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Development of a Systematic Object-Event Data Model of the Database System for Industrial Wastewater Treatment Plant Management

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ABSTRACT. Systematic information, derived from systematic data integration in diverse scales (spatial and temporal) and structures, is essential for clear understanding of environmental problems with hierarchical and interactive representation of natural system dynamics. To effectively support systematic integration of environmental data, a systematic object-event (SOE) data model has been developed and demonstrated by applying it to a database design for data management of an industrial wastewater treatment plant in this study. Comparing with a developed relational database, it is shown that the SOE database is more comprehensible and flexible for data access and integration at different levels with its embedded systematic logics. Data distributed in diverse SOE databases are more capable to be significantly integrated to provide adequate information for better utilization in emergent environmental modeling or knowledge mining tools, such as declarative modeling, semantic modeling, and agent-based software or information systems.

Keywords: systematic data integration, systematic object-event data model, database, industrial wastewater treatment plant

1. Introduction

Environmental data, whether recorded in numbers, characters, images, or other forms, are abstractions of scenes in the environment, and also the basic elements from which environmental information and knowledge are derived to solve complex environmental problems. Environmental characterization and decision making requires information that span multiple disciplines, have semantic differences, and mostly are collected and managed by multiple organizations (Chen *et al.*, 2007). Therefore, the way to efficiently collect, analyze, and integrate a very large number of data distributed in diverse data sources for accurate provision information necessary for environmental management decisions is a critical foundation (Pokorny, 2006).

Rapid progress in data storage technology over the last decade has led to the establishment of various databases and information systems to support individual environmental managerial tasks (Tzou, 2002). These databases, which arrange data in their fixed scheme, have indeed functioned as reliable data sources for their corresponding information systems to provide supportive information in a specific domain. However, the potential for data reuse, communication, and integration with other application tools (software or systems) is restricted. Extensibility and flexibility of a database are now the essential requirements to contribute to usability of data and data integration (Liaw *et al.*, 2006; Seltzer, 2005; Rizzoli *et al.*, 1998).

In recent years, data integration has been indicated as a collateral issue in environmental informatics studies. Due to the discussion of model integration, semantically aware approach is recommended to deploy environmental datasets and models by semantic annotation (Villa *et al.*, 2009; Rizzoli *et al.*, 2008; Chen *et al.*, 2007; Lee *et al.*, 2007; Villa, 2007). In compliance with the agent-based approach in environmental information system design, distributed database are ideal to be operated by data source agents to make actions, such as data transformation, communication, integration, and provision (Athanasiadis *et al.*, 2009; Tolchinsky *et al.*, 2009; Athanasiadis *et al.*, 2007; Purvis *et al.*, 2003; Wagner, 2003). These works offered important criteria for thinking of data integration, such as data accessibility, data categorization, semantics representation, object/agent application, unified paradigm, and personalized scale. But the majority of previous studies stood on the view of data application, which focused on improving successful data process and supply for models, information system or other application software.

This research started from a different point; we attempt to let databases prepare for adaptable data integration from the beginning of the data collection procedure, before data storage, for systematical data distribution. Therefore, our goal is to develop a systematic data structure that is extensible and flexible for standard data storage and systematic data integration. The systematic object-event (SOE) data model that is motivated by flexible data integration to provide systematic information has been developed. In order to demonstrate the implementation of

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the SOE data model, a database design for industrial wastewater treatment plant management was presented in this paper. Based on the concerns in Lee *et al*. (2008) of increasing measurement values obtained from the dynamic treatment system using modern devices, the SOE database was compared to a relational database and convinced to be a better way to make database as a rigid bases for progressive application software, such as multi-agent systems for adaptive decision making.

In the rest of this paper, more details of the development and implementation of the SOE data model are provided. The theoretical basis that was used to form the SOE approach for categorization of abstractions interpreting the real world is discussed in Section 2. In order to support the integrated information of decision making, a data model fitting the considerations of systems thinking for better decision making is required, and the SOE data model is proposed accordingly in Section 3. A database for operation management of an industrial wastewater treatment plant is designed as a case study and discussed in Section 4. Section 5 concisely concludes this study.

2. Approach

It is recognized that environmental data are records revealing particular meanings of the real world, and can be regarded as fragmental clues to understand the reality as well. Data integration accordingly can be seen as an action to gather fragmental clues together to reconstruct past circumstances, which are immutable but helpful to make right decisions for future. In this way, data should be identified as semantic implications and integrated in accordance with their semantic relations, rather than be regarded as observation context and integrated with considerations of their integrity in formats or granularity in temporal or spatial scales. This is exactly why a semantic framework was mentioned as a required paradigm for model and data integration in natural system science and ecology field (Villa, 2007), which is necessary for environmental researches. Therefore, the systematic object-event approach was proposed to clarify the semantic structure from the nature of the environment based on combination of reductionist thinking and systems thinking. Semantics of such a complex system as the environment can be flexibly illustrated through identification of relative objects and events in a systematic structure based on the approach.

2.1. Reductionist Thinking and Systems Thinking

In order to improve understanding of the nature of such a complex system with numerous elements and interactions, scientific reductionism and philosophical analysis have been applied to simplify the system into its individual constituents. Reductionist thinking and methods are based on the belief that a complex system is nothing but the sum of its parts (Knowles, 2002). With the tendency to study smaller spatial scales and organizational units, scientists have discovered more and more details about the minutest level of our nature. It has been proved that reductionism helps build an understanding of the universe. However, reductionist thinking has received criticism because an optimal decision that helps solve a small problem may have another serious side effect on the system. Discussions on the "the butterfly effect" and "the silo effect" clearly show that local successes may lead to failure of a global system. Therefore, systems thinking was proposed to cope with the practical demands of complex or confusing situations (Seddon and Brand, 2008). Standing in contrast to reductionism, tackling issues in a holistic manner is advocated in systems thinking.

