Integrated Management and Optimization of the Sanitation Cycle Using Intelligent Automation Systems and Communication Networks

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Abstract: – The recognition of the importance of our planet's water resources by human society increased significantly during the last decade. With a growing population and environmental degradation, an efficient management of water resources is even more vital to mankind. This article introduces a new systemic proposal for an efficient management of water treatment stations and also the entire sanitation cycle. Maximizing the efficiency of water resource management, as proposed in this article, requires the development and implementation of an automation system based on intelligent systems and communication networks. Therefore, the proposal of integrated management and optimization of the sanitation cycle presented in this article is a contribution to the improvement of sustainability for human evolution.

Keywords: Automation, Management, Sanitation, Sustainability, Intelligent, Instrumentation, Communication Networks

1. Introduction

1.1 Need of a Better Management of Water Resources

Population increase and economy development have significantly increased the demand nature's resources. It is notorious and evident that the concerns about water, or the lack of water, are among the challenges of this millennium. Water is also the main transmission vector of infectious diseases. Among environmental sanitation premises, water supply systems are the ones that cause the greatest impact on the reduction of infectious diseases. Thus, it is fundamental to properly equate the expansion and the operation of water supply systems in the cities, in order to meet the population demand and to supply a high-quality and low-cost product [1].

1.2 Automation as Improvement Tool to Manage Water Systems

Water supply system companies, either in the developed countries or in the developing countries, have an urgent need of improving their operational results due to the new needs imposed by civil and governmental society. Thus, thanks to the advances in electronic engineering in the last decades, it was possible to develop computing systems and sophisticated equipment destined to the water supply systems and sanitary sewage automation. Automation arises as a powerful tool to improve sanitation management, because as well as improving the process quality, it enables methodological collection of the data in an integrated and hierarchized way. The main purpose of this article is to present the proposal and the benefits of automation in a water treatment station using intelligent instrumentation (II), along with a systematization of the sanitation cycle process, with the help of intelligent automation systems and communication networks. In this way, we intend to contribute for an optimized and integrated management of the entire sanitation cycle. Figure 1 exemplifies the sanitation cycle, illustrating every stage of the process.

Figure 1. Sanitation Cycle - Source: Water Supply System Company of the State of São Paulo – Sabesp (2005)

2. Intelligent Sensing

Intelligent sensor is the term to designate the physical quantities evaluation measurement system that generally uses a digital computer (or a system with similar architecture) for the entire (or almost entire) processing of the signal and information. The intelligent instrument, after measuring a quantity, performs digital processing to refine the data, that is, filtering, average, linearization, automatic calibration and self-evaluation. So, it is possible to define [2] [3] [4] [5] [6] intelligent instrumentation as the set of techniques and devices used to observe, measure, register physical phenomena and perform actions with more reliability, with connectivity with other equipment and devices, and able to manipulate the quantities observed, aiming at its analysis and processing. Figure 2 shows the frequency measurement of a sine-shaped waveform by an intelligent instrument. It is possible to observe that in the sensor output, the information previously collected becomes data, and there is more immunity to noises during transmission.

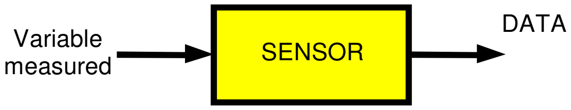

Figure 2 Illustration of Measurement with Intelligent Instrument.

3. Fields Network

In the definition by Instrument Society of America - ISA [2] "fieldbus is a serial, digital, bidirectional, shared-access communication line to interconnect automation primary devices. It includes transmitters/sensors, actuators and other simple devices, with local processing capacity, installed in the field area with control and automation devices of immediately superior level". Institute of Electrical and Electronics Engineers - IEEE presents it as a "bus for general interconnection of simple devices, used in instrumentation, process control and industrial automation". Fieldbus is a local network designed to work at the lowest hierarchic level in the systems, and one of its purposes is to enable communication between system components from any manufacturer. It is observed that the several models of open protocol field network have different features that may make them more or not so much adequate to a specific application. Therefore, the engineer in charge has the mission to decide which communication protocol is compatible with his installation, that is, which one gives him more flexibility and interoperability so that the instrument of a determinate manufacturer may be replaced with the instrument of another one without any disturbs. The choice of a certain type of network depends fundamentally on the control chains complexity level and on the type of such devices. Industrial networks are qualified according to the type of equipment to which they are connected and the kind of data they carry. Data can be bits, bytes or blocks. Networks with data in bits, or sensorbus, transfer discrete signals containing mere ON/OFF conditions. Networks with data in byte, or devicebus, may have discrete and/or analog packages of information, and the networks with data in blocks, or fieldbus, are able to transfer information packages of variable sizes. Figure 3 illustrates the types of network and the forms of data transmission.

