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Industrial-process measurement, control and automation – Life-cycle-management for systems and components

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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INDUSTRIAL-PROCESS MEASUREMENT, CONTROL AND AUTOMATION – LIFE-CYCLE-MANAGEMENT FOR SYSTEMS AND COMPONENTS

FOREWORD

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The text of this International Standard is based on the following documents:

FDIS	Report on voting
65/805/FDIS	65/820/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
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INTRODUCTION

In today's automation applications, an increasing divergence of the life-cycles of components, devices and systems in comparison to the life time of overall plants is evident. The increasing functionality of components, the advancing development of electronics and the innovation dynamics inherent to hardware and software are continuously shortening the life-cycle of individual automation components. Certain semiconductor components are only manufactured for a short period of time, for example, and subsequently abandoned.

By comparison, the time in use of automation systems is considerably longer. Moreover, there are considerable differences depending on the industry sector. The time in use of a production line in the automobile industry is usually identical with the period of time in which a new model is manufactured which is around 7 to 8 years today. By comparison, the operational life of a process plant in the chemical industry is typically some 15 years, while up to 50 years may be reached in the case of oil and energy, and power plants. The plant and product life-cycles have to be considered by the management for the overall plant functionality and economic considerations.

Increased utilization and integration of plant process data from automation systems towards enterprise and asset management systems has caused technology dependencies between hierarchy layers of automation systems. A more uniform way of dealing with Life-Cycle Management between these layers and all partners in the value chain is essential with respect to plant regularity, operability and security aspects.

Consequently, this necessitates different strategies to maintain the availability of the plant by. sophisticated maintenance strategies. As a result, considerable demands are made on the delivery capacity of automation products and spare parts, as well as the provision of services, such as maintenance and repairs. For example, when the planning of a new plant envisages the usage of a newer version of an engineering system, the producer has to ensure that this newer version can also be employed for older components and systems already in use in the existing plant and may have to develop upgrades accordingly. To an increasing extent, this calls for close cooperation between the partners along the value chain.

The presented situation illustrates that mastering these conflicting characteristics of Life-Cycle-Management will become increasingly significant in automation, not least in the ongoing discussions between plant users and manufacturers as well as manufacturers and suppliers. The interaction between global, legal and technical aspects – including demands for high functionality and efficiency, as well as the influence of IT technologies in automation – helps to demonstrate the scope of this topic.

This International Standard has been prepared in response to this situation. It is comprised of basic, complementary and consistent models and strategies for Life-Cycle-Management in automation. These generic models and strategies are then applied to various examples.

Consequently, this document represents a consistent general approach, which is applicable to automation in various industrial sectors. The economic significance of Life-Cycle-Management is a recurring theme of this document. The definitions of generic models, terms, processes and strategies form an indispensable foundation for a joint understanding between plant users and manufacturers and between manufacturers and suppliers regarding Life-Cycle-Management.

Proactive Life-Cycle-Management focuses on the selection of robust components, specifications, and technologies that consequently have long-term stability. The proactive approach includes the application of this set of generic reference models in the development of standards in order to be able to efficiently ensure sustainable interoperability and compatibility.

INDUSTRIAL-PROCESS MEASUREMENT, CONTROL AND AUTOMATION – LIFE-CYCLE-MANAGEMENT FOR SYSTEMS AND COMPONENTS

1 Scope

This International Standard establishes basic principles for Life-Cycle-Management of systems and components used for industrial-process measurement, control and automation. These principles are applicable to various industrial sectors. This standard provides definitions and reference models related to the life-cycle of a product type and the life time of a product instance, It defines a consistent set of generic reference models and terms. The key models defined are:

– Life-Cycle-Model;
– structure model;
– compatibility model.

This document also describes the application of these models for Life-Cycle-Management strategies. The content is used for technical aspects concerning the design, planning, development and maintenance of automation systems and components and the operation of the plant.

The definitions of generic models and terms regarding Life-Cycle-Management are indispensable for a common understanding and application by all partners in the value chain such as plant user, product and system producer, service provider, and component supplier.

The models and strategies described in this standard are also applicable for related management systems, i.e. MES and ERP.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

• IEC Electropedia: available at http://www.electropedia.org/
• ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
after-sales support phase
phase in the life-cycle of a product type which begins at the end of the selling phase and ends with product abandonment

3.1.2
backward compatibility
downward compatibility
fulfilment by a new component of all the specified requirements of the compatibility profile of its predecessor

Note 1 to entry: Antonyms are forward compatibility and upward compatibility, respectively.

3.1.3
capability profile
compatibility profile that represents characteristics of a product type

3.1.4
compatibility
ability of a component to fulfill the compatibility profile of another component

3.1.5
compatibility assessment
verification of an agreed compatibility level

3.1.6
compatibility profile
list of all compatibility requirements of a system, or a component of a system, depending upon the application

3.1.7
component
autonomous element of a system, which fulfills a defined sub-function

3.1.8
construction compatibility
fulfilment of the constructional aspects of a compatibility profile by a component

Note 1 to entry: Related requirements are physical dimensions, construction properties, connection method (including e.g. power supply) and the location with respect to environmental conditions.

3.1.9
data compatibility
fulfilment of the functional aspects related to data type and format of a compatibility profile by a component

3.1.10
delivery release
end of the manufacturing preparation process after which series production can begin

Note 1 to entry: The manufacturing preparation process is part of the development phase.

3.1.11
development phase
phase of the product life-cycle which begins with the decision to develop a product type and ends with delivery release of the product type

3.1.12
disposal
removal of a product instance following the time in use and disposal or recycling

Note 1 to entry: This is the final phase of the life-cycle of a product instance

3.1.13
end of sales
end of all active sales activities for a product

Note 1 to entry: This is also called discontinuation of a product.

3.1.14
end of service
end of all service activities for a product type

3.1.15
end of production
point of time when instances of a product type are no longer produced

3.1.16
full compatibility
fulfilment of all aspects of a compatibility profile by a component

Note 1 to entry: The aspects are function, construction, location and performance.

3.1.17
function compatibility
fulfilment of the functional aspects of a compatibility profile by a component

3.1.18
instance
concrete, clearly identifiable component of a certain type

Note 1 to entry: It becomes an individual entity of a type, for example a device, by defining specific property values.

Note 2 to entry: In an object-oriented view, an instance denotes an object of a class (of a type).

3.1.19
last-time buy
Life-Cycle-Management strategy in which instances of an abandoned product type are purchased before end of sales

3.1.20
level of compatibility
fulfillment of the requirements described in the compatibility profile

3.1.21
life time
length of time from the end of the creation of a product instance to the end of disposal

3.1.22
life-cycle
length of time from the start of the development phase of a product type to the product abandonment

3.1.23
Life-Cycle-Costs
sum of all instance costs for plant user incurred after purchase up to the end of the life time of a system

3.1.24
Life-Cycle-Excellence
holistic approach to managing changing conditions to ensure technical, application specific, economic and ecological robustness of the Life-Cycle-Management for products

3.1.25
Life-Cycle-Management
methods and activities for the planning, realization and maintenance of products for the life-cycle of types and the life time of instances

3.1.26
Life-Cycle-Management strategy
strategy for applying Life-Cycle-Management methods to ensure the availability of a system throughout the time in use

3.1.27
migration
replacement of components in an existing system by a component with extended or modified functionality or with a different technology while maintaining functionality

3.1.28
milestone
defined point in time with a specific meaning for example:

– 3.1.10 delivery release
– 3.1.13 end of sales
– 3.1.15 end of production
– 3.1.14 end of service sales
– 3.1.32 product abandonment

3.1.29
obsolete product
not available product from the original producer to the original specification

[SOURCE: IEC 62402:2019, 3.1.15, modified]

3.1.30
producer
company which develops a product type, maintains it during its life-cycle and manufactures instances of this type

3.1.31
product
commodity (goods or service) for operational business, with defined properties (of product type), which is created (product instance) in a value chain process with reproducible quality

Note 1 to entry: It is sold during a defined period and is technically and logistically supported until product abandonment. The value chain process can be a process for integrating components into a system (integration process). Products can be hardware, software, services or combinations thereof.

3.1.32
product abandonment
point of time when all service for a product type have stopped

3.1.33
product instance
Instantiated product types

Note 1 to entry: Instantiated expresses that the product has been produced, the service has been performed, the software has been registered, etc.

3.1.34
product type
definition of all characterizations for instantiated products

Note 1 to entry: Instantiated expresses that the product has been produced, the service has been performed, the software has been registered, etc.

3.1.35
re-design
Life-Cycle-Management strategy in which a new version of a product type is developed which typically fulfils or exceeds the specification, and therefore the compatibility profile, of a previous type

3.1.36
requirements profile
compatibility profile that represents characteristics of a role-based equipment, required to achieve its role

3.1.37
revision
defined status of a software or hardware, including all of its integrated components, which is explicitly identified by a revision number

3.1.38
robustness
capability of a system to continue to fulfill its function under changing conditions

3.1.39
sales phase
phase of life-cycle which begins at delivery release and end with end of production

3.1.40
sales release
point of time when active sales activities for a product type have started

3.1.41
service
total of all supporting activities for products (types and instances)

Note 1 to entry: Standard services end with product type abandonment. Supporting activities after product abandonment are subject to special service agreements.

3.1.42
signal compatibility
level of compatibility from the function view of the compatibility profile related to signal acquisition and processing

3.1.43
software compatibility
level of compatibility from the function view of the compatibility profile related to software

3.1.44
standard services
level of service without consideration of specific user requirements

3.1.45
substitution
Life-Cycle-Management strategy in which instances of a product type are replaced by instances of a compatible new type without repercussions for the system

3.1.46
system
defined and structured set of components which fulfill a function (system function) through interactions or interrelationships with each other

Note 1 to entry: Systems could have a hierarchical structure, i.e. they could consist of underlying systems (which are then considered components of the system).

Note 2 to entry: From a sales perspective, a system denotes a set of product types belonging to a specific portfolio line.

3.1.47
time in use
portion of the life time in which a product instance is actually in use for its intended purpose

3.1.48
update
new revision of a version designed for error correction and/or minor functional improvements

Note 1 to entry: For software, an update is called a patch which can include bug fix for general errors and hotfix for critical or urgent error corrections.

3.1.49
upgrade
product for upgrading a component to a newer version with improved or enhanced functionality

Note 1 to entry: The term upgrade can apply to hardware and software.

3.1.50
version
defined status of a product type, including all of its integrated components, which is explicitly identified by a version number

3.1.51
warranty period
time frame in which a replacement or repair of a faulty item is contractually assured

3.2 Abbreviated terms and acronyms

ASIC	Application specific integrated circuit
CE	Conformité Européenne
COTS	Components Off The Shelf

NOTE 1 Also used for Commercial Off The Shelf.

EMC	Electromagnetic compatibility
ERP	Enterprise Resource Planning
EU	European Union
FDA	Food and Drug administration
FPGA	Field programmable gate array
ID	Identifier
IT	Information technology
LCC	Life-Cycle Costing
MES	Manufacturing execution system
PLM	Product Life-Cycle Management
RoHS	Reduction of Hazardous Substances
TCO	Total Cost of Ownership
UML	Unified Modelling Language

NOTE 2 See Annex F.

USB	Universal serial bus

4 Generic models for Life-Cycle-Management

4.1 Product type and product instance

Requirements from industries result in a very wide range of factors which affect the life-cycles of products to varying degrees. Consequently, the Life-Cycle-Model specified in this document takes this into account. The differentiation between product types and product instances is fundamental. Each product instance is an instantiation (produced product, registered software, performed service, etc.) of a product type. As shown in the UML diagram of Figure 1, a product type can be represented by a UML class and a product instance by a UML object. The semantics of the UML elements used in this document are explained in Annex F.

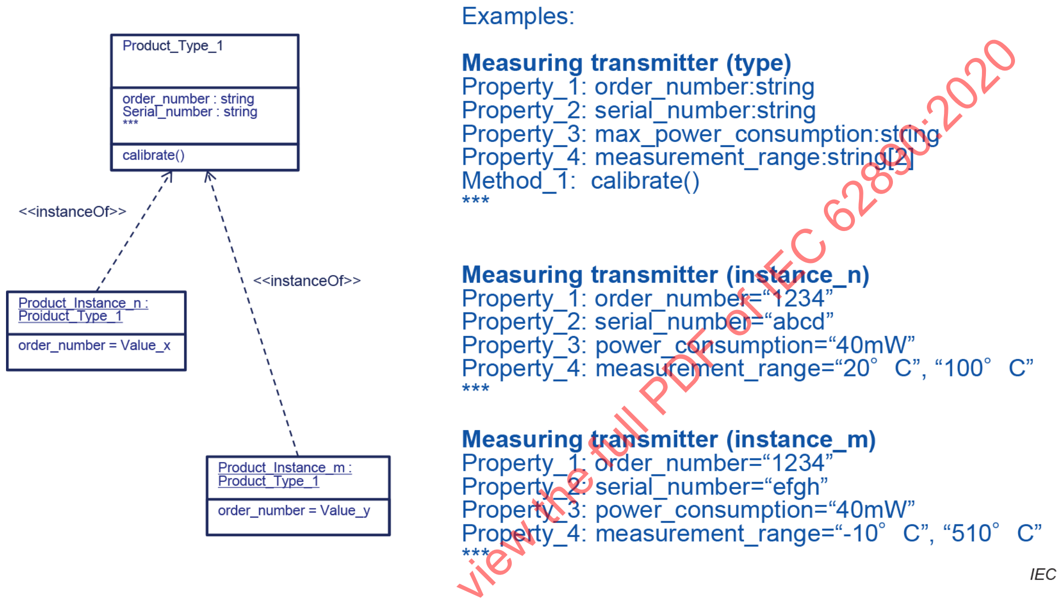

Figure 1 – Relationship of product type and its product instance(s)

A product type is characterized by an unambiguous product ID (for example the order number), a set of development documents, manufacturing and test descriptions, and technical documentation. For approval of a product type for specific applications, certificates can be demanded and issued. This definition of a product type is valid for hardware products, software products, and products that are hardware/software bundles. Typically, the right to use product types is regulated in reproduction licensing agreements. All activities that are performed regarding the development, maintenance, and service of a product type, regardless of how often it is manufactured, refer to the product type.

According to Figure 1, each produced unit of a product type represents a product instance of this type. The product instance is always an individual entity and shall be identified by an unambiguous identifier (such as a serial number). The right to use product instances of software products is regulated by license agreements.

NOTE 1 Some countries have specific guidelines. [9][1].

Activities for a product instance are: manufacturing, all services during the life time, etc. It is recommended to document activities related to the product instance throughout its life time for e.g. asset management (see Figure 2).

NOTE 2 In some cases, there exists recommendations or regulation for archiving of history beyond the end of the life time.

1 Figures in square brackets refer to the bibliography.

4.2 Life-Cycle-Model

The life-cycle of a product type is divided into phases as shown in Figure 2. Milestones are associated to these phases (see the filled diamond in Figure 2) and the announcements (see diamond in Figure 2).

NOTE 1 Each phase can be further detailed, if necessary.

