KEY PERFORMANCE INDICATORS IN PLANT-WIDE CONTROL

Sebastjan Zorzut, Vladimir Jovan
Jozef Stefan Institute, Jamova 39, SI-1000 Ljubljana, Slovenia

Alenka Žnidaršič
Metronik d.o.o., Stegne 9a, SI-1000 Ljubljana, Slovenia

Keywords: Key performance indicators; Production management; Decision support systems; Closed-loop control.

Abstract: To improve production performance it is necessary to define production goals with a proper implementation strategy and a suitable closed-loop control for their achievement. A promising solution is the use of the Key Performance Indicators (KPIs) approach. To verify the idea of production feedback control using production KPIs as referenced controlled variables, a procedural model of a production process for a polymerisation plant has been developed. The model has been used during a number of simulation runs performed with the aim of developing and verifying the idea of KPI-based production control.

1 INTRODUCTION

A production process involves several business and technical activities on and around the factory floor. Its effectiveness can be assessed using information hidden in a set of current and historical production data. The problem of extracting the relevant information from production data for fast and accurate decision-making can be solved by introducing a set of production KPIs (Vicens et al, 2001; Lohman, 2003) that show the operational and mid-term efficiency of the production. On the strategic management level, the problem of overall business efficiency in a production factory is already being solved with this approach (DeBusk, 2003), while on a production management level the implementation of KPIs is a rather new concept. The solution lies in defining an appropriate set of KPIs that are specific to the observed production process, and in defining the strategy for using KPIs to efficiently manage that process. Recently, a balanced set of general KPIs for the production management level has already been introduced (Rakar et al, 2004) and five principal KPIs for process-oriented productions were defined: Safety and Environment; Production Efficiency; Production Quality; Production Plan Tracking; and Employees Issues.

2 CLOSED-LOOP PRODUCTION MANAGEMENT PARADIGM

The desired global production objectives in the context of production management system can be more objectively defined as the reference values for significant measures of plant efficiency, production plant productivity, mean product quality and others. These production objectives are often called implicit objectives as they usually can be expressed only implicitly as functions of the measurable and manipulatable variables (Stephanopoulos and Ng, 2000). Since implicit objectives are not directly measurable, their translation into a set of output production process variables should be provided. These output production process variables should have the following properties (Skogestad, 2004): (i) they should be more easily measurable, (ii) it must be possible to handle maintaining their set point values by proper adjustments of manipulatable production process variables, and (iii) when maintained at the desired optimal set-points through the feedback control subsystem, they should inherently contribute to the overall profitability of a production process. These variables are denoted in this paper as “production KPIs” (see Figure 1).

Zorzut S., Žnidaršič A. and Jovan V. (2006).
KEY PERFORMANCE INDICATORS IN PLANT-WIDE CONTROL.
In *Proceedings of the Third International Conference on Informatics in Control, Automation and Robotics*, pages 179-182
DOI: 10.5220/0001201301790182

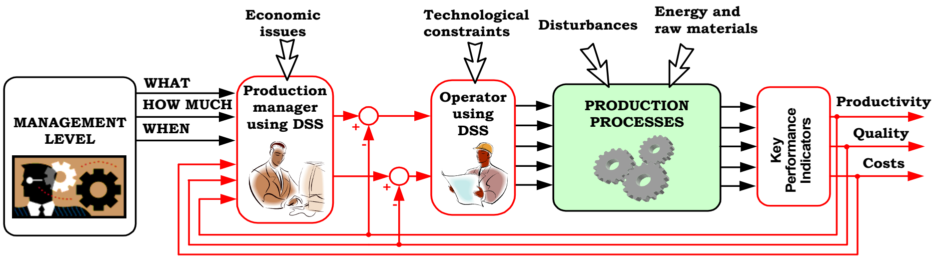

Figure 1: Closed-Loop Control Structure of the Production Process.

This production control problem can be mathematically formulated as in (Stephanopoulos and Ng, 2000):

Let z_{PROFIT} represents the operating profit:

$$z_{\text{PROFIT}} = \sum \text{product values} - \sum \text{raw material costs} - - \sum \text{production costs}.$$

The feedback-based solution leads to the following optimisation problem:

$$\text{Minimize}\left\| z_{\text{PROFIT,sp}} - z_{\text{PROFIT}} \right\| = \left\| \min_{\mathbf{u}_{\text{fb}},\mathbf{y}_{\text{fb}},\text{sp},\mathbf{C}(.)} z_{\text{PROFIT}}(\mathbf{u},\mathbf{y},\mathbf{d}) - z_{\text{PROFIT}}(\mathbf{u},\mathbf{y},\mathbf{d}) \right\|$$

subject to

$$\begin{array}{ll} \mathbf{y} = \mathbf{h}(\mathbf{u},\mathbf{y},\mathbf{d}) & \text{plant dynamics} \\ \mathbf{g}(\mathbf{u},\mathbf{y},\mathbf{d}) \leq 0 & \text{process constraints} \\ \mathbf{d} \in \mathbf{D} & \text{process disturbances} \\ \underline{\mathbf{U}} \leq u_{\text{fb}} \leq \overline{\mathbf{U}} & \\ \mathbf{u}_{\text{fb}} = \mathbf{C}(\mathbf{y}_{\text{fb}}). & \end{array}$$

where, $\mathbf{u}_{\text{fb}}$ and $\mathbf{y}_{\text{fb}}$ denote the manipulations and measurements involved in the feedback-based solution and $\mathbf{C}$ is the structure of the entire production control system.

