgenci, H, Meehan, P A, 2002. Duty monitoring and duty-based maintenance on mining equipment, in *Proceedings of the 3rd Asia Pacific Conference on Systems Integrity and Maintenance*

Gupta, S, Ramkrishna, N, Bhattacharya, J, 2006. Replacement and maintenance analysis of longwall shearer using fault tree technique, *Mining Technology: Transactions of the Institute of Mining and Metallurgy*, Volume 115, N2, pp.49-58

Hartman, H, 1992. *SME Mining Engineering Handbook* (Society for Mining Metallurgy and Exploration Inc.)

Kans, M, 2009. The advancement of maintenance information technology, *Journal of Quality in Maintenance Engineering*, Vol. 15 No. 1, pp. 5-16

Lee, J, Jun, N, Djurdjanovic, J, Qiu, H and Liao, H, 2006. Intelligent prognostics tools and e-maintenance, *Computers in Industry*, Volume 57, Issue 6, August 2006, Pages 476-489

Lewis, M and Steinberg, L, 2001. Maintenance of mobile mine equipment in the information age, *Journal of Quality in Maintenance Engineering*, Vol. 7 No. 4, pp.264-274

Nikolopoulos, K, Metaxiotis, K, Lekatis, N and Assimakopolous, V, 2003. Integrating industrial maintenance strategy into ERP, *Industrial Management & Data Systems*, Vol 103 No. 3, pp 44-8

Pancucci, D, 2000a. Take CMMS seriously, *Manufacturing Computer Solutions*. Pg. 25

Pancucci, D, 2000b. Taking maintenance out onto the web, *Manufacturing Computer Solutions*. Pg. 25

Jonsson, R, 2000. Towards an holistic understanding of disruptions in operations management, *Journal of Operations Management*, Vol 18, pp. 701-718

Sherwin, D J and Jonsson, P, 1995. TQM maintenance and plant availability, *Journal of Quality in maintenance Engineering*, Vol.1 No. 1, pp. 15-19

Tiryaki, B, 2004. In situ studies on service life and pick consumption characteristics of shearer drums, *The Journal of the South African Institute of Mining and Metallurgy*.

Zhang, J, Tu, Y, and Yeung, E H H, 1997. Intelligent decision support system for equipment diagnosis and maintenance management, *Innovation in Technology Management – The key to Global Leadership. Portland International Conference on Management and Technology*, p.733

PRODUCTIVITY IMPROVEMENT FROM ECONOMIC CONCEPT TO AN ENGINEERING TOOL

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ABSTRACT: In broad terms, productivity is defined as the ratio of all outputs to all inputs. In this paper, productivity is distinctly used as an engineering tool and from practical viewpoint. With such engineering look, productivity is an adequate tool for evaluation of the advancement in competitive market, work assessment, profit/loss analysis, decision and even developing or changing the activity. Productivity measurement seems to be an easy task but this is a misconception. In fact the concept remains to be one of the most complex and unknown criteria. It is for this reason that attempts have been made here to accurately define productivity and hence simplify its measurement. A case study has been adopted and the productivity of Eastern Alborz Coal Mines in Iran has been calculated for years 2001-2008. The resulting values and the component models are then subject to analysis. These results are examined in terms of practicability and it is shown that the method prescribed is a pragmatic approach in all similar system situations.

INTRODUCTION

Productivity is the effective use of each factors of production which is defined as output to input (Oraee, 1998). With measurement of productivity during time, the trend of changes is defined. Increases or decreases of productivity are directly proportional to profit of company. Moreover, determination of productivity defined the ability of companies in competitive markets (Oraee, 2006). Productivity can be computed as partial and total. The partial productivity describes the ratio of output to each of inputs, including manpower, capital, energy, and etc., while the total productivity is the ratio of output to sum of inputs (Oraee and Pymander, 1998). The productivity is calculated for various purposes ((Oraee and Pomander, 1998), (Oraee, 1996, 2006) such as:

- The strategic, in competitive markets for survival and/or improvement.
- Technical, for verifying performance of various divisions.
- Planning, to verify profit/loss and the necessary decisions.
- Management, for development or change in kind of activities.

The productivity as a standard uses for estimation of efficiency and profitability. It helps the optimum allocation of resources. Therefore, the productivity can act as a parameter in forecasting and planning (Oraee, 1998).