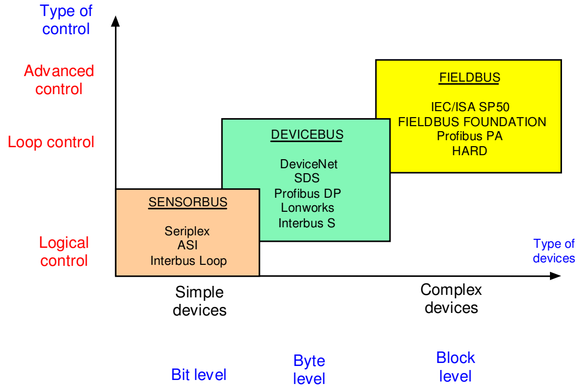

Figure 3. Application Domain of the Types of Network – Source: Smar (1998)

3.1 IEEE 1451 Standard for the Interface of Intelligent Sensors and Actuators

When attempting to interface the intelligent transducer with the several types of existing networks and protocols, IEEE, by means of IEEE P1451 standard, has published a series of standards composed by several parts. Its purpose is to make easier the task of creating solutions based in the existent network technologies, as well as creating standardized connections with the intelligent devices and common software architecture. This standard defines how sensors and actuators can be directly connected to a control network, including Ethernet. The main function of IEEE P1451 standard is to define the communication standard for hardware-independent intelligent transducers. The parts of IEEE P1451 standard are summarized in figures 4 and 5 [8] [9] of this article.

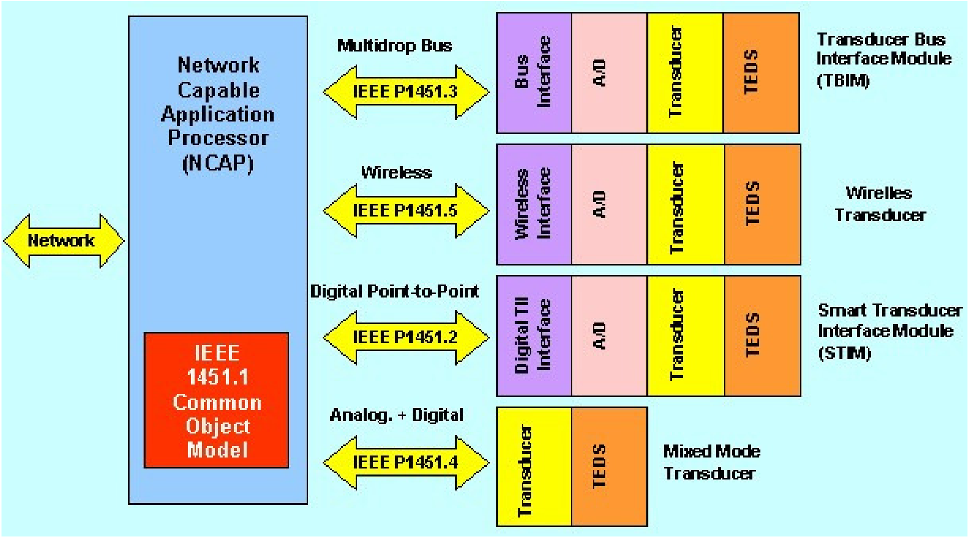

Figure 4. Illustration of the Options of Interfaces of Intelligent Sensors and Actuators –IEEE 1451 Standard - Source: IEEE (2006)