Systems thinking that brings system characteristics together (Petkov *et al*., 2008; Andrew and Richardson, 2008) and defining scenarios within complex systems (Seddon and Brand, 2008) is referred for proper analysis and synthesis of data abstracted from the world of systems. As a holistic approach, systems thinking lays stress on both how a system exists within the context of larger systems and how well it functions over time with external and internal interactions. The conceptual framework proposed by systems thinking has also been particularly useful in understanding and modeling dynamic systematic processes (Ozel and Kohler, 2004). Regarding static (structural) and dynamic (interactive) characteristics of systems (McLaughlin, 2008; Skyttner, 2006; Moore and Ausley, 2004; Rubenstein-Montano, 2001), systems thinking is required to reasonably compose complex systems and realize their dynamics.

To combine with the reductionist thinking and systems thinking, it is convinced that complex systems their irregular activities are the combinative result of various components and interactive actions and reactions. In order to flexibly capture the semantics of the environment, basic entities should be first identified follow the reductionist thinking. And next the diverse relationships between the entities should be differentiated to construct the specific system. Based on systems thinking, systematic relationships, and input-output relationship are essential for feasibility of systems' representation. With this logic, the systematic object-event approach is formalized in the following section.

2.2. The Systematic Object-event Approach

The systematic object-event approach is generated to abstract semantics of the environment, based on translating entity and activity, which imply the two basic (static and dynamic) components of the real world, into "object" and "event" and systematically recorded in the virtual environment (database). As any physical entity is a unique one in the real world, an object is its identity represented in the database environment. According to the reductionist thinking used to decompose a real-world entity, an object can be analyzed into smaller components, which can also be recognized as objects. At the same time, an object is a part of a larger system on the basis of systems thinking. Therefore, objects linking with their systematic relationships can be converted into systematic objects, as illustrated in Figure 1, while preserving the systematic structure. Consistent with systems philosophy, coherent and compatible relationships between objects should be correctly understood to compile the simulated system.

To appropriately express the dynamic processes within the real world, like activities caused by actions and reactions of entities, the term event is defined as the sequence of actions or reactions of an object. Thus, an event is the expression to abstract the process from an input stimulating an entity to the entity transforming the input into an output. The events view describes the cause, reacting process, and effect of an entity over a period of time to represent the dynamic complexity of systems. Connecting objects and events in accordance with their representative entities and activities, real complicated changes can be illustrated in the virtual environment at different scales with the systematic structure.

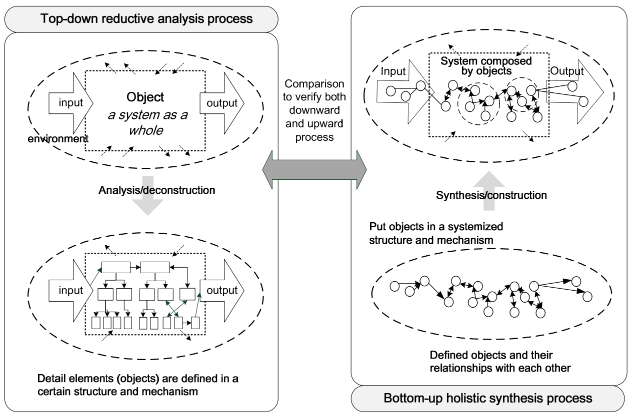

Figure 1. Integration of reductionist and systems thinking in the objects view.

3. Development of the Systematic Object-Event (SOE) Data Model

Conventionally, dataflow in a database is designed by information technology engineers who take data requirements as fixed goals to fit a specific information system or software. The method of treating all data elements as the same rather than recognizing their different meanings as representing some parts of reality is a common practice for creating databases. With increasing amounts of databases lack of interoperability to create more value-added application, it is emergent to find out a way to effectively organize numerous meaningful to improve our understanding of the complex systems.

Data model, which is the foundation of a database, defines how a database abstracts and represents facts from the real life (Brazhnik, 2007). The function of a data model is to provide an integrated collection of concepts for describing data, relationships between data, and constraints on data (Connolly and Begg, 2004). Since the manner in which a representation of reality in a database is made is still an issue of concern (Pequet, 2001), to enhance data model by not only semantic but also systematic concerns would be a better alternative for effective and efficient data integration and application.

The systematic objects and events approach is an approach that helps to analyze and synthesize the real world to improve understanding. It is rational to be an alternative way to organize data that are generated to represent a part of reality. Therefore, the systematic objects and events approach was applied to develop a semantic and systematic data model and discussed as followings.

3.1. Essential Data Types of Objects and Event

Data depicting phenomena are observation or measurement state of entities and activities in the real world, which are essential data types within object and event data in the virtual view. Therefore, to illustrate an object, identification is the first mark to specify its representative entity, which is different from anyone else. Furthermore, properties of an entity can be subdivided into attributes and behaviors (of organic bodies) or functions (of inorganic objects) to be essential data types within object data. Only individual object with its identification, attributes, and functions are not able to make the world work. To organize objects to resemble reality, various relationships between entities, which give the pattern of objects interacting under a specific scenario, are critical. Systematic structure and mechanism that link objects together to form a complete superior system can also be treated as a kind of relationship. For example, a relationship statement: "Mr. A and Mr. B are hired by the same company" gives a systematical picture that A and B (objects) are parts of the company (system). Thus, "attribute," "function," and "relationship" are classified here to the three classes used to categorize all explicit descriptions for properties of objects.