In this study, the productivity of Eastern Alborz Coal Mines (EACM) is calculated. For this propose the total of outputs and inputs are computed for calculation of the total productivity and partial productivity including productivity of manpower, energy, and capital.

MINING OUTPUT

The first step in computing productivity is the measurement of outputs. The output is something that is produced, hence in mining definition, the output is the minerals. The output for EACM should be calculated in physical units (tons). The output also can be calculated as monetary units (US dollars), but this type of measurement is mostly for mines that produces the different types of minerals (Oraee, 1998). Table 1 (IMPASCO, 2009 and Soltani, 2009) shows the production of EACM during 2001 to 2008. To accurate analysis, selling price of coal also included. Moreover, in order to eliminate the

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inflation, based on inflation price index of wholesale of Iran (Price Index and Inflation, 2009), the prices are inflation adjusted. For this reason, the year 2001 is selected as a base and the index of each year is divided to the base year and the result is multiplied in to the selling amount of the same year.

Table 1 – The total output in EACM during 2001 to 2008

Year	2001	2002	2003	2004	2005	2006	2007	2008
Extracted coal (ton)	467,000	532,000	512,000	537,000	650,000	681,000	670,000	691,000
Concentrate (ton)	268,000	290,000	284,000	279,000	321,000	281,000	313,000	324,000
Price per ton of coal (US $)	68	73	83	101	113	126	133	186
Total sales (1000 US $)	18,000	21,000	24,000	28,000	36,000	35,000	42,000	60,000
Wholesale price inflation index	175	192	211	242	265	297	341	422
Inflation adjusted (1000 US $)	18,000	19,100	20,000	20,200	23,800	21,000	21,600	24,900

In Figure 1 the trend of production growth and inflation adjusted selling price of coal in each year compare to previous, during 2001 to 2008 is depicted. As seen in this figure, the trend of production and income (from selling coal) show significant changes and in some cases no harmony. For example, in 2006, in spite of growth in production (as compared with 2005), the income is decreased, on the contrary in 2007 although production decreased, but the income has increased.

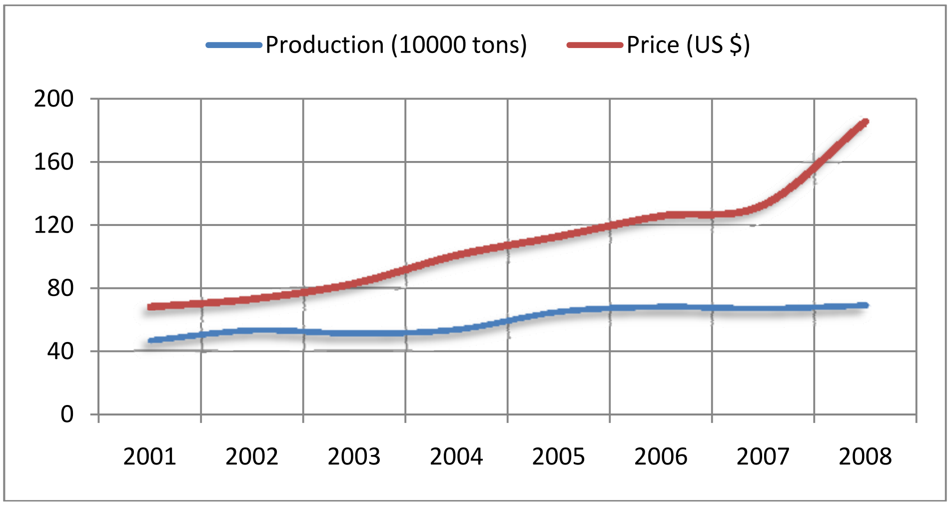

Figure 1 – The trend of production and inflation adjusted selling price of coal in EACM during 2001 to 2008

1. Mining input

The mine input is divided into various divisions that their summation is the total mine input. In this research, also the mine input of EACM is divided into three groups: 1) manpower, 2) energy, and 3) capital input. Accordingly each input is considered, separately.