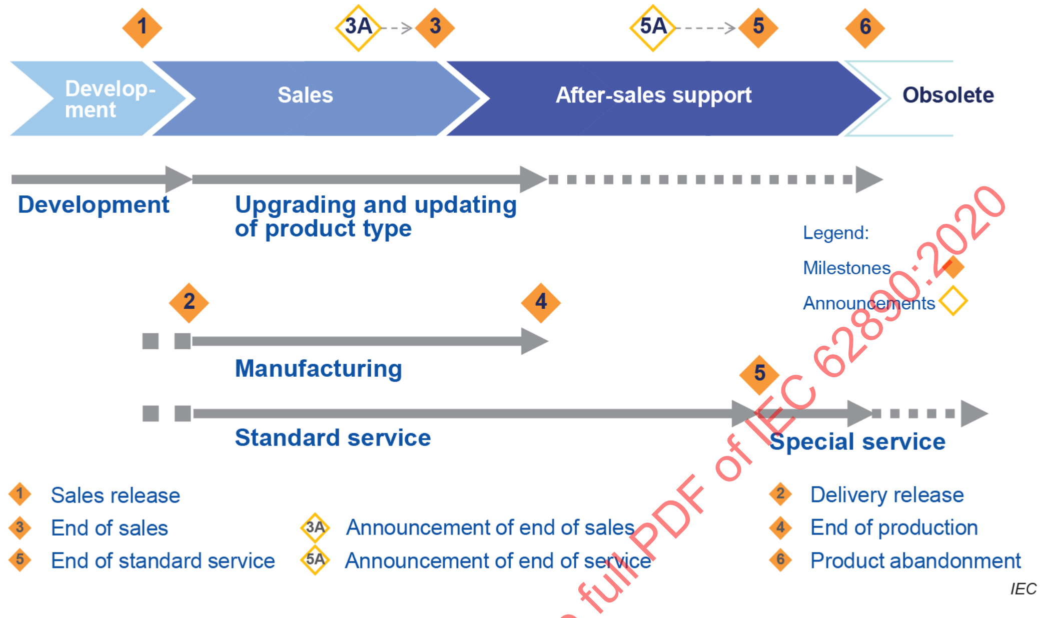

Figure 2 – Generic Life-Cycle-Model of a product type

The life-cycle begins with the development phase, in which the product is developed as a product type. During the development phase of a product type, the product type is developed by some activities such as designing, testing, sales preparation, and trials (piloting) in the targeted system environments. When the specified technical and commercial criteria have been met, the product is released for sale (see milestone 1). Following the conclusion of successful testing, Production preparation process and service preparation, the delivery release is achieved (milestone 2). This enables manufacturing of the product, which means, in the context of the introduced terminology, the instancing of the product type starts.

The sales phase follows the development phase. The operational business with the product type finishes with the end of sales (see milestones 3). the end of production (see milestone 4) is after the end of the sales phase and depends on technical and economic conditions. An announcement of end of sales (milestone 3A) should be communicated to enable plant users to cover their demands before end of production.

Standard service for the product begins with delivery release (see milestone 2) and ends with end of standard service (see milestone 5). The after-sales support phase begins with the end of sales (see milestone 3) and finishes with product abandonment. The end of standard service (see milestone 5) occurs in the after-sales support phase prior to product abandonment. This means that all product-related deliveries i.e. spare parts, documentation, etc. and standard services provided by the producer end with the product abandonment. An announcement of end of sales (milestone 5A) should be communicated to enable plant users to cover their service demands before product abandonment. In the phase between milestone 5 and 6 special services maybe available. After milestone 6, the product (type) is obsolete.

The sum of these phases for a product type is called the product life-cycle. The term "cycle" is meant to express that there is a recurring sequence in the context of the product evolution (Figure 3). These innovation cycles result in new product versions of the product. Rules for versioning of a product type should be specified.

Process descriptions are used for all activities required for managing a product life-cycle, enabling concurrent workflows while ensuring fulfillment of required quality criteria. This process is usually referred to as the Product Life-Cycle-Management process (PLM process) and comprises the type-related sub-processes portfolio management, definition, realization, commercialization, and after-sales support.

In order to manage the history of design and design change of a product type, version and revision are used. The product manufacturer should keep information regarding history of design and design change available.

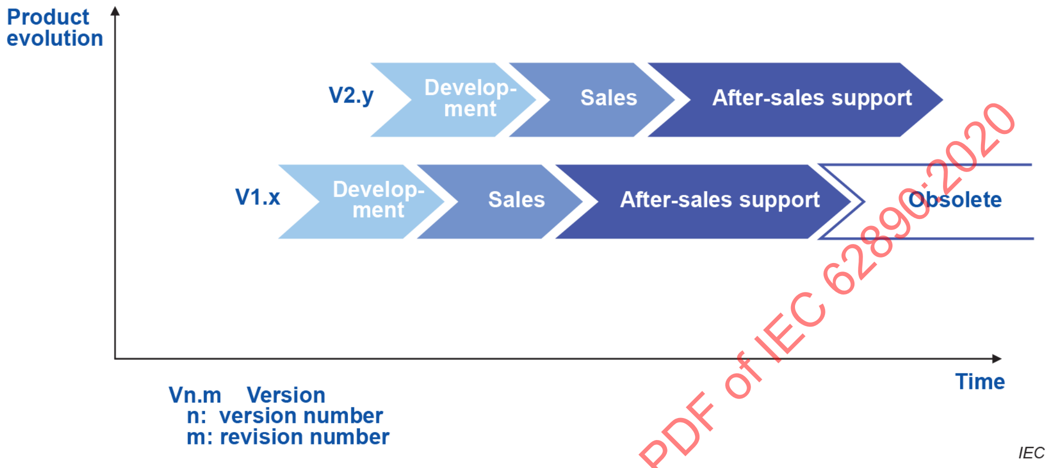

Figure 3 – Evolution of products (type with version and revision)

Product evolution is described by version number and revision number. More detailed versioning conventions may be applied, for example a third level for minor error corrections or a fourth level for build numbers of software products. This version information is highly relevant with regard to the compatibility and requires version management conventions. Typically, product types with different version numbers have their own after-sales support phase.

NOTE 2 In some industries, there are recommendations for version management for example the NAMUR recommendation NE53 [10].

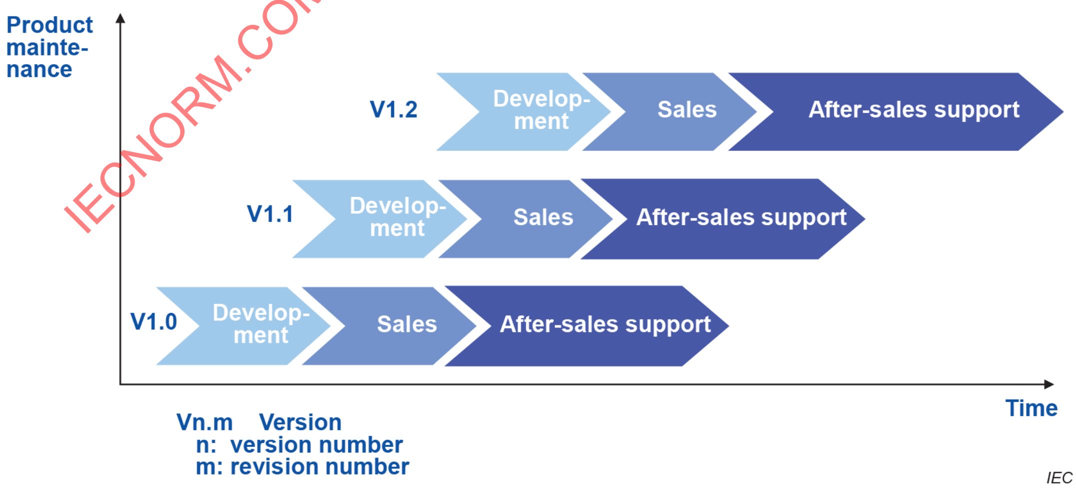

Figure 4 – Maintenance of products (type with version and revision)

The service provided in the after-sales support phase depends on service levels (see 5.7.2). Typically, product types with different revision numbers are not maintained as individual products. Instead, only the type with the latest revision has an after-sales support (see Figure 4). In case of specific service contracts (see 5.7.4), other revisions may be maintained as well. Each product instance has a life time (see Figure 5) that starts with production (milestone a), for example the hardware manufacturing, and ends with start of disassembling or with disposal of this instance (milestone f). The product life time can last significantly longer than the end of the life-cycle of the product type (milestone 6) (Figure 5). The essential section of the life time is the time in use, which begins at milestone c, for example with the software installation/activation, and ends with the decommissioning (milestone e), for example de-installation or irreparable defect. The time in use can be interrupted by outage times (down times).

The warranty period begins when the risk is passed to the customer (milestone b), for example the handover of a plant to the customer after acceptance and ends in accordance with legal regulations or customer contracts (milestone d). The warranty period is independent from the milestone "end of sales".

All deliveries i.e. spare parts, documentation, etc. and standard services provided by the producer, related to product types and instances, end with the product abandonment (milestone 6). Support may be extended through special agreement.

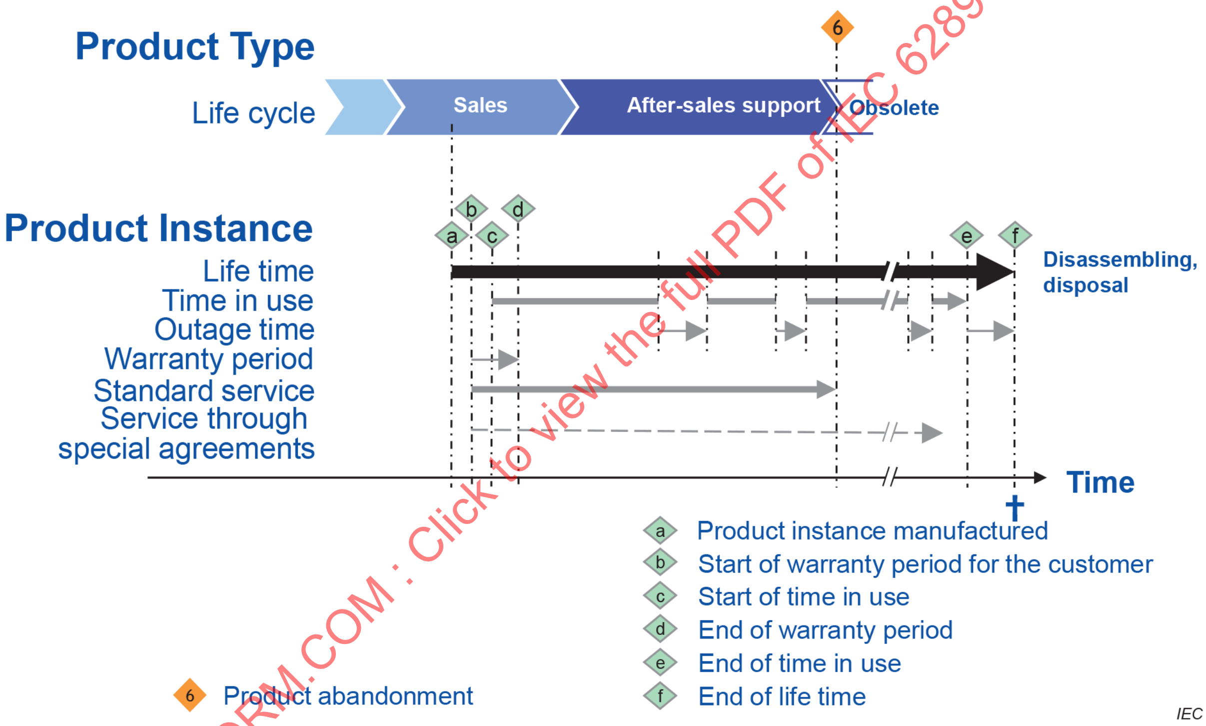

Figure 5 – Life time of a product instance

4.3 Structure model

A system can be understood as a defined, structured set of elements (components) which fulfills a function (system function) through interactions or interrelationships with each other. Systems can be hierarchically structured, which means that they can consist of underlying systems (which are then considered components of the system above). A UML diagram is shown in (Figure 6), emphasizing the system – component hierarchy. The left part contains the definition of an abstract system with an aggregation of (underlying) systems, each of it known as a Component to the system. The right part contains specific systems ("System (n+1)", "System n", "System (n-1)") that are derived from the abstract system. Additionally, the hierarchical relation is shown, indicating e.g. that "System n" is known by "System (n+1)" as its "Component (n+1).2", while "System n" itself knows "System (n-1)" as its "Component n.3" and so on.

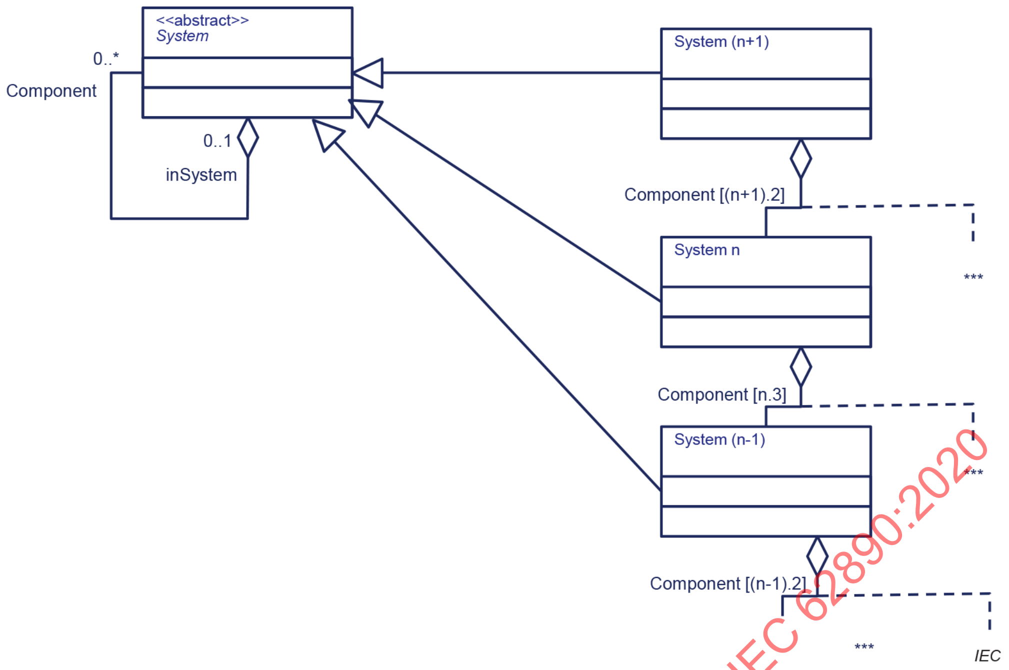

Figure 6 – UML diagram of a hierarchical system structure

For example, a "measuring transmitter" system consists of hardware components, such as the housing, connector and electronics (which again represent a system consisting of components such as capacitors, resistors, processer, memory, etc.). The "measuring transmitter" system is itself a component in the "instrumentation and control" system (Figure 7).

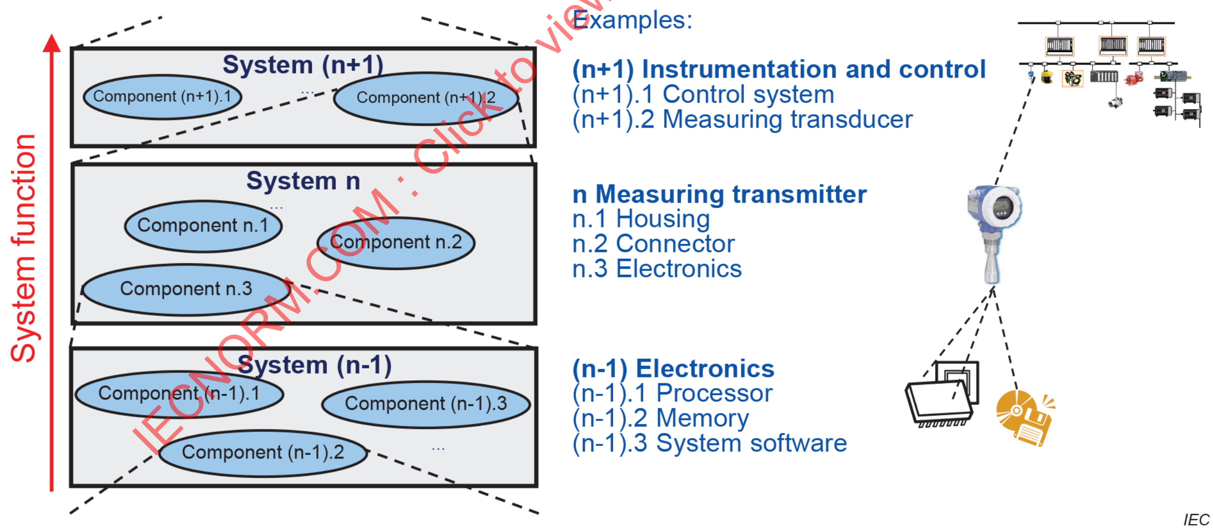

Figure 7 – Hierarchical system structure (example)

Regardless of the hierarchy level, each system has a life-cycle that can be depicted according to Figure 2. Each phase of life-cycle of a system needs to be covered by the corresponding phase or an earlier phase, of life-cycles of all components of the system (Figure 8).

