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# Information Systems Architecture for Operational Management and Control*

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Monitoring and control within process industries may be divided into discrete levels in a functional hierarchy. The respective levels have distinct charactersistics that determine the underlying systems architecture. The paper contrasts the functions of on-line monitoring and control with those of off-line operational management. A generic systems architecture is proposed in which these levels of control are supported by separate systems, connected by a standard data interface.

## 1. Introduction

The paper addresses the monitoring and control of continuous flow processes. Many production processes in the industrial and utilities sectors operate on a continuous basis. Examples of such processes may be found in the chemical, petro-chemical and minerals extraction industries. Water treatment and sewage processing are further examples from the water industry. The paper examines general features of information systems design within this class of applications.

Continuous flow processes usually consist of a sequence of stages or sub-processes. Mixers, reactors and separators are common examples of process stages within an industrial plant. Current technology enables many sub-processes to be monitored and controlled by automatic control systems. In cases where the whole plant process is understood sufficiently, and the interaction between sub-process stages fully identified, whole plants may be operated under control logic, programmed into a supervisory control system. The human plant operator may then only be employed in an alarm management and emergency override role. The impact that recent advances in computer hardware have had in process management is described by Prebble et al. The developments have brought about corresponding changes in organisational structure and working practices.

Outside the arena of real time plant monitoring there are other levels of management and control that recur across many diverse industries. The information systems triangle may be used to illustrate these (figure 1).

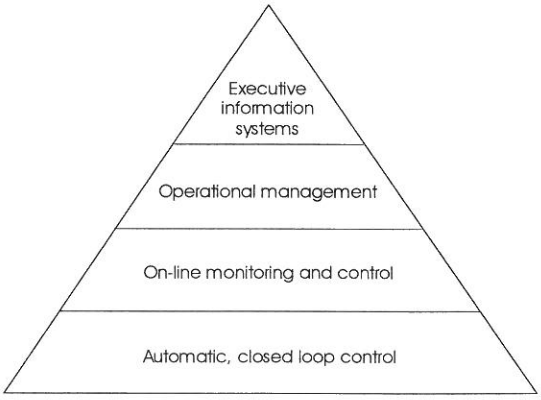

*Fig. 1.* Information System Hierarchy for Process Monitoring and Control

Three hierarchical levels are shown for the monitoring and control of continuous flow processes. The defining characteristics of three of the layers, automatic control, on-line monitoring and control, and operational management

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The paper draws a clear distinction between the functions of on-line monitoring and control, and those of operational management. It argues that the distinct functions of the two imply different system designs. The conclusion is drawn that separate processing platforms should be employed for these two levels within the overall systems architecture.

The paper further explores the data interface between the defined functions of monitoring and control, and operational management. The case for a standard protocol is established. This is underpinned by the outline of one such protocol, that has been implemented within a comprehensive system architecture matching that described in the paper.

## 2. Monitoring and Control Functions

There are certain common elements of computer hardware and information technology to be found within the architectures of most installed monitoring and control systems. These are shown in figure 2. Standard functions may be readily ascribed to the elements shown in the diagram.