The manpower input

The manpower input has an important role in productivity calculation. The accepted unit for manpower is either working hours (time) or number of workers (Oraee, 1996). While the level of education, technical knowledge, expertise, service records, and similar criteria effect on labor cost. Obviously the efficiency and therefore the cost of inexperience labor in compare to an expert one, and or the comparison of each expert labor with an engineer is far different. Therefore, if the manpower is defined by number or working hours it is required the labor cost be defined based on particular index. Obviously, such a calculation is not easy and accurate. Thus, calculations of manpower input based on labor cost solve this problem. As, the salary difference always is a criteria in position of a personnel. In other words, using the costs to calculate the manpower input, relying on market-power to adjust the value of each person with various skills. In the use of monetary unit for labor input must also be done inflation adjusted. Therefore, the consumer price index of Iran (Price Index and Inflation, 2009) has been used. The manpower data (Soltani, 2009) of EACM during 2001 to 2008 is presented in Table 2.

In Figure 2, variation in number and costs of personnel during 2001 to 2008 is shown. As can be seen, although the number and cost of personnel during these years have been declining, but reduce in rate of personnel number is more than personnel costs. In other word, the costs per person increases, that probably is due to technical knowledge and skills of personnel, or the policies of labor laws during 2005 to 2008. The first reason causes growth of total productivity, while the other's reduces the total productivity.

Table 2 – The manpower input in EACM during 2001 to 2008

Year	2001	2002	2003	2004	2005	2006	2007	2008
Total of personnel	2,248	1,983	1,692	1,466	1,240	1,117	1,058	973
Number of underground personnel	1,679	1,562	1,484	1,275	1,056	964	922	846
Number of coal face workers	319	298	207	206	161	174	149	150
Total wages and salaries (1000 US $)	13,000	9,000	10,000	9,000	10,300	10,000	10,700	13,300
Consumer price inflation index	178	206	238	275	308	339	402	504
Inflation adjusted (1000 US $)	13,000	7,800	7,500	5,800	5,900	5,300	4,700	4,700

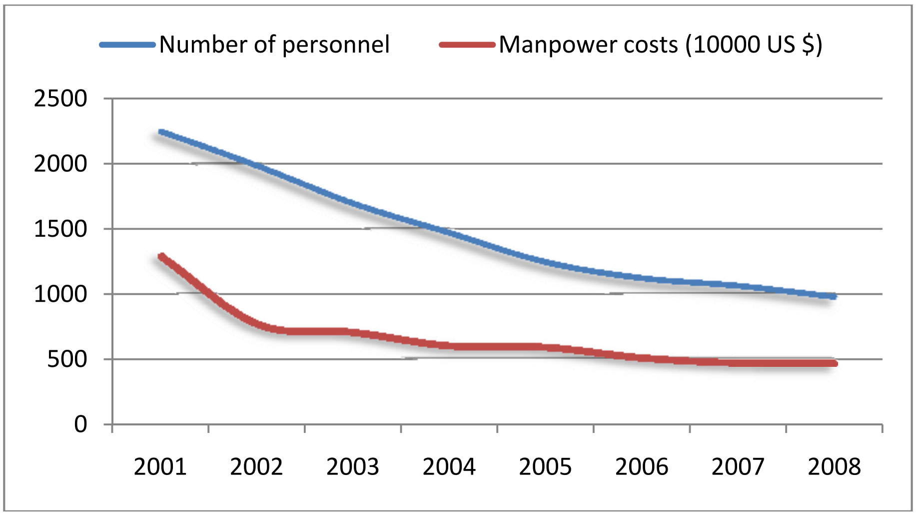

Figure 2 – The variation in number and costs of manpower in EACM during 2001 to 2008

Energy input

The energy is a part of the raw materials (Oraee, 2006), but in this research the energy input is calculated, distinctly. Because, the cost of energy is an important part of raw materials costs and in Iran, the variation of energy cost is not depend on variation of market prices and the laws of supply and demand. Energy is measured by the unit such as kilo-Watt per hour, kilograms, and litters. The summation of different type of energy the BTU unit is used. Since, the summation all inputs is for calculation of total productivity, in this study the total cost of energy is used. The electricity and fossil fuels are the main energy consumption in EACM, which in *Table 3* is given based on costs (Soltani, 2009). These costs by using consumer price index of Iran (Price Index and Inflation, 2009) for various years are inflation adjusted.

The trend of inflation adjusted prices variation during 2001 to 2008 is given in Figure 3. Although, the final price is decreased, however the sinusoidal fluctuations indicate the change in productivity during these years.

