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## CHAPTER 1

# Basics of the effective management methodology of web-based information systems

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### Abstract

The object of the study is the processes of functioning and maintenance, which together determine the stage of operation of a web-based information system for managing an enterprise or organization.

During the study, the problem of developing elements of the methodology for lifecycle management of a web-based information system was solved. Modern research in this area is mainly aimed at analyzing and developing individual aspects of managing the operation of complex systems. The main attention is paid to solving individual tasks of managing the operation of systems based on IoT or DevOps. General issues of creating and improving the System Lifecycle Management approach remain little studied.

During the study, the main provisions of the effective management concept of the life cycle of a web-based information system were proposed. This concept is based on a multi-level representation of the information system and the possibility of effective management of the system according to its properties. For further formal description of the proposed concept, the main concepts were defined and the ontology of this concept was developed. Based on this ontology, a generalized model of effective management of the operation of a web-based information system and a set of theoretical and categorical models that detail the description of the elements of this model were developed.

The resulting generalized model was taken as a basis for developing a formal problem statement of effective life cycle management of an operated information system as an IT service system. A formal description of the objective function and constraints of the problem of classical (permanent) life cycle management of an

operated information system was proposed. On its basis, a formal description of the objective function and constraints of the problem of effective life cycle management of an operated web-based information system was proposed. It was determined that the problem of classical (permanent) life cycle management of an operated information system is a special case of the proposed problem of effective management.

The practical application of the obtained research results allows improving systems for life cycle management of an operated information system without global reengineering of existing systems and technologies for data storage and processing.

### **Keywords**

Web-based information system, system property, operation management, ontology of effective management, theoretical-categorical model, attributive model.

## **1.1 Introduction**

The first quarter of the 21<sup>st</sup> century is characterized by the rapid development of web-based information systems (IS) for managing enterprises and organizations. The term "web-based IS" will be used here and further to refer to IS that uses web technologies to provide information and services to users or other information systems/applications [1]. One of the most important consequences of this definition is the perception of web-based IS as systems, which functions can be accessed from anywhere in the world (provided there is a working Internet connection) via a browser.

The modern view of the architecture of web-based IS recognizes the existence of several different approaches to describing this architecture. However, to reflect the above-mentioned perception of web-based IS, it is best to use the description of the architecture of such a system proposed in [2] (**Fig. 1.1**).

In **Fig. 1.1**, the following designations are adopted for the elements of the description of the architecture of web-based IS: DNS – Domaine Name System, a domain name system that ensures the operation of the Internet; CDN – Content Delivery System, a content delivery system that provides acceleration of the delivery of static HTML, CSS, JavaScript files and images (dotted lines separate the elements of the web-based system that are located on the system's web servers and can be located practically anywhere on the globe). Detailed descriptions of these elements are given in [2].

Creation, support and development of web-based IS with the architecture described in **Fig. 1.1** significantly complicates the solution of the problem of managing such IS within their life cycle (LC). Such management is necessary for any IT company that promotes web-based IS of its own production on the market of IT products

intended for the management of enterprises and organizations. The goal of such management in general should be to increase the competitiveness of web-based IS by maintaining the characteristics of efficiency and quality of this system at the level most desirable for all stakeholders.