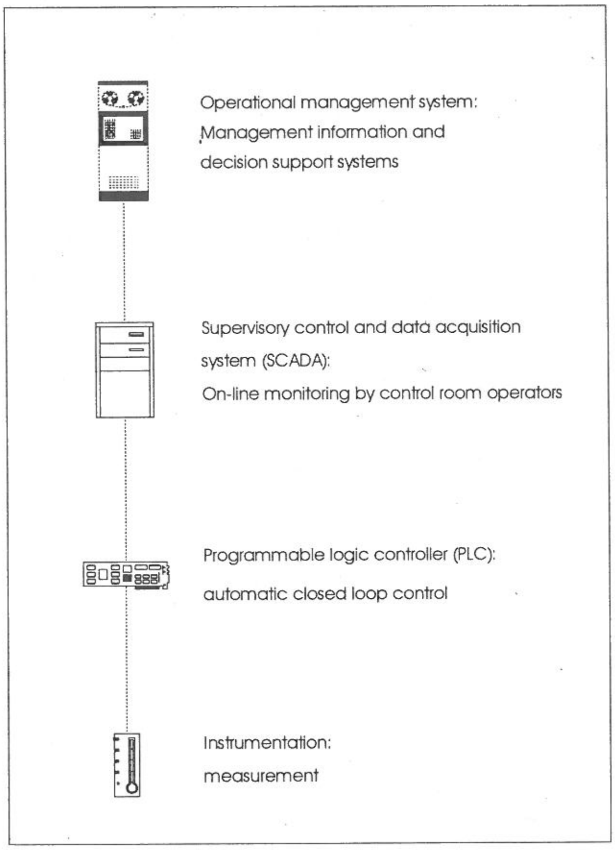

*Fig. 2.* Elements within monitoring and control systems

Measurement of process parameters is the first fundamental within the structure. Instrument design and the basis upon which parameter values are determined are extremely varied. The common principle that applies in all cases is that of capturing measurement values relating to process flows and making that data available for onward transmission.

Programmable logic controllers, (and their close relatives outstations and remote transmission units), fulfil a number of functions. Essentially their role is to perform automatic closed loop control and the transmission of data values and alarm conditions. (Specific proprietary products offered either as outstations or as remote transmission units may only perform a subset of these functions).

The power of microchip technology has been exploited at this level in the architecture. Complicated control logic may be loaded into programmable logic controllers (PLCs). In most cases today, the capital cost of the processor hardware is insignificant in comparison with the cost of process investigation and the definition of control loop logic. The PLC therefore offers a cheap means of instigating automatic control loops, where a process is sufficiently understood to allow this.

PLCs may be utilised in a standalone mode with no external connection to a supervisory control system. Where the connection to a higher level supervisory system does exist, the PLC will undertake the functions of data logging and data transmission. In addition the recognition of alarm conditions and the onward reporting of these is a standard function at this level in the architecture.

The next level identified within the generic architecture is that of on-line monitoring and control. The typical implementation of a supervisory control and data acquisition system, (SCADA), is in support of an operational control room. This may be on a works where many individual processes are linked together (in respect of PLC based control loops) in one plant area. The common alternative in the utilities sector is for a control room to monitor and control processes at many unmanned sites over a wide geographical area. The same principle applies in both cases — the control room operator is introduced into the monitoring and control loop. The specific role of the human operator varies from case to case and is dependent upon the control philosophy inherent in the overall design. At one extreme the SCADA system provides monitoring information; all control/switching operations are performed by the human operator. At the other extreme the SCADA system will contain control logic for the whole process; the control room operator is employed in a passive monitoring role and may override the SCADA system only in exceptional or emergency circumstances.

An analysis of the current state of the art of process control within the water industry is provided by Matthews and Dingley (1990). They conclude that the rapid implementation of automatic control and SCADA systems in recent years has led to improvements in plant performance at a reduced level of operating cost.

The term operational management applies to those monitoring and control functions that are performed outside of the immediate on-line monitoring environment. Operational planning and optimisation fall within the domain of operational management. In that respect operational management has a proactive role, managing the future. This contrasts with the largely reactive role of on-line monitoring and control.

The complementary role to the forward planning aspect of operational management is that of historical review. The continuous compilation of archive data quantifying past operational activity is important in most organisations. The analysis and reporting of performance falls most commonly within the domain of operational management.

In the context of this paper, decision support system refers to a set of calculations (algorithm, mathematical model are possible synonyms) which quantify the repercussions of alternative control actions. Decision support systems advise; resulting control actions are carried out by human intervention. This definition provides a clear distinction between control loop logic and decision support system . It also places decision support systems clearly within the domain of operational management: the off-line control used to proactively manage future operations.