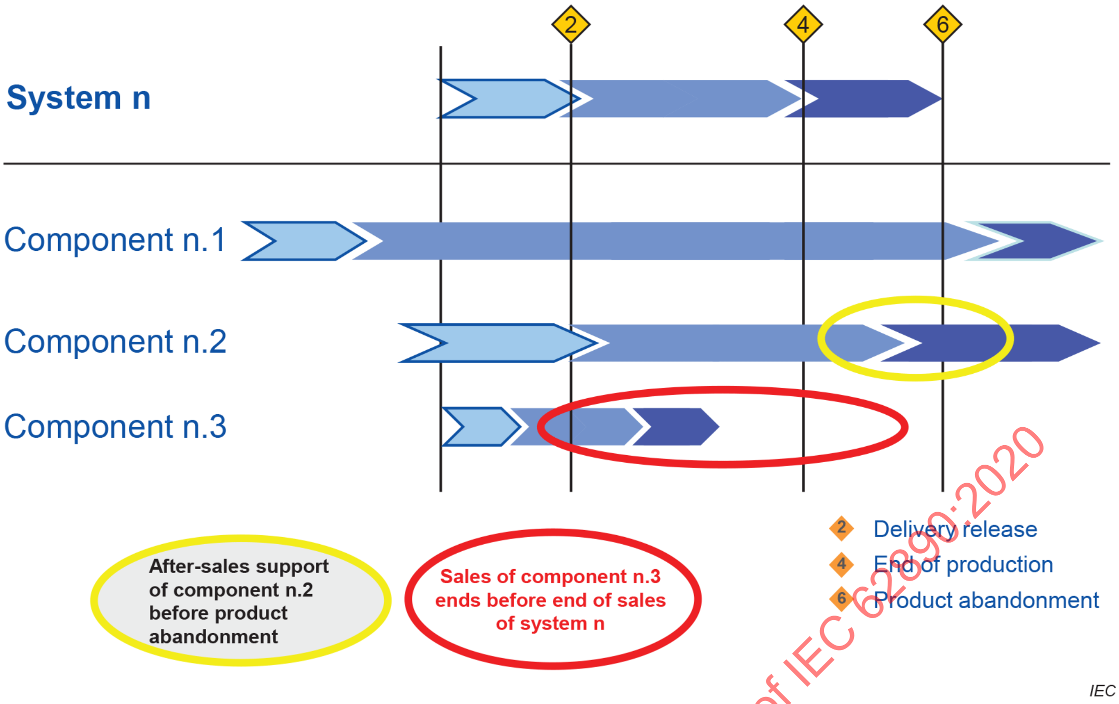

Figure 8 – Example for Life-Cycle-Management of a system (type) by integrating components (types)

System producers face a major challenge due to dependencies on the divergent life-cycles of components. The system producer is responsible for continuous, evolutionary development of his system to meet compatibility demands. For example, in Figure 8, the transition of Component n.2 into after-sales support takes places before product abandonment of System n (milestone 6). In order to ensure and extend the production of System n, some measures against the product abandonment of component n.3 are necessary.

Components are integrated into a system as shown in Figure 9 using Event-driven Process Chains (EPC). The integration process needs to be defined and documented. A specific role "System-Life-Cycle-Manager" should be assigned.

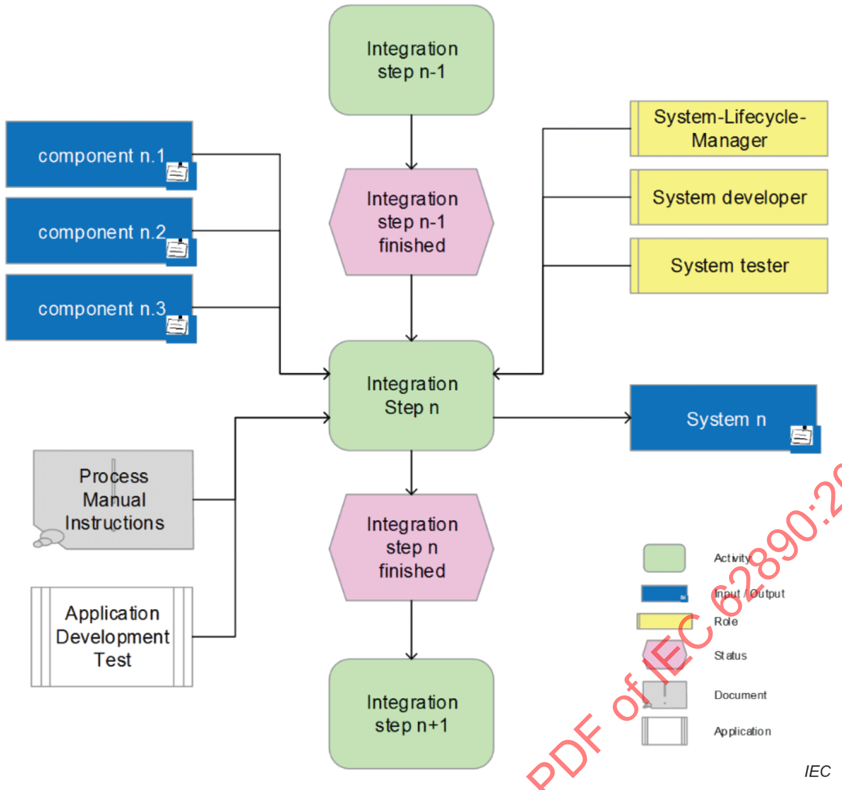

Figure 9 – Example of integrating components into a system

4.4 Compatibility model

In automation, compatibility is defined as the ability of a new component to satisfy the requirement profile of an original component based on technical properties. The compatibility model represents a view regarding the properties by using categories. The properties should be defined according to IEC 61987 (all parts).

A capability profile should be defined for each product type. A requirements profile should be defined for each role-based equipment according to its role.

The product producer shall describe the features (capabilities) of the product (type) using properties. He should make the capability profile available at sales release (see Figure 2).

The product user specifies product requirements according to the users use case e.g. with properties (requirements view).

A property of capability profile of a product type can be not relevant to some use cases. There are situations where requirements cannot be mapped to the properties of the capability profile.

In a compatibility assessment, two profiles are compared. This can be:

– requirements profile versus capability profile,

The compatibility assessment should be used for the selection of a product, based on a comparison of a requirements profile and a capability profile.

– two requirements profiles of different points in time,

A plant user maintaining the requirements should use the compatibility assessment to determine gaps in compatibility and associated risks.

– two capability profiles of different points in time.

A producer designing a new product type should use the compatibility assessment to determine the impact of the changes by comparing two capability profiles.

The use of properties is related to application, technical, economical, and environmental aspects as well as standards and regulation. These requirements can change over time and require maintaining of the profiles as described above.

The following lists of properties and blocks of properties are examples and thus do not claim to be complete.

NOTE 1 Properties can be defined in the same way as specified in IEC 61987 (all parts).

Typical properties and blocks of properties regarding function are the following:

- Processing functions for measuring, regulating, controlling, diagnostics, etc.;
- Functional interfaces (such as data type and format, service signature);
- Presentation (such as structure, resolution, color depth, aspect ratio);
- Handling (such as operating sequence, menu structure);
- Engineering (such as configuration, parameterization, data storage);
- Information management (such as archiving of production data);
- Communication services (such as time synchronization, security-related services);
- Security features;
- Safety features;
- Availability features (such as redundancy mechanisms);
- Diagnostic functions.

***

Typical properties and blocks of properties regarding construction are the following:

- Installation, mounting and dimensions;
- Connection facilities;
- Power supply;
- Main circuit;
- Input/output circuit.

***

Typical properties and blocks of properties regarding performance are the following:

- Cycle time;
- Response time;
- Telegram length;
- Memory consumption;
- Redundancy switchover time.

***

Typical properties and blocks of properties regarding location:

- Electrical environmental conditions (such as EMC);
- Climatic environmental conditions (such as temperature, humidity);

– Mechanical environmental conditions (such as vibration resistance);
– Protection type;
– Explosion protection.

***

Typical properties and blocks of properties regarding business are the following:

– Identification;
– Product price;
– Delivery time;
– Life-cycle status;
– Annual service cost;
– Certificates and standards.

***

The level of compatibility (level of exchangeability, consistency or equivalency) defines the fulfillment of the requirements. In practice, qualitative considerations have predominantly been established. A compatibility assessment shall be based on an agreed compatibility level with its criteria. A compatibility profile is the list of the values of the requirement criteria. The following terms are used for the level of compatibility:

- Full compatibility:

  See 3.1.16.
- Function compatibility:

  See 3.1.17.
- Software compatibility:

  See 3.1.43.
- Signal compatibility:

  See 3.1.42.
- Data compatibility:

  See 3.1.9.
- Construction compatibility:

  See 3.1.8.

NOTE 2 The compatibility levels of the data and connection compatibility can be seen in IEC 61804-2 and in IEC TR 62390.

Further levels may be defined, depending on use cases. Levels may be further detailed into sub levels.

Figure 10 illustrates the mapping of the above-mentioned compatibility requirements to a required level of compatibility. It is evident that to fulfill certain levels of compatibility, additional effort can be necessary. Meeting these enhanced compatibility requirements can lead to increased demands in testing and certification, for example to ensure compliance and interoperability of communication interfaces.

Properties and blocks of properties		Level of compatibility: Full compatibility	Function compatibility	Software compatibility	Signal compatibility	Data compatibility	Construction compatibility
Function	Results of processing functions	X	X			X	
	Functional interfaces	X	X	X	X	X	
	Presentation	X	X	X			
	Engineering	X	X	X			
	Information management	X	X	X		X	
	Communication services	X	X	X	X		
	Security features	X	X	X			
	Safety features	X	X	X			
	***						
Construction	Installation, mounting and dimensions	X					X
	Connection facilities	X					X
	Power supply	X					X
	Main circuit	X					X
	***						
Location	Electrical environmental conditions	X					X
	Climatic environmental conditions	X					X
	Mechanical environmental conditions	X					X
	Protection type	X					X
	***						
Performance	Cycle time	X		X			
	Response time	X		X			
	Telegram length	X		X			
	Memory consumption	X					
	***						
Business	Product price						
	Delivery time						
	Life-cycle status						
	Annual service cost						
	Certificates and standards	X					X
	***						

Figure 10 – Example of mapping of compatibility requirements to the level of compatibility

Based on Figure 10, the level of compatibility is used to determine which specific properties need to be considered to fulfill the requirements for a given application. Each requirement should be specified quantitatively.

The value of each property of the requirements profile is compared with the value of the corresponding property of the capability profile (Figure 11).

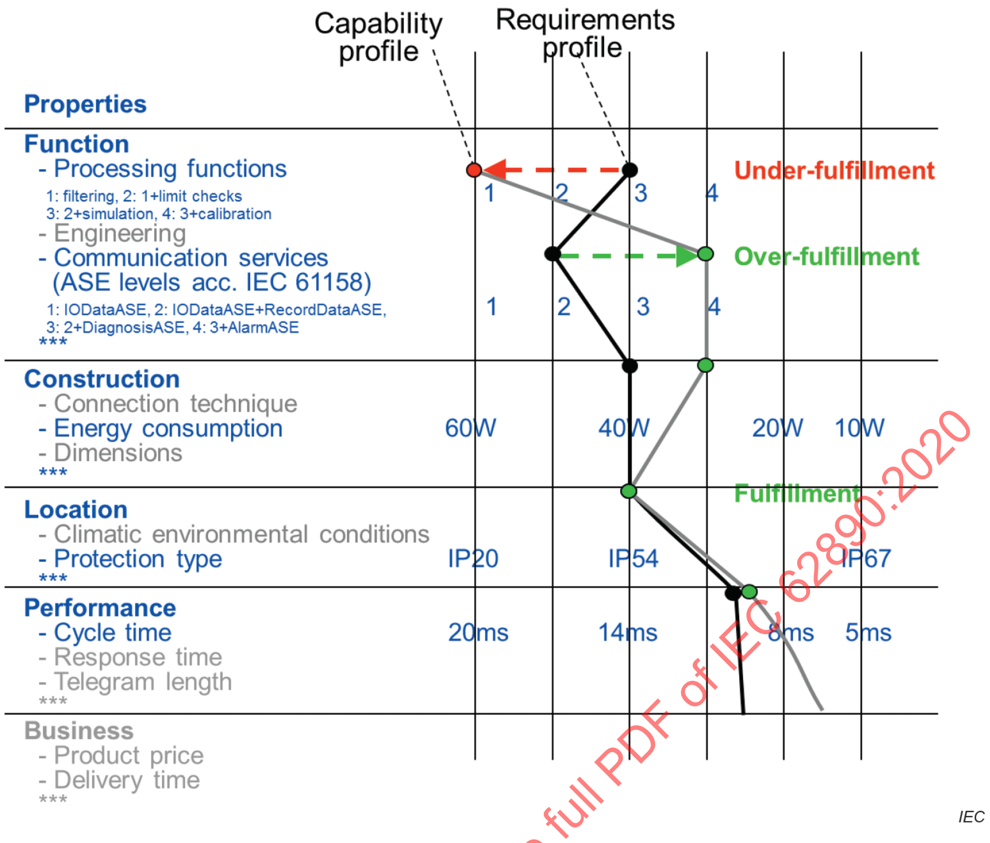

Figure 11 – Example of a compatibility assessment of a product

Fulfilment of every requirement of the requirements profile should be checked by comparing the requirements profile with the corresponding capability profile (Figure 11). Each property from the requirements profile shall be compared with the corresponding property from the capability profile.

5 Strategies for Life-Cycle-Management

5.1 General

When considering life-cycle aspects, the plant user's main goal is the economical operation during the time in use of the plant. System producers are requested to meet the life-cycle related requirements of the users. Consequently, the producers have to meet complex technical challenges while complying with their own economic constraints. Given that the length of the life-cycles of products (producer perspective) and plants (user perspective) usually diverge, Life-Cycle-Management strategies are needed to address the resulting, conflicting interests.

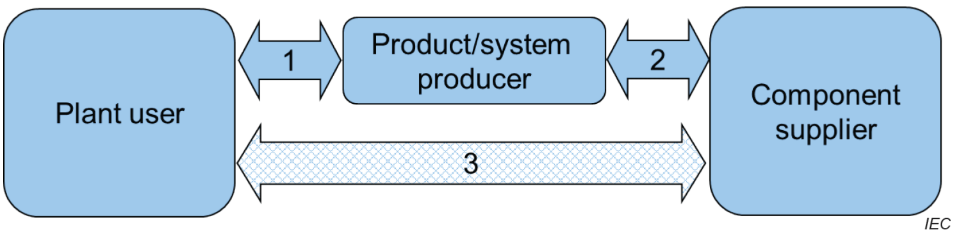

Figure 12 – Relationships between the partners in the value chain

Figure 12 illustrates the fundamental roles of the partners in the value chain and their relationships to each other. Each element of this value chain can itself represent a value chain in the sense of the hierarchy from 4.3 (Figure 6, Figure 7). Customer-supplier relationships exist between partners in this value chain and partners can take on multiple roles. The different roles result in different views and tasks (see Annex E). Responsibilities regarding Life-Cycle-Management depend on these roles.