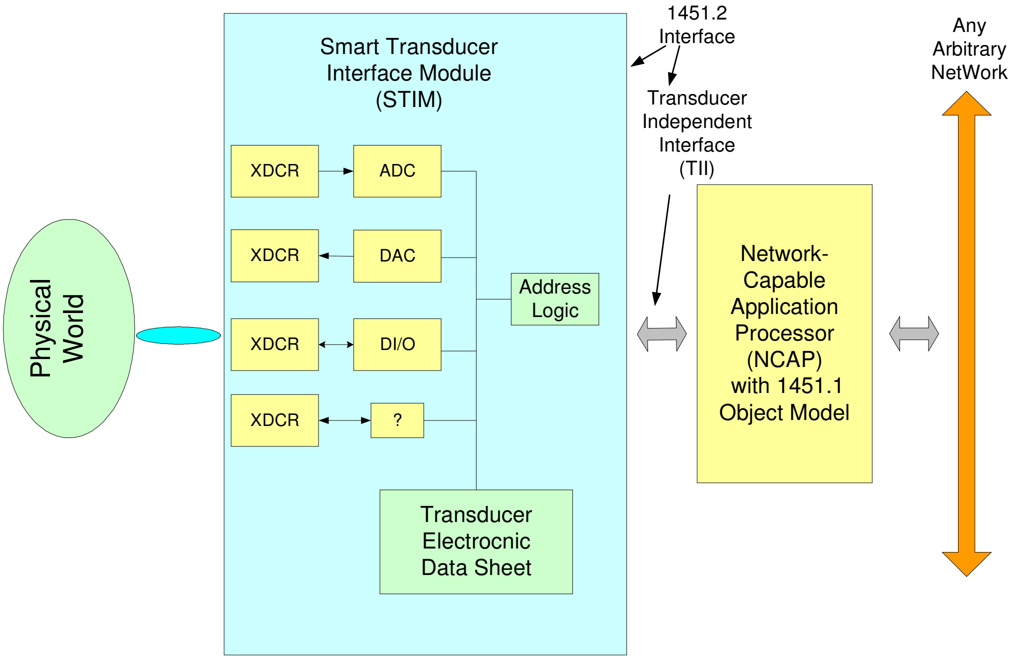

Figure 5. IEEE 1451 Standard Architecture - Source: IEEE (2006)

4. Intelligent Automation Systems

Automation is a tool that enables improving quality, optimization, productivity and management support. It consists in the use automatic devices and systems that require little or no human intervention during their operation.

Currently, in most automated companies automation involves systems interconnected by communication networks, supervisory systems and man-machine interfaces, in order to help the operator in the supervision and analysis of events that occur in an automated production plant. Automation enables also a methodological and accurate collection of data, which can be used to optimize the process. Figure 6 of this work illustrates a conceptual model of the hierarchic pyramid for Industrial Automation. Such model ranks the automation of a generic production plant in five levels. Level 3 involves control connectivity.

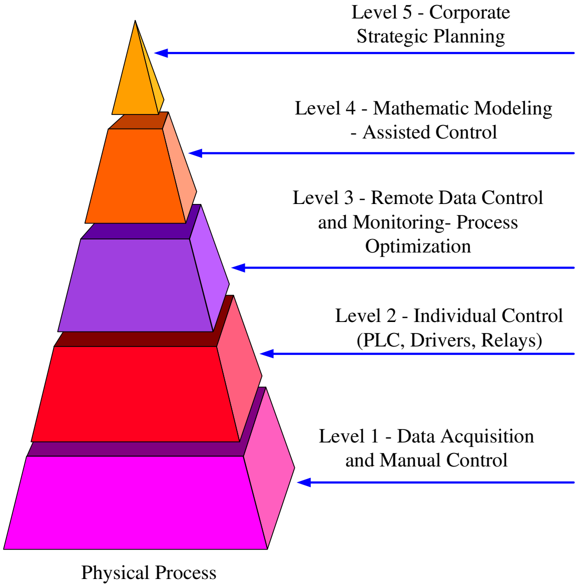

Figure. 6. Levels of Industrial Control – Automation Pyramid – Source: Webb (1992)

4.1 Supervisory Systems

The processes had grown more and more complex during the last three decades; consequently, the industries increasingly refined their management and production methods, and the need of equipment integration became more pressing. Several systems have been developed to meet such need, such as S.C.D.A. (Supervisory Control and Data Acquisition [11]), and particularly the supervisory systems (SSs). The latter can be defined as systems capable of exerting control over a given physical system and checking its performance in accordance with the desired action. These SSs are implemented with computers and include a man-machine interface – which allows a manual parameter entry, generates reports and represents the process in a pictorial fashion. Due to their practical importance, the SSs perform a key role in the third level of the automation pyramid. Most SSs have in common the fact that their input is provided by their operators, such as prescriptions, dosages, and empiric correction parameters. In other words, it is knowledge that – once entered in the SSs – will affect the operation of the automation system as a whole.

4.2 Artificial Intelligence

In simplified way, we can say that the area of Artificial Intelligence (AI) uses computers to simulate the human thought process during the resolution of certain problems. However, the way thought and decision-making are processed in human beings is not fully understood yet and several secrets remain to be unveiled [11], [12]. Many actual AI systems use computers to perform or automate tasks in an “intelligent” manner – that is, in a way that would be considered intelligent if performed by a human being. These systems are usually called “intelligent” systems; therefore, we can define artificial intelligence as the ability to apprehend or understand. A very simplified mode of AI is the study of mental faculties through the use of mathematical models. This is the part of computing science involved in the design of systems that exhibit characteristics we usually associate to intelligence in human behavior [12]. Several techniques are adopted in the AI area to achieve various kinds of “intelligent” systems – such as Expert Systems, Fuzzy-based Systems, Neural-based Systems and Systems based on Genetic Algorithms.

