REVIEWS AND CASE STUDIES

Study and analysis of maintenance performance indicators (MPIs) for LKAB

A case study

MPIs for LKAB:
a case study

325

Aditya Parida

*Division of Operation and Maintenance Engineering,
Luleå University of Technology, Luleå, Sweden*

Abstract

Purpose – The purpose of this case study is to identify and develop maintenance performance indicators (MPIs) for a mineral processing plant producing high quality iron ore pellets, as well as studying and analyzing the short plant stops and planned maintenance stops.

Design/methodology/approach – An action research approach was adopted for this study, with interactive process of interviews. The existing MPIs are analyzed and a set of MPIs are developed to measure the performance of balling area of the pelletization plant, where the effect of shorter stops in the process have been studied, analyzed and measured, and linked to the management's objectives. The utility of the MPIs are tested and validated within the framework of a multi-criterion and hierarchical maintenance performance measurement (MPM) framework. The plant stop data of the plant were collected and analyzed for MPIs and for maintenance decision making. Some other criteria were also considered from a holistic, integrated and balanced viewpoint in the model.

Findings – This study resulted in identifying a set of MPIs for the operational level of the pelletization plant of LKAB, after analyzing the short plant stops and planned maintenance stops data, and the stakeholders' requirements. This study has identified nine MPIs at operational level or shop floor level that describe the status of plant and at the same time facilitates linking of plant performance with corporate strategy.

Practical implications – The approach used in the paper to study, analyze and develop MPIs, can be useful for plant managers and asset owners to select and develop MPIs that can describe the health status of their plant and asset and that also can be linked to the corporate strategy. The framework used to verify the multi-criteria hierarchical framework can also be used by similar asset managers and infrastructure owners. This study has also lifted the impact of short duration stoppages, thus highlighting the total influence in terms of reduced life length, quality and productivity. This approach can be used by plant engineers, asset managers and infrastructure owners to assess the performance of maintenance process.

Originality/value – This paper presents an approach for identifying MPIs relevant to the plant status and facilitating measuring maintenance performance at corporate level in a structured way.

Keywords Maintenance, Performance measures, Productive capacity, Quality

Paper type Case study

The author gratefully acknowledges the grant of a research fund for this project during 2005-2006, by the management of LKAB, and would especially like to thank Anders Kitok, Sten Askmyr, Eyvind Fogman, Torbjorn Almqvist and other staff for providing full support in their organization for conduct of this research work. The author also acknowledges the total support of Uday Kumar, Arne Nissen, Gopi Chattopadhyay and Lina Helgesson during this research project with LKAB, including data collection and analysis.

1. Introduction

Performance measurement is extensively used by business units and industries in order to assess progress against set goals and objectives in a quantifiable way for effectiveness and efficiency. Performance measurement provides the required information to the management for effective decision making. Performance cannot be managed without measurement, as measurement can only indicate the present status of performance. Research results demonstrate that companies using integrated balanced performance systems perform better than those who do not manage measurements (Kennerly and Neely, 2003; Lingle and Schiemann, 1996).

Each organization spends considerable resources and time for measuring the performance and to assess the success of the organization. Performance measurement literature emphasizes the importance of maintaining relevant measures that continue to reflect the issues of importance to the business (Lynch and Cross, 1991). However, most of the organizations pay little or no attention to integrating the performance measurement system with their organizational hierarchical levels and the different measurement criteria linked to the external and internal stakeholders as well as the operational process. In addition, not enough importance is given to the external and internal effectiveness to achieve total maintenance effectiveness for the organization.

Considering all these aspects for measuring the maintenance performance, the concept used in the balanced, holistic and integrated multi-criteria hierarchical maintenance performance measurement (MPM) framework (Parida *et al.*, 2005; Parida and Chattopadhyay, 2006), was applied in this case study. This paper looks into the complexities of MPM and indicators, while studying the large number of unplanned and shorter stops of the balling area of a pelletization plant in LKAB. The performance indicators were identified at the equipment and system/subsystem levels, linking the improvement in performance speed and quality besides availability. The outline of this paper is as follows. Section 1 provides an introduction to this paper; section 2 provides an overview of various performance indicators and measurement techniques; and section 3 provides the research approach, data collection and data analysis of the case study. In section 4, the results and analysis of the maintenance performance indicators (MPIs) are discussed, followed by the conclusions in section 5.