The preceding description of the functions of operational management is far from definitive. The variations in control needs and in organisational structure in different industries makes generalisation difficult. However the common elements to recur across industrial sectors is that

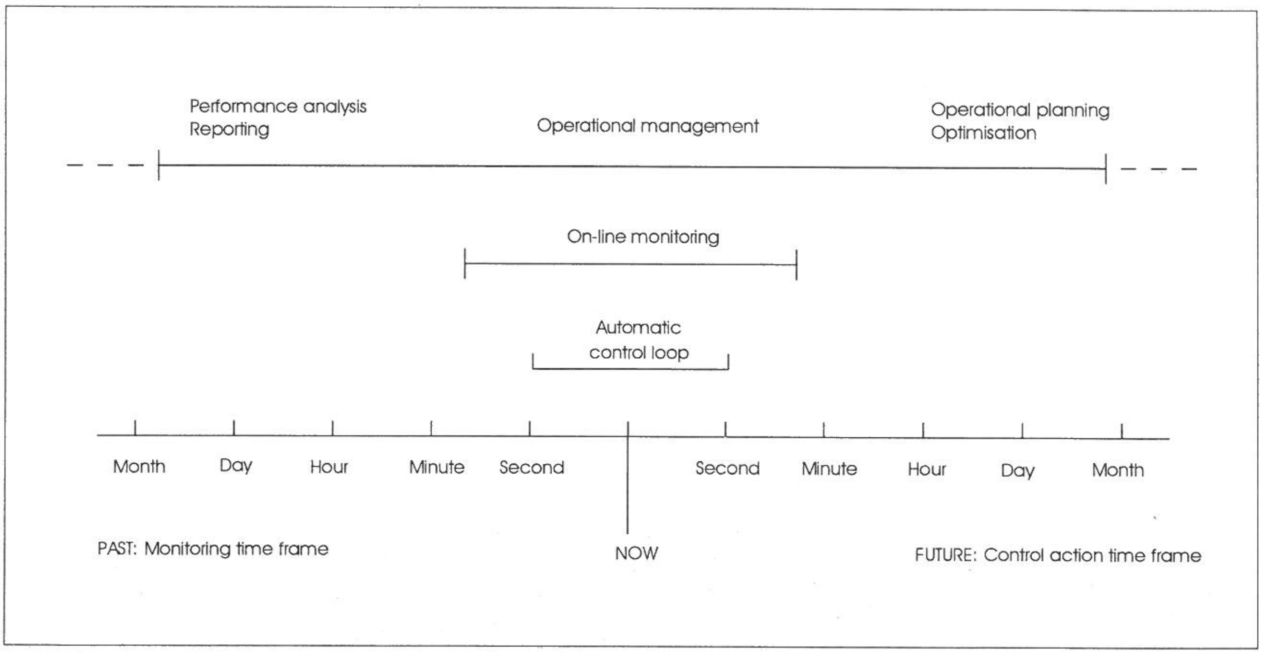

*Fig. 3.* Time Frames for Monitoring and Control Functions

operational management is the preserve of technical and supervisory staff, who are not directly involved in on-line monitoring and control.

The distinction may be shown by reference to the time frames of past, present and future. These are illustrated in figure 3. The automatic control loop operates in near to present time. The response cycle may be engineered to occur within milliseconds. On-line monitoring within control rooms also inhabits a time frame close to present time. The past and the future, as used in common parlance, are the domain of the operational management system.

The control cycle of:

monitor → analyse/evaluate →
→ control action → monitor

applies at each level in the hierarchy. The effectiveness of the cycle depends upon the accuracy of the monitored data values. The extent of data validation increases through the layers of the hierarchy. At the lowest level signal processing is applied in order to remove noise from the signal. At the SCADA level measurement values may be checked against limits. Also the human operator will be able to cross check signal values and identify obvious anomalies. At the operational management level data is routinely viewed in context with other values. The checking and correction of process data is necessary for certain reporting and decision support applications. This may involve the manual alteration of recorded values, and the maintenance of associated audit trails. It may be seen therefore that data validation techniques vary considerably through the layers of the system architecture.

The discussion above has covered the main functions within the information system architecture shown in figure 2. Those functions are summarised in table 1.