3 THE CASE STUDY

The polymer emulsion batch production process taken in this paper for the case study is a typical representative of process-oriented production where production effectiveness to a great extent relies on the quality of the production control system. The process is described in more details in (Jovan and Zorzut, 2006).

A procedural model of the case study production process has been developed to facilitate experimenting and the verification of the closed-loop control structure. The model was designed in the academically established *Matlab*, *Simulink* and *Stateflow* simulation environments. The simulated data are stored in the *MS Access* database and are available for different on-line or off-line processing.

Given the final objective of stabilising the existing production process, a promising idea is to introduce a closed-loop production management concept so that specific production KPIs serve as the reference values for the closed loop production control system. It is hypothesised that such an approach can contribute to more stable production and better final product uniformity and quality. Three production KPIs were chosen to characterise the case study production process:

- *Productivity* (also denoted as actual production rate or production yield). Productivity is defined for the described production process as the amount of all products that were produced over a set production period. All batches finished within the set time window (production period) are taken into account and the average amount of products produced in an hour is calculated.
- *Mean Product Quality*. The Mean Quality KPI is calculated as the mean value of the quality factors for the batches completed in the set time window.
- *Mean Production Costs*. Production costs consist of raw material costs, energy costs, other operating costs and fixed costs in the set time window. The mean production costs are calculated as the sum of all production costs within a time window, divided by the amount of all products produced in this time window.

These three KPIs represent the output (controlled) variables on Figure 1. Maintaining the predefined set points for these KPIs is achieved by properly adjusting the manipulated (input) variables, which are in this case: Raw Material Quality, Production Speed and Batch Schedule. Determining the influence of the input variables and disturbances on the output variables (selected KPIs) is essential for efficient production control.

3.1 Simulation Runs

To see how the production speed and the quality of raw materials affect productivity, product quality and production costs, a simulation run was performed. Simulation run was divided in three phases, where the production speed was changed from low to normal and finally to high. On Figure 2 the first phase lasts from 0 to 450 hours of simulation time, the second phase from 450 to 870 hours and the third phase from 870 till the end. In each phase the quality of the raw materials was subsequently increased from low to very high (0.85 to 1.1). The KPIs for Product Quality, Productivity and Production Costs were observed. The KPIs were evaluated every 12 hours for the time window of 120 hours.

Figure 2 represents the response of the Product Quality KPI. In the first phase of the simulation run the production speed was low, which represents the best working conditions in the production process. Over the simulation run the quality of raw materials gradually increased and the influence of this change on the Product Quality KPI can be observed. As expected, better quality raw materials contribute to better quality final products.

In the second phase of the simulation run the production speed is increased, which usually leads to decreasing production process quality. Raw material quality changed in the same manner as in the previous phase: from low to high. The Product Quality KPI first decreased and when it reached the bottom it started increasing as in the first phase. The change in product quality is momentary but the change in the Product Quality KPI is gradual. The KPI evaluation algorithm averages the product quality in the set time window, which can be seen in this section of the figure. The second interesting phenomenon is the influence of production process quality on product quality. The mean quality of the products decreases by about 10 %. In the third phase the pattern is repeated.

Figure 3 represents the Productivity KPI for the same simulation run. The Productivity KPI has slightly increasing trend with higher production speed. At the beginning of the third phase of the simulation run high production speed causes the significant decrease of productivity. This is the result of coincidence that the quality of the production process and also the quality of the raw materials are low. Consequently, some batches do not attain prescribed quality requirements and they have to be recycled, what affects Productivity KPI. The appearance of off-spec batches can be noticed on the Figure 3 (time period from 900 to 950 hours) where the reactor occupancy for some batches is increased due to the need of recycling of bad batches entering in the production process.

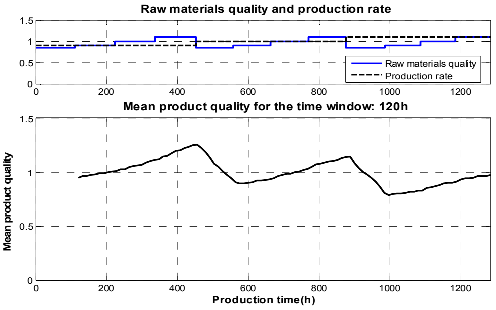

Figure 2: Response of the Mean Product Quality KPI to Raw Material Quality and Production Speed.

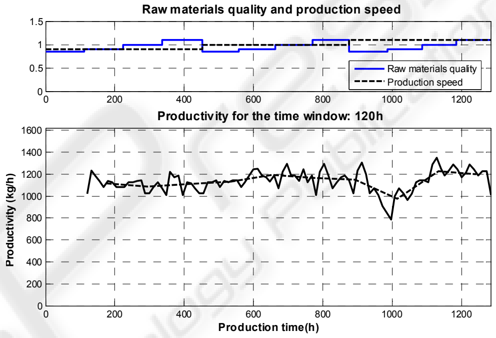

Figure 3: Response of the Productivity KPI to Raw Material Quality and Production Speed.