Each event is also a unique phenomenon captured from the real world activities. Every differentiable event is the only one that happens along the timeline so that identification is the first annotation of an event. Different from the objects view that identifies entities in the space scale, the events view emphasizes on defining activities that are located on a time scale. Based on the definition of the systematic objects and events approach, an event implies a complete reaction process where a specific object reacted and changed over time, within a period, or in one instant.

Different inputs that trigger the specific function of an entity may cause various activities. For this feature in the real world, the host object (representing the entity) and temporal descriptions of an event (representing the process of the activity) are the two most important items used to clarify an event. Furthermore, inputs that triggered the event, the changes that the object undergoes during the event, and the outcome of the event are also significant properties for the better understating of the cause and effect loops. In addition to input and output, the two specific types of relationships based on systems dynamics consideration, other relationships that indicate the correlation between an event and other object or events, such as the sponsor of an event, are also important to define the fact.

Consequently, "identification" of both the event and its host object, "event's attribute" of temporal characters, "input," "object changes," "output," and "event's relationships" are the major data types to comprehensively clarify an event. Data recorded abstractions of the real world, which can be treated as a part of object and event data. Based on this logic, these data types are used as the basis for classification of data elements to model data.

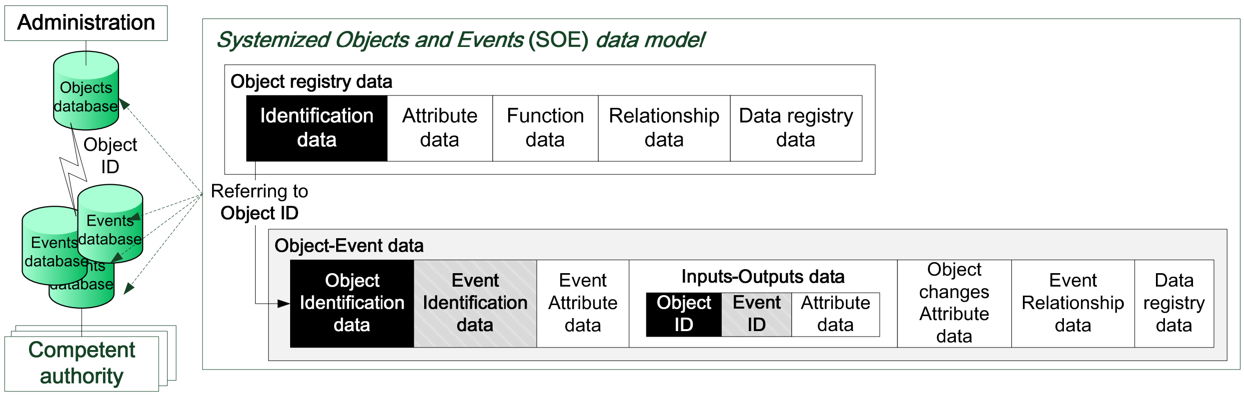

Figure 2. Scheme of the systematic object-event data model.

3.2. The SOE Data Model

The SOE data model based on the systematic objects and events approach attempts to provide a formalism to identify data according to the reality they represent. The scheme of the SOE data model consists of two modules, the object registry module and the object-event module, as shown in Figure 2.

The object registry module represents the pattern to arrange data of an object, which should be recorded while the object is produced, is discovered, or requires management. In accordance with the data types discussed in the previous paragraph, the four parts, identification, attribute, function, and relationship are regarded as categories to sort out data elements for describing objects. Object data recording in terms of the object registry module is the foundation for event data. Event data should refer to the identification of its host objects, as presented by an arrow between the object registry module and the object-event module in Figure 2.

In the object-event module, the identification of the object and event, the attribute, relationship, and the input-output of the event as well as changes of the object in the event are classes of data elements that illustrate the properties of events. In addition to the data types that follow the precedent of the previous discussion, another data type, called "data registry data" is formulated in both modules to allocate data elements with the characteristics described to record data. The contents of the SOE data model have been proposed to organize data systematically.

For the systematic objects and events approach to the organization management, the properties of an organization are objects and the management tasks for operating an organization are events. Different departments in an organization are in charge of various objects and events to achieve their mission and the data of those objects and events are used to support their decision making. The department responsible for object registry data is defined as the administration department, and the department taking care of the event data is called the competent authority department. Following the SOE data model, objects and events data can be generated by their corresponding departments in the same way objects and events are managed physically. To further explain this, a conceptual framework about related objects and events data and their administration and authorities is shown in Figure 3.