2. MPI and MPM framework

MPIs are used for measurement of maintenance impact on the process performance (Wireman, 1998; Parida *et al.*, 2003). MPIs need to be linked to down time, costs and wastes, capacity utilization, productivity, quality, health and safety (Parida and Kumar, 2004) to compare actual performance with a specific set of reference conditions (requirements) (EEA, 1999). Under challenges of increasingly technological changes, implementing an appropriate performance measurement system in an organization ensures that actions are aligned to strategies and objectives (Lynch and Cross, 1991). In fact, performance cannot be managed, if it cannot be measured.

The development and implementation process for indicators has been studied by Andersen and Fagerhaug (2002) and Engelkemeyer and Voss (2000). The development and identification of MPIs for an organization is undertaken from the vision, objectives and strategy points of view and on the basis of the requirements of both the external and the internal stakeholders (Kumar and Ellingsen, 2000). The MPIs are required to be considered from the perspective of the multi-hierarchical levels of the organization. The

first hierarchical level could correspond to the corporate or strategic level, the second to the tactical or managerial level, and the third to the functional/operational level. Depending on the organizational structure, the hierarchical levels could be more than three. However, only three hierarchical levels are adopted for our MPM framework. The maintenance indicators of the functional level are integrated and linked to the tactical or middle level to help the management for analysis and decision making at the strategic and tactical level. It is a challenge to integrate MPIs from a top-down and bottom-up flow of information. Another important challenge exists for the involvement of all employees in this MPIs development process, so that everyone speaks the same language. Subjectivity increases as we integrate the objective outcomes from the shop floor to get key performance indicators at higher level.

The effectiveness of any performance measurement system is meant to meet the needs of the operations and maintenance processes. The critical strategic areas vary from company to company, but generally include areas such as financial or cost-related issues, health safety and environment-related issues, processes-related issues, maintenance task-related issues, and learning growth and innovation-related issues, while at the same time comprising the internal and external aspects of the company. It is important to link and integrate the overall objectives and strategy of the company. The linkage between visions, objectives and strategy and measures of performance such as return on investments (ROI) and health, safety and environment (HSE) indicators are considered in the proposed MPM framework, as discussed and given in this case study. A logical cause-and-effect structure has been created, while identifying and deciding the different performance indicators for each critical strategic area to measure the maintenance performance. The proposed MPM framework is designed to be balanced considering different criteria, holistic from the entire organizational point of view and integrated as a link-and-effect structure to achieve the total maintenance effectiveness both from external and internal effectiveness, which would contribute to the overall objective of the organization and its business units.

3. Case study and methodology

In this case study, the MPIs were studied for one of the pelletization plant of LKAB, Sweden, a leading Swedish automated mining processing company, for its mineral processing plant, to link with the improvement in performance rate, availability and quality as MPIs, amongst others. During the autumn of 1999, LKAB restructured its organization as part of its improvement plan, to be a more process-oriented organization. The purpose of this improvement plan is to take advantage of the synergies that are available at that time and the company is ready to apply the experience and knowledge they have acquired for changing over to a more effective operational organization. The production and service are transferred to the production division, which is to act as the strategic driving force for quality and cost effectiveness. The goal of the improvement plan is to re-engineer the process for 20 percent more production before 2006. A preliminary study of these issues was performed during 2005 at one of the pelletization plants of LKAB. Personnel from process, production, automation and maintenance departments are interviewed and interacted with, besides visiting the plant for maintenance process mapping. During detailed discussions and study of the problem areas for the year 2004, it was noticed that a large number of shorter and unplanned stops occurred in the balling area of the pelletization plant. A

majority of these stops were due to faulty speed control and other issues of the conveyer belt. It was also felt that the failure cause and effect analysis of the shorter stops needed to study the failure pattern, cost, risk and capacity utilization. The analysis further suggested for undertaking appropriate maintenance approaches depending on the failure pattern and consequences, prioritizing the faults and maintenance works. It is also noticed that conveyer belts within each balling drum area had not been defined as the prioritized or critical ones, and therefore full and complete inspection of these conveyer belt was not carried out. The purpose of this case study is to identify and develop MPIs for LKAB, while studying and analyzing the short plant stops and planned maintenance stops. Also, the existing MPIs are analyzed and a set of MPIs like; ROI reflected through higher availability, production rate (speed), product yield (quality) and maintenance cost per ton, are considered to measure the performance of balling area of the pelletization plant, where the effect of shorter stops in the process are studied, analyzed and measured, and linked to the management's objectives.

