Technical Report

“Guideline for establishment of PLCS information models for the environment”

Rev 0.3

June, 2006

Electronic Commerce Promotion Center (ECPC)

Japanese Information Processing Development Center (JIPDEC)

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Introduction

Amid concerns that, as social infrastructure, plant facilities and large-scale factories, such as oil refineries, and nuclear and thermal power plants, are being used beyond their original design lives worldwide,, urgent measures are required to protect the natural environment in the face of crucial issues including energy consumption, environmental pollution and industrial waste.

Historically, environmental responsiveness has been considered for industrial products from their design phase, in order to minimize effects on the environment in the product life cycle phases of use and disposal. On the other hand, regarding plant facilities to produce industrial products, consideration to minimize effects on the environment in a plant facility life cycle from their implementation to disposal is not enough. Engineering companies and equipment manufacturers design facilities and equipment with the aim to prevent environment deterioration. However, when the facilities and equipments are combined with a plant facility and operated, engineering companies and equipment manufacturers must cope with owner companies, exchange useful information and plan towards realization of the most appropriate operation.

An objective of this guideline is to suggest mechanisms by which to improve existing facilities and to design new facilities by the following approach: engineering companies and equipment manufacturers set environmentally-friendly operational conditions at the design phase of plant facilities; they offer operational conditions in an organized form to an owner company; the owner company operates the plant facilities with consideration to the environment and transmit feedback information they gain after a period of operation to engineering companies.

Sophisticated systems, such as plant facilities, which are used over a long duration, change their components and specifications over the course of the operation phase of the life cycle. Therefore, these facilities need to be appropriately managed with detailed histories of operation and maintenance from the start of operation to eventual disposal. A suitable information model would provide the basis on which to use computers to manage the necessary information. In ISO/TC184 (Industrial automation)/SC4 (Industrial data), ISO 10303-239 (STEP AP239: Product life cycle support (PLCS)), which meets this objective, has been developed and published. The current AP239 does not provide content directly considering the environment, but adding necessary modifications to AP239 and establishing the revised PLCS information model can be an effective way by which establish the necessary capability to receive environment-conscious information from the design phase of plant facilities, combine this information with related information emerging during a period of operation and manage all the information.

This guideline explains how to set up the PLCS information model of plant facilities for the environment. For that purpose, it also explains necessary concepts, ideas of the PLCS information model for the environment and systems to establish the model.

1. Objectives and concepts of the guideline for establishment

Information management for PLCS data is necessary to consider the environmental responsiveness of sophisticated products that are used over a long duration. To build an information database for PLCS information management, designing and establishing PLCS information models for the environment is necessary. However, environmental information models require not only the conventional information models for development and manufacture of products, but also new, complex information structures, due to the large number of factors that should be considered for the environment throughout the product life cycle phases of operation, including upkeep, update and upgrade, and disposal. This document presents new concepts for the PLCS information model and guidelines to establish these concepts, together with an example of information models that consider the environment of plant facilities. This guideline can be applied to other products and facilities ,for example, machine tools, buildings, and so on.

To support product life cycles, not only assembly data, but also many types and large volumes of state data that emerge during and after operation are necessary. Conventional PDM (Product Data Management) systems deal with information necessary for production, requiring only information models that manage assembly data. However, once operation starts, the same products can have many different states and conditions depending on usage and information model structures that can incorporate both assembly data and state data are needed. The state information model can be realized by establishing an information model of state breakdown structures.

2 Scope

2.1 Subjects within scope

This guideline covers many different factors that affect the environment (energy consumption, including electricity, water, sewage, wastewater, exhaust gas, noise, vibration, ground pollution and so on) at industrial plants (process type and assembly type), and aims at explaining methods to establish an information model to contribute to the following activities.

a) For industrial plants, constrained conditions for factors that affect the environment are set at the design phase and should be transmitted to the operational phase and the plants should be operated with consideration to the environment.

b) When a result of operational evaluation shows elements harmful to the environment and the elements are caused by design decisions, the information should be transmitted back to the design process.

2.2 Subjects outside scope

a) Exception according to type of facilities
   1) Nuclear energy plant
      Special items such as radioactivity should be handled separately.
b) Exceptions according to object
   2) Raw materials, materials and consumables associated with plant operation
      Environmental considerations are already paid to materials and not enough to facilities.
   3) Items that engineering companies cannot influence (Offices not directly involved in production, welfare provisions such as catering facilities, logistics with outsiders such as incoming and outgoing of materials and research activities).
c) Exceptions during non-production phases
   1) Environment load during plant construction phase
      The construction company is responsible for environmental measures during building of the plant facility.
   2) Environmental load during disposal of plant facilities
      The 3R (reduce, reuse, recycle) of plant facilities will be one of the biggest issues, and there are many items that should be considered during the design phase. However, applicable technologies are not mature at this time, and this issue is excluded from this guideline, to be treated in the future.
      Items that have a cumulative environment load and can be seen upon clearing land, such as ground water and ground pollution, are not included in the exceptions.

2.3 Usage scenario

The following usages are assumed in this guideline.

2.3.1 Information exchange between an engineering company and an owner of plant facilities

At the design phase of plant facilities, an engineering company examines the way to reduce the emission of any substances with an environmental impact to zero or minimum, and lower the consumption of energy when running individual equipment. To that purpose, the engineering company must understand the most appropriate operational conditions by simulating environmental characteristics of individual equipment and those of a system composed of multiple equipments. Documents and data that are passed to an owner of facilities, after completion of construction, should include information on environmental measures. To motivate such behaviour, environment-conscious subjects should be included in inquiry and order specifications from owners, and documents and data on items that affect the environment in this guideline should be asked for.

On the other hand, owners accumulate actual operational data and evaluate items that affect the environment during the operation phase with following perspectives:

a) Check if environmental characteristics are as stated in a design specification. If not, what are the reasons?
b) Check if considerations given at the design phase are appropriate, regarding environmental characteristics of a set of facility systems. Furthermore, check how many of the environment-conscious subjects that will be needed practically, are covered.
c) What are the environment-conscious subjects that cannot be clarified until starting operation of facilities?