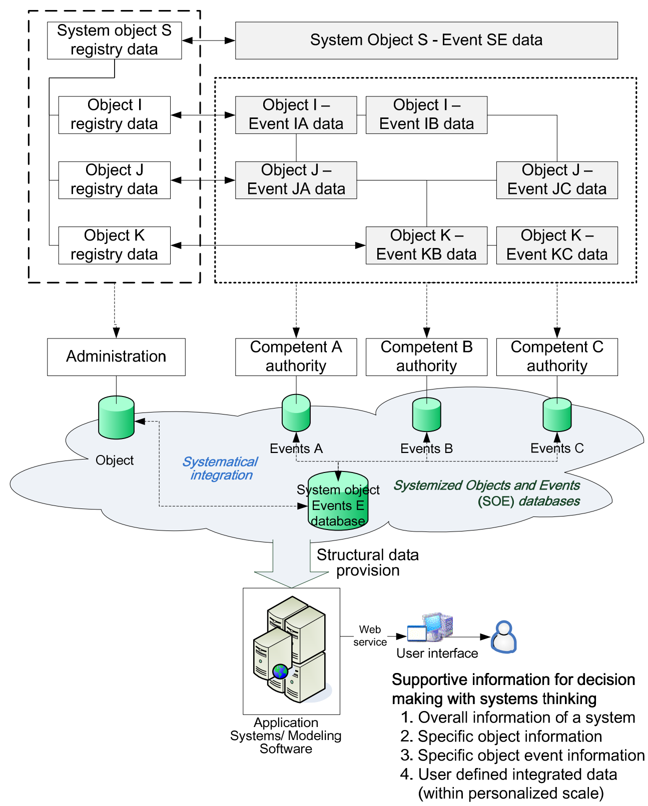

Figure 3. Arrangement of objects-event data in a systematic object-event database.

It is assumed that all the objects are managed together by the administration department in an organization. Management tasks A, B and C are managed by diverse authorities that are defined as competent authorities A, B and C. Object I participates in the management tasks A and B, which should be recorded as function data. Event IA happens while management task A is executed with object I by the corresponding authority. The data representing event IA should be recorded by authority A with

Table 1. Comparison of Data Models

Features Data models	Modeling Methods	Relationship presentation	Standard Abstraction	Network/ hierarchy	Derivation/ inheritance	Dynamic modeling
O-O	viewing the database as a snapshot of reality	Independent	Generalization Aggregation Classification Association	Network	Inheritance over classes	No
Event	viewing the database as a composite of transactions	Attributes	Generalization Aggregation	Hierarchy	No	Transaction modeling
E-R	viewing the database as a snapshot of reality	Independent	Aggregation	Network	No	No
SOE	viewing the database as a composite of transactions	Independent	Generalization Aggregation Classification Association	Hierarchical and systematic network	Inheritance over systematic relationships	Event based modeling

this logic by referring the object identification of object I. Events that happens to specific objects governed by responsible authorities can be explicitly defined and recorded as how they are conducted in the real world.

A systemic object S, consisting of objects I, J and K, is additionally assumed in Figure 3. This systematic relation should be defined by relationship data of each component object in the object registry module. With this systemic linkage, the event SE of object S can be regarded as an overall observation of events IA, IB, JA, JC, KB, and KC. Therefore, data describing events SE constitute integrated information with events data of the components of system S and can either be stored in a specific event database or not be stored but integrated in the database when required by users.

The SOE data model provides a convenient way for system designers to allocate data according to the physical management process within an organization. Multiple requirements of supportive information can be flexibly integrated with systematic objects and events data based on given constraints in temporal or spatial scale. The flexibility to integrate data or expand the database with new data elements is recognized because of the clear division of objects and events data. The newly created data for additional management tasks can be recorded by another event data table without affecting existing data tables.

Since correct decisions can be made only with adequate supportive information (Haag *et al*., 2004), the SOE data model is a formalism that can enhance systematic data integration among distributed data to adaptively support changing data requirements of decision making in complex systems.

3.3. Discussion

Development of the SOE data model intends to provide a systematic and semantic structure for data allocation and integration. According to the six parameters suggested by Peckham and Maryanski (1988) to compare the differences between semantic data models, the Object-oriented (O-O) data model, Event model and Entity-Relationship (E-R) model were selected for comparison with the SOE data model because of more similarities. In an O-O model, the objects encapsulate the partitioned knowledge of the actual system, and collaborate for the accomplishment of its operation (Spanou and Chen, 2000). The event model was first proposed by King and Mcleod, which is an approach to dynamic modeling (Peckham and Maryanski, 1988). The E-R model is the most widely accepted semantic data model (Batra *et al*., 1990; Chen, 1976). The results found using these four data models for the six selected features are summarized in Table 1.

It is obvious that the proposed SOE data model possesses all the features of the O-O, event and E-R data model. The SOE data model owns the ability to represent not only entities and relationships but also object characteristics within a systematic structure. Also, the SOE data model keeps the critical concept of dynamic modeling focused in the event data model; however, differing from the events defined in the event model is the message passed between objects. In the SOE data model, events are identified as abstractions of changing process happed to real-world entities, in database which can refer to a recorded object. With respect to both static structure and dynamic changes of reality, the SOE data model is believed to more capable clearly represent semantics of the complex environment through systematic data integration.

In addition, the SOE data model is more capable to cooperate with late development in the environmental informatics field. Declarative approach in environmental modeling claimed the transparency of a model by separated descriptions of variables and functions (Muetzelfeldt, 2004; 2007), which is similar to the notion to separate object data and event data in this study for more convenient integration. Agent-based approach in software engineering based on utilizing agents, the software entity characterized by autonomy, reactivity, and pro-activity, to flexibly treat complex fluxes of information (Athanasiadis *et al.*, 2009; Tolchinsky *et al.*, 2009). With the consistent awareness of treating data in the object (agent) view, a SOE database supported agent-based system may operation more efficiently and effectively. The conception of the SOE data model is equivalent to current trend of technological developments (XML-related technologies), which will pull in the direction of systematic and semantic data integration.