Figure 4 represents the mean Production Costs KPI. The production costs per product unit increase with the increasing quality of raw materials. There is a slight increase in costs with increasing production speed.

The following simulation run presents the open-loop control of the Product Quality KPI.

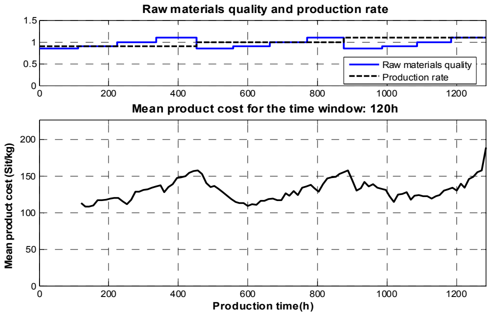

Figure 4: Response of the Mean Production Costs KPI to Raw Material Quality and Production Speed.

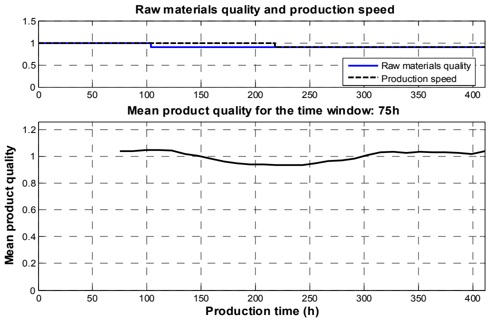

Figure 5: Open-Loop Control of the Product Quality KPI.

The experiment represents the execution of a normal schedule of production jobs using raw materials with normal quality at normal production speed. After a certain time period, a disturbance occurs in the form of a decrease in the quality of raw materials, which is reflected in the considerable decreased value of the mean of the Product Quality KPI (see Figure 5).

As an open-loop control action the production manager then slows down current production speed. The quality of both the production process and final product gradually increase, and consequently this is reflected in the increase in the mean value of the Product Quality KPI. This is not the only possible action that production manager could take, but in the presented case it was sufficient to eliminate the disturbance.

4 CONCLUSIONS

The ideal plant-wide control system should ensure that the production process is constantly working in an optimal manner. As a result of the plant-wide focus, a plant-wide control problem possesses certain characteristics that are not encountered in the design of control systems for single units, such as the following (Stephanopoulos and Ng, 2000): (a) the variables to be controlled by a plant-wide control system are not as clearly or as easily defined as for single units; (b) local control decisions, made within the context of single units, may have long-range effects throughout the plant; (c) the size of the plant-wide control problem is significantly larger than that for the individual units, making its solution considerably more difficult.

This paper proposes an approach to measuring and presenting the attainment of production objectives in the form of production KPIs. With this approach the implicit production objectives were translated into measurable values that can be extracted from existing production data. In this way the production control concept and the role of a production manager are slightly changed; instead of monitoring and controlling several tens and hundreds of process variables at a low production level, a production manager monitors and controls only a few major production KPIs with the aim of achieving the most important implicit production objectives, e.g. high product quality, high productivity and minimal production costs.

The procedural model of the case study production process has been developed and used in a number of simulation runs. The preliminary simulation results presented indicate that this work could evolve towards the implementation of a production KPI-based control system in a real industrial plant. The intention in future is to improve the existing production process model, validate it rigorously and incorporate it into a Decision Support System for production control in the polymerisation plant that was used as the case study production process in this paper.

REFERENCES

DeBusk, G. K., Brown, R. M., Killough, L. N. (2003): Components and relative weights in utilization of dashboard measurement systems like the Balanced Scorecard, *The British Accounting Review*, Volume 35, Issue 3, pp. 215-231.

Jovan, V. and Zorzut, S. (2006): Use of Key Performance Indicators in Production Management, *Proceedings of the IEEE International Conference on Cybernetics and Intelligent Systems*, 7.-9. June, Bangkok, 2006.

Lohman, C., Fortuin, L., Wouters, M. (2004): Designing a performance measurement system: A case study, *European Journal of Operational Research 156*, Elsevier press, pp. 267-286.

Rakar, A., Zorzut, S., Jovan, V. (2004): Assesment of production performance by means of KPI, *Proceedings of the Control 2004*, 6-9 September, 2004, University of Bath, UK.

Skogestad S. (2004): Control structure design for complete chemical plants, *Computers and Chemical Engineering 28*, pp. 219-234.

Stephanopoulos G., Ng C. (2000): Perspectives on the synthesis of plant-wide control structures, *Journal of Process Control 10 (2000)*, pp 97-111.

Vicens, E., Alemany M. E., Andres C., Guarch J. J. (2001): A design and application methodology for hierarchical production planning decision support system in an enterprise integration context, *Int. Journal of Production Economics 74*, Elsevier Press, pp. 5-20.