Based on this guideline, owners provide feedback of evaluation data to engineering companies. If necessary, the owners require improvements of facilities. The engineering companies suggest possible improvement solutions and implement selected solutions.

2.3.2 Information exchange between an engineering company and a facility/equipment manufacturer

Engineering companies ask for manufacturers to offer basic data on the environmental load of facilities and equipments, thus, allowing compilation of environment-conscious subjects to pass to owners.

Furthermore, feedback from the owners shows anything that facility/equipment manufacturers did not predict or understand and the engineering companies should pass this information to manufacturers so they can improve future designs.

Note: The usage scenario of section 2.3.1 can cover the usage scenario of section 2.3.2. Therefore, hereinafter only the usage scenario of section 2.3.1 is considered.

3 Normative reference

a) ISO 14000 series, Environmental management

A series of various standards regarding environmental management.

The series includes.

1) Environmental management system requirement items
2) Environmental auditing
3) Environmental labelling
4) Environmental performance
5) Life cycle assessment
6) Environmental management terms
7) Design for environment

b) ISO/IS 10303-239:2005, STEP Part 239, Application protocol: Product life cycle support

Specifies an information model to support in particular the operational phase of sophisticated products that are used for long durations.

c) ISO/CD 10303-235, STEP Part 235, Application protocol: Engineering properties for product design and verification

Specifies an information model to standardize procedures to measure and evaluate substances affecting the environment. (under development)

d) ISO/NWI 10303-241, STEP Part 241, Application protocol: Generic model for lifecycle support of AEC facilities

An extension of the PLCS information model focusing on AEC (Architecture, Engineering, Construction). (proposed)

4 Terms and definitions

Environment-conscious subjects

Subjects to consider when considering impact on the environment

Environment-conscious information

Information emerging as the result of examining environment-conscious subjects

Design for environment

Design to reduce environment load by examining the environment-conscious subjects throughout the life cycle (production/operation/disposal) of products

Operation for environment

Operation to reduce environment load with the environment-conscious information gained from the design for environment. If necessary, modify and optimize the environment-conscious information.

MP (Maintenance prevention) activities

In general, "activities to reduce maintenance cost or deterioration loss by using maintenance information and new technologies to design facilities with high-credibility, maintainability, safety, flexibility, and so on when new facilities are planned or constructed." However, in this guideline, focuses on feedback especially about environment-conscious subjects.

PLCS (Product life cycle support)

Delivery of a sustainable product capability by proper management of information throughout the life cycle of development, operations and disposal phases. PLCS is especially important for sophisticated products that are used for a long duration. Aircrafts, ships, automobiles, industrial plants, and so on are major examples of such sophisticated products.

PLCS information model

A model to represent various kinds of information on products in a way computers can process, in order to realize appropriate PLCS.

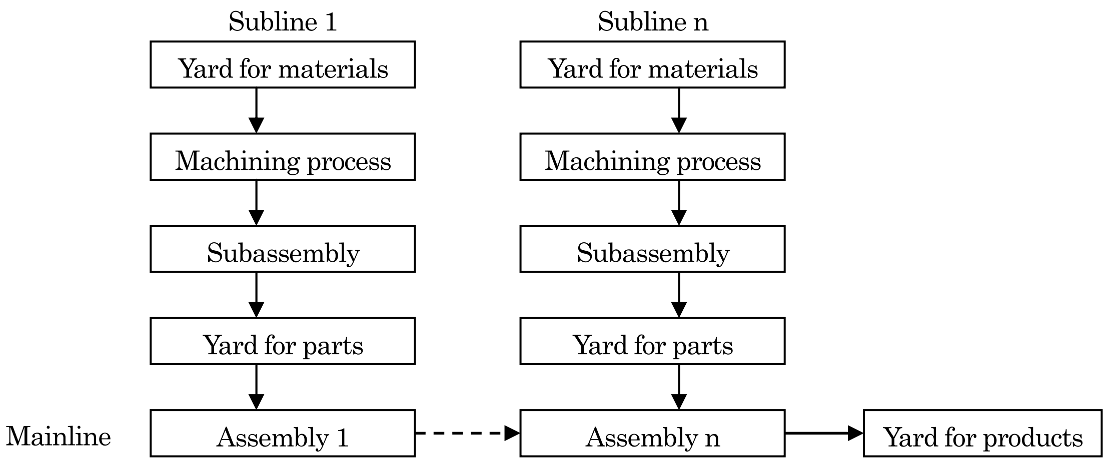
5 Adoption of PLCS information model for plant facilities

5.1 Envisioned plant facilities

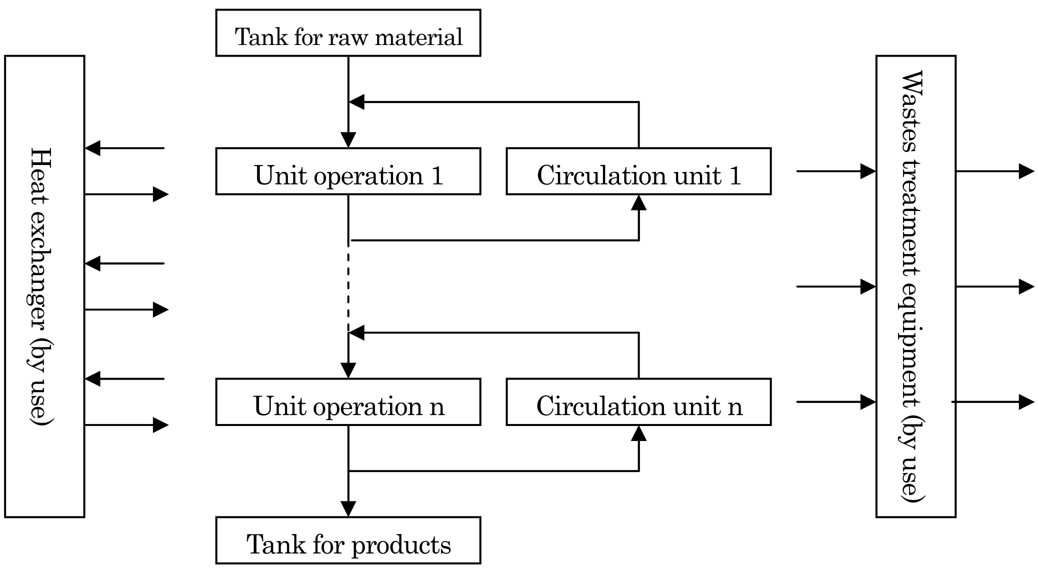
Plant facilities produce industrial intermediate materials or end products. What are produced at plant facilities are usually called products. However, from the perspective of engineering companies, plant facilities are also products. The products in which the PLCS model plays an important role are sophisticated products used for long durations. Therefore, the targets of this guideline are plant facilities. In the rest of this guideline, "plant facilities" is used instead of "products".

