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Application of Decision Support Systems in For-profit Enterprises: Insights for the Water & Wastewater Treatment Industries

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1 Introduction

Decision support systems (DSS), which apply a variety of analytical techniques to development of reasoning software applications, have been in use for over 30 years. Since the advent of computer software, technologists have strived to find ways for automation to improve the management of industrial organizational processes, including engineered unit processes and the business processes that are the management activities of an organization.

In water and wastewater treatment, the DSS experience over the past 30 years has been spotty. There are both great success stories that demonstrate the possible and miserable failures that cost utilities millions of dollars. In general, this industry has lagged behind private industry in large part because the driving forces for positive change are not related to the profit of the enterprise. The motivation for change in water and wastewater industries relates to a diffuse accountability - to the utility itself, to governing boards and political bodies that oversee the utility, to regulatory bodies that may fine the utility for poor performance, to ratepayers who expect a level of service, and to the environment whose protection depends on treatment quality. In comparison, private industry has one, clear driver; the need to generate revenue. Any company that does not create value for its customers and generate revenue in the process soon goes bankrupt. The sharp focus on revenue has an impact on DSS development in industry because technology is seen as an enabler that adds efficiency and drives out unnecessary costs.

There is benefit to be gained from the experiences and current practices of private, for-profit companies in development of DSS. A recent project, funded by the Water Environment Research Foundation (WERF, 2002) is completing a survey of past and current DSS applications described in the literature and taken from the corporate databases of private companies who specialize in DSS development. The project focuses on discrete and continuous manufacturing industries, which are most like the water and wastewater utilities, but also examines the telecommunications industry. This work highlights the evolutionary growth observed in DSS development towards architectures that are simple in design and driven by standards, better utilization of the wealth of analytical techniques available, and integration of data and information system functions on the basis of business process models. This paper includes excerpts from the findings of the WERF project and makes recommendations for water and wastewater utilities embarking on new or upgraded DSS capabilities.

1.1 Background

Advances in sensor technology, distributed control systems and computer technology have dramatically increased the amount and rate of flow of data that must be handled. Efforts over the past three decades have examined many areas of decision support, including trend analysis, fault detection and diagnosis, planning and scheduling. However, decision support systems typically function

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as isolated entities, and it has been difficult for industrial designers to build integrated systems that effectively combine disparate data from measurement, modeling and analytical applications. Considered in isolation, a DSS achieves its goals, but typically addresses only one of several drivers for development.

There are four major drivers for implementing decision support in industry, which are to improve organizational economy, safety, flexibility and environmental protection.

- **Economic Performance**

Profitability via competitiveness and the return on assets are the goals of a for-profit enterprise. To achieve these goals, an industry must take steps to improve efficiency and productivity, and cannot tolerate long shutdowns or abnormal situations. Most, if not all, decision support systems in industry have a cost/benefit profile that justifies development on the basis of improved economic performance. Few software projects in industry are undertaken without a guaranteed payback within a designated period of time, which is often less than a year.

- **Safety**

This is an essential motivation for all industries and a key element in most designs. Besides the obvious concern for the health and well-being of employees and customers, the practical reason for this is also the high cost associated with failures, injuries and loss of life. It is estimated that abnormal conditions such as these cost industry billions of dollars each year, and result in injuries to people and damage to equipment and the environment. Safety concerns sometimes may be at odds or compete with other organizational goals, including flexibility, economy and environmental protection objectives.

- **Flexibility**

In industry, products have lifecycles that must be carefully managed. In many markets, for example, high-tech electronics, the lifecycle of a product may be only a few months or even weeks. In other industries, it is necessary to switch production resources from manufacture of one product to manufacture of a host of others. In addition, customer demand changes across products and product lifecycles, making it necessary to construct facilities that run efficiently under periods of both low demand and high demand. These needs require facilities that are flexible and adaptable.

- **Environmental Protection**

Environmental protection is sometimes considered an external constraint on operation, in the sense that there is no direct link between this driver and value delivered to the organization's customers. Recently, efforts have been made to internalize the environmental aspects of a for-profit organization because the costs associated with environmental damage can be quantified. These include short and long term legal and public-relations costs.

1.2 The Evolution of Decision Support in Private Industry

Parallel industry has addressed the need for decision support in an evolutionary manner, so it is useful to briefly review the history in this area. Software technology for decision support has evolved with computing technology. As tools and techniques became available, industry implemented DSS applications in an isolated and haphazard manner. Nevertheless, many of these applications were successful and resulted in further advances in the technology. Advances in DSS technology included greater productivity in developing the software applications, for example, better user interfaces, development environments and more robust software, and the evolution of standards. Parallel advances in hardware technology significantly improved computational capabilities and speed. Decision support systems now are increasingly accepted as valuable tools within the broad context of the entire organization or enterprise.