This study was limited to the conveyor belts of balling area of the pelletization plant. Action research approach was adopted for this study, including interactive process of interview and detailed discussion. The methodologies adopted were as follows:

- The plant was visited and interviews were conducted with help of interview guide to understand the operation and maintenance process in detail, and to carryout a process mapping, integrating the process, production, maintenance and automation activities.
- The total maintenance effectiveness of the process was studied both from internal and external stakeholders' point of view to understand the requirement and identify the MPIs.
- The MPIs were studied both from multi-criteria and hierarchical levels based on the multi-criteria and hierarchical MPM framework (Parida *et al.* 2005).
- The plant stop data of the balling area were collected and analyzed for MPIs like the availability, production rate, maintenance cost per ton and quality amongst others, as well as for maintenance decision making.
- Some other criteria, although not directly related to maintenance performance, were also considered from holistic, integrated and balanced viewpoint in the framework.

3.1. Maintenance process mapping

Process mapping is a critical and important initial step to understand the existing flow of various work processes constituting operation and maintenance process and existing work practices in the plant. The process mapping was conducted under two phases – the process study and interviews.

3.1.1. Process study. The production area of the process industry under study was studied in detail for understanding the production process and to undertake a process mapping. The conveyor belts were studied in detail to understand their layouts, design, capacity and drawbacks. The bottlenecks and the critical spots were studied for any likely drawback to the production process. The maintenance department is responsible for planning and execution of the maintenance activities. This is primarily done during

planned maintenance stops. The production department takes an active role in performing the daily cleaning and maintenance checks, and initiating failure reports, as failure occurs or likely to occur. Simultaneously, the process engineer and the automation engineer also share their responsibilities to maintain the working condition of the system for achieving the desired production level. Besides, there are some external players, who are involved in condition monitoring, in maintaining the conveyor belts and rollers for the conveyor belts.

The existing maintenance strategy does follow the organization's vision and business objectives, based on which production targets are set and the maintenance strategy formulated considering the business strategy. The maintenance strategy adopted at the plant can be characterized by the following types of maintenance:

- planned stops – like yearly/half yearly/weekly stops;
- deferred maintenance;
- corrective maintenance;
- maintenance system recording (data collection); and
- operators' maintenance (cleaning and inspection).

In the maintenance work process, the operator/production supervisor reports the maintenance requirements through:

- Failure stops – whenever there is a stop due to failure of the sub-system/components.
- Likely failure – which is noticed due to partial/less operational failure of the components/sub-system.
- Operators inspection/observation – during these inspection/observations noticed for some failure or likely failure of components/sub-system. This is undertaken by the operators during the scheduled stops and corrective actions taken. These maintenance requirements are communicated to the maintenance planning mostly by the production chiefs.

Additional maintenance requirements are also obtained from:

- Inspections by the maintenance staff – these inspections are carried out during planned stops, so as to carry out detained inspection and checks.
- Monitoring/data analysis from the condition monitoring of components and sub-system. If this is the non-continuous type, then inspection is also carried out during a planned stop.
- Input from improvement group after analyzing the maintenance/inspection data of the sub-system/system.

The maintenance activity could consist of replacing, repairing, adjustments, inspection, pre-determined maintenance such as lubrication, modification, no failure found (checking), and routine cleaning. The maintenance planning is made for undertaking the maintenance tasks immediately or may defer it to be undertaken during the next daily/weekly stop or major maintenance stop depending on the urgency/priority of the maintenance tasks. Accordingly, the work orders are prepared and maintenance planning is worked out for provisioning of required manpower,

material, tools and external assistance, if any. The maintenance plan is then implemented as scheduled, after which the inspection/checks are carried out to ascertain the correctness of functional efficiency of the components or the sub-system. All these activities are documented in to the operational/maintenance software system. The data that are thus collected are analyzed and validated for any further operational improvements and to achieve the production targets.