There are two major types of industrial plants: assembly plants and process plants. In this guideline, the following plants are envisioned.

a) Assembly type



b) Process type



This guideline is applicable to both types, but process plants are used as an example to examine.

5.2 Application of PLCS information model to plant facilities

PLCS is originally a general idea that covers all the life cycle phases from development to disposal of products. However, in this guideline, the PLCS information model is applied in particular to the operational phase. However, environment-conscious information gained from examination of environment-conscious subjects should be incorporated to the PLCS information model.

5.2.1 Requirements on the PLCS information model for plant facilities

It is desirable to manage using an information model that has consistency throughout the life cycle from design to installation, operation and disposal. The Figure 1 shows information flows: environmental-conscious subjects are examined at the design phase; the information is provided to the operational phase to operate a plant facility appropriately and the evaluation of operational results is sent back to the design phase in order to improve the facilities.

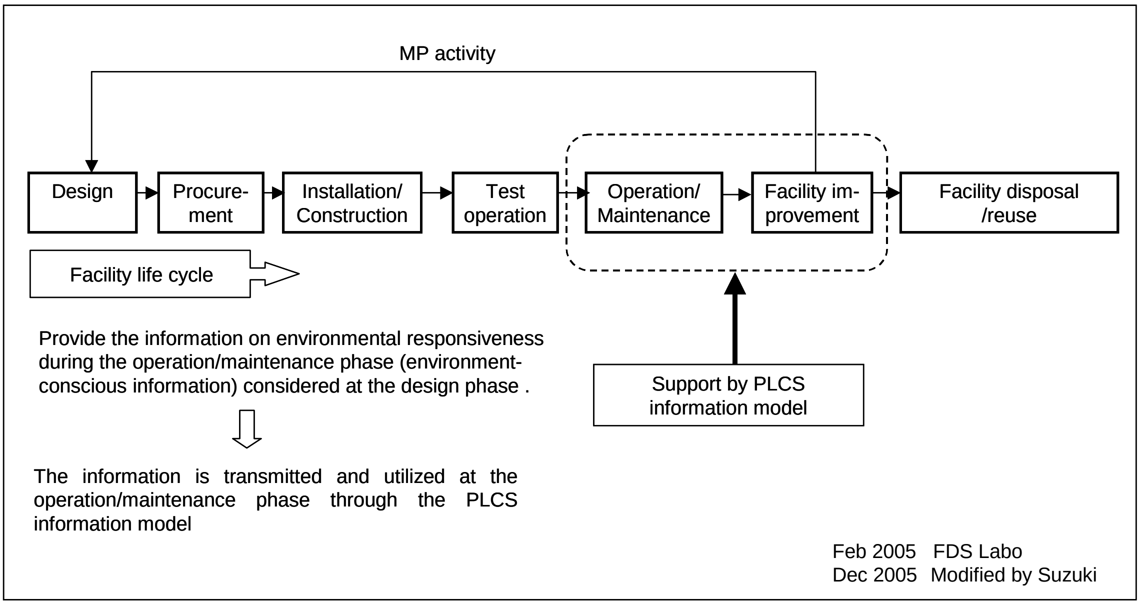


Figure 1: Configuration of PLCS that integrates environment-conscious information for plant facilities

In this guideline, a plant facility is considered as a group of equipments that have hierarchical structures. 10303-239 (STEP AP239: Product life cycle support (PLCS)) is developed by ISO/TC184/SC4 and specifies an information model to manage life cycles of sophisticated products which are used for long durations. Such products include plant facilities. AP239 is a generic information model for many kinds of products, so application to a particular product (in this case, a plant facility) requires reference data that is specific to the product and separate from the information model.

Furthermore, because AP239 is a generic standard to cover the whole life cycle, only subsets of the information model are necessary for specific tasks in the business environment. Such subset models are called DEX (Data EXchange set) specifications. Specific reference data are also applicable to these subsets.

The current AP239 information model does not include concepts directly considering the environment. However, environment-conscious information can fall within the scope of the generic information structures, and reference data can cover details for such environment-conscious information. However, more accurate data representation is perhaps possible by expanding the information model to cover environment-conscious information. The Figure 2 shows the above discussion.

