INSTRUMENTATION DESIGN AND UPGRADE USING AN UNCONSTRAINED METHOD WITH PURE ECONOMICAL OBJECTIVES

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Abstract

This article presents a methodology to design linear instrumentation networks, that is, networks that are designed to produce estimates of material flows, using economic goals only. To do this, a link between accuracy of key variables is linked to a value function and a net present value (NPV) function is then constructed. This NPV function is minimized over all possible configurations of sensors.

Keywords

Instrumentation Upgrade, Data Reconciliation.

Introduction

Instrumentation is needed in process plants to obtain data that is essential to perform several activities. The problem of instrumentation network design and upgrade consists of determining the optimal set of measured variables and selecting the accuracy and reliability of the corresponding instruments (Bagajewicz, 2000). One of the difficulties of the existing approach is that the model is based on thresholds of different instrumentation properties (residual precision, gross error detectability, resilience, etc), for which the process engineer has no feeling about their impact on cost. To address the above limitations, a multicriteria approach to the problem was proposed (Viswanath A. and S. Narasimhan, 2001; Cabrera and Bagajewicz, 2001; Carnero *et al*, 2001a,b). While exploring pareto optimal surfaces can tell what performance is obtained at different costs, it still leaves the practitioner with a vague notion about the monetary value of the project. For example, the cost benefit relationship of increasing error detectability cannot be obtained because there is no direct relationship between this property and profitability. To ameliorate these difficulties, Bagajewicz (2002) proposed to relate all sensor network properties (precision, residual precision, error detectability, etc.) to lost/increased revenue functions converting the problem into an unconstrained one based on cost or cost-benefit only, and illustrated the case of quality loss. In this paper, we extend the aforementioned ideas to quantifying the monetary value of precision of estimates of flows in process plants.

ECONOMIC VALUE OF PRECISION

A typical refinery consists of several tank units that receive the crude, several processing units, and several tanks were products are stored. All this can be summarizes in three blocks as in figure 1.

Figure 1. Material balance in a Refinery

In this figure, *H* represents hold ups and *m* flowrates. To help introducing concepts, consider for the time being the following simplistic scenario: 1) Raw materials are purchased and stored at the beginning of operations and are very well measured. That is, m_P is only non-zero for a small fraction of time close to the beginning of activities and *is* very accurately measured. 2) Sales take place at the end of the processing period and are also very accurately measured. In other words, $H_S(T)$ is known, but only at time *T*, not before. 3) Steady state.

Expected Downside Financial Loss and Risk: In the absence of leaks, the expected value of $H_S(T)$ is only related to the level of processing, that is to the true value of m_2. However, since m_2 is only known through its measurements throughout time, this true value is not known, only an estimate is. Consider now that a target production H_S^* at the end of the time period T is pursued. Therefore, only if $m_2^* = H_S^* / T$, there is certainty that the target will be met. Otherwise, the probability of not meeting the targeted production is $P\{H_S(T) \le H_S^*\}$, which in turn can be rewritten as $P\{m_2 \le m_2^*\}$, that is, it is equal to the probability of the true value of m_2 being smaller than the measurement. Suppose only measurements of m_2 are performed with variance $\sigma_{2,m}^2$. Since only a finite number of measurements are performed, then, assuming these measurement follow a normal distribution, an estimate of m_2, say $\hat{m}_2$ has a normal distribution of $\hat{\sigma}_{2,m}^2 = \sigma_{2,m}^2 / (N+1)$, where N is the number of such measurements. Thus $\hat{m}_2$ is the estimate one has of the true value of m_2. Consider then that production is adjusted to meet the targeted value, based on the estimate. Thus, if $\hat{m}_2 < m_2^*$, production is increased and vice versa, if $\hat{m}_2 > m_2^*$, production is decreased.

We now look at only a period of time, say a day, before the decision to increase or decrease production is made. We therefore need to assess the following conditional probability $P\{m_2 \le m_2^* | \hat{m}_2 \le m_2^*\}$, that is, the probability of missing the target given the estimate. Assuming these are independent, the above probability is equal to $P\{m_2 \le m_2^*\} P\{\hat{m}_2 \le m_2^*\}$.