3.1.2. Interviews. In order to understand the existing maintenance process, 38 personnel were selected depending on their positions and work assignments from the production, maintenance, automation, account and finance, and process departments at the shop floor and managerial levels of LKAB. Interviews were conducted with the help of an interview guide to:

- Understand the production process, maintenance and automation, and describing process of the balling area.
- Understand the types and classification of maintenance and analysis of maintenance tasks (process).
- Understand the maintenance working process, work order, job card, maintenance planning, inspection system, maintenance task reporting, and to describe the failure system of maintenance process.
- Understand how the maintenance task is carried out (implementation), and maintenance data analysis.
- Study the process design for conveyor belts, gear boxes, motor, screen, and drum, and ascertain the critical conveyor belts/components creating bottlenecks.
- Ascertain if these maintenance tasks/modifications can be planned to be undertaken during the maintenance stop.
- Study the process design, OEM specification (wherever required), check/discuss with operators, technician, process and automation for any other insight/suggestions.
- Study and check the productivity figures, maintenance costs, targets and capacity to establish a possible linkage, and how to improve the availability, speed and quality.

4. Data collection and analysis of the shorter stops for MPIs

Maintenance-related data are collected through the maintenance reporting system at the plant. In reporting, the important activities are: when the work order is initiated (time); when the work order is finished (time); which system is maintaining the information (data); what is cost of maintenance; and spare parts cost. Two different information systems are in use for recording data of maintenance activities:

- (1) the maintenance system; and
- (2) the failure report system (operation system).

However, compatibility needs to be improved between these two systems. For example, while the maintenance system provides information of work order initiation, the finished time is indicated by the failure reporting system only. A system of weekly meetings and improvement groups meetings are in practice to discuss various maintenance/operational issues and take on the spot decisions.

4.1. Number of failures and stop time for conveyor belts

The data for the number of stops and stop time are collected for analysis and are given in Figure 1. It is obvious that the number of stops and stop time will be higher than these values during 2005. Although there have been improvements made on the conveyor belts, they do not seem to affect the statistics in any higher extent. It must also be said that the stop time is waiting time and not actual repair time.

Number of stops and stop time are indications of good monitoring and control measures at the operational and tactical level of the MPM framework. The stop time in hours for the conveyor belts of the balling circuits (BA 1 to BA 5, given in Table I) provide a clear picture of the faulty conveyor belts, which need immediate management attention. The number of failure stops of the conveyor belts month-wise is given in Figure 2, which also indicates the belts requiring critical attention. As can be seen in Figure 2, belt A has the maximum number of stops during February to

Source: Lines represent the goal value set for a quarter

MPIs for LKAB:
a case study

Figure 1.
Number of failures and
stop time for conveyer
belts at balling area

Belt	BA 1	BA 2	BA 3	BA 4	BA 5	BA 6
Belt A	36	5	1	18	16	75
Belt B	1	7	26	8	8	50
Belt C	3	1	5	3	1	14
Belt D	0	8	1	1	0	10
Belt E	5	69	0	0	0	75
Belt F	78	10	81	6	0	175
Belt G	11	2	1	42	8	64
Belt H	23	3	0	40	0	67
	157	105	115	119	34	530

Note: >6 h/month marked in italics

Table I.
Stop time for all balling
areas and mixer showing
each conveyor belt 2005

Figure 2.
Number of failures for
conveyor belts at
balling area

Source: Belt A and B vary over time but the others not very much

March and June to September 2005. After taking corrective measures during the planned maintenance stops of April and October, the number of failures reduced almost to the desired level.

4.2. Availability

The maintenance department has the responsibility for achieving the stated availability of the system and this can be followed in the failure report system. Measuring the availability in a system where at least four units should work is not easy. Figure 3 shows the availability level of the balling area when combinations of five or four balling circuits are working. The availability state of the balling circuits provides the desired information to the managers at a tactical level for achieving the targeted production figure. If the availability figure is down to the desired level, the manager at the tactical level has to look in to the problems and the issues and find a quick solution.