Table 3 – The energy input in EACM during 2001 to 2008

Year	2001	2002	2003	2004	2005	2006	2007	2008
Costs of fuel and electricity (1000 US $)	390	540	560	520	590	630	820	780
Consumer price inflation index	178	206	238	275	308	339	402	504
Inflation adjusted (1000 US $)	390	470	420	340	340	330	360	280

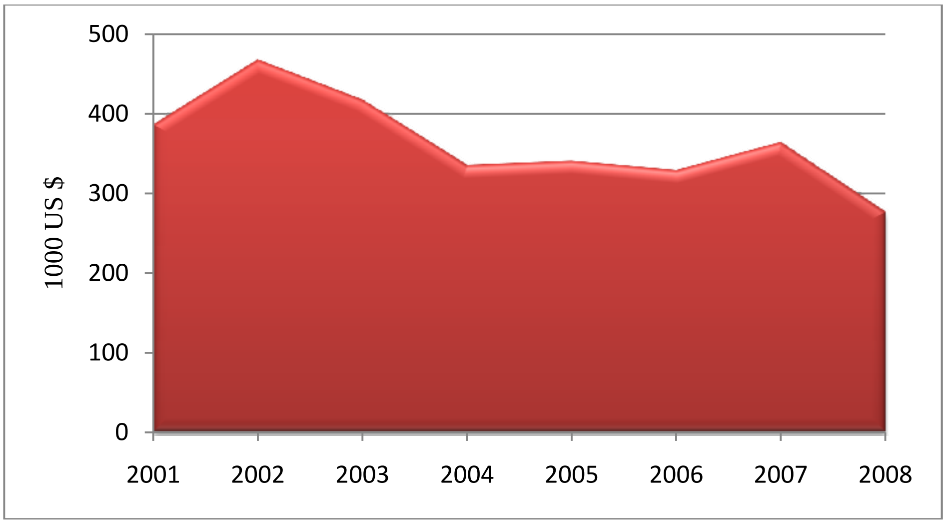

Figure 3 – The trend of inflation adjusted energy cost in EACM during 2001 to 2008

Capital inputs

The capital includes buildings, machinery, equipment, and the amount of reserves in a particular point of time, such as the end of calendar year (Oraee, 1996). Building maintenance and repairs are needed, machinery and equipments get depreciated and the new investments will be necessary. Therefore, the calculation of capital inputs is difficult. If the buildings and machineries be rented by company, the calculation of capital costs is quite easy (Oraee and Pomander, 1998). Otherwise, in productivity calculation the depreciation costs as a capital costs is used. In this research, the depreciation of building by straight-line method with life of 30 years is computed. The industrial machinery by declining-balance method with depreciation rates of 35 percent is depreciated. The light vehicles by straight-line method with life of 6 years have been calculated. Also, the properties and working equipments by declining-balance method with depreciation rate of 15 percent and the office supplies and furniture by straight-line with life of 15 years have been depreciated. Moreover, properties, machineries and equipments based on final price are included in the calculation. The cost of overhaul and maintenance and the minor repairs on occurrences are included as the current cost of the same year. The depreciation costs are given in Table 4 (Soltani, 2009).

The costs of spare parts, industrial parts and timber, arc and other tunnel equipments for the years of 2001 to 2008 given in Table 5 (Soltani, 2009). In addition, the wholesale price inflation index of Iran (Price Index and Inflation, 2009) has been used for inflation adjusted. The costs of transportation and maintenance of EACM during 2001 to 2008 is shown in Table 6 (Soltani, 2009). The costs for the said years based on the consumer price inflation index of Iran (Price Index and Inflation, 2009) are inflation adjusted.

Table 4 – The depreciation costs in EACM during 2001 to 2008

Year	2001	2002	2003	2004	2005	2006	2007	2008
Depreciation costs (1000 US $)	700	700	1,400	1,300	1,400	1,900	2,100	2,600

Table 5 – The costs of spare parts, industrial parts and timber, arc and other tunnel equipments in EACM during 2001 to 2008

Year	2001	2002	2003	2004	2005	2006	2007	2008
Spare parts, industrial parts (1000 US $)	1,000	1,000	900	1,100	1,200	1,400	1,100	1,000
Timber, arc and tunnel equipments (1000 US $)	39	16	8	2	8	8	18	18
Total (1000 US $)	1,000	1,000	900	1,100	1,200	1,400	1,100	1,000
Wholesale price inflation index	175	192	211	242	265	297	341	422
Inflation adjusted (1000 US $)	1,000	900	700	800	800	800	600	400

