OPERATOR SUPPORT FOR DIAGNOSIS IN A FERTILIZER PLANT

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Abstract: We describe a modular architecture for process information systems. Each process unit is represented by a separate module that is connected to its neighbours in the process flow sheet through connections that represent the process streams. The resulting system is easy to configure and to maintain. The scheme forms the basis for a successful operator support system that has been in operation in a fertiliser plant since November 1992.

Keywords: Diagnosis, modularity, fertilizer plant

Introduction

Reducing the emission of pollutants is a major challange to the process industries. This challenge was the outset for the system reported in this paper. Taking an overall view on the problem every plant consists of three main parts; the process plant itself, an information and control system, and the plant operation organisation. All three parts will influence the emission of pollutants, hence reduction of emission may be invoked through all three channels. A typical measure on the process plant itself is to introduce material recycling and new cleaning technology. The information system can decrease emissions by improved control performance and by providing the plant operation organisation with precise information on emission status and on the cause of violations. Finally, emissions can be reduced by educating and motivating plant personel.

The focus at the Glomfjord plant in Glomfjord, Norway was on improvement through the development of an information system. The plant is a moderately complex chemical plant consisting of a large number process units such as mixing tanks, distillation columns and heat exchangers. To be able to think constructively about a process plant of this size one must break down the information into manageable chunks. This generally means that some kind of hierarchical decomposition is needed.

The central theme of this paper is the development of a method to enable the construction of modular process information systems. We propose to represent each process unit by a single module, comprising both estimation and diagnostic information and routines. The models and diagnostic logic to be used should be determined by the type of process unit. A library of models for the required units should be available to the system designer. Using these building blocks it will be easy to build information systems for complex processes. The goal is to make a system that can be configured by connecting unit modules in the same way that they are connected in the process flowsheet. The method will be presented in section Method. Further, the implementation is discussed in section Implementation.

As mentioned earlier the focus at the Glomfjord plant was on improvement through the development of an information system. To gain full advantage of the improvement of one part of the overall plant it is usually necessary to harmonize other parts of the overall system. In our case this means plant personel. We will, hence, in the Discussion section focus on worker participation in system development and implementation.

Investments are usually initiated to achieve some primary goals, in our case the reduction of emission. An investment, especially in information systems, will typically trigger a chain-reaction not necessarily anticipated prior to the project. This will also be a theme in the Discussion section.

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Important references to this paper are Mjaavatten (1994) and Saelid, Mjaavatten & Fjalestad (1992).

Method

A chemical process plant may be represented by a directed graph with the process units as nodes and the process streams as edges. The directions of the edges reflect the normal flow direction in the stream. We define the term *process topology* to mean the connection structure of this graph. The process topology is independent of the geometry of the plant, and neighbouring nodes may well be situated on different floors or in different buildings. In this section we describe how a diagnostic search can be structured by the process topology. The aim of the diagnostic system is to detect and help explain all disturbances that negatively affect the environment or product quality, and propose actions to remedy the situation. We will assume that well-defined quality parameters exist, which allow plant management to set clear-cut quality limits that the process should be kept within. These limits will generally encompass product quality, energy consumption and pollutant discharge. We introduce the term *episode* to denote an event where one or more of these limits are violated. The role of the detection and diagnosis system is to detect all such episodes and to find the process unit where the disturbance started (the initiating unit). This search may be followed by a more detailed local diagnosis to find one or more possible *primary cause* of the disturbance. We also want to detect disturbances before they lead to episodes. These disturbances result in a *warning*. The role of warnings is to alert the operator and thereby avoid or minimise the episode.

The diagnosis system consists of four parts; episode detection, a diagnostic procedure that tracks disturbances to the initiating process unit(s), a set of decentralized estimators for estimating process variables, and an internal diagnosis scheme for each unit.

Detection

Detection of serious process disturbances is performed by *detection monitors*. These take the form of procedures that monitor the value of some measured or estimated variable, such as total release rate of a given pollutant. There are two types of detection monitors: episode and warning monitors. The episode detection monitors trigger when an episode is registered while the warning detection monitors trigger when a warning is registered.