4.3. Performance speed

The output from the balling area is very much dependant on the screen. A new routine was established in April that the screen should be checked every 2,000 h and it has

Figure 3.
Availability state with five
or four drums working

been proved that the production speed has increased since the planned maintenance stop in April. The adjustment was initiated by the process engineers and is seen as an improvement activity.

It is important to upkeep the maintenance standard and the maintenance department is responsible for keeping the screen in such a good condition that this is possible. In this work, more ore paste is put into the process (increase of speed) and the less oversized pellets are rejected (quality is increased). During the last quarter 2005, it is seen that the production speed has decreased and it is a sign that the standard is not being kept (see Figure 4).

4.4. Quality

In LKAB quality is defined as properties of the product and is nearly equal to the acceptable standard for selling to the customer. These qualities are quantified in the parameters such as:

- iron content;
- silica content;
- pellet size; and
- strength.

All these parameters are regularly and strictly measured, tested and ensured in the plant. There are no major quality problems existing in LKAB as of today. The cost will increase in case the product needs rework. In case of pellets production, the size-wise rejected pellets are re-circulated in to the balling circuits.

4.5. Identifying existing MPIs and linking with organizations objectives and strategies

A performance measurement (PM) system needs to be aligned to organizational strategy (Kaplan, 1983; Eccles, 1991, Murthy *et al.*, 2002). The total effectiveness based on the organizational effectiveness concept includes both the external and internal effectiveness of the organization. The external effectiveness is highlighted by stakeholders, who need ROI and customer satisfaction, which are the front-end processes. The internal effectiveness is highlighted through the desired organizational performance reflected by availability, performance speed and quality of product or services rendered and back processes such as the spare parts availability, supply chain

Figure 4.
Performance speed

management, and optimized resources like workforce excellence including knowledge up gradation and innovations. The internal effectiveness process is also called a back end process of the organization.

Different figures or targets set by top management are permeated down the levels of the organization up to the shop floor. For example, to achieve a set target of production, if the requirement is to achieve an OEE level of 75 percent at strategic level for the year 2006, the requirements at tactical or middle level are availability of 92 percent, production of speed of 610 ton/hour and a quality level of 92 percent. When these are translated to the shop floor level, the maintenance indicators are to keep the number of maintenance stops at 0.7 per belt per month or the stop time to remain below 0.7 hour per belt per month. The shop floor engineers and managers at middle level have to intervene and take preventive decision, once these limits are crossed. Similarly, when these indicators are aggregated upwards, it will lead to the aggregated target set by the top management. The maintenance indicators are specific and objective at the shop floor level and their objectivity converts to subjectivity as the aggregation level reaches upward at the top management level.

The existing MPIs identified are: availability, performance speed, number of stops, number of accidents, environmental complaints and quality complaint numbers. However, these MPIs are not analyzed frequently as they should have been. As a result, these do not reflect to an extent the effective utilization of the workforce and organizational performance.

5. Development of MPIs and multi-criterion hierarchical MPM framework

The internal and external aspects, which act as parts of a back-end or front-end processes, need to be analyzed before deciding the relevant criteria at various levels for the maintenance performance measurement. The front-end process is derived from the needs of the external stakeholders, e.g. the shareholders or owners, financiers, customers, suppliers and regulating authorities. Therefore, the front-end process needs could include higher productivity, HSE ratings, timely delivery and quality. The back-end process, which is derived from internal aspects like the capacity and capability of the organization, comprises the departments, employee requirements, organizational climate, and skill enhancement. The back-end processes are: cost reduction, employee retention and innovation. The MPIs at functional and tactical levels become aggregated at the strategic level. A balanced, holistic and integrated multi-criteria hierarchical framework linking MPIs is proposed in this model and given in Figure 5. The three hierarchical levels are the strategic/senior manager/plant, tactical/middle manager and functional/operators levels. The multi-criteria, which are considered and included in this MPM framework, are:

- (1) equipment-related indicators;
- (2) cost/finance-related indicators;
- (3) maintenance task-related indicators;
- (4) customer satisfaction-related indicators;
- (5) learning and growth-related indicators;
- (6) HSE; and
- (7) employee satisfaction-related indicators.