4.3 Expert Systems

There are many definitions for Expert Systems (ESs), such as “computer programs that intend to solve certain problems similarly to human experts, if submitted to the same conditions” [11], [12], [13]. Or “systems developed to contain the knowledge of one or more experts – that is, designed to solve problems and perform tasks, simulating the decision-making process of an expert in different areas”. One of the most widely used AI techniques is the one that includes Expert Systems or knowledge-based systems – in contrast with classic systems, where the data of a problem are handled in a sequential way to achieve results. Figure 7 depicts a classic software system.

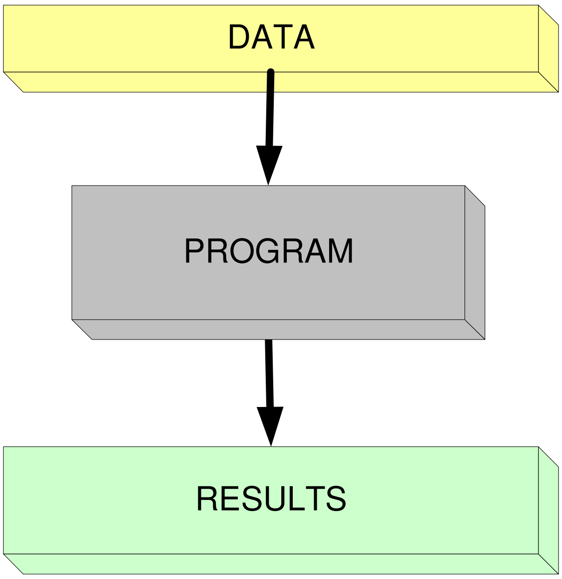

Figure 7. Structure of a Classic Software System.

In every expert system, there is an inference engine that uses the available data and the knowledge stored in its database to generate new data in an interactive way, until a solution for the problem is reached. Figure 8 shows the simplified operation of a generic expert system.

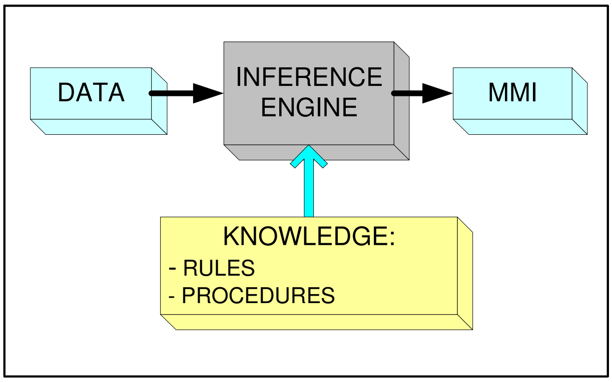

Figure 8. Architecture of a Generic Expert System.

In such systems, the required knowledge to solve a given problem is obtained and organized in a knowledge base, by means of rules or procedures. Achieving such knowledge or competence, along with the explicit organization of such knowledge, is the most difficult and time-consuming part of ES development. The inference engine is the dynamic core of any ES. This module contains a set of search algorithms to explore the knowledge base and then generate the desired conclusions and results. Consequently, this inference engine is a set of inference or reasoning rules. Another important stage of an ES is its interface with the user and other computing systems – where new information are requested and new data are obtained. Therefore, the expert systems try to incorporate, in their programs, some of the characteristics that are normally associated to human thought and intelligence – such as reasoning, memory and decision-making / planning abilities. They have been successfully used to organize, optimize and provide a great deal of knowledge from specific areas. The next items of this article will then introduce a management proposal and the benefits of Automation of a Water Treatment Station with Intelligent Instruments (AETAII), in addition to the use of expert systems and communication networks in the integrated management and optimization of sanitation cycles – which is called SIGASI (Integrated System for Automated Management of Intelligent Sanitation) in this work.

5. Typical Water Treatment Stations Control Algorithm

Water treatment is made up of several stages, represented by specific units, where physical or chemical processes take place. Such units require a high level of efficiency and accuracy and, above all, a management system that contributes to improvement operations and provides resources for the decision making. Figure 9 illustrates a general diagram about water treatment, where the stages that compose this process are summarized.