Interface 1 in Figure 12 shows the relationship between the plant user and the producer of a system. Individual, application-based services (usually engineering and maintenance) are provided here. In the context of the model described in 4.1, this is where products instances are created, configured and parameterized. Interface 1 includes responsibilities for all components of the delivered product, including all components from component suppliers via interface 2, for example COTS.

In contrast, interface 2 represents the relationship between the product/system producer and the component supplier. In the context of a value chain, system development always includes the integration of third-party components (Figure 9). With reference to the model described in 4.1, this is where product types are developed and maintained.

Interface 3 represents the direct relationship between the plant user and the component supplier. Because this bypasses the support of the product/system producer, it entails risks for the plant user. In this case, the user partially takes over the responsibility of the product/system producer (Figure 9). As changes are not coordinated with the product/system producer, this can lead to compatibility problems. Integration tests conducted by the product/system producer, with resulting releases and/or handling instructions, are indispensable for ensuring compatibility.

The producers and users of automation systems and components have developed methods and strategies that are intended to allow them to maintain both product types (Figure 2) and their delivered product instances (Figure 5) within a system generation. This is done in order to ensure their usability over a long period of time.

Maintenance methods have been introduced for ensuring the usability of product instances (in accordance with [11], for example inspection, (preventive) maintenance, and repair). Last-time buy of product instances, substitution of product types, re-design, and migration are specific strategies for preserving system usability. These strategies are often employed in combination.

The applicability of the individual strategies varies depending on the producer and plant user. Various criteria should be considered and assessed in order to select the suitable strategies. These include:

- Compatibility

  See 3.1.4

- Reaction time:

  The reaction time is the period of time between the onset of an event which reduces usability and the time when full usability is restored by means of the selected strategy.

- Sustainability:

  Sustainability describes how long usability can be ensured by means of the selected strategy, giving an indication of how future-proof something is – taking into account the expected remaining life time of a plant.

- Effort:

  Effort describes the amount of material, personnel and financial resources required for ensuring usability. Depending on the strategy, the amount of effort assigned to the producer and the user varies.

- Innovation potential:

  Innovation potential describes the capability of a system to be further enhanced through the addition of new features such as new functions and improved performance, serviceability, and profitability.

- Risk:

  Risk describes the threats and opportunities for the suitable strategy to help decision takers to understand the total consequence of chosen strategy (technological, operational, and economical risk) and evaluate it against remaining life time.

Annex A describes the current status of life-cycle aspects. Annex D describes an examples of Life-Cycle Management strategies.

5.2 Last-time buy

Last-time buy describes the purchase and storage of an abandoned component. The storage conditions shall ensure compliance with the technical properties specified by the producer over a defined period of time.

The last-time buy strategy is used after the component's end of production (milestone 4 as shown in Figure 2) and is applied by the producer for covering the demand in manufacturing and repair of the system and also by the plant user for stocking up on spare parts and for plant expansions. Last-time buy is also used to extend the time until another strategy is used (such as substitution).

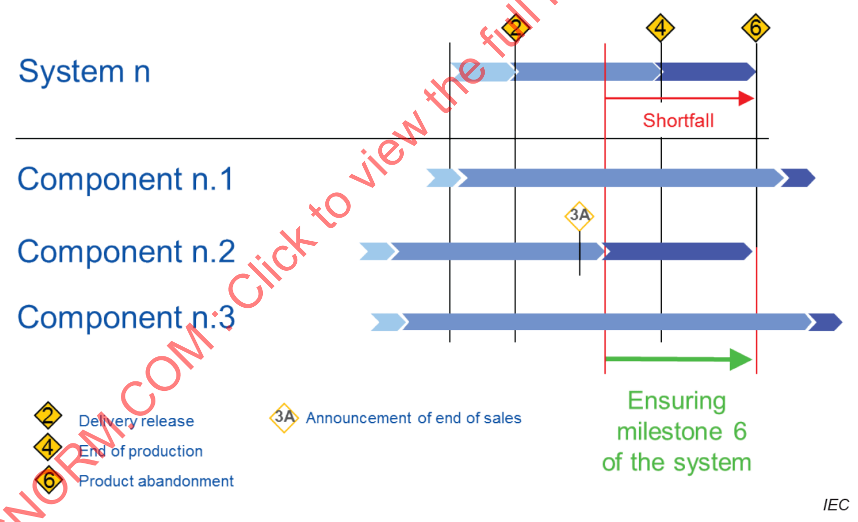

Figure 13 – Ensuring delivery of a system through last-time buy of a component

In Figure 13, the shortfall between the end of production of component n.2 and the abandonment of the system n is covered by an increased stockpiling of component n.2. The amount of stock needs to be sufficient for the demand that arises during manufacturing and after-sales support. Planning of stock piling of component n.2 should start at milestone 3A of this component at the latest. In addition to complying with the storage conditions, the last-time buy approach has to be considered from an economic point of view (committed capital, storage costs).

For example, the abandonment of an electronic part before the end of production can be countered by purchasing a sufficient quantity. In this case, it can be necessary to store the parts under defined climatic conditions, for example, with a protective gas.

If the last-time buy strategy is inappropriate from a technical or economic standpoint, then substitution or re-design strategies can be required in order to fulfill the product's life-cycle requirements.

Characteristics of the last-time buy strategy are:

- compatibility: no restrictions;
- reaction time: short, fastest strategy;
- sustainability: limited by physical properties (for example drying out of electrolytic capacitors) and availability of know-how, depending on the remaining expected life time of the plant;
- effort: costs for storage, capital commitment, costs of maintaining know-how;
- innovation potential: none, because it preserves the status quo;
- risk: typical low technological and economical risk, medium operational risk (no improvement).

5.3 Substitution

Substitution is a strategy whereby a component in the system is replaced with a compatible successor type in such a way that there are no repercussions on the system. The basis for this is a requirement specification which considers technical, economic, and regulatory aspects. Compliance with a compatibility profile as described in 4.4 is crucial. This profile contains the relevant requirements and their value ranges for product properties, for example, as specified in IEC 61987.

Substitution always requires integration effort. Substitution with a large amount of integration effort, for example due to a technology change, is classified as a re-design of the product type in the context of this document. Typical reasons for substitution can be abandonment of hardware components or COTS products. Innovation of the product type is not the goal of substitution.

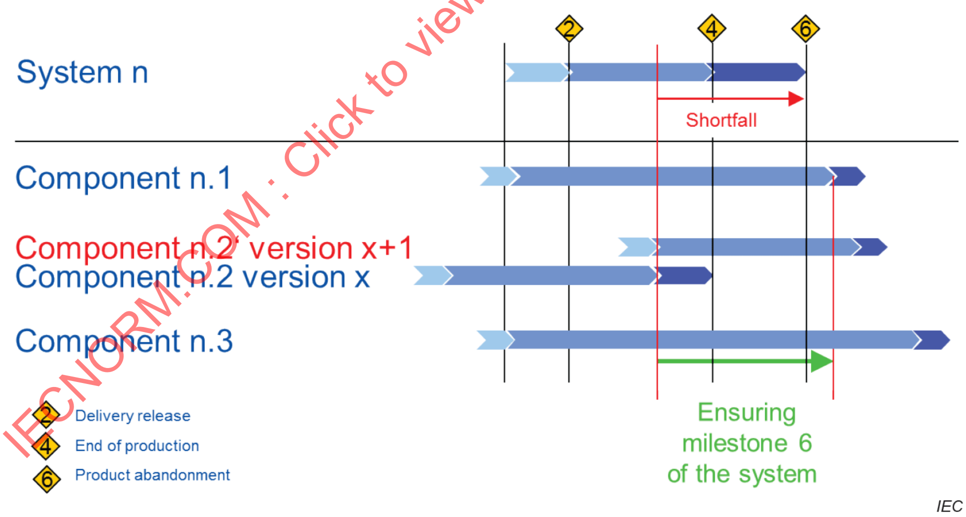

Figure 14 – Ensuring delivery of a system through substitution of a component

Figure 14 shows a shortfall for the system due to the end of production of component n.2 in version x. Substitution of a new version (x+1) for this component covers the shortfall.

For example, a change in the dimensions of a power supply can result in integration effort because adapters need to be designed. As another example, when new software versions are introduced, changes to the internal interfaces as a result of the new component require system integration effort.

The use of standardized hardware and software interfaces (external and internal) within the system architecture allows for and simplifies substitution, thereby having a large impact on the system integration effort.

NOTE Regardless of the un-effected compatibility of the system, in some industries there could be some restrictions requesting a re-certification.

Substitution is inappropriate when essential properties of the compatibility profile cannot be fulfilled. As a result, substitution may not be justifiable for technical or economic reasons.

Characteristics of the substitution strategy are:

– compatibility: no restrictions;
– reaction time: longer than last-time buy, typically shorter than re-design (depending on the integration effort);
– sustainability: better than last-time buy, depends on the life-cycle of the successor type or the remaining expected life time of the plant;
– effort: costs for substitution (ensuring integration without repercussions), avoiding last-time buy costs;
– innovation potential: limited, as it generally preserves the status quo;
– risk: typical low technological and economical risk (what you have is what you get), medium operational risk (no improvement)

5.4 Re-design

Re-design is a strategy whereby a new version of a product type is developed. The new version typically fulfills or exceeds the product specification, and therefore the compatibility profile, of a previous type. This includes the activities for maintaining the required qualification and certification.

Typical causes for re-design for both producers and plant users are:

– abandonment of a component if the last-time buy or substitution strategies are not suitable solutions;
– fulfillment of changes in standards and legal regulations (such as RoHS, environmental ordinances, export laws).

Typical causes for re-design for producers are:

– optimization of manufacturing and testing technology;
– improvement of profitability (re-design to cost).

Typical cause for re-design for plant users are the compatibility restrictions of a successor product.

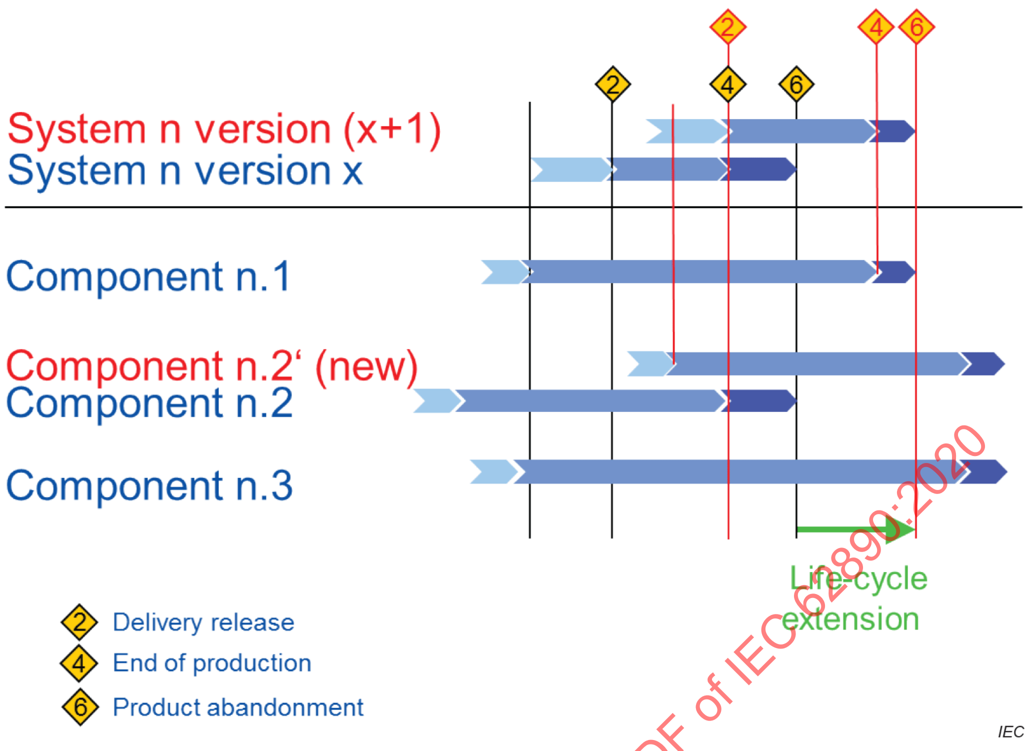

Figure 15 – Re-design of a system due to end of production of a component

In Figure 15, component n.2 is replaced by the new component n.2'. This necessitates the development of a new version for the system n (version x+1) while taking into account compatibility requirements. This can result in extending the life-cycle of system n through postponing the end of production (milestone 4) and abandonment (milestone 6).

NOTE The life-cycle of a component which is different to the replaced one (component n.1 in the figure) can determine the length of the life-cycle of the system.

For example, abandonment of a processor can lead to a re-design of the system if substitution through a new type is not suitable for technical reasons. There can be other causes for re-design, particularly due to wildcards such as RoHS.

Characteristics of the re-design strategy are:

– compatibility: restrictions are to be expected;
– reaction time: longer than substitution, typically shorter than migration (depending on the integration effort);
– sustainability: better than substitution, depends on the life-cycle of the new system version and the remaining expected life time of the plant;
– effort: costs for development, testing, qualification, etc., including system integration; avoidance of last-time buy costs;
– innovation potential: exists, new version can include new functions;
– risk: typical medium technological and economical risk, more complex solution then last time buy or substitution but with lower operational risk.

5.5 Migration

Migration solutions are applied when the above-described strategies of last-time buy, substitution, and re-design are not justifiable.

Migration refers to:

– the (partial) replacement of existing components with new components with extended or modified functionality in an existing system configuration;
– the extension of an existing system configuration through components of a new generation. This generally includes a change of technology.

Generally, migration is necessary when the effort required to maintain and enhance the existing system is not justifiable.

This strategy can be applied to different levels (see Figure 16).

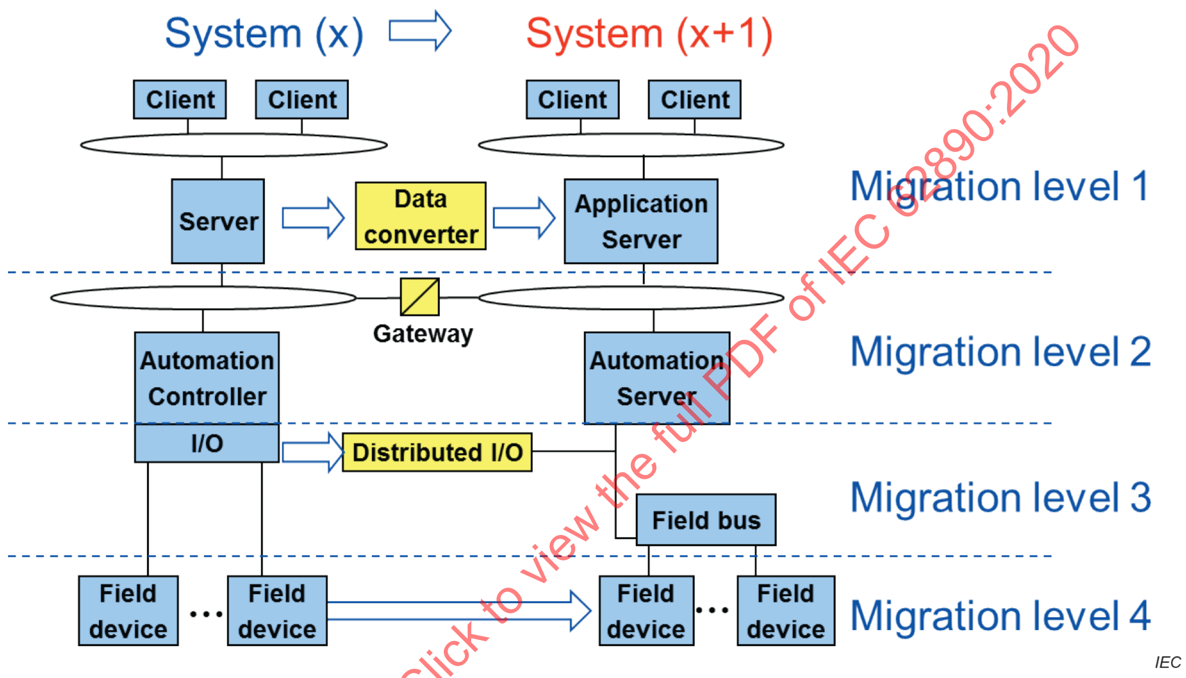

Figure 16 – Level model for migration steps

NOTE The migration levels are not the functional levels defined in IEC 62264-1.