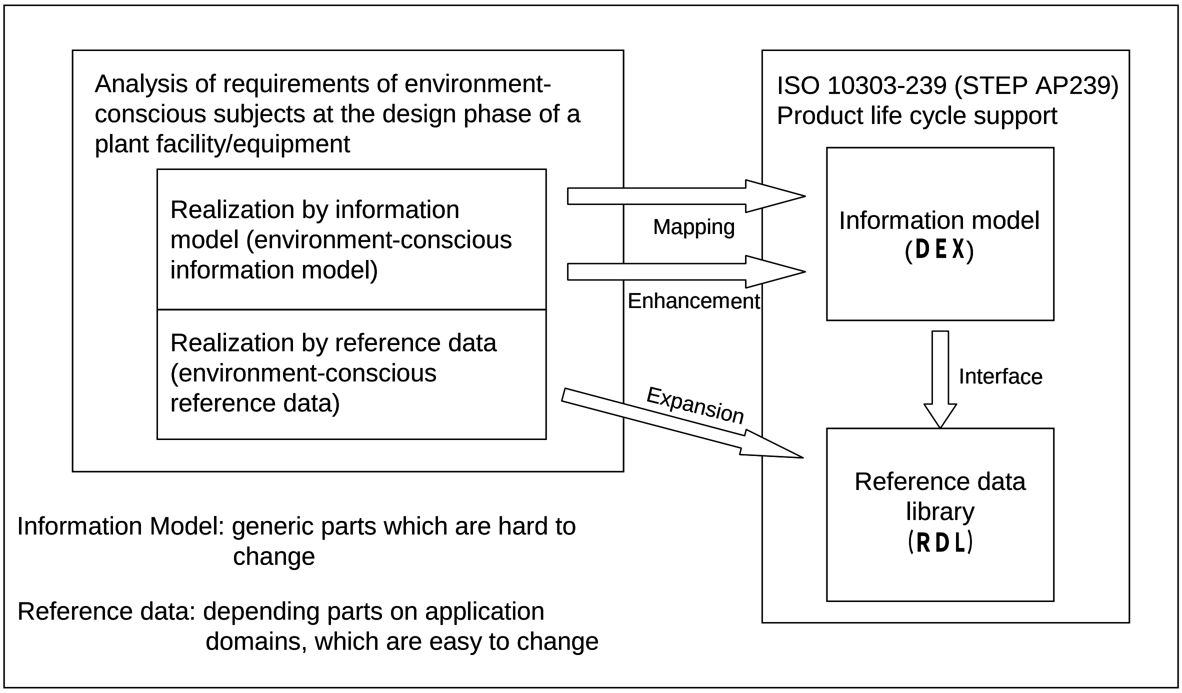


Figure 2: Application of the PLCS information model to environment-conscious information

5.2.2 Useful functions of AP239

a) Design models and management of individual facility or equipment

In AP239, objects to be managed are called “product” or “part”, but these are generic terms to indicate any type of products. In the case of plant facilities, the objects are not only the products produced by the facilities, but also the facilities and equipment themselves.

Products at the design phase (Product_as_designed) are identified by equipment item numbers, indicating the design result. Products at the production phase (Product_as_individual[1]) are identified by production numbers, and products at the operational phase (Product_as_realized) are identified by serial numbers. These latter two identifiers distinguish each facility or equipment produced multiply according to a common design. AP239 can manage these relationships appropriately. In this guideline, the capabilities of AP239 are utilized to pass the environment-conscious information examined at the design phase to the operational phase.

To design plant facilities and equipments with consideration to the environment is called "design for environment", and to take over the information and operate with consideration to the environment is called "operation for environment". Figure 3 shows the relationships mentioned above. In the case of plants, products and parts mean facilities and equipments.

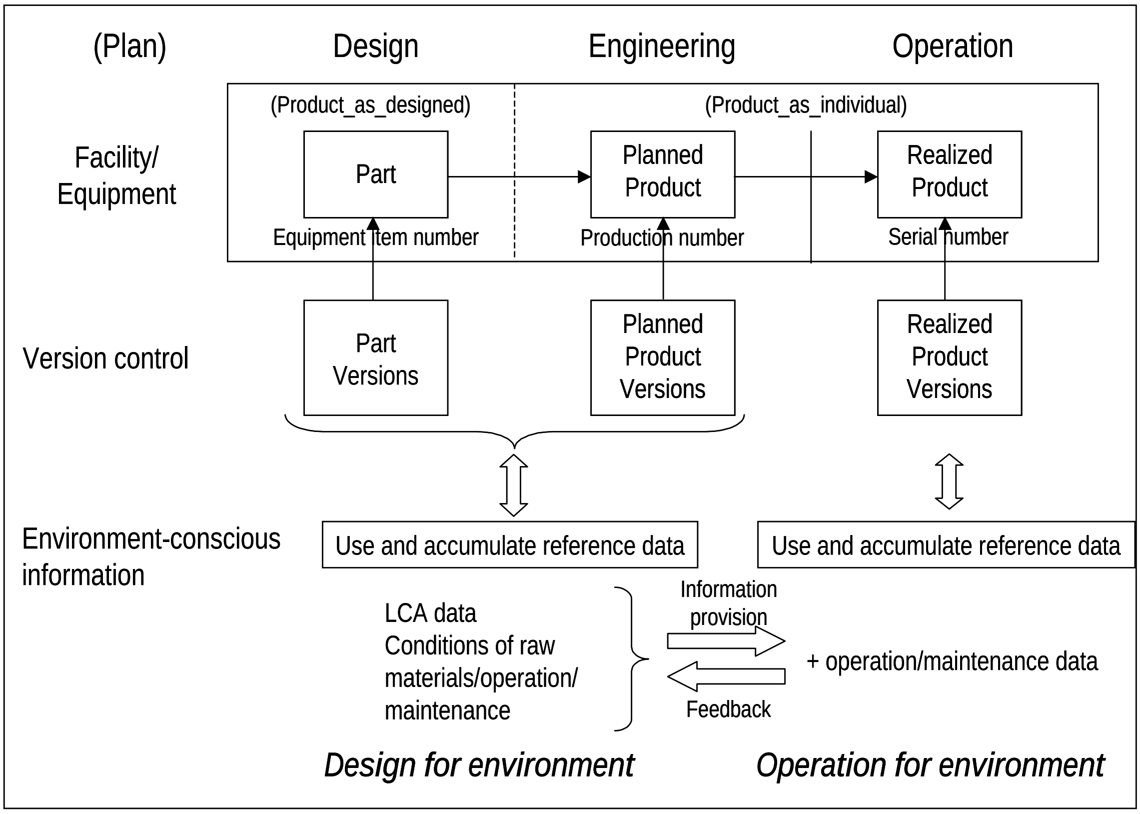


Figure 3: Application of the PLCS information model to plant facilities and equipments

b) Breakdown structure

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[1] Products at the production planning phase are called "Product_as_planned" and products after they are produced are called "Product_as_realized". "Product_as_individual" is the generic term.

To describe the structures of plant facilities, it is necessary to describe not only assembly structures consisting of facility products and parts, but also their relationships with related facilities necessary for installation and facilities and equipments necessary for maintenance at the operation phase. AP239 offers not only "assembly structure" to describe products, but also a "breakdown structure", which can describe relationships of functions, roles, locations of products and equipments. With "breakdown structure", it is possible to manage facilities after installation from perspectives that differ from those during the design and production phases. Figure 4 shows the relationship between assembly and breakdown structures in AP239, and Table 1 describes each element.