Source: Adapted from Parida *et al.* (2005)

Figure 5.
Suggested multi-criteria
maintenance performance
measurement (MPM)
framework for balling area
of KK3 Plant of LKAB

The new set of MPIs developed under these seven criteria was critically checked both qualitatively and quantitatively for the balling area of KK3 Plant of LKAB. The MPIs are:

- downtime (hours);
- change over time;
- planned maintenance tasks;
- unplanned tasks;
- number of new ideas generated;
- skill and improvement training;
- quality returned;
- employee complaints; and
- maintenance cost per ton.

The existing and new set of MPIs under seven criteria of the multi-criteria MPM framework for balling area of KK3 Plant of LKAB is given in Figure 5. Some of the corresponding values for the indicators using the real data are given for the year 2006 in this figure.

6. Conclusion

An attempt has been made in this case study to study the existing system, identify the relevant maintenance indicators and adapt a balanced, holistic and integrated MPM model for the balling area of KK3 plant of LKAB and to align the plant performance with the corporate strategy. The short plant stops and planned maintenance stops data have been analyzed and relevant maintenance indicators were identified for effective monitoring and control of maintenance, during the conduct of this study.

References

- Andersen, B. and Fagerhaug, T. (2002), "Eight steps to a new performance measurement system", *Quality Progress*, Vol. 35 No. 2, p. 1125.
- Eccles, R.G. (1991), "The performance measurement manifesto", *Harvard Business Review*, January-February, pp. 131-7.
- Engelkemeyer, S. and Voss, R. (2000), "Bearing the gift of royal performance indicators", *Quality Progress*, Vol. 33 No. 2, pp. 35-9.
- European Environment Agency (EEA) (1999), *Environmental Indicators: Typology and Overview*, Technical Report No. 25, EEA, Copenhagen.
- Kaplan, R.S. (1983), "Measuring manufacturing performance: a new challenge for managerial accounting research", *Accounting Review*, Vol. 58 No. 4, pp. 686-703.
- Kennerly, M. and Neely, A. (2003), "Measuring performance in a changing business environment", *International Journal of Operation & Production Management*, Vol. 23 No. 2, pp. 213-29.
- Kumar, U. and Ellingsen, H.P. (2000), "Development and implementation of maintenance performance indicators for the Norwegian oil and gas industry", *Proceedings of the 14th International Maintenance Congress (Euro Maintenance 2000)*, 7-10 March 2000, Gothenburg, Sweden, pp. 221-8.
- Lingle, J.H. and Schiemann, W.A. (1996), "From balanced scorecard to strategy gauge: is measurement worth it?", *Management Review*, March, pp. 56-62.
- Lynch, R.L. and Cross, K.F. (1991), *Measure up – The Essential Guide to Measuring Business Performance*, Mandarin, London.
- Murthy, D.N.P., Atrons, A. and Eccleston, J.A. (2002), "Strategic maintenance management", *Journal of Quality in Maintenance Engineering*, Vol. 8 No. 4, pp. 287-305.
- Parida, A. and Chattopadhyay, G. (2006), "Development of multi-criterion hierarchical framework for maintenance performance measurement", *Journal of Quality in Maintenance Engineering*, (submitted for publication).
- Parida, A. and Kumar, U. (2004), "Application of overall equipment effectiveness (OEE) as a process performance indicator: a case study from Kiruna Mines", *ENTMS 2004*, 11-12 May, Bhubaneswar, India, pp. 32-5.
- Parida, A., Ahren, T. and Kumar, U. (2003), "Integrating maintenance performance with corporate balanced scorecard", *COMADEM 2003, Proceedings of the 16th International Congress*, 27-29 August 2003, Växjö, Sweden, pp. 53-9.

Parida, A., Chattopadhyay, G. and Kumar, U. (2005), "Multi criteria maintenance performance measurement: a conceptual model", *Proceedings of the 18th International Congress of COMADEM, 31 August-2 September 2005, Cranfield, UK*, pp. 349-56.

Wireman, T. (1998), *Developing Performance Indicators for Managing Maintenance*, Industrial Press, New York, NY.

**MPIs for LKAB:
a case study**

Corresponding author

Aditya Parida can be contacted at: aditya.parida@ltu.se

337