Use of Flow Control on Car Dumpers
A Case of Success at Vale

Bruno Eduardo Lopes and Luis Freitas Coutinho
Vale, Departamento de Inovação e Desenvolvimento, Av. Dos Portugueses, S/N, Itaqui, 65085-580, MA, Brazil

Keywords: Car Dumper, Flow Control.

Abstract: The flow control of the car dumper (VV, in Portuguese) used to be done in open loop, i.e., operators used to manually adjust the speed of the feeders (AL, in Portuguese) to make the actual flow equal to the desired flow. The problem was that these manual adjustments were not always performed properly and the result was a loss in productivity and the occurrence of overflow on the feeders. This work demonstrates the techniques of control, modelling and identification used for the implementation of flow control in closed loop in the car dumpers at the Ponta da Madeira Maritime Terminal, Vale.

1 INTRODUCTION

The car dumper (VV) is a structure that turns the wagon at around 160° (max 180°) on its horizontal axis. While turning the wagon is locked in its position by an anchoring system. During the turn, the iron ore falls into a system called *feeder* and is directed to a conveyor belt leading to the material storage yard or directly to the ship. The use of car dumpers brings great agility to the process of unloading wagons in comparison to other methods used today.

Vale's unload area at the TMPM (Maritime Terminal of Ponta da Madeira) is currently composed of four car dumpers, with a nominal production capacity of 8,000 ton/h, being able to unload two wagons simultaneously.

The car dumper installed at the TMPM has the following systems which operate in an integrated manner:

- Turner
- Car Pusher
- Winch of the Car Pusher
- 2 Hoppers
- 2 Feeders
- Reversible Movable Conveyor Belt
- Subsystems (hydraulic units, lubrication units, hydraulic locks, etc.).

Previously, the flow control of the car dumpers at TMPM was done in open loop, i.e., to control the flow the operators had to manually adjust the speed of the feeder, as shown in Figure 1, until the actual flow reached the desired value.

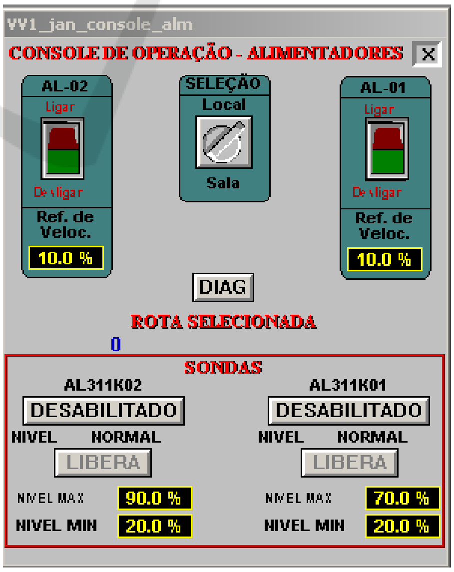

Figure 1: Manual adjustment of the feeders speed at VV01.

However, in order to maintain the levels of the hoppers under each car dumper close to each other, the operator had to increase or decrease the difference in speed between the feeders, and then try to find a new speed relationship to make the actual flow equal to the desired setting. The problem was that these manual adjustments were not always performed properly, and the end result was a loss in productivity or the occurrence of overflow at the

Eduardo Lopes B. and Freitas Coutinho L..
Use of Flow Control on Car Dumpers - A Case of Success at Vale.
DOI: 10.5220/0003990505800584
In *Proceedings of the 9th International Conference on Informatics in Control, Automation and Robotics* (ICINCO-2012), pages 580-584
ISBN: 978-989-8565-21-1

feeders.

Basically, the flow control implemented in the car dumpers is a closed loop control, where the process variable is the estimated flow of the material at the output of the feeders and the control variables are the rotational speeds of these feeders. The estimated flow of material is calculated from the velocities and currents of the feeders and corrected with the readings of the existing physical flow scale at another point in the discharge line. The logic diagram of the flow control is shown in Figure 2.

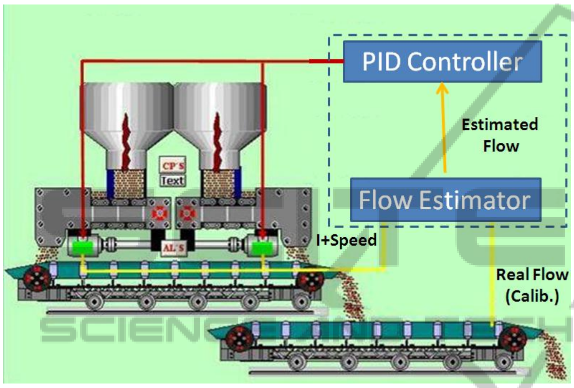

Figure 2: Logical diagram of the flow control.