4. Application of the SOE Data Model in Database Design for Operation Management of an Industrial Wastewater Treatment Plant

To demonstrate the process applying the SOE data model, a case study is presented below on the design of an operation management database of an industrial waste water treatment plant.

4.1. Definition of the Scope of Operation Management

In an industrial park, a corresponding wastewater treatment plant is built to properly treat the wastewater generated by various industrial processes. Figure 4 shows the entire operation of an industrial wastewater treatment plant that includes an outer and an inner component which are separated by a concrete boundary of buildings of the plant.

The outer component contains the wastewater collection and transportation systems. The collection system includes all related pipes and pumping stations that are used to collect and convey wastewater from outlets of factories to the waste water treatment plant. The transportation system consists of the components responsible for transporting effluent water from the wastewater treatment plant to the receiving water body.

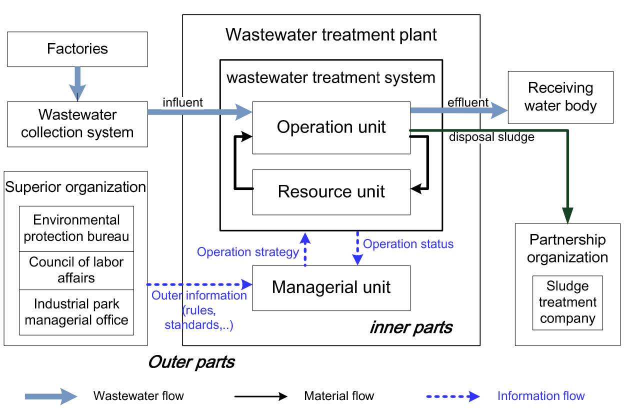

Figure 4. Operation structure of an industrial wastewater treatment plant.

The inner component is the wastewater treatment system containing the functional treatment units and the properties and managerial departments responsible for the function of wastewater treatment. Based on the priority of the operational outcome of the plant, the inner component is selected as the system's scope to develop a supportive database that helps us systematically arrange increasing amounts of data abstracted from the complex interactions of the treatment system.

4.2. Objects Analysis

Referring to the definition that any physical substance can be regarded as an object if it is necessary to be managed as discussed in Section 2, the objects related to the operation of an industrial wastewater treatment plant can be realized hierarchically by systematical reduction analysis. The result of analyzing a wastewater treatment plant in the downward view is shown in Figure 5. The treatment plant management and operation groups make up the two main subsystems. On the left side of Figure 5, the management groups shown are competent departments including employees involved in hands-on work. The other side shows the "treatment system," which represents the operational aspects of the wastewater treatment plant. Not only treatment processes but also supportive tools, such as pumping machines, electricity suppliers, chemical, etc., are needed to make the system function well. Therefore, objects are defined referring to the practical items used in a treatment plant.

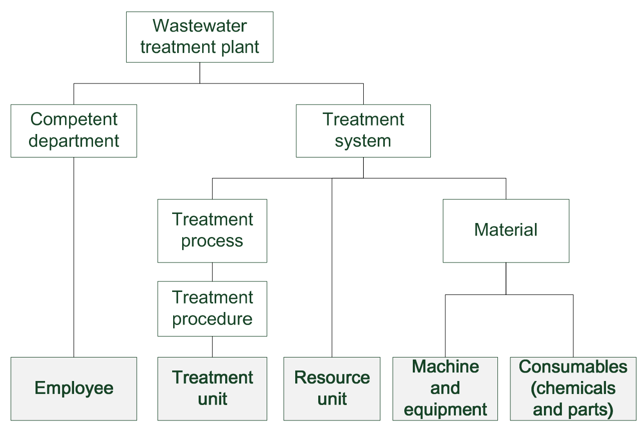

Figure 5. Hierarchical structure of systematic objects.

The objects shown with a grey background, "employee," "treatment plant," "resource unit," "machine and equipment," and "consumable" are the fundamental elements that constitute a functional wastewater treatment system. The other objects, with a white background, are the system objects that are characterized by grouping specific objects. For example, a treatment procedure is a system object formed by several treatment units and also one of the components of a treatment process. Objects and system objects with their systematical relationships can be suitably defined using this logic.

On the basis of the identified objects, the relationships between objects that form the mechanism of the whole system should also be clarified before data table design of the objects. The configuration of the wastewater treatment plant composed of the objects, system objects and their interactions is illustrated in Figure 6. There are four departments in the management unit of the wastewater treatment plant. One department specialized to deal with the affairs of the outer component has been ignored