The history of expert systems technology demonstrates the gradual acceptance and increasing application of decision support systems found in industry. During the late '70s and early '80s, a software technique called expert systems, which derived from work in the field of artificial intelligence, achieved prominence because of the successful demonstration of expert system-based applications in medical diagnosis and computer configuration problems, among others. The foundation of an expert system is a set of if-then rules, developed by human experts, which can draw conclusions based on input data provided to the expert system. For example, a medical diagnostic expert system might take as input a patient's blood analysis data and, based on rules that relate the value of specific analytical results to conclusions about the patient's illness, determine the illness and specify remedial actions to correct that illness. As it runs, an expert system may ask questions to direct its chain of inference, or provide explanations of its reasoning to the user, either in a live question-and-answer session or by exchanging information with on-line data sources (databases, control systems, laboratory systems, etc.). It has been found that expert systems can emulate the reasoning of human experts as they detect events, diagnose conditions and respond intelligently to diagnostic assessments.

Expert systems were constructed for a variety of purposes in the 80's. Most of these expert systems were, at the time, standalone applications that addressed diverse issues in financial, manufacturing, medical, pharmaceutical, and telecommunications markets. As the scope of these applications increased, they grew larger, more complex, and more proprietary. Each vendor had its own tools and methodology and linking these applications with other applications or other sources of data became increasingly difficult. Advancement was limited by access to data and there was no sensible integration within the organization either horizontally with other operational software, or vertically through the various levels of management.

In the 90's, hardware and software platform standardization motivated expert system vendors to create tools with better user interfaces and that permitted better integration. Microsoft Windows became as prominent as UNIX operating systems and software integration standards emerged that for the first time offered the promise of eliminating costly point-to-point integration between the expert systems and disparate data sources or applications.

Also during the 90's a growing number of organizations focused at the management level on business and organizational changes as part of a business re-engineering trend, which had as a focus business processes defined as a sequence of tasks or activities incorporating decision logic expressed in part as rules. Business process management now is a growing segment of the software industry that has as a goal the modeling, validation, automation and continuous improvement of business processes. This trend has resulted in development of more expert systems in management settings because 'business rules' have been identified as critical both to understanding how a business works, and for process improvement. Expert systems today are a key part of many business management applications.

The most effective DSS interact with other applications and support all levels within an organization in a way that advances the goals of the organization. Many challenges remain in DSS development and new complications have arisen from the need for greater collaboration and information exchange amongst business partners participating in supply or value chains. The broader view of business process management within a value chain perspective is the expected theme for development of decision support systems in the next decade.

2 Business Processes and the Value Chain Emerge

Parallel industries have achieved greater re-use and proliferation of business best practices by defining standard reference models. These reference models define standard processes, establish a glossary of common terms, and relate business processes to performance metrics. The linkage of processes and metrics enables analysts to pin-point problems when metrics degrade. Methodologies developed by consultants and the model-user community help businesses to develop a plan of action for change required to improve their business processes.

To understand why business process reference models are important to DSS development, consider that any DSS, whether it is advising on the best set-point for a treatment process control loop, or guiding the master plan for a utility, must be designed to help that organization meet its goals. This obligates a DSS developer to ensure that the DSS has access to the right data, outputs information useful to the organization as a whole and considers interactions with other parts of the organization. Controlling the set point of a treatment process has a strong impact on energy and asset utilization and the total cost of operations. The lack of an overall, business perspective on DSS development in the past has resulted in numerous 'silo', or standalone applications that may work as designed but do not support the overall goals of the organization. Business process models are important to DSS development because they specify the kinds of DSS systems needed, the data required and the relationships between data and processes that must be considered when making decisions for the benefit of the business as a whole.