The innovation cycles of the components of migration level 1, along with economic considerations, lead to this level generally being the starting point for migration. The effort for migration increases from level 1 to level 4. As a result, the frequency of migration decreases from level 1 to level 4.

Migration should not cause significant repercussions. To limit the repercussions, it is necessary to develop suitable adaptation solutions while considering general regulatory conditions. The compatibility model presented in 4.3 is a means for assessing the repercussions. For migration, the fulfillment of the functional compatibility requirements is the focus. Examples of adaptation solutions in the respective migration levels include data converters, gateways, proxies, virtualization of operating resources, and replacement of central I/O devices with field bus coupled distributed devices.

Migration is most appropriate when productivity gains or cost reductions are expected, for example from new functions, standards or technologies. Migration offers the greatest innovation potential, but at the same time it represents the most complex strategy. The migration from proprietary communication interfaces to open field bus systems can be seen as an example.

Characteristics of the migration strategy are:

- compatibility: preservation and expansion of the function, function compatibility is typically fulfilled;
- reaction time: depending on the migration level, can be considerably longer than re-design;
- sustainability: high level of sustainability due to the introduction of a new system;
- effort: greatest effort, costs for development, testing, qualification, etc., including adaptation solutions and system integration;
- innovation potential: greatest innovation potential because the latest, most advanced technologies can be taken into consideration;
- risk: typical medium technological and high economical risk, depending on the compatibility but with lower operational risk seen in a life-cycle perspective.

5.6 Comparison of the strategies

In practice, these Life-Cycle-Management strategies are applied in various combinations. Life-Cycle-Management should include a risk assessment and a definition of measures as early as possible. Generally, this is a part of the product and system planning process. In practice, however, it is not possible to avoid unplanned events. External influences, such as a component fault or the abandonment of components, play a crucial role here.

With the various strategies, the steps to be taken should be evaluated from technical, time, and economic points of view and the consequences should be considered. The following overview (Figure 17) is intended as a starting point and can be used to provide orientation for selecting a suitable strategy or combinations thereof. The typical characteristics (see 5.2, 5.3, and 5.4) are shown in colors. The weighting of the characteristics depends on the individual case, which makes a detailed analysis indispensable.

	Compatibility	Reaction time	Sustainability	Effort	Innovation potential	Risk
Last-time buy	very good	very short	poor	low	low	low
Substitution	very good	short	good	high	low	low
Re-design	good	long	good	high	high	med.
Migration	poor	long	very good	very high	very high	high

IEC

Figure 17 – Typical characteristics of the Life-Cycle-Management strategies

Because the considered components and systems differ greatly, it is important that the specific problem is reflected by the respective strategies. Often multiple strategies are applied either sequentially or simultaneously.

The described strategies can be applied individually or in combination at different times throughout the time in use of a plant. It is important to plan and implement a coordinated strategy for the system based on the individual life-cycle considerations of the components. This has to take the plant user strategies into consideration (see productivity maintenance or productivity optimization in Annex E).

5.7 Application of Life-Cycle-Management strategies for service

5.7.1 Service regarding Life-Cycle-Management

Life-Cycle-Management services are applied to product instances during the time in use (see Figure 5). The objective of Life-Cycle-Management services is to maintain the system (instance) throughout the time in use by ensuring that the utilized components can be maintained. Life-Cycle-Management services can also cover the disposal of product instance. The services support the plant user in achieving his productivity and availability goals.

For Life-Cycle-Management services for components and systems, the strategies described in Clause 5 can be applied individually or in combination.

Life-Cycle-Management services can essentially be divided into standard service and service through customized special agreement.

See Annex C for examples involving Life-Cycle_Management.

5.7.2 Service levels

Service may be defined on different levels. These levels are a consistent foundation for both standard service and service through special agreements. Examples for service level definition may be:

- level 1: on-site service;
- level 2: service via hotline;
  - level 2-1: service via hotline in local language
  - level 2-1: service via hotline in other language (i.e. English)
- level 3: service including development support.

5.7.3 Standard service

Standard services describe a degree of service without consideration of specific user requirements. These services end when the product type is abandoned (Figure 5). Update and upgrade, the provision of spare parts and repair services are examples of this. Standard services can include training offers, commissioning, and remote support (such as telephone, hotline and remote maintenance).

5.7.4 Service through special agreement

Service through special agreement refers to instances and may be available after product abandonment. They are based on individual service agreements (contracts) between the service provider and plant user in order to support the user's strategy for plant operation. These agreements differ from standard services in terms of the scope of services offered or the respective period of time. Technical feasibility and economic viability can limit the application of this service.

Special agreements can ensure the preservation of the status quo of the installed system (instance) for example by means of extended ability to deliver spare parts or software support that continues beyond the end of service for the type.

6 Life-Cycle-Management

6.1 Proactive Life-Cycle-Management

Clause 4 has identified that comprehensive Life-Cycle-Management begins as early as the planning phase of a system and includes thorough consideration of the requirements. In essence, this involves the active management of the life time of a plant including its components. This calls for proactive Life-Cycle-Management [12] that – according to IEC 62402 – begins already in the phase of the product development and supports the lowest possible effort for migration and re-use of configuration data in the event of a technology change. For this purpose, a Life-Cycle-Management mindset should already be present when a system is being developed, because foreseeable influences such as technology changes or changing regulatory requirements should already be taken into consideration during this early phase [13]. A robust design should include the consideration of life-cycles of the system's components in order to prevent situations as shown in Figure 8 for component n.2 and n.3. This approach ultimately leads to an expanded quality concept because comprehensive planning also means planning ahead for the sustainability of the products and components and continuously anticipating replacement and re-use solutions. Thereby, interoperability and compatibility are better anchored in the long-term development strategy. For example, a system design based on standardized product profiles with pre-defined compatibility levels (see IEC 61804-2 and IEC TR 62390) reduces long-term system maintenance effort. This has far-reaching consequences for the structural and technical system and product design. To ensure long-term sustainability, the diversity of system components should be minimized in favor of platform strategies. In addition, the complexity can be limited by creating modular solutions based on stable and standardized interfaces. Consistent development documentation of the product type based on standardized processes and regulations is indispensable for achieving this.

Annex B describes requirements, influencing factors, industry-specifics.

Proactive Life-Cycle-Management also means the sustainable optimization of a plant throughout its time in use. Measures for ensuring the sustainability of Life-Cycle-Management can only be based on intensive cooperation between plant users and producers. Thereby, analysis of the following factors is necessary:

– the life time of the plant and the life time of the products that the plant manufactures,
– the life time of the system components (for example based on probability of failure),
– the supplier selection based on life-cycle relevant criteria, such as financial stability, availability of second source, or ability to deliver,
– the delivery terms and conditions for products and services, including those for software [9].

Proactive Life-Cycle-Management contributes substantially to minimizing the costs, which makes this aspect an essential part of TCO considerations (Clause B.1).

Proactive Life-Cycle-Management results in changes to the evaluation criteria for decision-making processes and new opportunities for partnership-based relationships between users and producers. Proactive Life-Cycle-Management of components and systems enables the development of suitable strategies for a plant's time in use. An optimized, plant-specific strategy is created by combining the goals of the user and the capabilities of the producer regarding the products that are employed and their life-cycle specific characteristics. The strategies described in Clause 5 form the basis for this work.

This approach leads increasingly to strategic partnerships within the industries. This can result in the introduction of new business models in which producers of instrumentation and control systems assume the responsibility for the availability of the user's production processes. In addition to the different cost schedules, criteria for task allocation within the partnerships specifically includes the tolerable reaction time, the available personnel resources, and, above all, the specific know-how.

Proactive Life-Cycle-Management also leads to requirements related to standardization. Only in this way can requirements regarding compatible innovation be fulfilled from the outset with low effort. This requires open, vendor-independent conventions for creating products and processes which can only be defined in standardization committees.

In addition to standardization of technical content, it is necessary to develop uniform and accepted methods for the holistic consideration, assessment, and calculation of TCO.

NOTE Examples of approaches for this can be found in [13] and [14].This would allow evaluation and comparison of different strategies with regard to economic aspects.

6.2 Life-Cycle-Excellence

The conclusions based on the different industry requirements (see Clause B.5), the generic Life-Cycle-Model (see 4.2), and the presented strategies for Life-Cycle-Management (see Clause 5) show that Life-Cycle-Management in industrial-process measurement, control and automation is highly complex and requires holistic consideration. This includes application-, technical-, time-, and economic-aspects, as well as the use of the models defined in this standard (see Clause 4), compatibility assessments (see 4.4), and the anticipation of wildcards.

NOTE The reliability of the properties stated in the profiles (see 4.4) is an important prerequisite for Life-Cycle-Excellence.

It also became clear that successful Life-Cycle-Management has a great influence on the competitiveness of products, systems, services and consequently the respective company.

In this context, four fundamental requirements regarding the robustness of the Life-Cycle-Management of components, products, and systems can be identified.

- Technical robustness:

  To allow compatible system enhancement and substitution of components for a particular system generation, specific technologies shall be selected, and rules shall be defined for the system development. This calls for proactive measures, particularly the anticipation of changes due to technical innovations, standards and regulations. It also includes the modularization of systems (see 4.3), the definition of open interfaces with long-term stability, and the definition of compatibility profiles for components (see 4.4). Technical robustness can only be achieved if the differing lengths of the life-cycles of the various component types (Figure 15) are considered. Technical robustness also includes support for changing the system generation with suitable migration solutions (see 5.5).

- Application robustness:

  Application robustness describes the capability of a system to adapt to changes related to the operation of the plant. For example, this includes product changes (batch), changes in production quantities, changes to input materials, and changes to production processes or revision times. Also included are changes, which increase the degree of efficiency or availability, and changes due to standards, and industry-specific stipulations.

- Economic robustness:

  Economic robustness describes the capability of a system to adapt to changes in the economic goals and constraints of the plant operation during the time in use. This includes external influences such as altered economic conditions, market fluctuations, competitiveness, general legislative conditions, and changed business strategies and decisions. These goals and constraints can lead to changes in the planned time in use of the plant, the plant operating models and, consequently, to changes in the criteria for selecting Life-Cycle-Management strategies.

- Ecological robustness:

  Ecological robustness describes the capability of a system to adapt to changes in the ecological goals and constraints of the plant operation during the time in use. This includes external influences such as altered ecological conditions, environmental regulations and standards, and changed business strategies and decisions regarding environmental and sustainability aspects. This can lead to changes in the criteria for selecting Life-Cycle-Management strategies.

Optimal profitability is always the highest priority when selecting suitable strategies. Strengthening of requirements on security, safety and environment protection is expected over time. Thus, these requirements will drive Life-Cycle-Management, especially during operational phase.

Life-Cycle-Excellence is the term for managing the influencing factors for the robustness of the Life-Cycle-Management of components, components and systems by means of holistic consideration (see Figure 18). Life-Cycle-Excellence is based on standards and the common models described in this document.

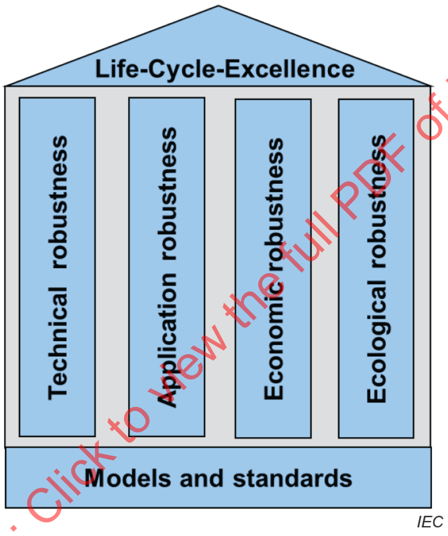

Figure 18 – Life-Cycle-Excellence

In the context of robustness, the dimension of time includes the life-cycle of types (components, products, and systems) and the life time of their instances. Life-Cycle-Excellence is achieved if the product Life-Cycle-Management satisfies these demands throughout the entire time range – sustainably. Life-Cycle-Excellence can only be achieved by means of cooperative, continuous, and proactive Life-Cycle-Management.

Annex A
(informative)

The current status of life-cycle aspects

Modern production facilities and installations are structured and subdivided into different functional areas. These functional areas are assigned to instrumentation and control equipment that consist of a multitude of individual components which form a distributed system. As shown in Figure A.1, the components are assigned to different functional levels. Each of these components and its elements (microprocessor, capacitors, firmware, etc.) is defined by specific characteristics of its life-cycle. Awareness and mastery of the life-cycles of the individual components and their interactions throughout the life time of the plant – Life-Cycle-Management – represents the fundamental precondition for maintaining the economical operation of the plant throughout the planned time in use.

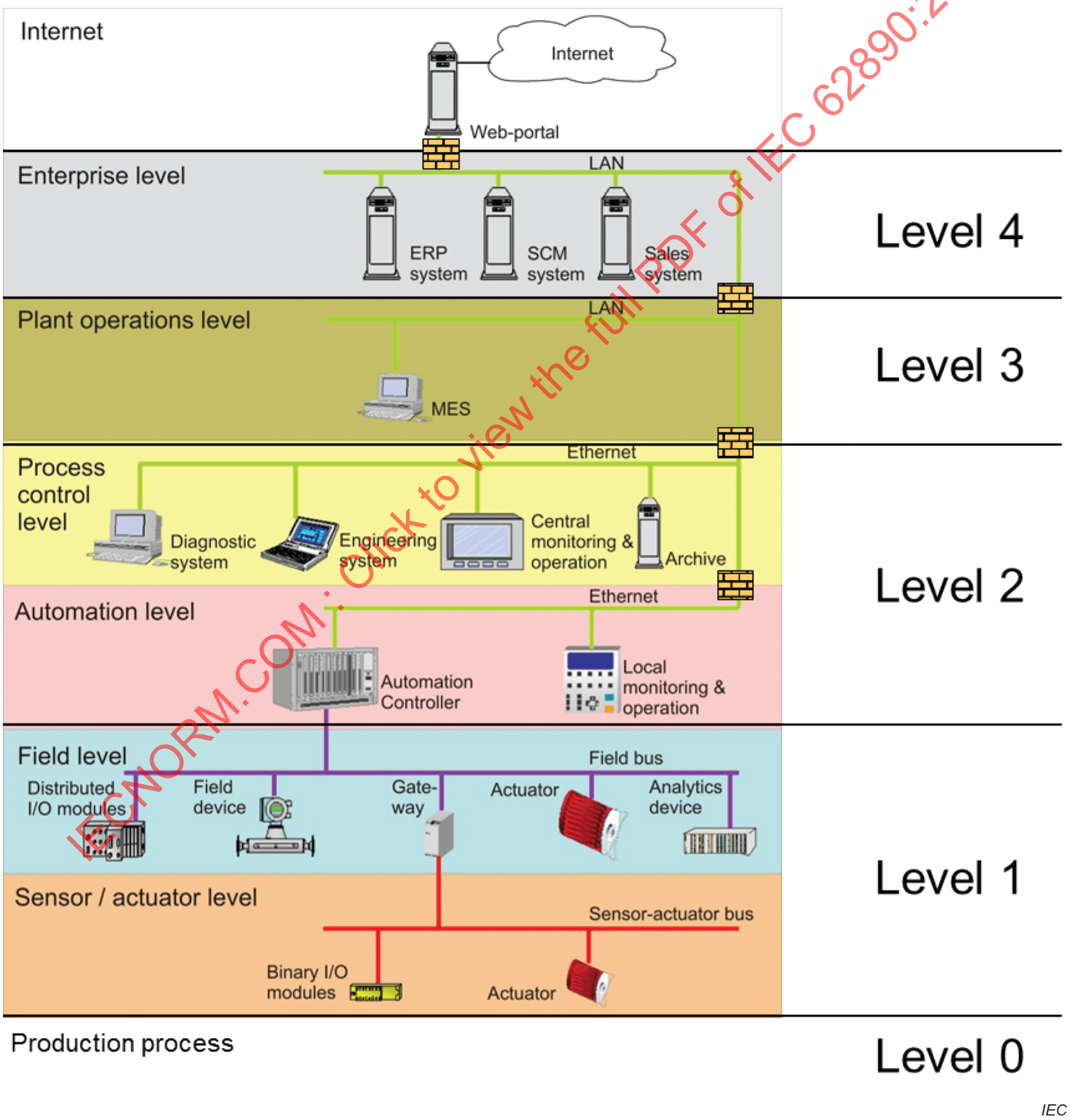

Figure A.1 – Typical structure of an instrumentation and control system with functional levels according to IEC 62264-1