This article demonstrates the theories used to carry out the implementation of this flow controller and the results obtained with this implementation.

2 FLOW ESTIMATOR

2.1 Mathematical Modelling

Due to the distance between the car dumper and the flow scale located at the discharge line, and its consequent time delay, which would hinder the implementation of a flow control, it was necessary to develop a mathematical model that would represent the flow at the discharge line (estimated flow). Using the estimated flow as the process variable (PV) eliminates the effects of the time delay, also known as dead time (Smith, 1957; Astrom et. Al, 1994; Hagglund, 1992; Astrom et. Al, 1995), allowing the implementation of the flow control logic.

For the development of the estimated flow it was first necessary to perform the data acquisition of the actual flow (through the flow scale in the discharge line), current and speed of the feeders. After the acquisition of the data, a mathematical model relating the data acquired was created in order to obtain the estimated flow. In order to mathematically represent the estimated flow, the ARX linear model (Aguirre, 2007), was used together with the Extended Least Squares Method (Aguirre, 2000) to estimate the parameters. To determine the order of the model we used the Method of Analysis of Eigenvalues for linear models (Lopes et al., 2010).

The mathematical model for the car dumper 01 (VV01), obtained using the least squares estimator is shown below.

$$y(t) = (-3.445 * u1(t)) + (80.31 * v1(t)) - (0.5513 * u2(t)) + (89.11 * v2(t)) \quad (1)$$

Where: y= Estimated flow, u1= Current of the motor powering feeder 01, v1 = speed of the feeder 01, u2 = Current of the motor powering feeder 02 and v2= Speed of the feeder 02.

The model was implemented in a PLC (Programmable logic controller) controlling the car dumper VV01 and Figure 3 shows, through actual data extracted from the PIMS (Process Information Management System), a comparison between the estimated flow (Green) and the real flow (Pink). The analysis of the graphic shows that the estimated flow is a good representation of the actual flow.

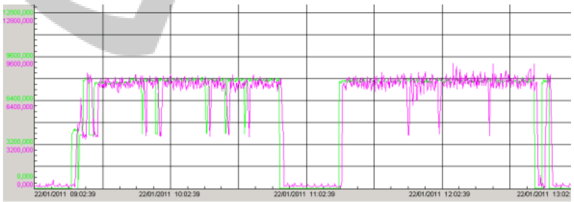

Figure 3: Comparison between estimated and actual flow.

2.2 Reinforcement Learning

To ensure that the estimated flow is corrected over time, a new technique of reinforcement learning was implemented. This technique consists of comparing the results of the estimated flow with the actual flow to create a correction factor. This correction factor is then applied to the estimated flow. The reinforcement learning logic was implemented in the car dumpers supervisory system.

As shown in Figure 4, each car dumper may operate on four of the discharge lines and a discharge line may be used by more than one car dumper.

The reinforcement learning technique was based on the following information:

- Knowledge of the discharge line being used by the car dumper;

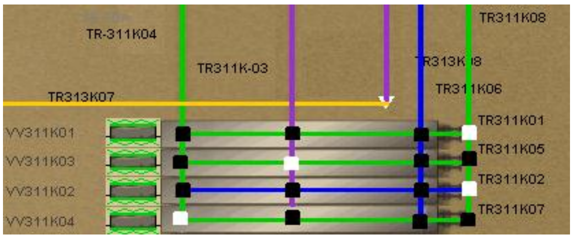

Figure 4: Car dumpers (VV) and their discharge lines.

- Whether there is another car dumper using the same discharge line. If so, the flow control should be disabled;
- Knowledge of the time delay between the car dumper and the flow scale at the selected discharge line.

In order to allow the operator to verify the estimated flow, the information shown in Figure 5 was made available. The operator may, through the supervisory system, check the value of the estimated flow, the value of the calibration factor obtained by the technique of reinforcement learning and may also enable/disable the calibration of the estimated flow.

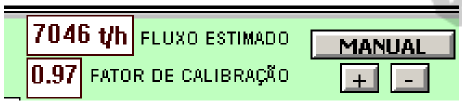

Figure 5: Information for monitoring the estimated flow.