However, $P\{\hat{m}_2 \le m_2^*\}$=0.5 and $P\{m_2 \le m_2^*\}$=0.5, because the expected value of $\hat{m}_2$ is m_2. Therefore

$$P\{m_2 \le m_2^* | \hat{m}_2 \le m_2^*\} = 0.25 \qquad (1)$$

The downside expected financial loss is $DEFL(\hat{\sigma}_{2,m}) = K_S T \int_{-\infty}^{m_2^*} (m_2^* - \xi) g(\xi, \hat{\sigma}_{2,m}) d\xi$, or $DEFL(\hat{\sigma}_{2,m}) = K_S T \gamma_{0.5} \hat{\sigma}_{2,m}$, where K_S is the value of the products sold and $\gamma_{0.5} \approx 0.2$.

Thus, there is a 25% chance that the target production is not met. If happens, the average flowrate deviation from m_2^* is $\delta^* = DEFL(\hat{\sigma}_{2,m}) / K_S T = \gamma_{0.5} \hat{\sigma}_{2,m}$. The above 25% probability can also be seen as the risk one is incurring. The above idea can be generalized to an arbitrary value of probability/risk, considering a downside deviation from the target production m_2^*.

DATA AND INSTRUMENTATION UPGRADE

Now consider a new and smaller value of $\hat{\sigma}_{2,m}$, say $\tilde{\sigma}_{2,m}$ obtained from performing data reconciliation and/or new instrumentation. Then the economic value of upgrading the data handling systems and/or the instrumentation to obtain the new estimate is given by the difference of downside financial loss expected with less precise instrumentation and the corresponding downside expected financial loss with the new instrumentation: $V(\hat{\sigma}_{2,m}, \tilde{\sigma}_{2,m}) = DEFL(\hat{\sigma}_{2,m}) - DEFL(\tilde{\sigma}_{2,m})$, which is given by: $V(\hat{\sigma}_{2,m}, \tilde{\sigma}_{2,m}) = K_S \gamma (\hat{\sigma}_{2,m} - \tilde{\sigma}_{2,m})$

Thus, the net present value of the upgrade program is:

$$NPV = V(\hat{\sigma}_{2,m}, \tilde{\sigma}_{2,m}) \sum_{i=1}^{N} d_i - Investment \qquad (2)$$

where d_i is the discount factor and N is the number of years. This formula can be used for example to justify the purchase of new data reconciliation packages and/or to justify the installation of new instrumentation.

EXAMPLE

A flow sheet of a vacuum unit for crude distillation is shown in Figure 2 (U12 represents the furnace U13 the main column and U14/1/4 are side strippers). The values of mass flow for process streams and the reconciled values are given in Table 1.

Net Present Value of performing data reconciliation: From Table 1, one can notice that without data reconciliation, the total production can be obtained by adding streams 28 through 34. This amounts to 146940 kg/h with a standard deviation of 562 kg/h. After reconciliation the total flow of products amounts 145303kg/h with a standard deviation of 405 kg/h. The downside financial loss (with 50% probability is) $K_S T \gamma_{0.5} \hat{\sigma}_{2,m}$ =49800 \$ per five years.

Net Present Value of new instrumentation: Table 2 shows the net present value obtained from adding one instrument in the indicated streams. The data used is as follows. Investment cost of flow meters: 11,000\$ (1% standard deviation), life time: 5 years, prices of products: 0.58\$/kg-stream 28, 0.53\$/kg-stream 29, 0.48\$/kg-stream 30, 0.43\$/kg-stream 31, 0.38\$/kg-stream 32, 0.15\$/kg-stream 33 and 34, and crude oil 24\$/barrel. Table 3 explores the net present value of adding more instruments.