Table 6 – The costs of transportation and maintenance in EACM during 2001 to 2008

Year	2001	2002	2003	2004	2005	2006	2007	2008
Maintenance costs (1000 US $)	700	600	800	900	2,200	2,400	1,500	2,600
Transportation costs (1000 US $)	600	700	500	800	1,400	600	1,800	2,200
Total (1000 US $)	1,300	1,300	1,300	1,700	3,600	3,000	3,300	4,800
Consumer price inflation index	178	206	238	275	308	339	402	504
Inflation adjusted (1000 US $)	1,300	1,100	1,000	1,100	2,100	1,600	1,500	1,700

Also, the costs of work equipments, stores, bank loans, and the other capital expenditures with annual interest rate of 15 percent (Soltani, 2009) are given in Table 7 (Price Index and Inflation (2009).

Table 7 – The costs of work equipments, stores, bank loans, and etc. in EACM during 2001 to 2008

Year	2001	2002	2003	2004	2005	2006	2007	2008
Work equipments and store (1000 US $)	800	500	2,400	2,000	1,900	1,800	1,600	1,400
Bank loans (1000 US $)	0	0	0	0	0	300	0	0
Other capital expenditures (1000 US $)	0	0	0	0	0	0	0	0
Total (1000 US $)	800	500	2,400	2,000	1,900	2,100	1,600	1,400

Table 8 shows the total of capital inputs of EACM during years of 2001 to 2008 which are calculated **based on tables 4 to 7.**

Table 8 – the total of capital inputs in EACM during 2001 to 2008

Year	2001	2002	2003	2004	2005	2006	2007	2008
Total of capital costs (1000 US $)	3,800	3,200	5,500	5,200	6,200	6,400	5,800	6,100

In Figure 4, the trend of capital inputs of EACM is depicted. According to this figure, the capital inputs showing the increasing trends, which can reduce the capital productivity or even the total productivity.

In Figure 5, the share of each cost in total costs during 2001 to 2008 is given in percentages. As can be seen, the share of personnel costs are reduced during these years, but the share of capital costs with the same ratio has increased. While, the energy costs is almost constant.

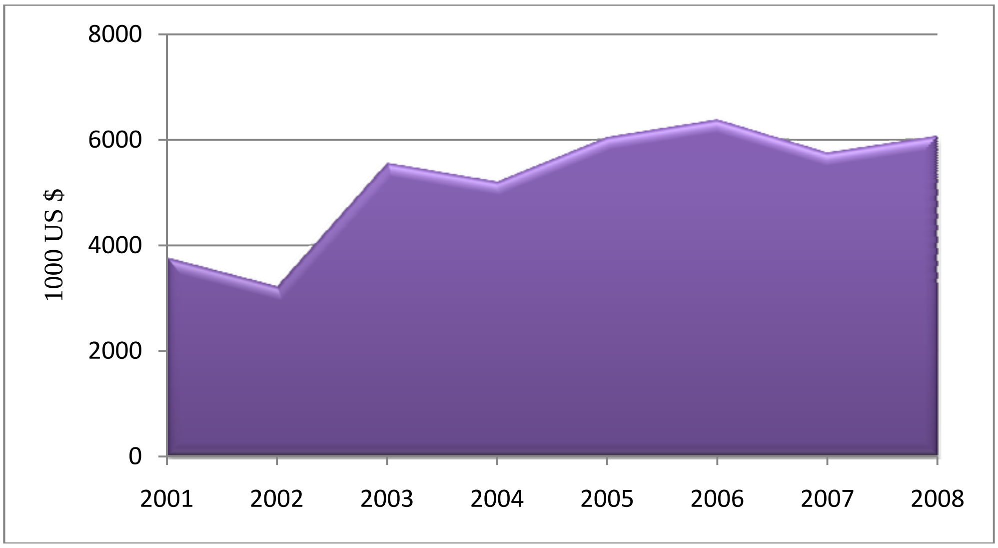

Figure 4 – The trend of capital cost in EACM during 2001 to 2008

Thus, the total inputs of EACM including the manpower, energy, and capital are as in Table 9.