Topological search

The triggering of an episode or a warning must be followed by a search for the cause of the disturbance. This search uses another kind of monitor, called a *search monitor*. This monitor may test for disturbances in (the estimates of) all components of the process state vector, or in combinations of these components. Furthermore, the search monitor tests a time window, and not only the present state. Search monitors are passive until interrogated during a diagnostic search. Before describing the search monitor in more detail, we need to explain the diagnostic search procedure. The detection of an episode or a warning triggers a diagnostic search for possible initiating units. When a detection monitor is triggered, it starts a procedure that recursively searches for disturbances in upstream units and streams. The tests for disturbances are performed by the search monitors. In process units with more than one inlet stream the search branches out to search all inlet streams. The search is pursued only along streams where the search monitors report disturbances. When the search reaches a unit where no inlet streams report disturbances, this branch of the search stops. It is decided that a primary cause is possibly to be found in this unit, since it cannot "blame" the disturbance on any upstream unit. The path from the triggering detection monitor to the initiating unit is called a diagnostic path. Diagnostic paths are highlighted on the operator's computer screen by changing the colour of the stream and the process unit symbols. There are some possible problems associated with the search procedure related to controlled flows, the choice of time window for the search monitor, and feedback loops in the process. Details on this can be found in Mjaavatten (1994).

Estimator

Our approach depends critically on the availability of the current *process states* (flow, composition, temperature and pressure) in every stream, since the search procedure is based on comparing the process state to nominal values. Since it is impossible to measure the composition of every stream it is necessary to introduce model-based estimators to compute the process states. To comply with the modular structure of the system we want these estimators to be local in the sense that the estimator for a unit only depends on information, ie. estimated process states, from neighbouring units together with local measurements. If we further restrict this by limiting the information to that coming from neighbouring upstream units as well as local measurements we obtain a convenient one-way structure for computing the estimates of all units. A limitation is that downstream measurements cannot be used to improve estimates in upstream units. This does introduce problems as discussed in Mjaavatten (1994). It should be emphasized that all "local" estimator schemes are sub-optimal compared to a structure where every unit has access to all measurements.

Internal diagnosis

For every initiating unit, an internal diagnosis is started to find the primary cause for the erroneous situation. The level of sophistication of this diagnosis may vary, in the simplest case the primary cause is immidiately reported as "Problems with unit A", leaving the details to the operators.

Implementation

This section describes the Operator Support System (OSS) installed at Norsk Hydro's fertiliser plant in Glomfjord, Norway. The OSS is closely integrated with a Reporting and Documentation System (RDS). The compound system is called the Integrated Pollution Control system (IPC). The IPC system was described by Fjalestad, Gravklev, Mjaavatten & Saelid (1994). The description in the present paper is limited to the implementation of the distributed estimation and the topology-based diagnosis. The OSS is implemented in the real-time expert system shell G2 (Gensym 1992). We use the modular approach that is described in the Introduction. Each process unit is represented in the OSS as an object with a number of attributes. The attributes include estimation and diagnostic procedures and an icon for graphical representation of the unit on the computer screen. See for instance Booch (1991) for an introduction to object-oriented design.

In the OSS, both detection monitors and search monitors are objects. Each detection monitor is restricted to monitoring one value only. The detection monitors are polled every minute, to check for disturbances.

The OSS system has a graphical user interface as shown in Fig.1. The central upper window is called the overview window. It gives a general view of all process sections. A process section may be activated by pointing and clicking in this window. A detailed view of the corresponding process section is then displayed in the area window at the lower left. The upper right hand window shows graphs of total discharge of pollutants together with energy and water consumption. The menu window at the lower right displays a set of buttons that trigger various functions. Messages from the system to the operators are displayed in the message window at the upper left.

The icons used for process equipment are modelled on the icons used in the DCS and in the P & I diagrams, so that operators can easily recognise the process sections and equipment. Most operations are done by pointing and clicking. The keyboard is used only for entering comments. In Fig.1 an ammonia discharge episode in the sewer has been detected by the on-line analyser. This is indicated by a bold (or actually red) arrow in the sewer symbol in the area window. The stream coming from the stripper section is also highlighted in red, and the triangle shown in the stripper section in the overview window indicates that the disturbance comes from this section. If the operator wants to show the stripper section in the area window he can either click on the triangle at the left end of the highlighted stream, or he can click on the stripper section in the overview window.

Discussion

The Operator support system has been characterized as a success by the users and the company. Reasons for this will be reviewed in the sequel. In addition, the system's impact on plant performance as well as the company will be discussed.

System performance

The system performes well in the sense that it gives the operators valuable advice on emissions and the cause of these. One reason for this is that the plant lends itself to the unit-process decomposition, the search procedure, and the estimator scheme which utilize local and upstream information only. This is because the plant has a predominantly one-way cause-effect flow. In plants with stronger two-way interaction between units this approach may not be viable.

The method utilizes plant models on two levels, a structural model of the process topology and mechanistic models of each unit. Hence, both structural plant knowledge and knowledge of the characteristics of each unit are captured by the models. This knowledge is merged with process measurements to form a system that efficiently utilizes all relevant knowledge. The lesson to learn from this is that it is important to develop diagnosis methods that are able to capture as much as possible of relevant knowledge of a plant.