The cornerstones of business process reference models are standard processes, best practices, metrics and standard terminology. A process is defined as a sequence of tasks, where each task represents a single activity in the process. Each task may be constrained by the availability of resources (human or machine). Examples of business processes are the tasks of assigning operators to shifts in a schedule, the processing of orders for supplies, and all the activities that comprise the development of a utility master plan. A 'best practice' is a process that has been identified as superior to other possible processes for meeting specified objectives. For example, to optimize the timely, accurate delivery of supplies to a plant, a best practice for exchanging information between the plant and supplier is to use a standard order form and electronic communication of the form, such as by e-mail, between the buyer and the seller. Standard terminology makes it possible to establish consistency in communicating the meaning of a business reference model. In industry, misunderstanding of even simple metrics causes confusion, such as the definition of 'lead time' or the amount of time required to fulfill an order. Various definitions are used and meaning is lost unless there is consistency in interpretation,

We can imagine the creation of reference models that describe an organization, and that widespread agreement on the suitability of the model is possible. But if the reference model describes only one company that participates in a network of companies interconnected by virtue of their buyer-supplier relationships, then the model is insufficient. Optimizing the operation of one part of the network doesn't ensure the success of the whole network, just as optimization of a single unit treatment process doesn't guarantee that effluent limits will be met. This reality has given rise to a new, broader perspective of the role of a company or organization as one part of a larger network of entities participating in a 'value chain'. This same concept applies to the water and wastewater industry, where we can think of the network as a 'quality chain' that has as its primary objective, the delivery of quality effluent.

In industry, the first wave of software applications built to automate important inter-company processes were referred to as Enterprise Resource Planning (ERP) applications. Companies such as SAP, Baan, J.D. Edwards, Manugistics and PeopleSoft have built an industry around delivery of ERP software applications and they have been successful in automating business processes within company boundaries. The next wave of business applications were focused on Customer Relationship Management (CRM) that addressed the needs of the company's demand side, that is, its customers. On the supply side of the company, a third wave of innovation resulted in development of business applications for Supply Chain Management (SCM), in essence linking the company to its suppliers and its suppliers' suppliers in a network of collaborating buyers and sellers. Any modern company must have this broad supply chain or value chain perspective to compete in today's economy.

Two organizations have developed business process reference models that have applicability to the water and wastewater industry. These are the Supply Chain Council's Supply Chain Operations Reference (SCOR) model and the Telemangement Forum's Telecommunication Operations Map (eTOM) model. These models, and the value that they bring to the water and wastewater industry are discussed in the next section.

2.1 The Supply Chain Operations Reference (SCOR) Model

The SCOR model was developed by the Supply Chain Council (SCC), a consortium of continuous and discrete manufacturing industries (SCC 2002). The SCOR model was designed to bring together elements from business process reengineering, benchmarking and best practices. These three elements have become the pillars of many business process improvement methodologies, so it is natural that standard reference models would have as a centerpiece the consolidation of these elements.

There are four essential processes in the SCOR model. These processes, their definition and their analogous process in the water/wastewater domain are shown in **Tab.1**[1].

The SCOR processes define essential process elements, which then can be linked together to model a company. For example, a single manufactur-

[1] The SCOR model includes a fifth process called Return. Refer to the SCOR documentation (Supply Chain Council 2003) for more information.

Tab.1 Supply Operational Reference Model Processes and Similar Processes in Water/Wastewater Treatment.

SCOR Process	Definition in the Manufacturing Domain	Similar Processes in the Water/Wastewater Domain
Source	Processes concerned with obtaining raw materials that are used in production from suppliers	Processes concerned with managing raw water (clean water) or raw wastewater for treatment; also securing chemicals and other materials for use in treatment
Make	Processes concerned with converting raw materials into finished products	Treatment processes
Deliver	Processes concerned with delivery of finished products to customers	Distribution of clean water and transport of treated wastewater
Plan	All the plan processes for the company, including Plan Source, Plan Make, Plan Deliver, Plan Return and Plan Supply Chain	Processes for scheduling treatment, controlling processes, planning the sequencing of treatment events, and utility master planning

ing plant contains each of these elements, that is, raw materials are procured by Source processes, whereas finished good are manufactured in Make processes and delivered to customers by Deliver processes. Plan processes ensure the smooth operation of the manufacturer. In contrast a warehouse doesn't have a Make processes, because it is simply a storage location for goods.

The power of SCOR lies in its definition of subprocesses, metrics and best practices comprising each of the essential elements. The SCOR model is hierarchical, describing business processes on several levels where each level is a decomposition of higher levels. As shown in **Fig.1**, the SCOR model defines Level 1 as a 'node' in a supply chain. Each node may have many upstream, or supplier nodes and many downstream or customer nodes. The Plan, Source, Make & Deliver process elements are the Level two processes, which are further decomposed into SCOR-defined Level 3 process categories. SCOR does not define level 4 elements; rather it states that these processes are company-specific. At Levels 1, 2 and 3, the model identifies key metrics, specifies standard definitions for terms and links processes to common industry best-practices.