A breakdown structure provides a capability to allow multiple appearances of each element, in contrast to an assembly structure. A breakdown structure can present elements that combine and divide nodes in the product assembly structure to satisfy applications such as installation, operation (start-up/shutdown, ordinary operation, emergency response) and maintenance of facilities. The same elements can be contained in different breakdown structures many times. Therefore, if the breakdown structure is defined for environmental management and necessary elements are structured and related, appropriate environmental management can be achieved.

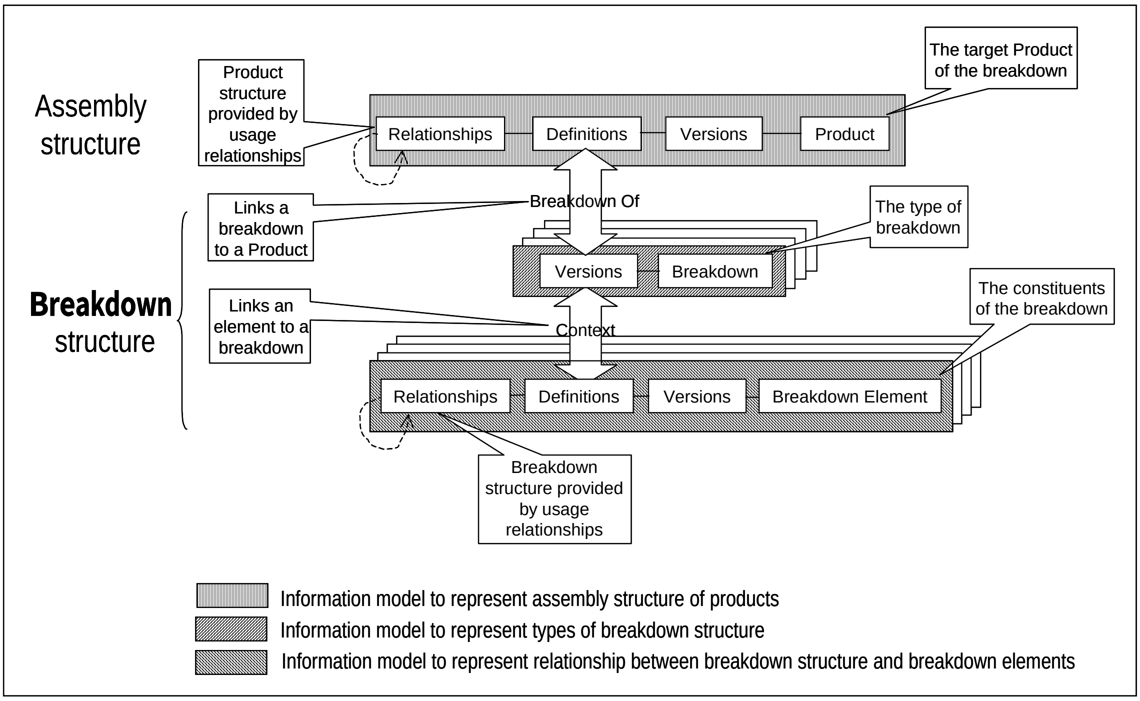

Figure 4: Relationship between assembly structure and breakdown structure in AP239

Table 1: Description of each element in Figure 4

Element	Description
Product	General products existing or going to be created, including parts and documents.
Breakdown	(Subtype of Product.) The product can be divided by a certain criteria into breakdown elements.
Breakdown Element	(Subtype of Product.) An element within the Breakdown.
Versions	Version of the product. Also covers versions of the breakdown and the breakdown elements, which are both subtypes of Product.
Definition	Collects together characteristics of product versions according to application areas or stages of the life cycle. Also applies to breakdown element versions.
Relationships	To relate two different definitions, and indirectly relate two versions.
Breakdown of	Relationship between the breakdown and the product
Context	Relationship between the breakdown and its breakdown elements.

The following types of breakdown exist within AP239:

1) System breakdown : divided from the perspective of systems.
2) Functional breakdown : divided from the perspective of functions.
3) Physical breakdown : divided from the perspective of physical configuration.
4) Zone breakdown : divided from the perspective of spatial configuration.
5) Hybrid breakdown : combination of any of the breakdowns mentioned above.

The following are examples of which breakdown to choose according to the target objective:

1) Monitoring leakage of hazardous gas and liquid→ "Physical breakdown (P)"
   It is appropriate to see a plant facility as a structure consisting of tanks, reaction towers, valves attached to equipments, etc.
2) Energy consumption → "System breakdown (S)"
   It is more important to understand the amount of energy that a system as a whole consumes rather than separate consumption of electricity, steam and fuel.
3) Vibration and noise → "Zone breakdown (Z)"
   Where effects vary depending on the distance from a point of release, it is necessary to understand spatial relationships.

When overall environment load is assessed, it is important to pay more attention to functional rather than physical evaluations. Evaluation on individual equipment, “which equipment of which company at which plant for which process, and so on”, is not helpful, since a product is produced in various combinations of facilities, which have different functions. In order to comparatively evaluate environment load indicators of each company, it is desirable to focus on the higher level, “functions”, than individual equipment and evaluate the load caused by the functions. Hereinafter, each breakdown may be indicated with the first letter (S, F, P, Z, H).

The above is different from assembly structure in the way that each divided element can overlap with others. Any breakdown elements can be combined and a hierarchy can be defined according to objectives, such as installation, operation and maintenance. Table 2 shows usage examples of the breakdown structure at a plant facility.

Table 2: Breakdown elements at a plant facility

Types of breakdown	Examples of breakdown elements	
	Process type plant	Assembly type plant
System breakdown	distillation system, reaction system, heat exchange system, raw material supply system and piping system	conveyer system, crane system, machining process system, assembly system, welding system, painting system, washing system, measurement system, inspection system and monitoring system
Functional breakdown	distillation function, reaction function, heat exchange function, raw material supply function and transportation function	transportation function, machining process function, assembly function, welding function, painting function, washing function, measurement function, inspection function and monitoring function
Physical breakdown	distillation tower, reaction tower, heat exchanger, raw material tank, product tank, valve, pump, and piping	belt conveyer, crane, transportation robot, machine tool, press machine, assembly robot, welding robot, jig, measuring instrument and monitoring instrument
Zone breakdown	site, facility/equipment installation area, maintenance work area,	assembly line, parts waiting place, parts slot, conveyer area, robot self-propelled passage, assembly

	piping area, and safe space area	worker area, and product temporary depository
Hybrid breakdown	Raw material tank (P), piping (P), pump (P), and valve (P) are included in raw material supply system (S), and they are on the side of the adjacent plant (Z) from which the raw material is supplied (Z).	At the final assembly line (Z) of electric products (P), sub-assemblies (P) made at other assembly lines (Z) are assembled on belt conveyer (P), and operation and performance of products are confirmed by inspection system (S) and the products are finalized at the end.