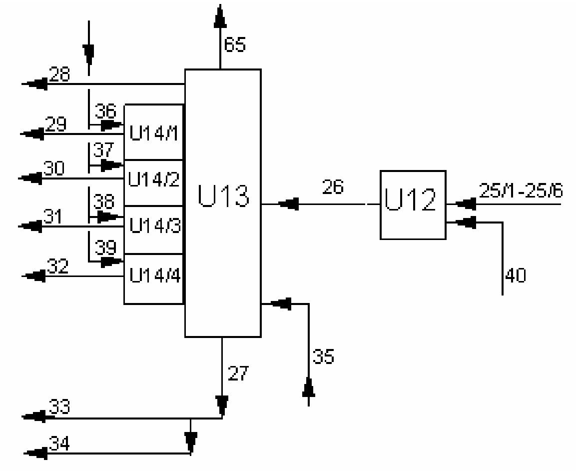

Figure 2: Flow sheet for vacuum unit

Table 1: Stream Data

Stream	Measured flow rate [kg/h]	Standard deviation [kg/h]	Flowrate after reconciliation (kg/h)	Standard deviation after reconciliation [kg/h]
25/1	23824	238	24118	228
25/2	24132	241	24434	230
25/3	23927	239	24223	228
25/4	24185	242	24488	235
25/5	23721	237	24012	227
25/6	23738	237	24029	227
26	-	562	145300	405
27	-	-	47424	311
28	18921	189	18736	183
29	19835	198	19632	192
30	23864	239	23568	227
31	18187	182	18015	175
32	18097	181	17927	175
33	27791	278	27391	261
34	20245	202	20034	195

Table 2: NPV of instrument addition

Stream/ location of new sensor	Standard dev. of new instrument [kg/h]	NPV [$]
25/1	238	-10,200
25/2	241	-10,170
25/3	239	-10,190
25/4	242	-10,180
25/5-6	237	-10,200
27	480	-5,740
28	189	15,240
29	198	14,080
30	239	15,400
31	182	6,930
32	181	4,420
33	278	-760
34	202	-3,350

Table 3: Effect of new flow meters on savings

No of streams-location of new sensors	Standard deviation of new instruments [kg/h]	NPV [$]
28, 29	189, 198	29,700
28, 30	189, 239	31,030
28, 31	189, 182	22,980
28, 32	189, 181	21,180
29, 30	198, 239	30,300
29, 31	198, 182	22,200
29, 32	198, 181	20,500
30, 31	239, 182	23,600
30, 32	239, 181	21,500
28, 29, 30	189, 198, 239	45,400
28, 29, 31	189, 198, 182	37,400
29, 30, 31	198, 239, 182	38,000
28, 29, 30, 31	189, 198, 239, 182	52,450
28, 29, 30, 32	189, 198, 239, 181	50,650
29, 30, 31, 32	198, 239, 182, 181	43,060
28, 30, 31, 32	189, 239, 182, 181	43,800
28, 29, 30, 31, 32	189, 198, 239, 182, 181	57,850
28, 30, 31, 32, 33	189, 239, 182, 181, 278	42,480
28, 29, 31, 32, 33	189, 198, 182, 181, 278	41,400
28, 29, 30, 31, 32, 33	189,198,239,182,181, 278	56,400
28, 29, 30, 31, 32, 34	189,198,239,182,181, 202	54,200
28, 30, 31, 32, 33, 34	189,239,182,181,278, 202	38,900

It is quite obvious that after a certain point the addition of new instrumentation either reaches the maximum amount of investment that a company is willing to make or the net present value starts to decline. While simple enumeration works well for this example, a systematic search of the optimal solution for larger systems can be done using existing procedures (Bagajewicz, 2000; Bagajewicz and Cabrera, 2002). A discussion of the efficiency of such procedures in large systems is beyond the scope of this article.

CONCLUSIONS

This article has introduced the basic concepts upon which an unconstrained approach to instrumentation network design and upgrade rest. Several issues remain unexplored: influence of biases, leaks, excess inventory, etc. Emphasis has been put in conceptual development rather than on case studies and solution procedures.

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