*Table 1.* Monitoring and Control System Functions

| Element | Function |
|---|---|
| Instrument | Measurement |
| PLC<br>(Automatic control) | Closed loop control<br>Data logging, transmission<br>Alarm generation |
| SCADA<br>(On-line monitoring, control) | Real time monitoring<br>Remote control switching<br>Control logic<br>Alarm response, management<br>Data storage |
| Operational mamagement system<br>(off-line monitoring control) | Corporate data archive<br>Manual data validation<br>Analysis, reporting<br>Decision support systems<br>Operational planning, optimisation |

## 3. Systems Architecture

### On-line Monitoring and Control

Processors for SCADA applications are invariably dedicated to that one application. SCADA systems are usually purchased on a joint hardware and software basis under the proprietary brand name of the supplier. The purchased system will be tailored to the specified application. Key parameters in the sizing of an installation will be:

- number of analogue and digital signals polled
- polling rate
- number of monitor screens supported.

Under normal conditions a SCADA system processor operates under a steady workload. (The exception occurs in emergency conditions, when alarm messages may increase processor load significantly). Routine processing is dominated by the polling of data sources and the refreshing of monitor screens. The specific characteristics of these two processing tasks has led proprietary system suppliers to adapt the underlying operating system and the application software for maximum performance. The key design criteria centre upon the cycle of communications which demands both very frequent and very regular accesses to many other devices.

Resilience is an important factor in the overall design of monitoring and control systems. This is commonly achieved by dual redundancy of hardware. The requirement for resilience also encourages functionality to be built into the lowest level of the architecture possible. It is common practice for PLCs to contain control logic which may be altered by changing set point values through a remote SCADA system. A failure of the SCADA system will not affect the continuing operations of the PLC.

SCADA system suppliers have sought to extend their product offering by the inclusion of reporting applications and data analysis facilities. The difficulties in supporting the additional functions arise from the core system design. The processor load arising from these additional functions is different in nature from the core monitoring tasks. The core tasks are driven internally by the system manager; SCADA screens are refreshed regardless of whether an operator is viewing them. The additional reporting functions are user driven; they are activated by user input requests. The net effect can be for performance to deteriorate as additional CPU hungry applications absorb processor power. A second practical consideration is that SCADA system screens are usually located in relatively secure control rooms. Wider access to the system for general reporting purposes requires a choice between two unattractive options. One alternative is to install additional screens. This causes yet more load on the central processor. It is also likely to lead to a reduction in the security of the control system. The second option is to allow a wider set of users access to control rooms and existing SCADA terminals. The additional usage does not complement the normal on-line monitoring role.

To summarise: SCADA systems are tuned to a particular set of processing tasks; installations are matched to an on-line monitoring and control need. The scope for expansion into a wider set of operational tasks is limited, especially when additional users do not work in the immediate control room area.

## Operational Management Systems

Installed operational management systems that accord with the general specification developed earlier in the paper are, by their nature, one off and unique. The respective design criteria for different industries and specific installations promotes bespoke development. The inevitability of this is confirmed by consideration of the database design. The database for an operational management system will contain both time series data, (process measurement values obtained from field instrumentation), and reference and configuration data which is static by nature. The latter will contain the information necessary to interpret the time series data and ensure correct report generation. It is interesting to note that plant configuration information is commonly held within mimic diagrams in SCADA systems. Unfortunately that expedient cannot be applied in operational management systems because of the much greater diversity of reporting that is required.

The operational management system is the natural repository of a corporate process operations database, within the overall monitoring and control systems architecture. The design must therefore incorporate appropriate data archiving and retrieval facilities. The balance between on-line storage and off-line data archive will depend upon cost and retrieval time criteria. It is certain however that this will be an important area of consideration within the design. The importance will be reinforced by the steady growth of archived time series data through time.

Under the generic system architecture put forward in the paper an operational management system provides the access to process information to a wide audience of users based outside control rooms . The important characteristics of system access are the large number of users and nonuniform load determined by user requests. This use profile, considered in conjunction with the functions of data validation and archiving/retrieval, influence processor specification. They suggest a processor configuration suited to multi-tasking under varying load conditions and a mix of processing needs in respect of disk input/output and CPU usage. The support of a corporate database also implies a single site configuration and a single logical database within that layer of the architecture. The management of distributed databases over independent processors is not a viable option. Database management systems are not sufficiently well developed to support this at present.