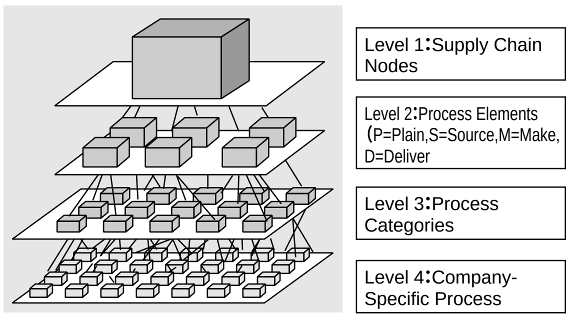

Fig.1 The SCOR Model is hierarchical.

Additional information on the SCOR model can be obtained from the Supply Chain Council's web site (www.supply-chain.org).

2.2 The Telecommunications Operations Map (TOM)

TOM is a business process reference model for the telecommunications industry. The TeleManagement Forum, an international non-profit organization serving the information services and communications industry developed the TOM to address standardization needs of the telecom industry.

The TOM is a blueprint describing major processes in telecommunications operations. It is used for internal process reengineering, developing partnerships, outlining boundaries of software components, and defining required functions, inputs, and outputs that must be supported by software products. As shown in **Fig.2**, the TOM consists of a high-level identification of the primary processes of Fulfillment, Assurance, and Billing, and subprocesses within each, including detailed descriptions of the activities of each sub-process.

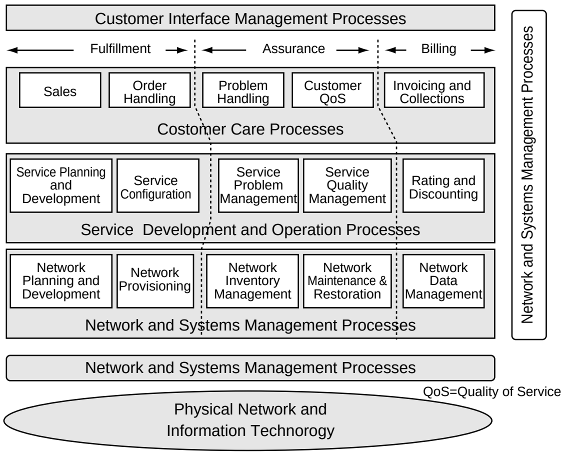

Fig.2 The TOM Model is focused on Service Provision and Billing.

Inspection of **Fig.1** and **Fig.2** show many similarities. Both models are hierarchical in nature, with high-level processes describing essential process elements and comprised of many sub processes. The sub processes define the many applications that support a company in logical groupings using standard terminology and specifying interactions between processes where they occur. Both the SCOR and TOM model provide an efficient framework for integration of software components, and a suitable reference for identifying decision support needs.

Further details on the TOM model can be obtained from the TM Forum Site (www.tmforum.org).

3 A Common Architecture for Decision Support

Decision support tools and techniques developed over the last two decades conform to a common architecture for decision support. Decision support systems address two management issues;

design of plant and business process systems, and,

control of plant and business process systems.

Design and control decision support applications differ in their intended audience. Plant or process designers are concerned with design issues and are less interested in connection to live data sources. Design methodologies use simulation to compress time and make projections. In contrast, plant managers and operators are concerned with operational control issues and must have connectivity to live data in order to control the plant or process systems in real time.

The following three features are common to both design and control tasks;

1. an objective is clearly stated, for example; make the product within a specified time frame, achieve a high product quality, control the concentration to a desired set point, etc.,
2. the objective is achieved by manipulating variables that impact the ability to meet the objective, for example; add more administrative resources to eliminate order processing delays, send advance notifications to alert customers of an incoming shipment, etc., and,
3. models are employed, for example, dynamic models of fermentation or inventory control business process models.

Design and control problems have many of the same features, and this is a key to developing a single architecture that helps engineers develop software systems for decision support. The essential elements in this architecture are:

1. feedback of information to respond to the state or condition of the process being managed,
2. feed-forward of information to proactively alter the system state or condition of the process,
3. models, both of the physical system and of how we manage or control the physical system.

The latter are decision processes described as strategies, control algorithms or business rules.

These elements come together in the model-based decision support architecture.

- **Model-Based Decision Support Architecture**

The decision support architecture, shown in **Fig.3**, is a common architecture for DSS in industry. The architecture applies to DSS development at any level in a business from the plant floor to corporate management. This architecture is based upon the 'double-loop' model, developed by Psychologists as a theory of change and action (Sterman 2000).