Figure 6 shows the performance of reinforcement learning technique. It is possible to verify that there is an error between the estimated flow (red) and actual flow (blue) shown by the flow scale. The moment was activated estimated flow calibration (using reinforcement learning technique) estimated corrected flow (Green) is now correctly represent the actual flow.

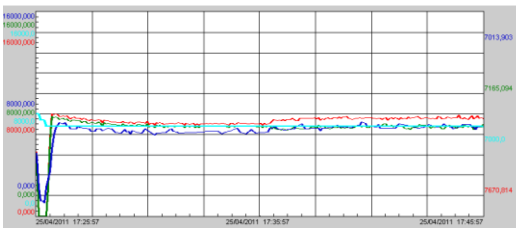

Figure 6: Comparison of the actual flow in ton/h (Blue) X Estimated Flow (Red) X estimated corrected flow (Green).

3 FLOW CONTROL

The flow control needs the operator to inform the desired flow (SP – Set Point) and a PID controller adjusts the speed of the feeders (CV - Controlled Variable) to make the estimated flow equal to the corrected desired flow.

In addition to informing the desired flow the operator can adjust through the supervisory system the speed difference between the feeders. The goal is to make the level of the hoppers always close to each other. If the operator activates the level control, this difference in speed is calculated automatically by the control system.

Figure 7 shows the screen that was developed in the supervisory system for adjusting the set point, the speed difference between the feeders and to enable or disable the flow control.

Figure 7: Screen to adjust the set point and speed difference between feeders.

Both the mathematical model used to estimate the flow and the PID controller used to control the flow were implemented on the PLC responsible for controlling the car dumpers.

3.1 Flow Control Integrated with Level Control

The car dumper has a hopper that collects the load of the cars being turned. The hoppers on each side must have a level transmitter that checks the material that is unloaded from each wagon.

This system monitors the level of ore in the hoppers, as shown in Figure 8. The level is measured during the intervals when the wagons are not being turned. In order for the level measurement to work, the following logic must be implemented in the PLC:

- Low level in the hopper: Disable flow control and reduced speed of feeders;

- Very low level of hopper: Disable flow control and shutdown of feeders shoe;
- Very high level in the hopper: Keep active flow control and turners blocked for discharge.

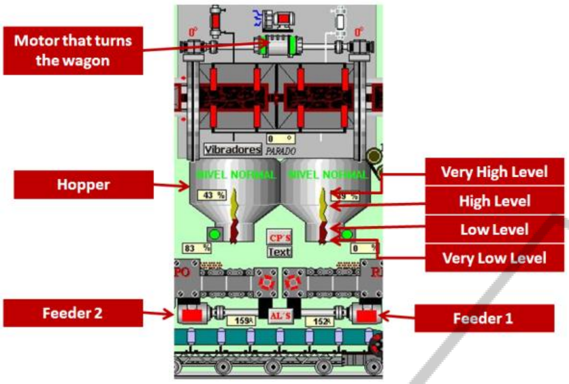

Figure 8: Monitors the level of ore in the hoppers.

Using a level transmitter it was possible to implement a cascade control between the levels of the hoppers and the discharge flow. The goal is to control the speed difference between the feeders in order to maintain the level between the hoppers always close to each another, keeping the output flow at the desired value.

4 RESULTS

4.1 Flow Control

The performance achieved with the implementation of the flow control can be seen in Figure 10, where the operator provides different values of set point (Red) and the controller automatically adjusts the speed of the feeders to make the estimated corrected flow (Green) equal to the established set point.

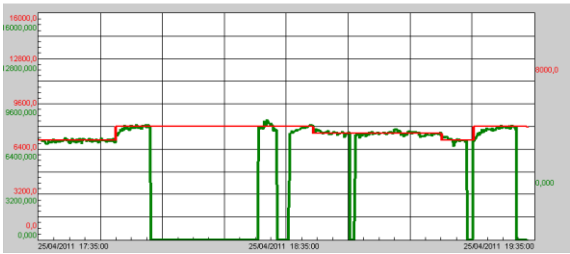

Figure 9: Flow Control Performance.

As can be seen in Figure 9 the flow control performed well, because every change made to the set point was rapidly followed by a correct change to the speed making the flow equal to the estimated set point.

The main gain with the implementation of flow control was to reduce the standard deviation and variability of the average rate (in ton/h) of the discharge flow. This result is shown in Table 1.