In conclusion, the mix of functions that fall within this layer of the system architecture, together with the characteristics of user access, determine the processor characteristics. These are single central processor configuration, supporting data access and all aspects of archiving and retrieval. The variable loading on the processor will require an internal system manager capable of dynamic allocation of processor resources.

### Data interface — SCADA to Operational Management System

The earlier sections have discussed system design criteria in the most general of terms. On the basis of broad generalities the paper has sought to establish natural layers of functionality for process monitoring and control systems. It has proposed that the functional layers are best served by separate processors, within a defined systems hierarchy. One implication of this generic design is that a data interface is necessary between the SCADA and operational management system levels. In this area the paper is able to describe a protocol based upon an implemented data interface.

The protocol specification outlined below was developed for the generic SCADA and operational management system interface. The main design principle underlying the protocol is one of flexibility, to meet changing requirements for transferred data. The need for flexibility arises from the regular changes in installed field instrumentation and the set of measurements made. A routine batch data file transfer would be inadequate. It would be subject to frequent changes as the population of available time series data alters.

The protocol, which will be referred to by the acronym GPDI (General Purpose Data Interface), supports a dynamic interface between the two layers in the system architecture. GPDI consists of a set of message definitions. The operational management system layer is empowered to send requests for time series data to the SCADA level. In this respect it acts as a client to services provided by the SCADA system. The client sends requests for data values for measurements already configured within the SCADA system. The collection and despatching frequencies are specified for each measurement. The data are transmitted by the SCADA system as engineering values, with specified units. This minimises data conversion prior to storage.

The GPDI protocol contains fourteen messages. Four of these are for the request and transfer of time series data. A further three messages cover the housekeeping tasks of acknowledgements and notification of the end of transmission. The protocol also supports the transfer of configuration data between the two layers in the architecture. An example of configuration data is the units in which a measurement is made — the common alternatives for volume are litres, cubic metres and megalitre. The configuration data describing time series data is not itself static. The protocol lays the foundation for manual updates to be made once only. Machine processes then ensure that all copies of the configuration data are updated and kept in line with the master version. A further seven message types are defined within the protocol for configuration data transfer. These facilities ensure that manual intervention to maintain and update the systems interface are minimised.

## 4. Implementation

The material in the paper is drawn from the design of the monitoring and control system for London water. During the past two years Thames Water has introduced a comprehensive set of facilities for the control of water distribution. This is being extended to the water treatment works, to ensure complete coverage from abstraction point to the customers tap. A representation of the completed system is shown in Figure 4.

Four of the SCADA systems referred to in the diagram are operational. They cover distribution control and one of the large water treatment works that serves London. The operational management system is installed and operational. It is linked to the SCADA systems and acquires process data from them on a regular basis.

The SCADA systems support on-line monitoring in control rooms. These are manned by shift operators on a 24 hour day basis. The operational management system supports a variety of users and applications. These range from water accounting to the support of pump scheduling systems with validated data.

The SCADA systems that Thames Water has installed for London water treatment and distribution are a proprietary product from an external supplier. The operational management system