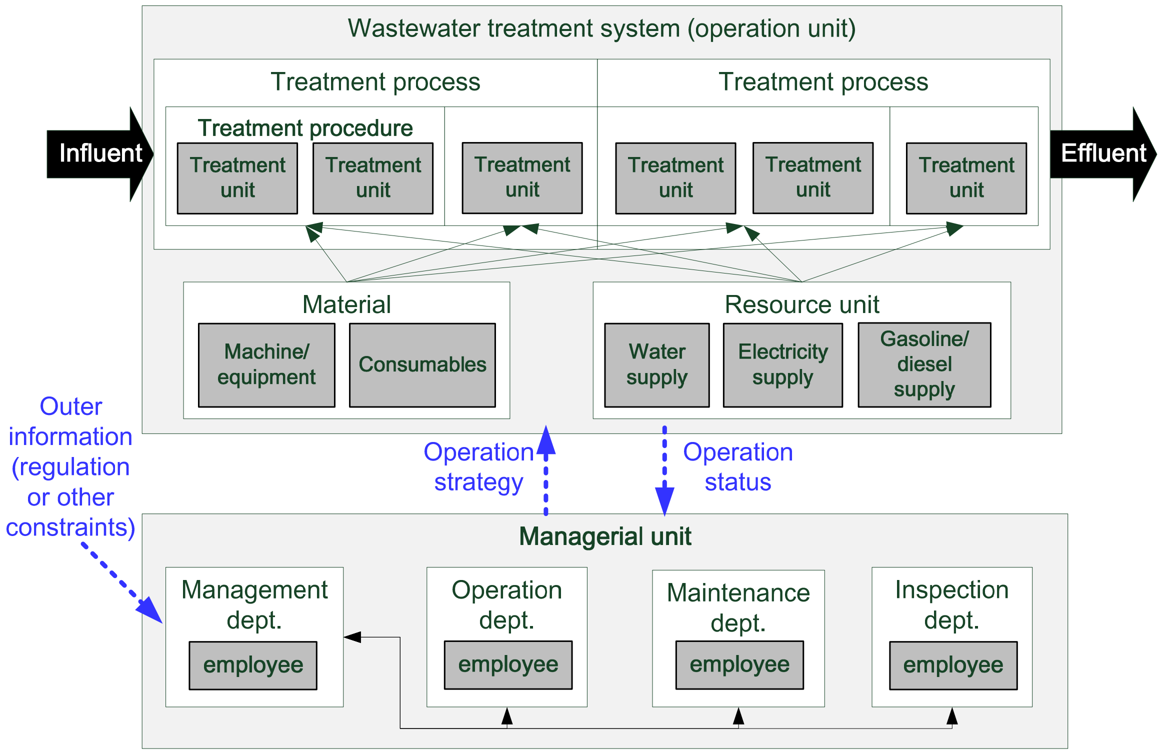

Figure 6. Configuration of the wastewater treatment plant.

here. Considering the identified objects, events can then be clarified by operation management tasks of the wastewater treatment plant.

4.3. Events Analysis

Based on the division of labor in the wastewater treatment plant, tasks of each department can be addressed separately as follows.

The administration department is responsible for management of the plant's properties, including human resources, finances, and materials. The financial part of the resources is reserved here since it has significant interactions with outer organizations. Accordingly, tasks related to the administration department are "employee," "resource unit," and "material." Objects "resource unit" and "material" are only registered to the administration department for their unique identification. The object "employee" is not only registered but also has sequential events during the management process of the administration department. These events that happen to the object "employee" include on or off duty, educational training, competency assessment, and work plan with execution result.

Operating the treatment units and keeping their functions in a good working condition to purify the influent wastewater and discharge the effluent conforming to the effluent standard is the major task of the operation department. For this purpose, the objects "treatment unit", "resource unit", "machine and equipment", and "consumables" are involved in the operation tasks. The events required to operate treatment units are monitoring the quality and quantity of wastewater and sludge, sampling of wastewater and sludge for further analysis, adjusting operation factors, and abnormity control. The object "consumable" included in the operation work indicates that the chemicals used in according to the operation strategy, such as the polymer or PAC used in the coagulation tank. Therefore, the event of object "consumable" is consuming chemicals. In objects "resource unit" and "machine and equipment", operators should check their running states as daily patrol and inform the maintainer immediately if there is any problem to ensure successful operation.

Maintaining the working condition of mechanical tools is the major task of the maintenance department. Thus, "resource unit" and "machine and instrument" are two objects that relate with maintenance affairs and have the same events of inspection, repair, and adjustment. The object "consumable" is also involved because various parts for machines are used in the maintenance work.

The duty of the analysis department is mainly to conduct sample analysis and keep the instruments in a good working condition to obtain accurate examination results. Analyzing the samples from treatment plants links the relationship between the object "treatment unit" and the analysis department since the examination result is an abstraction of the treatment unit at a specific time. The objects "consumable" and "machine and equipment" are also related to the analysis work as chemicals, filter papers and instruments are required in the analysis processes. The event of consumables is the consumption of chemicals, and

Table 2. Events Analysis with Corresponding Departments and Host Objects

Department Object	Administration	Operation	Maintenance	Analysis
Employee	• attendance • training • qualification • work plan and execution	-	-	-
Treatment unit	-	• measurement of environmental factors • measurement of wastewater quantity • wastewater quality monitoring • setting parameters for wastewater quality and sludge control • wastewater and sludge sampling • handling wastewater and sludge anomaly	-	• analysis result of wastewater and sludge quantity
Resource unit	-	• general check • recording measurement of resource consumption	• general check • inspection and repair • adjustment	-
Machine and equipment	-	• general check	• inspection and repair • adjustment	• inspection • adjustment
Consumable	-	• using chemicals	• handling mechanical accident • using parts for machines	• laboratory experimental requirements

that of equipment is its regular maintenance. Based on the above discussion, the events of the treatment system with the corresponding department and the host objects are given in Table 2.

4.4. Design of the Systematic Object-event Database

According to the SOE data model, 34 data tables were created based on the analysis results, including 9 object registry data tables for the 5 basic objects and 4 system objects and 25 events referring to the 5 basic objects. The object and event data tables for object "treatment unit" have been proposed here to demonstrate a simple design.