The following example illustrates the influence of component life-cycles (see also Annex C) on economically maintaining operations (Figure A.2):

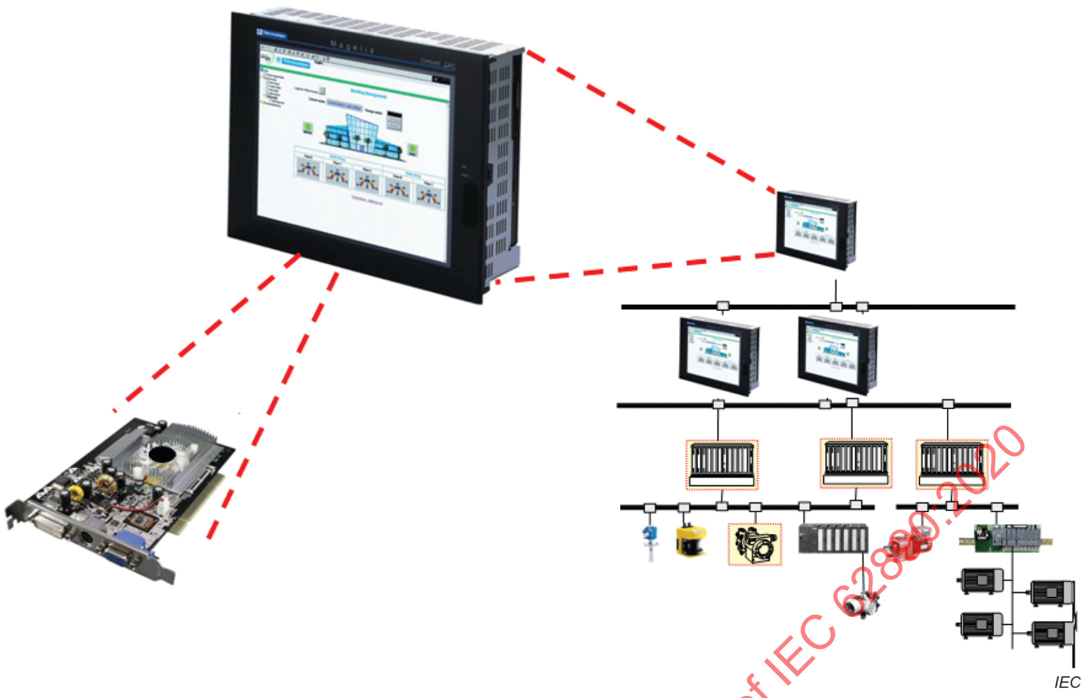

Figure A.2 – Example of the effects of component failure

In a computer – which performs fundamental functions within a process control system of a plant that has been operational for a number of years – a graphics card needs to be replaced because of a defective component. Repair work is not possible. As this particular type of graphics card is no longer available, it is necessary to use a suitable replacement. While the replacement graphics card is functionally compatible, a graphics card driver that is compatible with the installed operating system does not exist. It is also not possible to change the operating system as the applications (software) running on the process computer have not been approved and released for use with the newer versions of the operating system.

A solution to this conflict could involve the replacement of all of the computers of the process control system, including the operating system, upgrading of the application software and the adaptation of applications to the altered conditions. Within the context of these changes, the employees have to be retrained and a software maintenance agreement has to be made with a service provider.

This example illustrates the complexity of maintaining plant functionalities, and how extensive the effects on the plant can be. These effects can also apply to parts of the plant that are operating correctly and are not directly linked with the defective component. A comparable situation is discussed by Hauff and Weigel [12].

One of the reasons that maintaining plant and system functions is so complex is the fact that over the life time of a plant, the innovation cycles and the related life-cycle of components vary considerably (Figure A.3). The life time of the plant itself and the associated, specific requirements (such as the planning of maintenance cycles) are highly dependent on the respective industry – the time in use of a process plant, for example, is between 15 years and 40 years, while a production line in automobile manufacturing is usually changed to meet new requirements of the production of a new model.

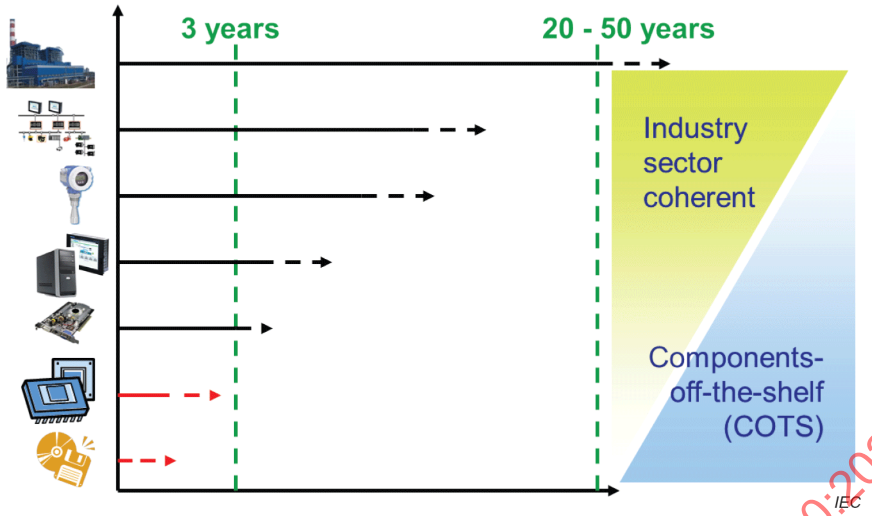

Figure A.3 – Life-cycles of plants and their components

Plant operators in particular do not evaluate the cost efficiency of their investments solely based on the procurement costs (planning and setting up), but increasingly they also consider the costs of maintaining plant operation across the entire life time (Life-Cycle-Costs). In this way, the overall costs and the total benefits of a project can be evaluated in a transparent manner by including all of the follow up costs. As various studies [19] have shown, the costs for the operation of a system may exceed the procurement costs (initial investment) many times over. This is due to the long time in use of plants where costs of operation and maintenance reoccur periodically. Therefore, the total costs calculated across the life time of the plant – also referred to as TCO [20] – assume the character of an iceberg, whereby the total volume is not readily visible (see Figure A.4).

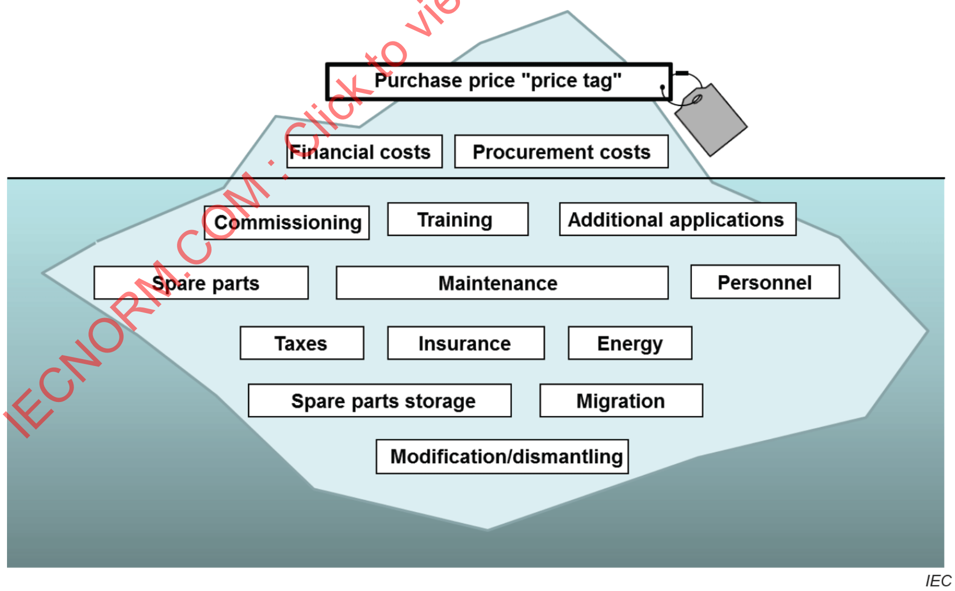

Figure A.4 – The iceberg effect

At first glance, only the purchase costs are visible (the "price tag"), while the follow-up costs that are implicit in this investment usually remain concealed or tend to be overlooked [21].

In summary – due to the speed-up of the innovation rate – Life-Cycle-Management is a significant topic in automation – especially in the discussions between end users and manufacturers as well as between manufacturers and suppliers. The interaction between global, legal and technical aspects – including demands for high functionality and efficiency, as well as the influence of IT technologies in automation – helps to demonstrate the scope of this topic.

Annex B
(informative)

Requirements, influencing factors, industry-specifics

B.1 General requirements

Driven by innovation in electronics and software technology, the functionality of automation components is continually increasing. The breadth of the functionality of components is a key sales argument. This breadth is a result of meeting customer demands for flexibility, open systems, extensive application areas, high availability and deliverability of components, with ever decreasing costs. At the same time, producers improve their products not only in order to offer their customers new functions, but also to improve applications, handling, operability and costs. As a result, the complexity of the system increases considerably due to the added complexity of the integrated components.

The increasing speed of innovation in hardware and software continuously shortens the life-cycle of components – however the life-cycle of systems cannot be shortened in a comparable manner as it relates to the life time of the plant.

Not only do the life-cycles of components and systems differ, but they are also viewpoint-specific. This is due to the perspectives of the different roles which work closely together for the planning, set-up and operation of a plant. For example, for the use of a new version of an engineering system, the producer ensures that the new version can also be used with the installed device versions, or they may have to develop and deliver upgrades. To maintain compatibility, not only could hardware and software changes be necessary, but services, and possibly also contractual issues, should be taken into account.

Customers, suppliers and producers are partners within a value chain. Normally, this results in different viewpoints such as that of the supplier or the customer. The producer of a product generally integrates components which have individual life-cycles. When the producer sources these components from a sub-supplier, the producer assumes the role of a customer.

It is important to note that these suppliers and their products are less and less geared towards the automation requirements. As a result of worldwide rationalization and market changes, producers of basic components, such as semiconductors and operating systems, are merging. These merges lead to consolidated product portfolios – which often results in less product specialization.

The importance of life-cycle aspects is increasing continuously for all industrial goods and systems with long life times. This is due to the growing complexity of components and systems as well as the rising application of generic components, for example COTS, that are made for the consumer goods industry. However, compared with the consumer goods industry, the demand emanating from the automation industry is so low that the respective requirements are hardly given consideration. Industries such as home entertainment or mobile communication – with considerably shorter product life-cycles – generally optimize their products with the goals of low cost and new functionality, rather than compatibility and long-term service. This has a major impact on the deliverability of components and spare parts. Due to the low demand from the automation market, prolongation of production only for this industry is not profitable for the major semiconductor manufacturers.

In addition to requirements which result from the long time in use of components, automation-specific application requirements include real-time behavior, functional reliability, safety and defined interfaces. Many diverse standardization activities address these requirements. This is a continuous process and an important precondition for ensuring the interoperability of components and systems over the long term. To an increasing extent, the harmonization efforts are influenced by standards and specifications which come from outside of the automation area. The widespread integration of IT technologies in many automation areas leads to openness, flexibility, and increased functionality of the components. This integration results in reduced costs and accelerated innovation; however it is also accompanied by a lack of continuity from the viewpoint of the life-cycle of automation components and systems. Automation users, producers and suppliers demand long-term usability for IT technologies, or at the least a transparent migration strategy in order to ensure usability over the life time of the plant. This becomes even more critical when there is a dependency on a certain technology.

The life-cycle in automation is additionally affected by legislation and normative constraints. The continued sale of products, and the development and production of new products, is affected by software usage rights, open source license conditions, the internationalization of standards, national legislation and international directives such as RoHS (Restriction of Hazardous Substances) [17]. These demands can considerably affect strategies for maintaining long-term usability.

All of the influencing variables described so far impact the economic efficiency of a plant. Life-cycle related evaluation methods aim to collect and analyze the entire cost related to automation equipment that arise across the whole life time of a plant from planning to construction, erection, operations and finally dismantling (TCO). With the help of such cost evaluations, it is possible to analyze the relationship between procurement cost (initial investment) and the resulting follow-up cost (Life-Cycle-Costs). Decisions made in the planning phase, for example, can incur effects much later during the system's time in use. This is precisely why the Life-Cycle-Costing (LCC) method was developed. In addition to transparently presenting the distribution of costs over time, the method also helps to identify opportunities for optimizing economic efficiency. The aim of Life-Cycle-Costing is to determine what proportion of the total costs is incurred during the time in use, in order to minimize TCO. This forms the basis for optimizing the balance between the initial investment and operating and maintenance costs by selecting the most appropriate products. The commonly used term for this balancing of costs is trade-off (see Figure B.1) [13].

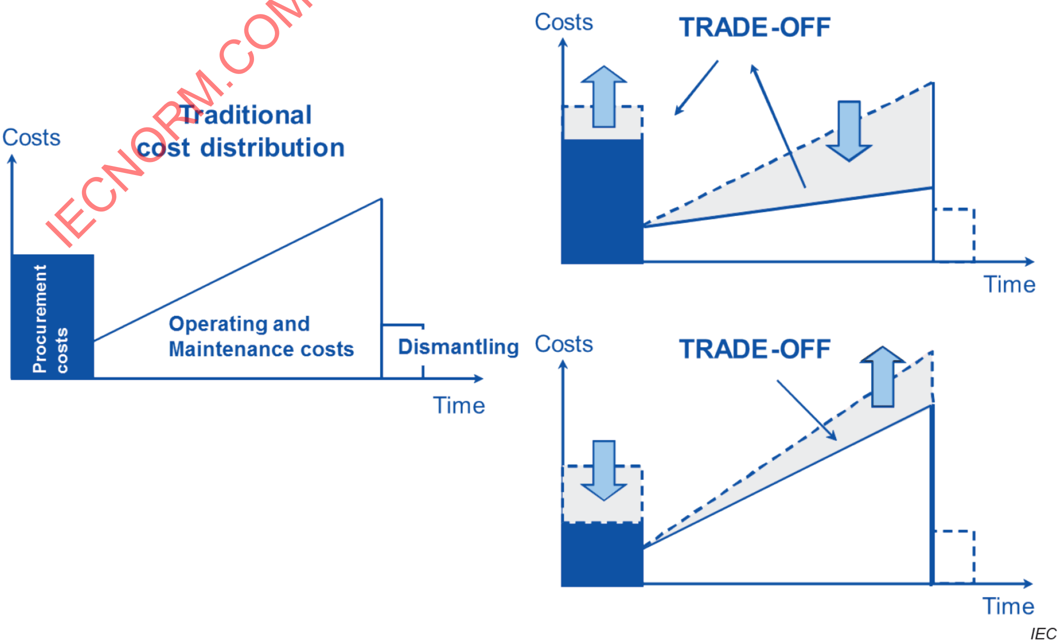

Figure B.1 – Trade-off between procurement costs (initial investments) and costs for operating and maintenance

In this context, the traditional production and sales cycles of individual components become less important, while the overall life-cycle of the investment becomes the main focus. Consequently, and in contrast to conventional cost analysis, with the Life-Cycle-Costing approach, the decision-making process for the initial investment takes into account the long-term impact on the TCO of performance capability, future usability and Life-Cycle-Costs. Because of the long-time horizon, this approach reveals hidden cost drivers, but also potential benefits throughout the entire life-cycle. Thanks to the identification of cost drivers, it becomes possible to make target-oriented analyses of the processes and to improve economic efficiency through optimization and redistribution of services among the value chain partners.