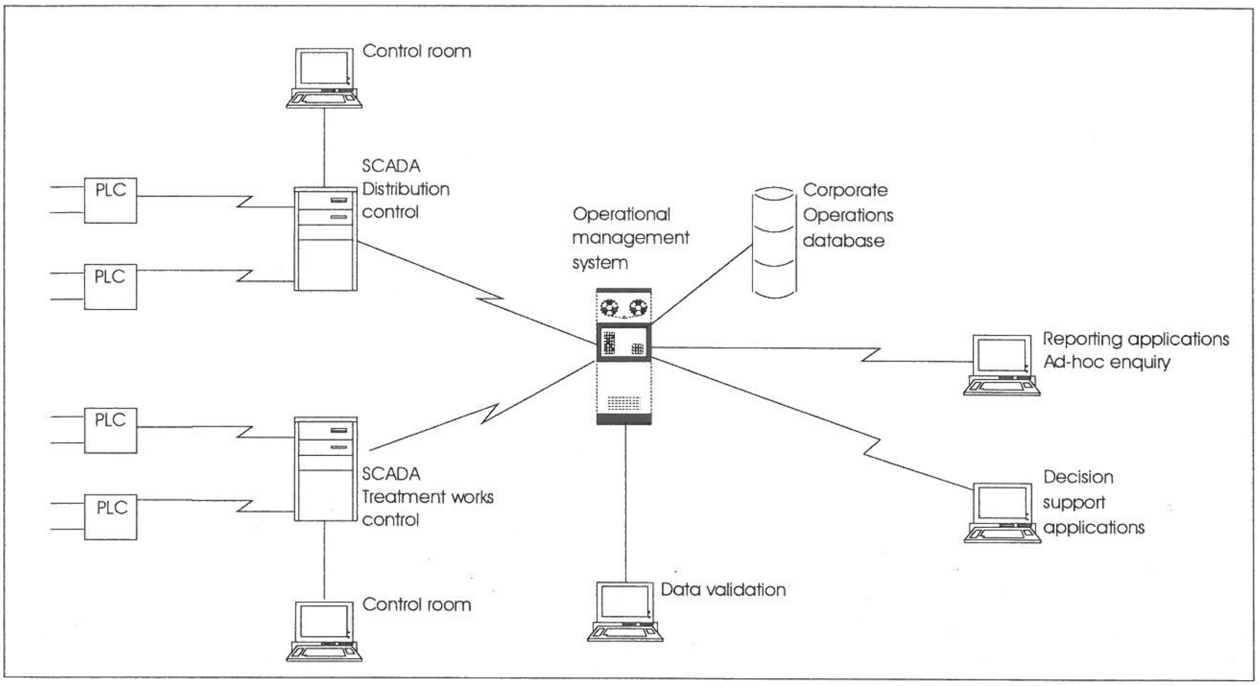

*Fig. 4.* London water implementation

is a bespoke development. It is an internal design, developed with assistance from external software houses. A client-server approach was adopted as the basis of application design. The method of implementation has been discussed fully by Brignall (1992). A general teatise on good practice and pitfalls in client-server system development may be found in the work of Inmon (1992).

The GPDI protocol has been implemented in the data interface between the SCADA and operational management systems. Program code has been written and installed within both systems. The data interface is now in operational use.

Thames Water has commissioned the development of GPDI software by another preferred supplier of monitoring and control systems. This will enable a standard system architecture to be applied across the company for this application area.

The approach taken by Northumbrian Water Group PLC in water distribution systems management is described by Dixon (1990). The same requirement to provide summary information from local control systems for management reporting and control is identified. This has been extended to incorporate process data within a geographical information system.

## 5. Summary and Conclusions

The paper has sought to establish a general architecture for monitoring and control systems applied to continuous flow processes. The respective roles of on-line SCADA systems and other off-line monitoring and control functions have been delineated. Within this area a generic systems architecture has been formulated. The demands that the respective application areas make upon processor facilities have been shown to be distinct. It has been concluded that the SCADA and operational management system layers in the architecture are best served by separate processors.

The separation of processors, and by implication databases, within a closely coupled information system implies the need for a data interface. A protocol has been developed for these particular circumstances. It meets the need for flexibility with the minimum of human intervention. The protocol avoids the alteration of file formats when a change is required in the dataset to be transferred.

The principles put forward in the paper have been incorporated within one major control system that has been implemented and is operational. The GPDI protocol described in the paper has been applied in practice. The interface is operational, between a proprietary SCADA system and an in — house operational management system.

It is the policy of Thames Water to promote the GPDI protocol as a general standard. A standard protocol would offer advantages to both SCADA system suppliers and system developers with a requirement to extract data from online monitoring and control systems.

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