Table 9 – Total inputs in EACM during 2001 to 2008

Year	2001	2002	2003	2004	2005	2006	2007	2008
Manpower input (1000 US $)	13,000	7,800	7,500	5,800	5,900	5,300	4,700	4,700
Energy input (1000 US $)	390	470	420	340	340	330	360	280
Capital input (1000 US $)	3,800	3,200	5,500	5,200	6,200	6,400	5,800	6,100
Total (1000 US $)	17,200	11,500	13,400	11,300	12,400	12,000	10,900	11,000

PRODUCTIVITY CALCULATION IN EACM

Productivity calculated according to the either monetary units or physical units. Using monetary units in define of output and input indicating the economic productivity or profitability (Oraee and Pomander, 1998). At this point, by using the ratio of output (as monetary unit) per total inputs, the total productivity and next with using the inputs of personnel, energy and capital, the partial productivity of the EACM during 2001 to 2008 are calculated and presented in Table 10.

Figure 6 shows the trends of total and partial productivity including personnel, energy, and capital based on monetary unit during 2001 to 2008. According to this figure, the trend of the personnel productivity changes and the capital productivity are compatible with the total productivity. These three productivity indexes reduce significantly in 2003, but showing almost constant onwards. The sinusoidal fluctuations in trends of productivity are a sign of system instability.

The trends of the energy productivity during these mentioned years were instable. As such after dramatic decrease in 2005 and 2006, reaching to a constant trends in 2007, but shows the sudden increases in 2008. According to the Figure 6, the increases of the energy productivity in 2008, is an unusual result as the capital productivity decreased and also the global price of energy has been increased in the same year.

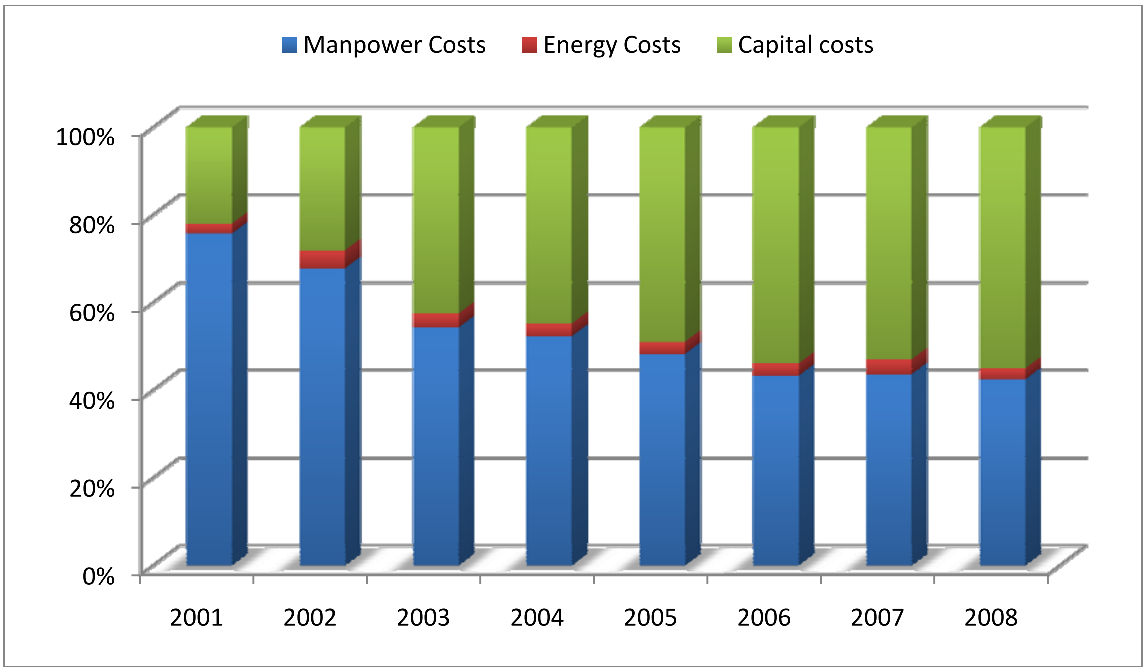

Figure 5 – The share of each cost component in EACM during 2001 to 2008

Table 10 – Productivity at EACM based on monetary units during 2001 to 2008 ($/$)