B.2 Consideration of industry-specific requirements

The industry-specific requirements related to Life-Cycle-Management of automation solutions differ due to the planned time in use of a plant – where the period of time extends from a few years in automobile manufacturing to several decades in the areas of energy and rail transport. Other requirements which arise during the course of operations also diverge. In order to identify industry-specific requirements that are relevant for the life-cycles, the following industries have been analysed:

– chemical industry;
– energy industry;
– automobile rail transport;
– manufacturing;
– machine tool manufacturing.

General characteristics of the individual industries are described along with the derived Life-Cycle-Management requirements. Each analysis is completed with the expected industry trends. Table B.1 and

Table B.2 show an overview of the requirements which were derived from these analyses. Time-related, technical and service requirements are presented for each industry.

One characteristic used to differentiate the industries is time. This includes the life time of the plant from the conclusion of commissioning to dismantling, the time between possible production line changes (to produce a different product), as well as the cycles for modernization and revisions of the plant.

The technical requirements include compatibility (see 4.4) of function-, construction- and location-related properties. The following aspects are analyzed in the categories for the industries addressed:

– function-related properties:

  monitoring and operating, controlling, information management, interfaces, data types and data formats;

– construction-related properties:

  mechanical and electrical;

– location-related properties:

  setting and environment.

The analysis is performed with a focus on the relevance of the properties to the product and system life-cycles. The compatibility of data types and formats, for example, is essential for migration and protecting investments. Further requirement clusters include the carrying out of and the maintenance of documentation, qualification, certification and approvals for products and plants.

In addition to the technical and time-related requirements, service requirements also influence Life-Cycle-Management. These include maintenance (for example repairs in the case of defects, including delivery of spare parts if necessary), as well as troubleshooting and the correction of faults. Service requirements also include update services for error correction and upgrade services for upgrading to newer versions with improved or extended functionality.

The requirements of the energy industry have been selected as an example to illustrate the analysis method.

Table B.1 – Overview of industry-specific requirements

Requirements	Description	Energy	Chemical	
			Batch process	**Continuous process**
Time-related requirements				
Time in use of plant	portion of the life time during which the plant is actually in use for its intended purpose	> 25 years nuclear power plant > 40 years	typically 5 years to 10 years	typically 10 years to 25 years
Product change	changeover of a plant for the production of a different product, including all operational business processes	no product change	product changes possible throughout the time in use of plant	product changes possible throughout the time in use of plant
Modernization cycle	time between each period of modernization of technical equipment through new technology, with the goal of maintaining or increasing value to the plant user	typically 15 years to 20 years	typically 5 years	typically 15 years
Revision cycle	period of time between plant revisions (planned interruption of production for inspection and maintenance of the technical equipment in a plant)	typically ≥12 months	in principle, possible between two batches, typically < 1 year	typically 5 years
Technical requirements				
Compatibility				
Function-related requirements				
Monitoring and operating	information presentation, operating sequences and actions, user interface to plant	≥15 years time in use for nuclear power plants	time in use of plant, ≥ 5 years for PC-based systems	time in use of plant, ≥ 5 years for PC-based systems
Automation functions	measuring, controlling, monitoring and diagnosing	time in use of plant	time in use of plant	time in use of plant
Information management	archiving data, evaluating production and quality data, providing data to MES and ERP systems	life time of plant, possible specific regulatory requirements	typically life time of plant, possibly imposed by life time of the produced product or specific regulatory requirements	typically life time of plant, possibly imposed by life time of the produced product or specific regulatory requirements
Interfaces	service and functions, addressing, data volumes, quality of service, profiles	time in use of plant	time in use of plant	time in use of plant
Data types and formats	structure, syntax and semantics of data	time in use of plant, supported by conversion routines	time in use of plant, supported by conversion routines	time in use of plant, supported by conversion routines

Requirements	Description	Energy	Chemical	
			Batch process	Continuous process
Construction-related requirements				
Construction and connection technique	physical dimensions, mounting, pin assignments	time in use of plant	time in use of plant	time in use of plant
Power supply	electrical supply data, power consumption, uninterrupted supply, grounding and shielding, overload protection	time in use of plant	time in use of plant	time in use of plant
Location-related requirements				
Setting and environment	electrical-, climatic-, mechanical-environmental conditions, protection type, explosion protection	time in use of plant	time in use of plant	time in use of plant
Documentation	1. system documentation, e.g. device manual 2. plant documentation, e.g. plant configuration, circuit diagrams, parts lists, application programs, operating instructions	in accordance with regulatory requirements, typically life time of plant, content changes should be documented and, where applicable, recertified	in accordance with regulatory requirements, typically life time of plant, content changes should be documented and, where applicable, recertified	in accordance with regulatory requirements, typically life time of plant, content changes should be documented and, where applicable, recertified
Qualification	documented evidence of fulfillment of technical requirements according to specifications	in the event of a change of ownership and when there are changes during the time in use of plant	in the event of a change of ownership and when there are changes during the time in use of plant	in the event of a change of ownership and when there are changes during the time in use of plant
Certification; authorization	documented evidence of conformity with standards and regulations for products, systems, solutions and processes; allowance or authorization from a regulatory authority to use a system (e.g. CE, FDA, explosion authorization, railway)	in accordance with regulatory requirements, typically to be maintained throughout the time in use of plant (nuclear power plant: life time), main focuses are failsafe and nuclear power plant applications	in accordance with regulatory requirements, typically to be maintained throughout the time in use of plant, main focus is failsafe	in accordance with regulatory requirements, typically to be maintained throughout the time in use of plant, main focus is failsafe
Service requirements				
Repair	process for returning a defective product to the specified state	time in use of plant (nuclear power plant: life time); when necessary through special service agreements	time in use of plant; when necessary through special service agreements	time in use of plant; when necessary through special service agreements
Spare part delivery	service for delivery of spare parts	time in use of plant (nuclear power plant: life time); original parts or compatible (nuclear power plant: certified) spare parts	time in use of plant; original parts or compatible spare parts	time in use of plant; original parts or compatible spare parts

Requirements	Description	Energy	Chemical	
			Batch process	Continuous process
Fault repair	measures for eliminating nonconformity in the behavior of a product or system with respect to the specified behavior, including fault analyses, fault elimination and additional services	time in use of plant (nuclear power plant: life time); when necessary through special service agreements	time in use of plant; when necessary through special service agreements	time in use of plant; when necessary through special service agreements
Update service	service for implementing an update for an instance following a specified procedure	time in use of plant (nuclear power plant: life time); when necessary through special service agreements; nuclear power plant: update only after qualification and certification where applicable	time in use of plant; when necessary through special service agreements	time in use of plant; when necessary through special service agreements
Upgrade service	service for implementing an upgrade in the instance following a specified procedure	time in use of plant (nuclear power plant: life time); when necessary through special service agreements; nuclear power plant: upgrade only after qualification and certification where applicable	time in use of plant; when necessary through special service agreements	time in use of plant; when necessary through special service agreements

Table B.2 – Overview of industry-specific requirements

Requirements	Rail transport		Automobile manufacturing	Machine tool building
	Rolling stock	**Signaling**		
Time-related requirements				
Time in use of plant	typically 40 years	designed for 30 to 40 years; in reality 60 years	car: 7 to 8 years HGV (Heavy Goods Vehicle): 15 years to 20 years	universal machine: typically 25 years special machine: typically 5 years
Product change	no product change (transportation service)	no product change (transportation service)	car: 2 to 3 years (face-lifting) HGV: 7 to 10 years	universal machine: designed for product changes special machine: limited product changes
Modernization cycle	typically 15 years to 20 years	typically 20 years to 25 years	In line with face-lifting	universal machine: typically 10 years special machine: in exceptional cases
Revision cycle	dependent on mileage, typically < 1 year	typically 20 years to 25 years	typically 6 to 12 months	typically 12 months
Technical requirements				
Compatibility				
Function-related requirements				
Monitoring and operating	typically 15 years to 20 years; presently subject of international standardization	typically 20 years to 25 years	time in use of plant, ≥ 5 years for PC-based systems, possibly upgrade to increase productivity/quality	time in use of machine, ≥ 5 years for PC- based systems
Automation functions	typically 15 years to 20 years	time in use of plant	time in use of plant	time in use of machine
Information management	life time of plant, possible specific regulatory requirements	life time of plant, possible specific regulatory requirements	typically life time of plant, possibly imposed by life time of the produced product or specific regulatory requirements	universal machine: within the typical life time of the produced product special machine: typically life time of machine, possible specific regulatory requirements

Requirements	Rail transport		Automobile manufacturing	Machine tool building
	Rolling stock	**Signaling**		
Interfaces	typically 15 years to 20 years	typically 20 years to 25 years	time in use of plant	universal machine: typically 10 years special machine: in exceptional cases
Data types and formats	time in use of plant, supported by conversion routines	time in use of plant, supported by conversion routines	time in use of plant, supported by conversion routines	time in use of machine, supported by conversion routines
Construction-related requirements				
Construction and connection technique	time in use of plant	time in use of plant	time in use of plant	time in use of machine
Power supply	typically 15 years to 20 years	time in use of plant	time in use of plant	time in use of machine
Location-related requirements				
Setting and environment	time in use of plant	time in use of plant	time in use of plant	time in use of machine
Documentation	life time of plant, content changes should be documented and, where applicable, recertified	life time of plant, content changes should be documented and, where applicable, recertified	life time of plant, content changes should be documented	life time of machine, content changes should be documented
Qualification	authorization documents in accordance with national requirements	authorization documents in accordance with national requirements	in the event of a change of ownership and when there are changes during the time in use of plant	in the event of a change of ownership and when there are changes during the time in use of machine
Certification; authorization	authorization documents in accordance with national requirements	authorization documents in accordance with national requirements	in accordance with regulatory requirements, typically to be maintained throughout the time in use of plant, main focus is failsafe	in accordance with regulatory requirements, typically to be maintained throughout the time in use of machine

Requirements	**Rail transport**		**Automobile manufacturing**	**Machine tool building**
	Rolling stock	**Signaling**		
Service requirements				
Repair	dependent on contract; typically 15 years to 20 years	dependent on contract; typically 20 years to 25 years	time in use of plant; when necessary through special service agreements	time in use of machine; when necessary through special service agreements
Spare part delivery	dependent on contract; typically 15 years to 20 years	dependent on contract; typically 20 years to 25 years	time in use of plant; when necessary through special service agreements	time in use of machine; when necessary through special service agreements
Fault repair	dependent on contract; typically 15 years to 20 years	dependent on contract; typically 20 years to 25 years	time in use of plant; when necessary through special service agreements	time in use of machine; when necessary through special service agreements
Update service	dependent on contract; typically 15 years to 20 years	dependent on contract; typically 20 years to 25 years	time in use of plant; when necessary through special service agreements	time in use of machine; when necessary through special service agreements
Upgrade service	dependent on contract; typically 15 years to 20 years	dependent on contract; typically 20 years to 25 years	time in use of plant; when necessary through special service agreements	time in use of machine; when necessary through special service agreements

B.3 Requirements of the energy industry

B.3.1 General industry characteristics

The energy industry is usually subdivided into the industries of power generation, energy transport and energy distribution. Clause B.3 describes power generation demands which are typical for all sectors in the energy industry.

Power generation utilizes different sources of primary energy such as fossil fuels (coal, gas and oil), nuclear energy, wind, solar energy (e.g. photovoltaic), hydro energy and geothermal energy. Depending on which primary energy source is used and the respective process for energy conversion, the plants differ in terms of electricity output, the utilization focus (for example base or peak load), and the geographic distribution. Today, most of the power production worldwide is generated by centralized, large scale plants using fossil fuels with up to 1 000 MW per power station unit, and nuclear power plants with an output of up to 1 600 MW per unit. Wind energy plants tend to be more modular and decentralized, frequently in the form of wind parks. At the time of publication, the maximum output per wind energy generator is 6 MW.

Power generation plants are characterized by typical shared properties:

– low product diversity:

  as opposed to many other process industries, there are a very limited number of products, i.e. electricity and process heat (steam) and there are no product changes;

– continuous, non-interruptible processes:

  as a matter of principle, the processes are continuous and are operated over a period of many months without being interrupted. Consequently, control system changes should be made while the system is running without any repercussions to the process;

– complex functionality:

  the sub-processes of a power station are physically closely related to each other, which means that an event in one sub-process will quickly affect other functional areas of the plant. This complexity and the demand for high efficiency call for specific instrumentation and control solutions;

– high dynamic demands:

  functional areas of the plant, such as turbine control, make extremely high dynamic demands on instrumentation and control systems;

– high data volumes:

  in comparison with other production processes, power stations are characterized by very high data volumes. The process control system should be able to process this information in real-time and compress, archive and present all the relevant data for the operator in both graphic and tabular form;

– highest demand for availability:

  production downtimes in large power stations result in very high financial losses within a very short period of time. Consequently, the most stringent demands are made on instrumentation and control systems, and many components therefore have a redundant (back-up) design;

– very high safety requirements:

  for protection of people, machinery and the environment, power generation should comply with standards and laws stipulating very high requirements. In plants which use fossil fuels, boiler protection is particularly relevant. In nuclear power plants, specific redundant architectures are employed which use diverse technologies. The approval procedures for instrumentation and control systems require highly intensive effort for both the construction and for changes during the life time of the plant;

– revisions at large time intervals:

  in order to minimize financial losses due to production downtimes, plant revisions are planned and conducted at large time intervals, with the goal of the shortest possible downtime. All of the revision activities which cannot be performed when the system is running are planned to be implemented during plant revisions;

– very long time in use of the plant:

  typically, power plants are in use for several decades, whereby periods of 40 years and more are not uncommon.

B.3.2 Life-cycle related requirements

These industry characteristics result in high demands made on the Life-Cycle-Management of instrumentation and control systems.

– Time-related requirements

  In order to be able to operate a power plant across several decades in a cost-efficient manner, plant users have very high expectations regarding the manufacturer's ability to deliver products and services.

– Technical requirements

  High compatibility requirements should be met when making changes in the instrumentation and control systems, such as in the case of replacing a defective product. These requirements are made up of function-, construction- and location-related properties. Plant users expect producers to be able to provide original products, substitutes or migration solutions during the entire life time of the plant. Due to increasingly shorter innovation cycles for hardware and software components, manufacturers are confronted with rising technical and economic challenges.

– Service requirements

  In order to support power station users during the life time of the plant, producers offer standard services. Depending on the life-cycle phase of the process control system, these offerings consist of a graded portfolio of services. These services range from spare parts stockpiling, to upgrades to newer system versions and all the way through to the migration to a new process control system which partially reuses components and data.