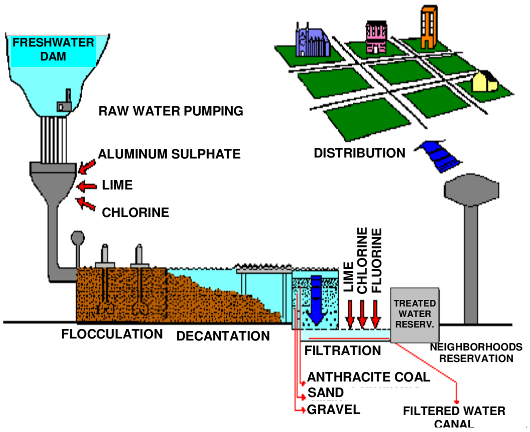

Figure 9. General Diagram of a Water Treatment Station. Source: Water University (2006)

In several countries, most of the water treatment stations are operated and controlled by human intervention twenty-four hours a day. In Brazil, generally Ministry of Health or regulatory agencies establish the rules for the water treatment and supervision. Ordinance 518/2004 by Ministry of Health [16] determines that the water produced and distributed to human consumption must be monitored in order to assure the potability and the quality standards established.

This instrument defines the minimum amount of samples and the frequency of the collections, as well as the parameters and limits established to assure water potability for human consumption. Some samples to control variables are collected at least every two hours, generally in the process output. The samples for the control of other variables required in the process are collected at higher time intervals. All of the results of the laboratory analysis are compiled in monthly reports and made available to the surveillance body. Since water treatment processes are manually operated, the operators are the people who make the collections, the analysis and also eventual corrections in the system.

Due to economic matters and to the lack of reliability of the field instruments, when employed with conventional automation in great distances such as in the medium and big sized water treatment systems, in Brazil, most of the sanitation companies control the different stages of the process also manually. Since water treatment companies are worried about the quality of the services provided, it is perfectly natural that the operators keep the dosage coagulant above the specified value for safety reasons. However, additions of more than 1,0 mg/L in the aluminum sulfate optimal dosage, in medium and big sized stations, may represent a 10% increase in the consumption of this product, or approximately one ton per day, besides the corresponding increase in the lime dosage. This reflects a significant raise in the final cost of water. Hence, non-automated water treatment stations, despite the operators' devotion, are subjected to all of the problems inherent to manual operation, such as: slow response time, quality variability, vulnerability to external factors, raw material waste in the dosage, manual report generation, and lack of anticipation skills to correct deviations in the process.

According to the comments in this chapter, variable analysis for corrections and changes are performed in the end of the process, in agreement with Ministry of Health resolution. However, this kind of procedure delays the responses on the part of the system and lots of fluctuation in the process output. So, many water treatment companies would rather perform such actions manually and, when automated, they use conventional instrumentation in every stage of the system. Figure 10 illustrates in a diagram the manual work in all of the stages during the process [18].

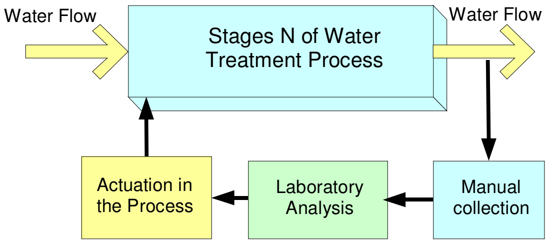

Figure 10. Schematic Representation of Manual Work in Every Stage of the Process in Typical ETA

Water treatment processes cycles are daily performed in different intervals, that is, sometimes variable control is performed at the end of the process and other times it is performed during several stages of the process. Controlled variables in the end of the process aim at fulfilling the resolutions of the surveillance body.

6. Proposal of Hardware Architecture of an Automated ETA With Intelligent Instrumentation (AETII)

The architecture proposed to water treatment stations in this article is made up by intelligent instruments interconnected to a fieldbus. In this architecture, the instruments transmit the process information by means of data bus, that is, information transmitted by the intelligent sensor is data. [18]. This proposal will enable every sensors and actuators to communicate digitally, and also transmit data to the management level, by means of field network, control networks and corporate networks, interconnected in a hierarchic way. Figure 11 represents a hardware architecture proposal using intelligent instruments and fields network in an automated ETA with intelligent instrumentation (AETAII)

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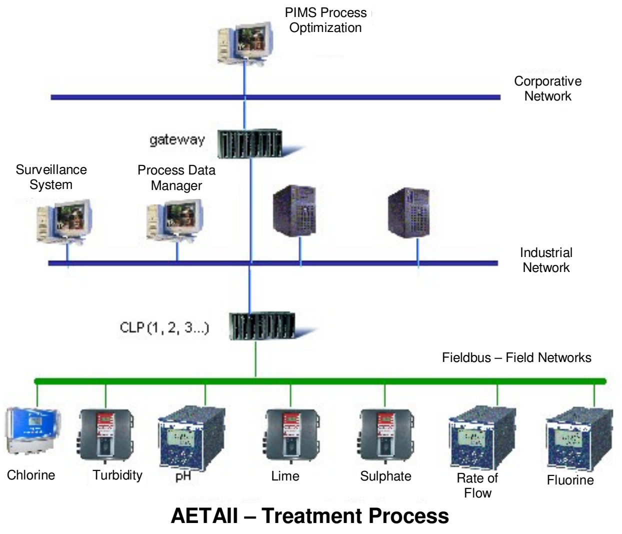