For the treatment unit, the data elements have been designed to express its property as presented in Table 3. The column "category" shown in the middle of Table 2 is used to classify the meaning of the elements. The categories defined in the object registry module, Identification, Attribute, Function, Relationship and Data Registry are indicated by I, A, F, R and DR, respectively, in the table. The column "notation" describes linkage between data tables.

With this logic, data tables for objects registry can be created and linked by the integrity rule of the relational database system. The relationship diagram of the database system is presented in Figure 7.

Table 3. Design of the Object Data Table "treatment_unit"

Data element	Data type	Notation
ID	I	Primary Key
Name	I	
Length	A	
Width	A	
Depth	A	
Diameter	A	
Volume	A	
Material	A	
operation_rule	A	
life_expectancy	A	
set_up_date	A	
revocation_date	A	
Function	F	
organization_in_charge	R	**
super_system	R	**
water_discharge_unit	R	*
sludge_discharge_unit	R	*
register_time	DR	
user_ID	DR	**

* The value filled in this data element should refer to the primary key of the table itself.
** The value recorded in this data element should refer to the primary key of other data tables, which is known as the foreign key.

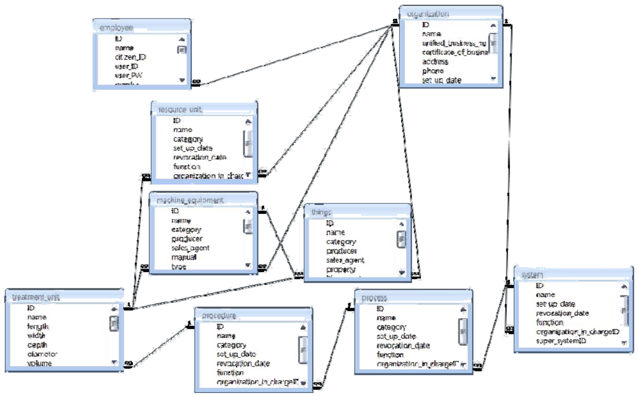

Figure 7. Relationship diagram of the object registry data tables.

It can be seen from Figure 7 that the table "treatment-unit" located in the left side links to the table "procedure" with the systematical relationship of treatment unit and treatment process in reality, which is in the same way that the table "procedure" relates to the table "process" and the table "process" links to the table "system." The tables "resource-unit" and "machine-equipment" have linkage with "treatment-unit", thus representing the realistic activities, for example, resource suppliers and machines or equipments are located and utilized on treatment units. In this way, the structure constructed by objects is just a simplified sketch of the real world, which consists of systematically related elements.

Table 4. Design of the Event Data Table "treatment_unit_water_quantity"

Data element	Data type	Notation
OID	OI	**
EID	EI	Primary Key
measure_time	EA	
water_consumption	OA	
influent_unitID	I-OI	**
inflow_rate	I-OA	
effluent_unitID	O-OI	**
outflow_rate	O-OA	
measurer_ID	ER	**
register_time	DR	
user_ID	DR	**

** The value recorded in this data element should refer to the foreign key.

For the treatment unit, eleven data tables were used to record its events, which are: "environmental-factor", "water-quantity", "water-quality-monitoring", "water-sampling", "water-quality-analyzing", "water-quality-parameter", "water-quality-anomaly", "sludge-sampling", "sludge-analyzing", "sludge-parameter", and "sludge-anomaly." The table "water-quantity" is chosen to demonstrate the design in the same format as the object-event module in Table 4.

The characters in the middle column of Table 4 are categories retrieved from the object-event module of the SOE data model where the category names are abbreviated as follows: Object Identification as OI, Event Identification as EI, Event Attribute as EA, Object Attribute as OA, the Event Relationship as ER, and Data Registry as DR. The classes within the input-output data include Object Identification, Event Identification, and Object Attribute, which are also denoted as OI, EI, and OA. But the extra characters "I-" or "O-" should be added in front of the abbreviations to indicate it belongs to input or output of an event. In accordance with the data tables design, these eleven events referred to the treatment unit have been created.

Figure 8 presents a reductive relationship diagram that consists of the six event data tables related to wastewater treatment and the object data table of the treatment unit. It is shown that the crossing relationship loops are presented in a radial pattern. This is because the object data table is in the middle of Figure 8, which is the common reference of event data tables. Based on the design of recording input and output units of each treatment unit, three relationships are linked between the object table and "treatment-unit-water-quantity" event table.

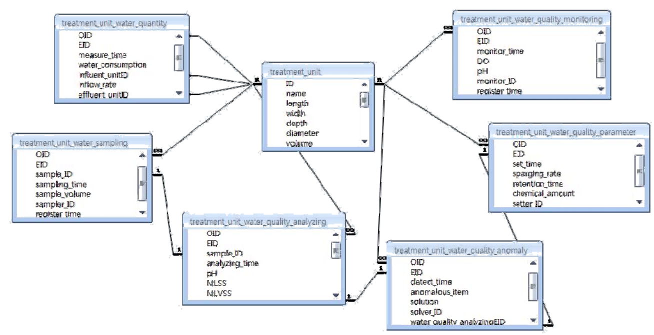

Figure 8. Relationship diagram of the object-event data tables of the treatment unit.