Concrete usage methods are explained with an example of the process plant in Figure 5.

Table 3 shows a kind of breakdown structure for the reaction system of Figure 5

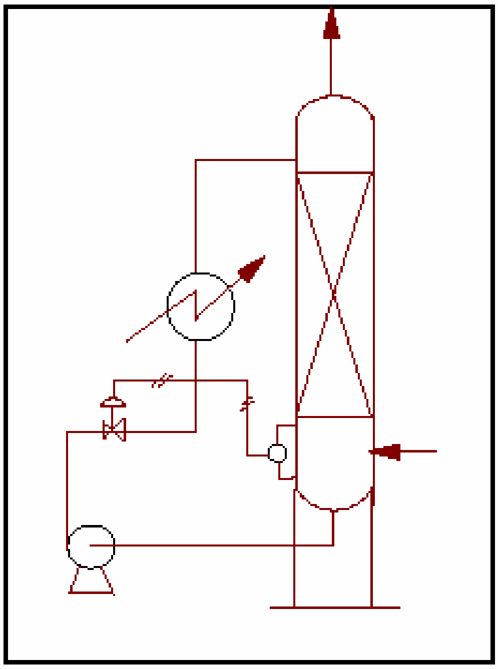

Figure 5: Example of process plant

Table 3: Breakdown elements in the reaction system of Figure 5 (1)

Type of breakdown	Breakdown element
System breakdown	Reaction system
Functional breakdown	Reaction function
Physical breakdown	Reaction tower
Zone breakdown	Facility installation area

Table 4 shows a hybrid breakdown for the reaction system of Figure 5.

Table 4: Breakdown elements in the reaction system of Figure 5 (2)

Type of breakdown	Breakdown element
Hybrid breakdown	Reaction system (S) is composed of reaction tower (P), inlet pipe (P), outlet pipe (P), measuring instrument (P), heat exchanger (P), pump (P) and so on, and located in the facility installation area (Z).

Utilization of a breakdown structure for environmental management is described in 6.3.

5.2.3 DEXs of AP239

Standardization of DEX specifications is undertaken by the PLCS TC (Technical Committee) of OASIS (Organization for the Advancement of Structured Information Standards), which is a consortium-based standardization organization. Table 5 shows DEX specifications that have been defined. More definitions will be added as needed.

Table 5: Defined DEX specifications

DEX No.	Name of DEX
D001	Product breakdown for support
D002	Fault states
D003	Task set
D004	Work package definition
D005	Maintenance plan
D007	Operation feedback
D008	Product as individual
D009	Work package reporting

It is desirable to define DEX specifications to handle environmental issues, but the followings are some existing highly relevant DEX specifications.

a) D001 (Product breakdown for support)

This supports the initiation and progressive development of the breakdown for support of a particular product, whose design (assembly structure) is evolving over the product life cycle.

The viewpoint of the product structure, and hence the breakdown for support, could be at any point in the product life cycle. This may be from the design baseline (as-designed view) through to a product baseline (as-designed, as-built or as-maintained view).

The DEX allows the user to update the product structure using new versions of exchange data. The DEX also provides the capability to create and populate 'placeholders' within a structure to hold or point to reference data.

b) D005 (Maintenance plan)

This DEX enables the transmission of information on a set of maintenance tasks to be performed on a product. This set of information is named a maintenance plan.

This DEX supports the initiation and progressive development of a maintenance plan for support of a particular product, throughout the product life cycle.

A maintenance plan is initially prepared during the latter stages of the detail design and development phases and is continuously assessed and adjusted throughout the life of a system or product. The plan is prepared and established based on logistic support analysis (LSA), including:

1) failure analysis of the product;
2) analysis of maintenance resources and supportability characteristics of an established or assumed maintenance concept;
3) analysis of use and reliability performance requirements of the product.

c) D007 (Operational feedback)

This DEX enables the transmission of information on the condition and usage of an actual product.

NOTE: An actual or individual product is an individual artifact that is realized from a design.

The DEX may be used to exchange information relating to the observed configuration, location, state or properties of an actual product, and to the usage of that product, in a given operational context, in performing recognized roles and functions.

The DEX also allows reference to be made to the FME(C)A analysis that identified and defined the observed fault states, the communication of work requests to resolve issues arising from feedback, and the referencing of work orders, which have caused changes to actual product configuration or state.

d) D008 (Product as individual)

This DEX supports the initiation and progressive development of the identification and attributes of a particular product throughout the product life cycle.

The DEX supports the initiation and collation of the planned and realized product as individual for a serialized part, whose product structure changes over its life cycle. It distinguishes the actual planned and realized product baseline from the permitted design baseline by allocation of a through-life unambiguous serial identifier. This identification enables the management of realized products through reference by other life cycle events. The defining attributes of a realized product begin with the design and manufacturing processes yielding a serialized realized product configuration that is managed throughout its life cycle.

Product as individual identification is conducted with the following objectives:

1) capture all significant events from the point of design and manufacture of the product to its disposal on completion of its life;
2) provide the reference source for all other DEXs and Capabilities regarding realized products;
3) support the production of life cycle breakdown structures populated with realized products for management of configurations, maintenance, analyses, and redesigns.

The information content of this DEX includes the following:

1) identification of the configuration design baseline that defines the product;
2) manufacturing, test and inspection records of the configuration product baseline;
3) product configuration information including part number, manufacturer code, serial number, batch number or lot number of the realized product;
4) product structure including slot, next higher assembly and variance.