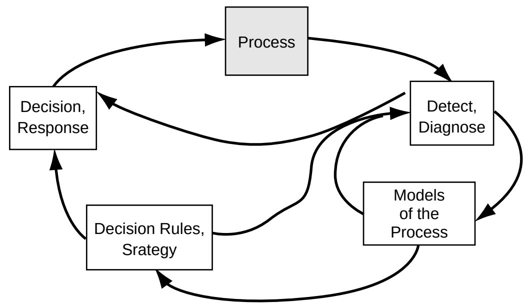

Fig.3 A Common Architecture for Decision Support.

The system to be managed or optimized is shown in **Fig.3** as the Process. The essential loop in this architecture is the feedback loop (top loop in **Fig.3**). The feedback loop detects events, diagnoses process conditions and responds to maintain process conditions, but in a purely reactive manner. All decision support systems implement one or all of detection, diagnosis and response tasks. For example, an early 'expert' decision support system application was developed to detect and diagnose bacterial infections and then recommend courses of action to treat the infection. A proportional-integral-derivative (PID) control algorithm is an example of an implementation of this loop. These are both control examples; however, there are also many design examples, such as deciding to build a new distribution center in response to increases in product demand, and specifying the structural steel requirements for a building to be constructed in response to the need for more office space. Note the role of models in these examples; PID parameters are derived from models of the process being controlled, and supply network models help determine where to site a new distribution center.

Models augment the first loop and are applied in decision support in two ways. Models of the process are used to forecast future states in order to proactively adjust, according to a defined strategy, the real process to meet an objective. This is shown in the right-hand side loop, which shows the interaction between a process model and the detect/diagnose activity. The model of the process is an aid that confirms the detected state of the process, refines a diagnosis or predicts a future desired state. The outer loop applies process models and models of decision rules or strategies. Both may be applied in detection/diagnosis logic and in the decision responses that change the behavior of the process.

The model-based decision support architecture explains the essential modules that developers must prepare to implement decision support and tells us how these modules work together. The four main modules are:

1. Detection: monitoring, conversions, filtering, pattern recognition, raising alarms / notifications, secondary metric calculation etc.
2. Diagnosis: assessment of state, message correlation, etc.
3. Response: calculation of changes to manipulated variables, determining remedial actions, planning, scheduling, etc.
4. Models: models of the physical system or models of how we detect events, diagnose conditions or respond to maintain process state.

Modules for Detection are common in many industry and some applications (e.g., in telecom network management) have elaborate Diagnostic modules with sophisticated alarm creation and escalation procedures to execute remedial actions and alert management without human intervention. In all industries, the Response modules are by far the most difficult to develop and implement. Scheduling and planning packages are examples of Response modules that use optimization techniques based on various types of Models describing how to plan or schedule tasks. One reason that Response modules are difficult to develop is that these modules must be proactive to work well, and projections require the ability to forecast the future effectively.

4 Conclusions and Recommendations

The work completed to date for WERF has demonstrated the evolution and current state of the art of decision support systems in industry. The following conclusions can be drawn based on this work;

- Decision support systems found in industry have evolved from standalone or 'silo' applications to integrated applications that support the goals of a company viewed as a participant in a value chain. Without the larger context provided by a model of the water/wastewater industry business, development of decision support capabilities will be limited to silo applications.
- Business process reference models are being developed in industry and these models are enabling greater proliferation of best practices.
- A broad range of analytical techniques are being applied in decision support systems and a model-based architecture is evolving that serves as a useful guide for developers.
- Business process models drive the definition of data and its integration, and common data models are evolving.

We make the following reccommendations based on a broad examination of decision support technology found in industry;

- A business process reference model should be developed for the water/wastewater industry that encompasses elements from source supply through treatment and distribution of treated water. This model should focus energies on improving the industry as a whole by specifying important organizational processes, interactions, opportunities for decision support, and data. Promulgation of this model as a standard will help to promote quality, reduce cost and encourage information sharing.
- A first step in realizing a comprehensive reference model for the water and wastewater industry is to view treatment facilities as participants in a 'quality' chain. This emphasizes the positive role of water and wastewater treatment and the impact this industry has on improving the environment.
- Decision support applications developed in the water and wastewater industry can move from standalone or 'silo' applications to integrated, high-value applications through a better understanding of the relationship between business-level strategic management processes and operations-level engineered unit processes.
- Pilot projects are needed to demonstrate the following key concepts of enterprise decision support;
  - Automation of important business processes important to water or wastewater treatment facility management
  - Vertical integration of process control systems with asset management
  - Conceptual development of a business reference model for water and wastewater utilities including common business processes and related standard metrics and best practices
  - Application lifecycle support enhancement - from design, through validation, delivery and continuous improvement - that results through the application of a reference model

References

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