Table 1: Gains obtained with the Flow Control.

Month	Average Rate (ton/h)	DP Within (ton/h)	Cpk
April	7698	312	0.21
May	7866	192	0.64
June	7859	170	0.70
July	7894	154	0.85

Using the table we can see that after the implementation of the Flow Control a 51% reduction in standard deviation (DP Within) rate and a 303% reduction in variability (Cpk). With this solution we have a controller that automatically adjusts the speed of the feeders to follow the desired flow, thus eliminating the need for operator intervention. As a result, a 2.5% increase in the average rate of sinter feed, which is equivalent to over 8 hours of operation per month.

Using the estimated flow variable, it was possible to develop a solution for tracking the productivity of the car dumpers online. With the development of this solution was possible to increase the level of information in the discharge process, because only then it was possible to obtain some information online, such as productivity, volume turned and run time for each day of operation of the car dumpers. Figure 10 shows this information being monitored through PIMS.

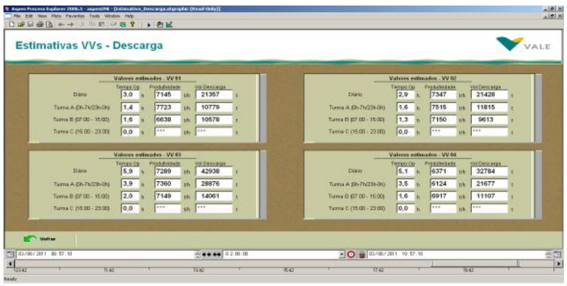

Figure 10: Screen created for monitoring the estimated variables.

We conducted a comparison between the estimated values and data extracted from SGOP (System developed by Vale to Management of Port Operations) for car dumper 1 (VV01) during the month of May 2011 and the result can be seen in Figure 11. This figure shows that the percentage of accuracy of the estimated data is close to 100%.

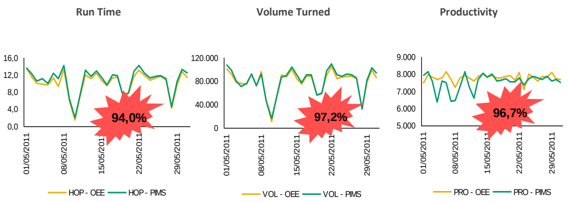

Figure 11: Comparison between data extracted from SGOP and the estimated values.

It is worth emphasizing that the biggest difference in the comparisons between the PIMS and SGOP is in the amount of hours of operation. The amount of hours informed by operator is always lower than that calculated by the PIMS. This shows a possible problem with the appropriation of hours informed by the operator.

5 CONCLUSIONS

The results presented in this paper showed that the new standard adopted by Vale to control the discharge flow of iron ore at the TMPM car dumpers brought a significant reduction in variability and standard deviation with a significant increase in productivity. The reductions were the main gain of the project, because the constancy of the flow is healthy for the equipment, as well as for the entire process route.

Because of the gains obtained with this new flow control standard developed at the TMPM terminal it was established as the standard to be used by other ports of Vale.

REFERENCES

Aguirre, L. A., 2000. A nonlinear dynamical approach to system identification, *IEEE Circuits & Systems Society Newsletter* 11(2): 10-23, 47.

Aguirre, L. A., 2007. Introdução a Identificação de Sistemas. Técnicas Lineares e Não Lineares Aplicadas a Sistemas Reais. *Editora UFMG*, Belo Horizonte - MG. Brasil, 3a edição.

Lopes, B. E, Corrêa, M. V., Teixeira, R. A. and Moura, J. P., 2010. Método de Análise dos Autovalores para seleção de ordem de modelos lineares. *Anais do 18º Congresso Brasileiro de Automática*, Bonito MS, pp. 498 — 504

Astrom, K., Hang C., Lim, B., 1994. A New Smith Predictor for Controlling a Process with a Integrator and Long Dead Time. *IEEE Transaction on Automatic Control* 39(2): 343-345

Hagglund, T., 1992. A Predictive PI Controller for Processis with Long Dead Time. I*EEE, Control Systems*, pp57-60.

Smith, O. J. M., 1957. Closed Control of Loops With Dead-Time, Chem. Eng. Progress; 53:217-219.

Astrom, K. J., Hagglund T., PID Controllers: Theory, Design, and Tunning. *2ª Edition, Instrument Society of America*, 1995.