Workers' participation

An interactive operator support system will make little difference to plant operation without a commitment from the work force to actively utilize the system in plant operation. To obtain this, it is imperative that there is a close cooperation with the users during development commisioning, and modifications, and that a support system is based on the underlying concept that the user always should be in command.

Even though a computer based control system had been in operation for some time before the operator support system was introduced, this was a completely new tool. The system is quite complex, but this complexity is hidden from the users.

In the Glomfjord project plant personnel were informed continuously during the development phase and their views on the user interface and on which features to include were taken into account. The resulting system thus met many of the real needs of the users, as opposed to the needs perceived by the system designers. After installation, one person from the development team was stationed in Glomfjord for six months. During this period estimators and diagnosis were tuned, bugs were fixed and some new functions were added, based on discussions with the users. Items that turned out not to be useful were removed in order to avoid unnecessary confusion. This close follow-up was crucial to the success of the system.

The philosophy behind the diagnosis and advice part of the Glomfjord system is that the user always has the final say. This implied that the system was viewed as an advisory system and thereby used to the extent the individual operator felt it improved his/her decision making. Experience in Glomfjord has shown that this strategy was successful in the sense that all operators within short time actively used the system in their day-to-day work.

To elaborate further, there are some characteristics of the Scandinavian work environment that seem to favour the introduction of new and advanced concepts (Emery & Thorsrud 1976), (Qvale 1992).

There is a strong egalitarian tradition within the society. This simplifies communication between operators, system developers, and production management. Hence, it promotes the use of all relevant resources in the different phases of a project, ie. development, commisioning and modification. Furthermore, the egalitarian educational tradition contributes to the existence of a well-educatied work force. This, again, is important to take advantage of advanced concepts among workers.

The Norwegian Work Environment Act (§12) states that all workers have a right to participate in specifying his/her own work environment. This proclames a general attitude which again is helpful in "Glomfjord-like" projects since all parties involved are obliged to contribute to the project (Gustavsen & Hunnius 1981).

In traditional manufacturing industries, like Glomfjord, virtually all workers are members of the trade union. If used constructively this is an instrument to convey new ideas to the work force, and utilize advice from the work force. The reason is that it forms a well-established two-way communication channel between workers and management.

Impact

The impact of this project has been quite diverse.

There is a concensus among all the involved parties that a significant reduction of emission episodes can be related directly back to the diagnosis system (Mjaavatten 1994).

The decentralized estimator scheme provide plant personel with estimates of non-measurable variables, in particular quality variables. An example of this is the nitrogen to phosphorus ratio in selected parts of the process. These estimates are used to monitor product quality. This can be viewed as an add-on effect, caused by the choice of methodology.

The infrastructure represented by the Operator Support System will be used as a basis for implementing new functionality into the system such as planning and documentation. Since the operators have been through a period with major changes in their information system environment and this has had a positive impact on plant operation, further changes are in general welcomed. This is a major asset for a company since change will be the normal state of operation in the future.

The Glomfjord application has become an important reference for the Norsk Hydro company because of the significant rediction of pollutants. Having, in addition, received a prize from the Norwegian minister of environmental affairs for the project's enviromental impact helps defining Norsk Hydro a.s. as a 'Green Industrial Company' in the eyes of the public, the market, and the politicians. This, again, is an important asset in tomorrows business enviroment.

The first effect can be seen as a direct consequence of the Operator Support System. The other effects can be viewed as add-on effects that were difficult to foresee. These follow-on effects, however, are significant and may, in the long run, be the most important.

Conclusions

A diagnostic tool for use in an operator support system for chemical process plants has been designed. This system uses a highly modular representation of the process, and it has been successfully implemented in an industrial operator support system.

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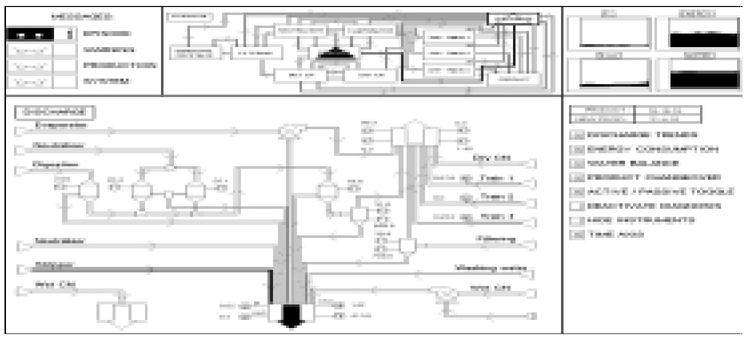

Figure 1: The OSS user interface. Process units, sections and streams involved in a pollution episode are highlighted.