5.2.4 PLCS DEXs for environmental purposes

As a result of considering the environment during the design phase of plant facilities, environment-conscious information is provided from an engineering company to an owner company by "D001: Product breakdown for support" and "D008: Product as individual". For the owner company to operate with consideration of the environment, it is desirable to create a new DEX, "Dnnn: Environmental assessment". This DEX combines environment-conscious information from the engineering company and know-how of environmental response accumulated by the owner company for environmental evaluation on plant facility operation. Taking the result of environmental evaluation into consideration, better operation for the environment can be planned by improving the initial maintenance plan by "D005: Maintenance plan". These evaluation results and history data of operation and maintenance are accumulated in "D007: Operation feedback". The data necessary to transmit to the design phase is extracted and provided to the engineering company. The engineering company uses the data for improvement proposals and better future designs. The above scenario is shown in Figure 6.

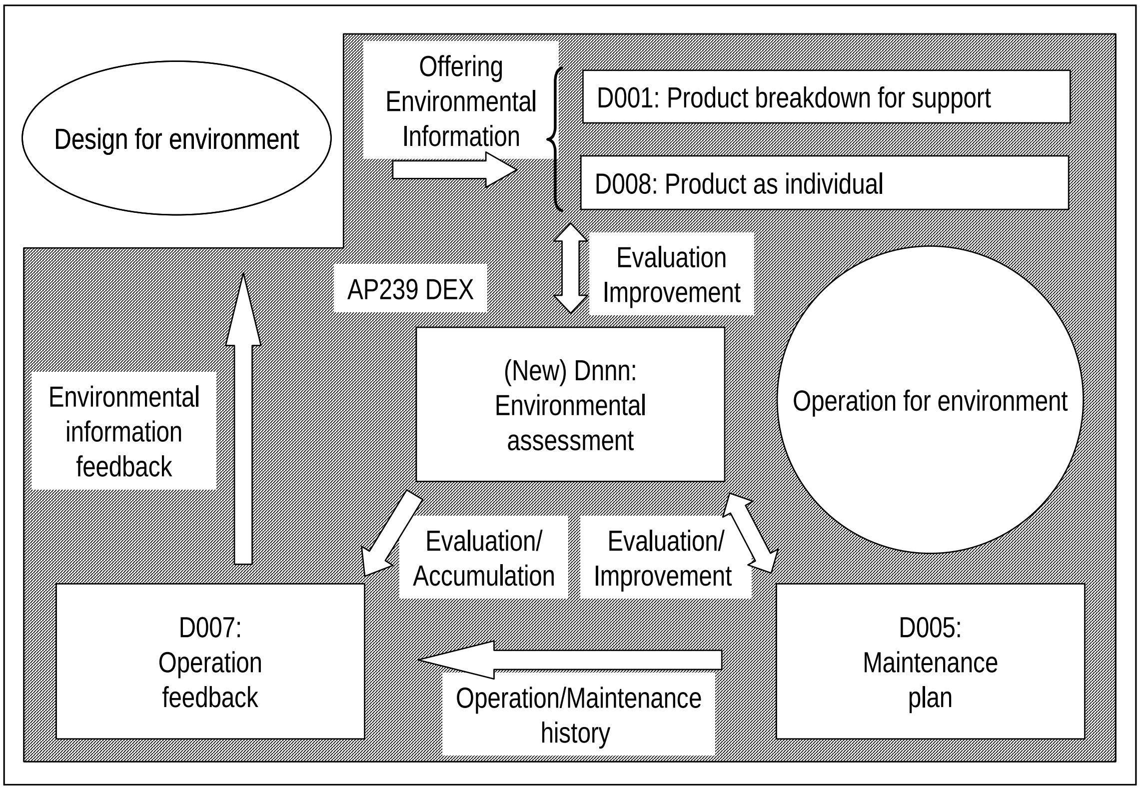

Figure 6: PLCS DEX specifications and operation for environment

Requirements for a new DEX "Dnnn: Environmental assessment" are as follows:

a) Structuring of relationships between facilities and equipments and environment-conscious subjects;
b) Setting initial conditions of environment-conscious subjects;
c) Collecting operational performance data;
d) Evaluating operational performance from an environmental perspective;
e) Revising conditions to improve environmental impact;
f) Accumulating history of environment-conscious subjects combined with operational performance.

6 Design for environment of plant facilities

6.1 Target environment-conscious subjects

In recent years, the performance of companies in respect of the environment is becoming a focus of close attention. Companies conduct environmental assessments, clarify environmental risks from the standpoint of CSR (Corporate Social Responsibility) and are starting to make sustainability reports open to the public, in order to be known as a company with proper concern for the environment.

In Europe, experts are starting to evaluate companies with respect to environmental performance and use the evaluation as advice to their clients on the stock exchange.

For environment-oriented management, such experts have to ask for information to understand the environment load of companies involved with manufacturing, sales and services. Furthermore, evaluation indexes of environmental impact that cover operation, maintenance and disposal of facilities by a company should be clear.

Table 6 shows environment-conscious subjects for the design phase of plant facilities and requirements to the supporting information models.

Table 6: Environmental elements which are considered at the design phase of plant facilities

Environment-conscious subject	Affected elements	Requirements of information model
Energy consumption	Energy balance at the design phase	System elements/overall energy consumption
	Conditions for raw material of use	Classification of materials and acceptable amount
	Operational conditions	Operational mode and allowable range of operational conditions
	Environmental conditions	Product market, environmental variance range
Generation of volatile organic compound (VOC)	Conditions for raw material of use	Classification of materials and acceptable amount
	Operational conditions	Allowable range of operational conditions Emissions when operational mode is changed
	Environmental conditions	Allowable range of environmental conditions such as characteristics of the region
CO_2 emission	Kyoto Mechanism	Allowable range of operational conditions Evaluation index for emission rights trading
Other emissions and waste accompanying operation	Operational Conditions	Allowable range of operational conditions Consumed materials and emissions and amounts at modification of

		operational mode Classification of tasks and execution conditions Conditions of equipment and materials of use
Life of facility or equipment	Operational conditions	Allowable range of operational conditions
	Maintenance conditions	Classification of tasks and execution conditions Spare parts at periodic inspections
	Facility renewal and disposal conditions	Environment load accompanying with facility disposal
Degree of ease to reuse and disassemble	Considerations at the design phase	Degree of ease to separate components Energy consumption amount during recycling

6.2 Environmental measure levels of facility

For any particular function necessary in a plant facility, various equipment can be used. And also, even with the same type and level of performance, the level of environment load can be different. A design including proper environmental measures will often be expensive. It depends on the policy of the owner (purchaser) as to which level of environmental measures is necessary. This often results in a tradeoff between cheaper cost and reduced environment load. Efforts of companies with respect to environmental measures should be transparent, and standardization of a per-equipment "facility environmental measure level" is needed to judge the efforts of companies according to fair indices. If the level is specified in a specification, this can be used as an index to choose an appropriate equipment vendor.