In addition to the linkages between the host object and events, the cause and effect loop is also shown in the data schema. The relationship linked by the tables "treatment-unit-water-sampling" and "treatment-unit-water-analysing" is an abstraction of the activity that samples will be analyzed after the sampling work is done. And the linkage from the table "treatment-unit-water-analysing" to the table "treatment-unit-water-quality-anomaly" explains that a water quality anomaly will be tackled if the result of the sample analysis is abnormal.

With the pilot case study, it has been demonstrated that the concept of systematic objects and events is a new way to design a database, and is different from the present physical interactions in a database. This is a definite contribution since the development of the SOE data model matches the claim that the use of semantics in data models should be increased (Hines, 1998; Kim, 1990). Design databases with the SOE data model can support the decision making more effectively in the real world on the basis of systems thinking.

4.5. Comparison Between the Systematic Object-event Database and the Existing Relational Database

In order to treat wastewater properly and stably, a database has been designed to support the decision making in operation management processes in this study. The database can be evaluated on five aspects: (1) to deal with a contingency situation; (2) to control the system; (3) to review the outcome of the operation; (4) to plan the operation strategy; and (5) to make an early warning of a system failure. With these five considerations, the differences in the steps to provide supporting information are compared between the database designed by the SOE data model and that designed by the traditional relational data model (Sung *et al*., 2002; Sung, 2001) were discussed. The major results of the discussion are summarized and presented in Table 5.

Table 5. Comparison between the Systematic Object-event Database and the Traditional Database in Their Ability to Support Operation Management

Types Aspects	SOE database	Relational database (Sung, 2002; Sung, 2001)
Tackling contingency	Problematic data can be traced and organized automatically by systematical relationships to present integrated information and possible solutions.	Problems are manually analyzed by operators, and the related data are collected and organized by information technicians.
System controlling	The cause and effect loops of control strategy and reacting status can be systematically integrated using historical data and can provide operators alternatives for system control.	Data relative to system control strategy and condition can only be retrieved manually.
Review of outcome	Relationships built up in a systematical structure allow flexible data integration and provide information in a variety of views to support effective review.	Statistical information by calculating selected data in specific operating formulas can be efficiently provided for routine review.
Strategic planning	Information integrated by systematically organized data help clarify the cost benefit status within the system and also ensure the feasibility of the next strategic plan.	Comparative figures can be drawn to show the range of historical objectives and be the reference to make the next strategic plan.
Failure prediction	Systematically organized data can fit various needs of simulation models and help reveal problems in advance.	The function to provide necessary data for simulation models is not clear.

The SOE data model has the advantage of the embedded systemic structure, which is a significant advancement for computational agents to systematically collect, organize, and integrate data. Taking regards of systems thinking in the design of the data model, information that fit the need of decision making with systems thinking can be effectively and systematically integrated and provided. The SOE data model can be used for the design of new databases as well as the analysis of the data structure of existing databases. Existing data elements can also be systematically organized if they are re-defined and marked up in accordance with the logic of the SOE data model.

5. Conclusions

In this study, the systematic objects and events approach was proposed to develop the SOE data model. This approach combines advantages in reductionist and systems thinking to achieve a more expansive view of semantics. Accordingly, the systematic objects and events approach is regarded as a feasible method to analyze and realize the real world for a better decision making. Abstractions of the reality, which are recorded as extensive amounts of data, determine the success or failure of the decision making process. Taking into accounts of characteristics of data, a flexible and extendable conceptual data model with systematic semantics, the SOE data model has been created.

The data model is used to correctly allocate data in a manner conducive to effective and efficient decision making. The SOE data model has the capacity to represent structures and interactions of the real world in accordance with the systematic objects and events approach. Systematic structure is considered in dataset design, indicating the hierarchical structure in the category "relationship" of the object registry module and the dynamics of cause and effect in the category "input-output" of the object-event module. Embedding the systematic logic in the data model increases the ability of the database to provide a clearer picture of reality for a better decision making.

The SOE data model has opened a new way allowing users to recognize data structure easily rather than address the concerns of database analyzers and programmers. This innovation makes the database designed by the SOE data model become more quickly understood, and it can be used to flexibly and effectively to satisfy the needs of supportive information. In summary, four main improvements the SOE model in constructing database can be condensed as followings:

Extensibility: In SOE databases, data elements are able to be flexibly extended by adding object or event data tables and modifying existed relationship data without destroying the database structure.

Consistency: The SOE data model was originated from the object concept and developed for efficient data integration for systematic information, which are consistent with the tendency of agent-based programming and declarative modeling to integrate models for advanced knowledge, which proves it is utility.

Personalization: Data distributed in the SOE data models can be flexibly integrated to fit user-specified extent or granularity for different demands by whether temporal, spatial, cause-effect, or domain-specific constraints.

Utility: Any SOE database originally developed to support a single application system for a simple purpose can act as a data provider for other software system at the same time through web-service for multiple data integration.

In this paper, a SOE database for operation management of an industrial wastewater plant was developed as a demonstration in this study. Concrete evaluation of the database relies much more on the application system, and thus not included in this study. Although the database created was only a simplified one with some assumptions it can be easily expanded into a complete database to support the overall operation management requirements of the wastewater treatment plant by adding more object and event data tables based on the considerations of additional management tasks.

There is a tendency in the industrial wastewater treatment plan toward increasing the number of the monitoring devices for better understanding the treatment system to promote operation performance. As a result, the SOE database is a beneficial way tool to arrange the increasing data properly which can match late developing decision supporting tools, such multi-agent systems or simulation and optimization models.

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