Year	2001	2002	2003	2004	2005	2006	2007	2008
Total productivity (1000 US $/1000 US $)	1.0	1.7	1.5	1.8	1.9	1.8	2.0	2.3
Labor productivity (1000 US $/1000 US $)	1.4	2.4	2.7	3.5	4.0	4.0	4.6	5.3
Energy productivity (1000 US $/1000 US $)	46	41	48	59	70	64	60	89
Capital productivity (1000 US $/1000 US $)	4.7	6.0	3.6	3.9	3.8	3.3	3.7	4.1

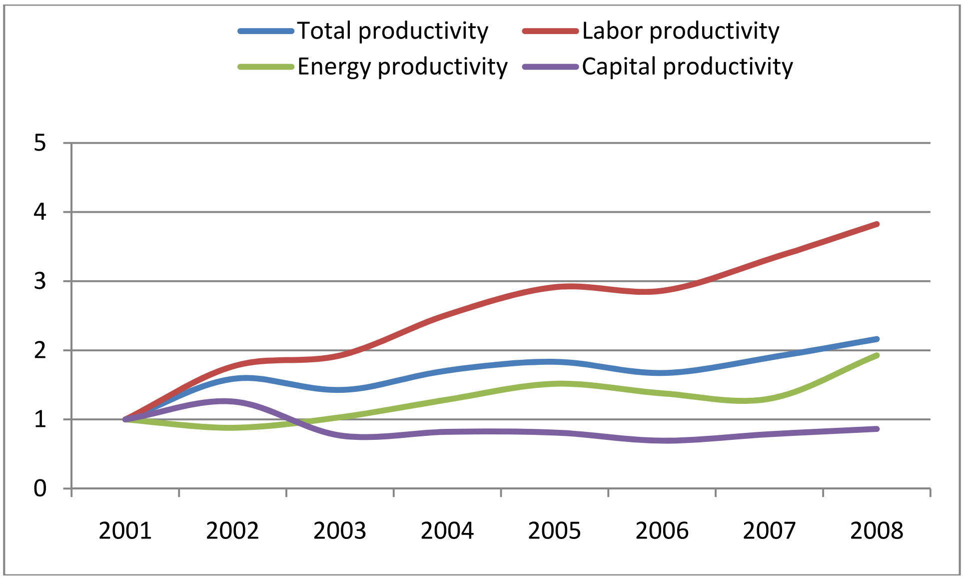

Figure 6 – Variations in total productivity and partial productivity based on monetary units during 2001 to 2008 ($/$)

The productivity of EACM based on physical units (physical per monetary unit) during 2001 to 2008 is given in Table 10.

Table 10 – Productivity at EACM based on physical and monetary units (ton/1000 US $) during 2001 to 2008

Year	2001	2002	2003	2004	2005	2006	2007	2008
Total productivity (ton/1000 US $)	27	46	38	48	52	57	61	63
Labor productivity (ton/1000 US $)	36	68	68	93	110	128	143	147
Energy productivity (ton/1000 US $)	1,197	1,132	1,219	1,579	1,912	2,064	1,861	2,468
Capital productivity (ton/1000 US $)	123	166	93	103	105	106	116	113

In Figure 7 also the trend of total productivity and partial productivity that includes productivity of manpower, energy, and capital based on physical unit per monetary unit are presented. As can be seen, the trend of total productivity variation with productivity of manpower and capital are similar, but the trend of energy productivity is different and shows the sinusoidal behavior.