For example, in the case of centrifugal pumps that are very common in process plants, there is a wide choice of models, including various manufacturers, to meet a specification stating a required flow volume and head type. The initial investment cost can vary widely depending on characteristics such as satisfaction of process conditions, efficiency, durability, compatibility and maintainability. Flow rate control is possible with less electric power consumption by controlling rotation rate with an inverter rather than with a discharge valve. This has been a practically viable solution for many years. However, choosing an inverter increases the initial facility investment compared to a discharge valve.

Another simple example is choice of the type and thickness of the heat insulator that is used to for high-temperature equipment and piping. Such a choice is usually decided by the economic balance between the cost of the heat insulation installation and the annual energy cost by heat loss. If environment load is also considered, it is natural that the eventual decision can differ from one made on just economy in the narrow sense.

Table 7 shows an example of levels one can set. Of course, these are too simple to be practical. There are many factors like characteristics of products and processes. At any rate, if it is said that these criteria all depend on each company and plant, they cannot be judged fairly from outside. Therefore, persuasive indexes are necessary.

Table 7: Setting of facility environmental measure levels

Facility environmental measure level	Criteria for judgment
Level 0	Minimum facility investment cost.
Level 1	Minimum total cost including long duration of operation of facilities.
Level 2	Choice and design of facilities focusing not only on local economic optimization, but also on environment load throughout the facility life cycle.

6.3 Support by information models

6.3.1 Support at design phase

Information on configuration structures in the range of plant facilities that an engineering company compiles is related to assembly structures in AP239. Environment-conscious subjects and elements affecting them are also related to reference data. In the beginning, reference data of the environmental response is not prepared, so it is necessary to start with preparing an initial set of reference data. Afterwards, additional reference data can be defined as needed, when new environment-conscious subjects and elements emerge. The usage of AP239 and contents of the reference data shall be standardized across the whole industrial sector. The process shall be open to owner companies, and their understanding is necessary.

6.3.2 Support at operation phase

Information on plant facilities installed and passed to an owner is combined with information the owner has. This requires use of breakdown structures and appropriate relevant reference data. Table 8 shows examples of the usage of breakdown structures for environmental management in the reaction process of the process plant of Figure 5. The hybrid breakdown method is used here, but detailed elements unique to the process plant shall be prepared as reference data in addition to information models of AP239.

Table 8: Utilization of breakdown structures for environmental management of a reaction process

Breakdown elements		Managing elements	Attribute of reference data
Upper-level elements	Lower-level elements (Reference data)		
Reaction system (S)	Raw material (P)	Component and quality of raw material	Classification and allowable amount of materials
	Catalyst (P)	Amount of disposal due to deterioration	Classification and allowable amount of materials
	Solvent (P)	Amount of disposal due to deterioration VOC	Classification and allowable amount of materials
	Main product (P)	VOC	Classification and allowable amount of materials
	By-product (P)	VOC	Classification and allowable amount of materials
	Waste gas (P)	VOC, CO_2, H_2S, and so on	Classification and allowable amount of materials
	Waste fluid (P)	Component of waste fluid and amount of poisonous substance	Classification g and allowable amount of materials
	Operational condition (F)	Scope of optimum operational condition	Temperature, pressure, flow volume
	Consuming energy (P)	Energy efficiency	Energy balance
Reaction function (F)	Synthesis function (F)	Synthesis efficiency	Yield
	Analysis function (F)	Analysis efficiency	Yield
	Reaction heat (P)	Heat exchange efficiency	Heat balance
Reaction tower (P)	Inlet (P)	Range of optimum condition	Temperature, pressure, flow volume

	Outlet (P)	Range of optimum condition	Temperature, pressure, flow volume
	Reaction room (P)	Range of optimum condition	Temperature, pressure, flow volume
	Heating function (F)	Range of optimum condition	Heating condition
	Stirring condition (F)	Range of optimum condition	Stirring condition

In the case that conditions set at the design phase of facilities are not appropriate, it is necessary to understand the reasons and optimize conditions and provide feedbacks to the design phase.

7 Utilization at the operational phase of environment-conscious information which are set at the design phase

7.1 Transferring information models from the design phase to operational phase

From the installation or construction phase to the operational phase, breakdown structures for objectives are developed from assembly structures of AP239, and relationships with reference data on the corresponding environmental-conscious information are defined. In addition, owner companies sometimes add breakdown structures and reference data based on their own know-how about operation for the environment. There are both cases when engineering companies undertake these tasks and when owner companies perform these tasks on their own. In both cases, it is desirable for both parties to work together to make it easy to exchange feedback in the future.

7.2 Operation for the environment

A plant shall be operated in consideration of the environmental conditions that are set during the design phase of plant facilities, gaining actual environment evaluation data, analyzing the reasons and performing adjustments, if the data varies from the optimal value. Then, these data shall be accumulated and managed for feedback in the future.

Besides environmental responses of each facility or equipment of a plant, it is important how to deal with emerging environmental issues when these systems are combined. As mentioned above, there are some elements that cannot be determined at the design phase of plant facilities. They might belong to the know-how of owner companies, but those which need to be considered as well at the design phase shall be sent as feedback to engineering companies based on prior agreement.

7.3 Evaluation of operational results and feedbacks to the design phase

Among environmental evaluation data accumulated at the operational phase, the information that need to be transmitted to the design phase shall be provided to an engineering company in the same standard form used at the delivery phase. As mentioned in the previous section, environment-conscious subjects unique to the operational phase shall also be shared with owner companies, engineering companies and equipment manufacturers for the sake of improvement of plant-wide environmental response.