Figure 11. Illustration of Hardware Architecture Proposal Using Intelligent Instrumentation and Fields Network

6.1 AETAII Automation Algorithm

This hardware architecture proposal will enable, among other events, the implementation of more elaborated control algorithms. The objective of the proposed automation algorithm is, besides replacing manual control, to manage resources and administrative decisions. With the proposed algorithm, execution cycle is continuous, so, it is possible to act and to monitor simultaneously in many more points in a fast, accurate and economic way. Figure 12 illustrates the new scheme for the control algorithm correction in all stages of the process of Automating Water Treatment Station with Intelligent Instrumentation (AETAII).

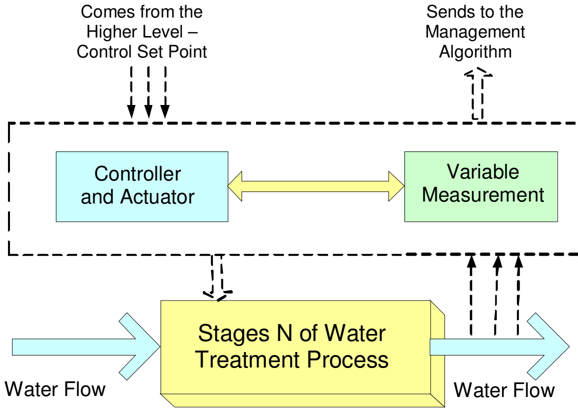

Figure 12. Illustration of the Proposal of Control Variables of Every Stage of the Process in AETAII

Figure 12 shows that the process variables are measured in every stage and the information is processed by the controller who receives the management algorithm set points. It is observed that the information about the variables is also sent to the management algorithm [18].

6.2 AETAII Management System Proposal

This article presents and describes some administrative procedures of a generic AETAII. It is possible to implement, for example, chemical product storage and acquisition administrative procedure. This acquisition can be planned in real time with suppliers by means of publication on the web, because all of the process data are available in the corporate network and stored in the database of the PIMS – Process Information Management Systems. It is possible to effect the automatic calculation of the daily consumption of chemical products, to obtain the current stock level, to automatically control input and output of the lots and loads to return and to receive, as well as the automatic emission of the pertinent report. So, unnecessary acquisition and storage of the inputs are avoided, which reduces costs. Variables such as level, concentration and weight of aluminum sulfate, fluorine and lima tanks, number of existing containers, suppliers invoices and product weight are fundamental to the establishment of this kind of procedure that will certainly be stricter and more efficient in relation to the processes manually operated or with conventional instrumentation automation. Another possible procedure is the elaboration of a historic base to improve management and control algorithms. Most of the process control variables are automatically monitored and transmitted to the corporate system database. Thus, it is possible to generate automatically the water treatment process algorithm history for subsequent evaluation and elaboration of mathematical models to its improvement.

Another possible administrative procedure is the maintenance management. The integration of data on equipment maintenance to the operation control system is extremely important to the effectiveness of the water treatment process. Information about equipment operational conditions, situation of the scheduled and pending corrective maintenance, preventive maintenance schedules with or without equipment paralyzing, characteristics and equipment operation parameters can provide resources to properly manage AETAII. Figure 13 presents an illustration of the management administrative model proposed in this article.