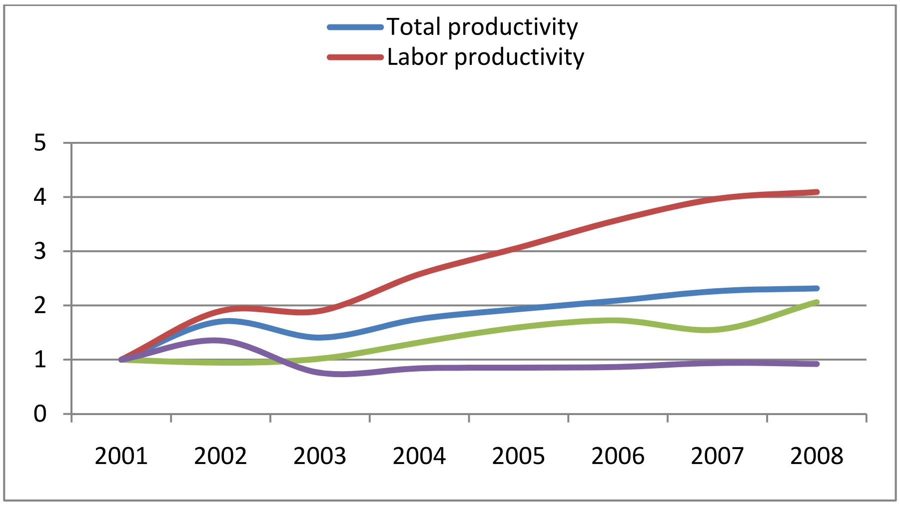

Figure 7 – Variations in total productivity and partial productivity based on physical and monetary units (ton/$) during 2001 to 2008

The Figure 8 shows the trend of total productivity based on monetary unit (US dollars/US dollars) and physical unit (ton/US dollars) during 2001 to 2008. As expected, until year 2004 these two indexes of total productivity are similar, but in 2005 the trend of total productivity based on monetary unit extremely decreases in opposite of the other index! In 2006 it reaches to lowest limit and increases progressively for the two next years!

CONCLUSION

Although, the productivity is a simple economic concept defines as an output to input ratio, but from an engineering view is a critical tool. Such a tool is a key role on evaluation, analysis, comparison, and generally in decision-making processes for knowledge-base economy. The trend of variation of total productivity based on physical per monetary unit shows that the EACM may lead to an unsuitable economic status. While the trend of changes on total productivity based on monetary unit indicating a partial growth in recent years. Such a growth may be either based on inflation index stated by central bank of Iran during these periods or based on engineering and economic concept. Perhaps, growth in partial productivities such as productivity of manpower, capital and particularly, energy may be essential for improvement of EACM. In this connection, mechanization is key factor as it improves productivity beside the other important factors like administrative and management. To ignore the above said factors would reduce the competitive ability of EACM in market. With increases the production costs especially, energy cost (based on real price, not subsidies) producing of coal may not have economic justification, ever.

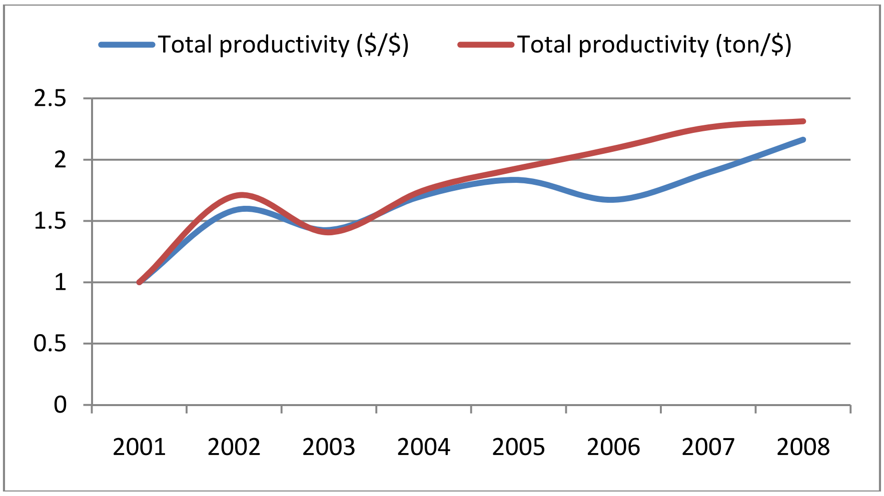

Figure 8 – Variations in total productivity and profitability at EACM during 2001 to 2008

REFERENCE

Oraee, K, Pomander, M S, 1998. Analysis and measurement of productivity, Amirkabir University Press, Iran.

Oraee, K., Mining Economics, Amirkabir University Press, 1996.

Oraee, K., Economics for Non-Economists, Amirkabir University Press, 2006.

Production Reports, IMPASCO. Available online at: http://www.impasco.com (accessed 06 October 2009).

Report of Price Index and Inflation, Central Bank of the Islamic republic of Iran. Available online at: http://www.cbi.ir/simplelist/1591.aspx (accessed 08 October 2009).

Soltani, M. R., 2009, The statistical reports of eastern Alborz coal mines, research and technology centre – IMPASCO, 2009.