In addition to these high Life-Cycle-Management requirements for instrumentation and control systems in conventional power stations, the utilization of products in nuclear power plants should meet additional conditions:

– Freeze of product versions and revisions

  The approval process for instrumentation and control systems in nuclear power plants is very complex and extensive. The products that are certified for these applications cannot be modified, i.e. it is not permissible to make changes to hardware, firmware and software.

– Approval process and maintaining certifications

  In order to enable the approval of products for application in nuclear power plants, standards and regulations covering the entire development and production process should be adhered to. If product changes (type) are unavoidable during the life-cycle, for example when components are no longer available, complex and extensive approval measures for maintaining the certification to also include the new version or the new revision will be necessary.

B.3.3 Industry-specific economic aspects

The requirements of the energy industry as described above make high Life-Cycle-Management demands – for plant users and producers alike. These demands require substantial cost and effort that should be dedicated to plant-specific strategies and cost efficiency calculations. Of particular importance are:

- very high initial investments in instrumentation and control systems for planning, approvals, procurement, erection, commissioning and acceptance. Consequently, plant users require producers to offer efficient and sustainable long-term strategies and support during the life time of the plant in order to protect their investment;
- due to the long time in use of plants which can span several decades, considerable costs will arise for modifications and optimizations of production processes and therefore also for instrumentation and control systems. Particularly important are expenditures which arise from changes to regulations and statutory requirements (such as environmental-related CO_2 policies, safety standards) as well as the optimization of plant efficiency and availability;
- an additional substantial cost factor for plant operation includes the preventative and corrective maintenance costs for ensuring proper functionality of the system (for example repair costs, spare parts). In view of the long time in use of the plant, significant costs are also incurred for provision and maintenance of the infrastructure, documentation, repair know-how, and the supply and warehousing of compatible, qualified components and spare parts. The negative aspect for the producer is that these costs increase during the product (type) life-cycle while the turnover for selling the product (instance) declines;
- another result of the extensive time in use – but also for fulfilling statutory requirements – is the obligation to provide qualified personnel. Training costs that accumulate over the years, as well as costs for maintaining personnel qualifications, represent a significant factor in the calculation of economic efficiency.

With regard to calculations of economic efficiency, it should be kept in mind that many of the Life-Cycle-Costs show a non-linear increase over the time in use of the plant. This is true for both plant users and producers.

B.3.4 Anticipated industry trends

From roadmaps for the energy industry, the following trends can be derived:

- greater diversification of the primary energy sources utilized;
- increase in the share of regenerative power generation within the energy mix;
- increasing number of smaller power generating plants with decentralized distribution;
- virtual power station configurations which integrate power plants of different types and sizes;
- intelligent networks with new topologies (smart grids) and controllable load;
- more complex energy management systems.

In view of these trends, it can be deduced that new products will emerge and that product diversity will increase. Within the context of decentralization, favorably priced, short lived COTS will find increasing use. As a result, Life-Cycle-Management for automation systems and products will have to adapt to meet these new demands.

B.4 Industry-neutral aspects

B.4.1 Overview

In addition to the industry-specific requirements described above, a number of additional, influencing aspects need to be considered. Technical, economic or legal influences continually emerge and are usually not foreseeable.

B.4.2 Examples of external technical influences

Standard technologies from the consumer and office area have been adopted for use in automation. Examples include Ethernet as a basic system communication, Internet or wireless technologies for data transmission and USB interfaces for exchanging data. In addition, manufacturers of automation products are forced to respond to new programming languages, operating systems or Internet technologies. In some cases, security solutions, such as virus scanners or automatic updates, may even require the upgrading of software components. Examples show that, although the manufacturers use these technologies, they have little influence on their development as their share of the market is comparatively small. As technologies such as new operating systems have not been developed with automation applications in mind, there is almost no opportunity to influence further developments.

B.4.3 Examples of the influence of standardization and legislation

To meet legal requirements and to ensure quality and compatibility, norms and standards are adopted to define product features. In particular, the European guidelines and their national implementation, as well as international and national regulations play an important role. For example, the RoHS guideline called for a ban on products containing lead substances which led to the introduction of lead-free soldering processes and the use of new electronic components. As a result, products had to be partially adapted (re-design) or taken off the market entirely as previously used components, such as integrated circuits and processors, were no longer available.

When norms and standards change as a result of technological developments, producers are forced to adapt their automation products and their components accordingly. It is important to note that a particular automation product is usually not affected by just one standard. In fact, in most cases, country-, industry- and application-specific norms and regulations are applicable when launching a product in different markets. Additional industry- and/or application-specific regulations define special application requirements, for example in the food industry or in areas with explosion risks. All of these norms and regulations may be changed due to new country-specific legislation or new industry-specific requirements and may therefore require product modifications.

De facto standards are industrial standards that apply to products, in addition to the generally valid norms and standards. These standards are defined by companies or organizations. As these de facto standards are widely applied and help to ensure low cost levels, they are accepted worldwide. Examples include standard operating systems, interface definitions and electronic components derived from de facto standards (special processors, controllers, ASICs). Companies that define de facto standards solely by way of their market position may change the de facto standard without coordination with other parties and within a short period of time. In this case, the changes have a direct and strong impact on the Life-Cycle-Management of automation products. For example, new operating systems, changes to processor designs, or a new ASIC may mean that compatibility requirements are no longer fulfilled. Users of the respective systems and plants should monitor these changes and respond to such situations through appropriate Life-Cycle-Management strategies, such as stock-piling spare parts. Such changes can also impact certification or the approval to operate the plant.

B.4.4 Examples of socio-economic influences

In addition to technological and legislative influences, socio-economic aspects are also significant. In connection with current environmental discussions, the demand for energy efficient products and manufacturing processes is growing. This has a direct impact on the use of the technologies deployed, as well as on products and components. Similar effects result from the tightening of emission limits, which directly impacts the materials and substances used, as well as production and disposal processes. These socio-economic influences are not always the results of legislation but are initiated and advanced by public discussion and related trends. In order to maintain their market position, producers are forced to respond and to adapt products and production processes accordingly.

Globalization of competition leads to globalization of manufacturing. The key drivers for this include the demand for increased local content, the flexible response to currency fluctuations, and the reduction of logistics costs (for example transportation and import duties). In addition, the process of economic consolidation and economic crises can lead to far reaching changes in the area of supply. Company mergers, for example, usually result in a revision and reduction of the product portfolio. In many cases, the required components may become unavailable within a very short time.

Globalization is associated with the decentralization of development and the associated processes. This is possible due to the increasing know-how in the emerging markets and is driven by the need to reduce development costs.

These examples demonstrate that the majority of external influences are not usually foreseeable. This results in risks as planning for these influences is problematic.

B.5 Summary

The requirements of the industries analyzed (chemicals, energy, rail transport, automotive and machine tool) together with the industry-neutral aspects illustrate the complexities facing users and producers. An initial impression of the specific characteristics and external influences of the respective industries can be derived from the general examination of each industry based on the general industry characteristics, the derived life-cycle related requirements and the anticipated industry trends. On closer examination, and in the course of discussions with experts, it becomes evident that there are no great differences in the way industries approach this topic – describing the requirements throughout the life-cycle. This is also illustrated in Table B.1 and

Table B.2, in which the Life-Cycle-Management requirements are structured and the specific industry requirements are described. The outcome is a cross-industry presentation of the time-related, technical and service requirements.

Although there are similarities, differences can be seen in the value-range for a specific requirement between industries (for example time in use of a plant can be between 5 years and 50 years). The different industries also use varying terminology (for example batch processes and continuous processes). Finally, the plant users and producers have different expectations regarding the required and described properties of components and systems. With regard to life-cycles, there are significant variances in the requirements which could be partially contradictory.

The time in use of the plant is the most important aspect, and it can be segmented into periods of time from 5 years to 10 years, 10 years to 20 years and 20 years to 50 years. A concrete evaluation of time-related requirements involves the examination of additional criteria, such as planned downtimes, that are derived from the type of manufacturing process (continuous, discontinuous), product changes and revision cycles. This analysis of time-related criteria leads to segmentation of the time in use of the plant. This segmentation influences the application of Life-Cycle-Management strategies during the time in use, such as re-design and migration (Clause 5). This is a key precondition for planning machine or plant (or associated component) changes with minimal impact on availability. The longer the intervals between the planned downtimes, the higher the demands on Life-Cycle-Management, the systems and components deployed. This necessitates changes or updates during run time.

Additional requirements arise due to the need for qualification, certification and approval. The range of these requirements extends from component-related requirements (for example producer's declaration according to CE marking) to requirements affecting the system as a whole (for example nuclear power plant). In the first case, the producer would be able to declare each revision status of its products with relatively little effort and expense. By contrast, in the second case a complex, expensive and time-consuming qualification process for maintaining the certification should be followed. This is relevant not only to the energy industry but also to many systems in the chemicals/pharmaceutical and rail transport industries.

Across all industries, compatibility, as described in detail in 4.4 is of exceptional significance. The need to maintain the availability of machines and plants during their time in use with the least possible effort and expense leads to compatibility requirements. The exchange of a component should not result in the loss of system functions.

In addition to the requirements of individual industries, there are influencing variables that impact the life-cycle such as innovation, which leads to technology change, and wildcards. These are only indirectly represented in Table B.1 and

Table B.2, but they have a major impact on Life-Cycle-Management. Wildcards are unexpected events such as standardization, legislation, leaps in technology or socio-economic influences. By contrast, the continuous innovation of a technology is a process which can largely be planned for. Both aspects may lead to restrictions in the use of components or systems and may call for suitable Life-Cycle-Management strategies (Clause 5).

Figure B.2 describes the range of the requirements and influencing variables for the industries examined. The inside green line and the outside red line reflect the minimum and maximum requirements respectively. The closer the requirements and external influences are to the maximum line, the more difficult they are to manage.

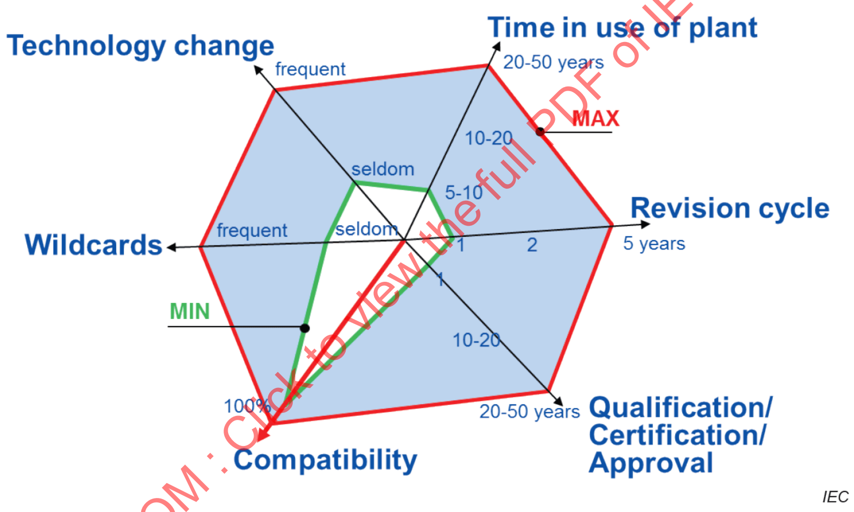

Figure B.2 – Typical ranges of variables which influence the life-cycle

Producers and plant users have different points of view regarding the described requirements and influencing variables. From the viewpoint of the plant user, the relevant requirements and influencing variables are the ones that keep the risks and costs of plants low over the entire time in use. This is necessary for achieving economic goals.

Consequently, the objectives of the plant user are the replacement of components without side-effects, and the efficient expansion and optimization of machinery and plants throughout the entire time in use. Additionally, cost savings are expected through introducing new technology.

Essentially, the task of producers is to meet the requirements of plant users while ensuring that products remain compatible despite their continued development. As can be seen from the industry trends, producers need to continuously innovate their product portfolio in order to meet the future demands of the markets and their customers.

Therefore, from the viewpoint of the producer, the relevant requirements and influencing variables are innovations through new technologies, competitive strength, and economic efficiency.

The relevance of Life-Cycle-Management depends on the producer's business model (product, system or plant supplier), the business area and the portfolio lines. Producers are increasingly required to be globally active. This results in additional complexity for Life-Cycle-Management. Demands for "local content" result in regional sourcing of components and require a consistent strategy for ensuring compatibility throughout the life-cycle.

Investments in automation should always take optimal economic efficiency into account. In the various industries, analyzing the total costs of the plant over time (TCO) is becoming increasingly more common. In addition to considering the initial investment costs, this approach also includes follow-up costs (i.e. future operating, maintenance and dismantling costs) of the investment over a defined period of time. This approach removes the boundaries between the individual phases in favor of a comprehensive, holistic view. As a result, the decision is made to select the alternative which offers the lowest total costs over time, including the planning, construction, set up, operation and dismantling.

The TCO paradigm leads to changes in decision making criteria and the producer-user relationship. The goal of TCO is to give complete cost transparency, since the follow-up costs of various investment alternatives and/or service packages are included. This approach offers the potential for optimizing costs through the cooperation of all participants.

Annex C
(informative)

Life-cycle considerations for selected examples

C.1 Component life-cycles

The range of requirements for Life-Cycle-Management will be explained using several examples.

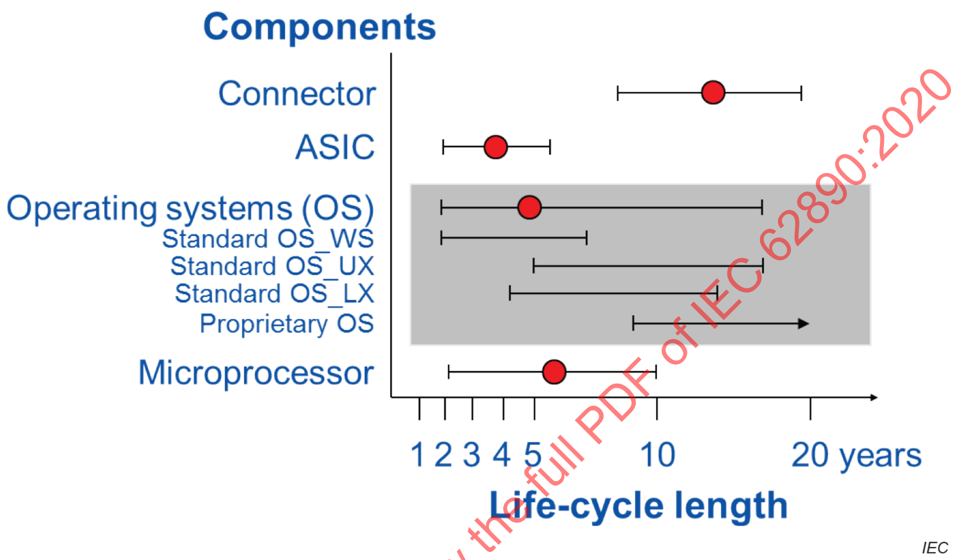

Figure C.1 – Examples of component life-cycles

The lengths of life-cycles for component types differ significantly between components of different classes (for example, connectors versus ASIC) as well as between representatives of a given class (such as operating systems from different vendors). This fact is shown in Figure C.1 by the length of the bar. The weighted center is shown by the red point.

These differing life-cycles should be taken into consideration during the development of a product, seen as a system made up of components. In order to ensure that a product type is deliverable throughout the planned life-cycle, suitable Life-Cycle-Management strategies have to be applied (see Clause 5).

C.2 Microprocessors

An outstanding example of a component with an application focus in the consumer area is the microprocessor. Originally employed in microcomputers, the application of microprocessors spread extremely rapidly due to usage in PCs. The large increase in microprocessor quantities resulted in a downward price spiral. Thanks to the large quantities and the extensive range of applications, the maturation process was and will continue to be considerably accelerated. The favorable price levels, the standardization effect, and the accelerated maturation process led to increased utilization in industry.