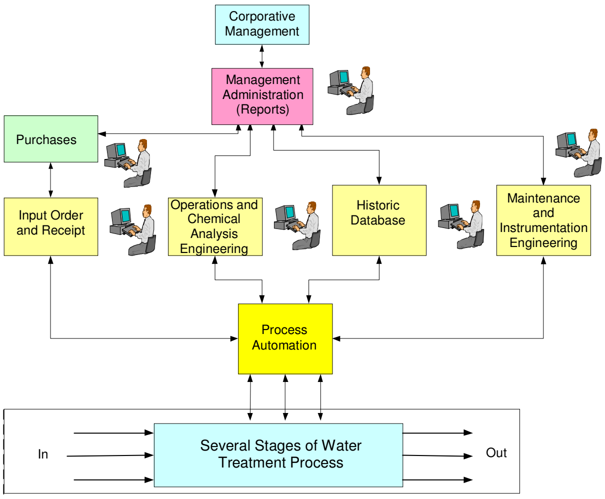

Figure 13. Illustration of Generic AETAII Management Model

7. Integrated System for Automated Management of Intelligent Sanitation (SIGASI)

Automating the sanitation cycle through intelligent automation techniques enables a more efficient and optimized data acquisition from the operational process, and a later conversion of such data into information – which by its turn will be converted in knowledge for decision-making and management processes. The automation structure of a sanitation system is composed by three basic sets: automatic control, electronic supervision and data acquisition. Depending on the system and site, however, each one of these sets can be used in an individual way. It is evident the high number of variables involved in the sanitation process. Additionally, the operational plant of sanitation systems exhibits widely distributed geographical characteristics, thus making more difficult any data collection for processing and management purposes. Typically, an automated sanitation system is composed by the stages described in the items that follow:

7.1.1 Automatic control

The automatic control is in charge of keeping the operating conditions of the process within predefined parameters, thus minimizing the need of human intervention. This process is governed by the following algorithm: reading of process variables, comparison to reference values, actuation of dosing devices, inverters, valves, motors, etc.

7.1.2 Electronic supervision

The electronic supervision uses data communication technologies and computing systems to concentrate all information of a system, involving the facilities of a single operation site. With electronic supervision, one or more operators can control many pieces of equipment, distributed throughout a very wide area.

7.1.3 Data acquisition

The data acquisition process employs communication technologies, computing systems and databases to store and analyze process data. The stored data can be displayed in tabular or chart formats, in order to show a real time view of the progress of a given process. In a general way, the stored data are used to: optimize control parameters, make analyses based on long time periods, determine the cause of faults, perform predictive maintenance and monitor the system's hydraulic behavior when a given pump is turned on or off (analysis and events).

Although the managers know most of sanitation subprocesses, such knowledge is not fully systematized. Consequently, the knowledge of subprocess managers is not always used in an assertive and efficient fashion in automation systems. In this case, the adoption of Knowledge Engineering and Expert Systems in level 3 of the automation pyramid – more specifically at the base of supervisory systems – can provide a systematization of that knowledge and can enable knowing any unknown processes. In this way, this work (called SIGASI – Integrated System for Automated Management of Intelligent Sanitation) shows the possibility of systematizing the knowledge, and especially supporting the decision-making process in the sanitation cycle management with the use of Expert Systems (ESs). Figure 14 shows the overall architecture of SIGASI.

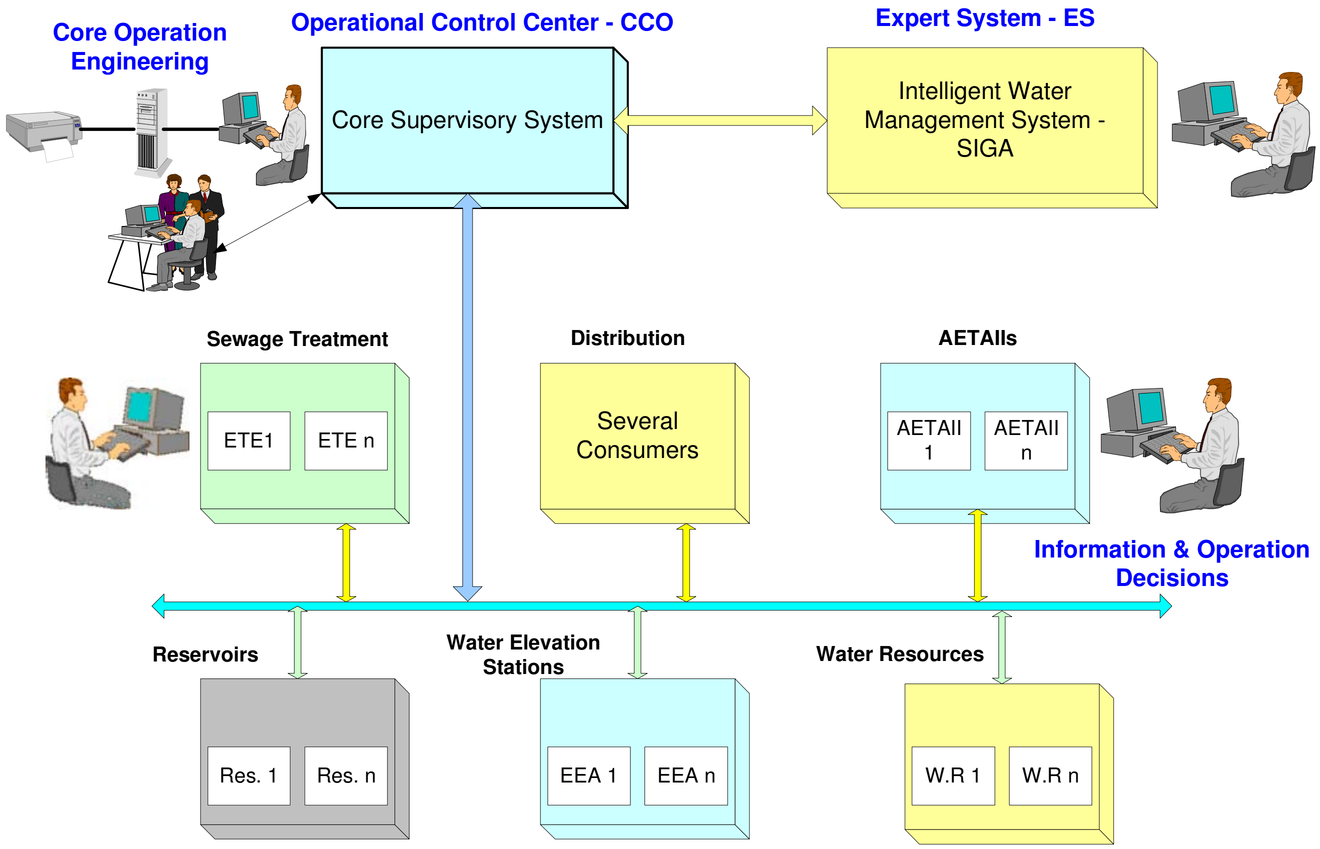

Figure 14. Overall Architecture of SIGASI

As shown by Figure 14, the proposed SIGASI allows a full operating integration of the system, covering the entire sanitation cycle. Therefore, it involves: all AETAIIs, all Sewer Treatment Stations (ETEs), all Reservoirs, all Water Elevation Stations (EEAs) and all sources of Water Resources. Please observe that each one of the SIGASI components must have its respective automation system deployed up to level 3 of the automation pyramid. In this way, the supervisory systems of all SIGASI components are interconnected (through a communication network) with the SS of the Operational Control Center – C.C.O., where the core operation engineering carries out analyses and decision-making processes. Due to the high complexity of this system as a whole, the core SS is connected (in real time) to the Expert System (ES) in charge of the module that belongs to the Intelligent Water Management System (SIGA). By integrating the Core SS to the SIGA (Andrade, 2001) [14], the latter can learn from system operation in real time, and also support and carry out the decision-making process, in order to optimize the integrated management of sanitation cycles.

8. Conclusions and future researches

The benefits provided by the proposal presented in this article can be divided in two items:

- Benefits reaped from the improvement of operating and management efficiency of the AETAIIs;
- Benefits reaped from the improvement of operating and management efficiency of the sanitation cycle using SIGASI.

Benefits reaped from AETAII: One of the first benefits of the proposed architecture is the initial reduction of interconnection and hardware cables, enabling that only the necessary to start the operation is acquired. So, the instruments become more important in this process, since they become capable of performing self-diagnosis, signal compensation processing, filtering and linearization.

AETAII proposal primordial functions are to generate reports, graphs and information in a more rational and scientific way, and to provide the elaboration of an administrative management model that contributes to the operation of the water treatment process.

Management supported in rational and scientific databases leads to a significant increases of productivity, to a greater reliability of the water treatment process, to the improvement in the quality rates and to the efficiency in terms of power supply. This reflects in revenue increase, production increase and minimization of operation and production costs, mainly in medium and big sized water treatment stations, where thousands of registrations of data are generated everyday.

To sum up, the conclusion is that AETAII brings numberless technical and economic benefits as compared to manual operation and automation of Water Treatment Station with Conventional Instrumentation - AETAIC. This new topology proposed to sanitation sector will contribute to the improvement of instrumentation and, consequently, of automation.

Benefits reaped from SIGASI: the integration of all facilities involved in the sanitation cycle (which involves also all facilities of AETAIIs) will certainly enable a management that is significantly more efficient. The intelligent automation of sanitation systems will allow taking operational decisions in a way to optimize resources and maximize operational gains. The integrated, intelligent automation will also enable the assembly of a history series containing occurrences, taken decisions and respective results. The analysis of such history series will also allow engineering studies to improve both the system and the management model. Consequently, the corporate level of sanitation companies will be able to manage the system as well, with the purpose of improving the corporation's financial performance, based on operating data.

We can then conclude that the integrated and intelligent automation is a powerful tool to reach the performance operating levels that enable economic results associated to sustainability parameters. Automation, with the new concepts presented in this article arises as a powerful tool in sanitation management and water resources. This article also proposes that new research initiatives on sanitation management of water resources and environment with the use of automation are developed.

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