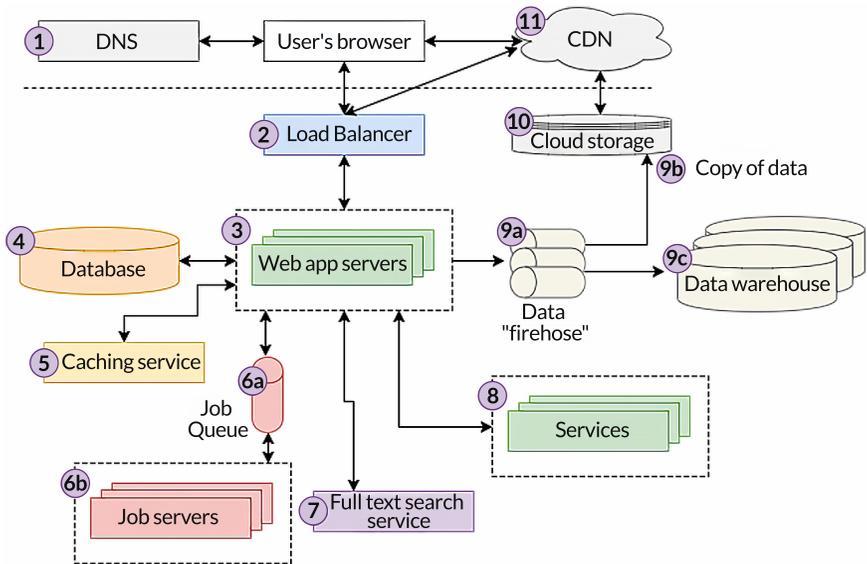


Fig. 1.1 Description of the architecture of a web-based system  
Source: [2]

The modern approach to the creation and functioning of IS management of enterprises and organizations conceptually considers such systems as a type of system for providing IT services to operators and users [3]. Here and further, the term "service" will be understood as the performance of actions, work or duties, which is self-sufficient, consistent, discrete and can be composed of other services [4]. Based on this definition, the term "IT service" was proposed to be used to refer to an independent functional task in IS, the use of which is economically and technically feasible for performing a separate activity of the process of an enterprise or organization or for managing this activity [5].

The results of implementing this approach in the IT industry are [6]:

- the concept of an IT service management system as a system for managing and controlling the activities of managing IT objects of an IT company;

- an approach "Product Lifecycle Management" (PLM);
- an approach "Application Lifecycle Management" (ALM).

The term "PLM" will be understood as an approach to managing processes and methods that are used or created during the LC of products or systems. Its scope mainly covers the hardware parts of the system [7]. The term "ALM" will be understood as an approach focused on the software LC. It is designed to monitor, control and manage artifacts and processes that arise during the program LC. These processes include requirements development, source code management, test management, release management, etc. [8].

To solve the problem of managing services during their LC, a separate type of management system was created – service management systems. According to the modern understanding, such systems should be perceived as systems for managing and controlling the activities of the service provider from the point of view of service management [3]. However, although the PLM and ALM approaches arose on the basis of the same concept of an IT service management system, the ISs created within these approaches developed in different ways. In order to eliminate the difference between these ISs, a new approach was developed, the main difference of which is the integration of PLM and ALM into the interdisciplinary management of the system's LC (SLM) [9]. Unfortunately, the creation and development of the SLM approach occurs mainly at the conceptual level. The reasons for this should be considered different approaches to the structuring of hardware and software, as well as to the integration of elements of this software into systems. In addition, the phases of the software and hardware LCs also differ, even if there are similarities [10]. Therefore, conducting theoretical and theoretical-applied research devoted to the development of methodological foundations of the SLM approach at the conceptual and formal levels is relevant.

## **1.2 Analysis of modern research in the field of effective management of web-based information systems**

Modern information technologies (IT) and IS based on PLM are aimed at managing large amounts of information and artifacts that arise and accumulate during the product LC [7]. Such PLM-IT and PLM-IS are considered as a center that ensures the existence of compatible data flows (for example, data from CAD products, modeling or architecture data, etc.) and solving the problems of managing these data flows. This is due to the fact that PLM grew out of CAD (Computer Aided Design) and PDM (Product Data Management). For this reason, PLM-IT and PLM-IS are only limitedly suitable for displaying and supporting the software LC [9].

The use of PLM-IT and PLM-IS for managing the IS LC in enterprises and organizations is complicated by the need to manage changes that arise during the creation and operation of such IS. Thus, in [11] the reasons for these complications are the lack of compatibility of product change notifications, low data quality, and the lack of direct traceability and tracking of changes to the final product. To eliminate these complications, [11] proposes to integrate PLM-IS and IT asset administration (Asset Administration Shell). Such integration should improve cooperation between PLM-IS and IS of enterprise and organization management, improve data quality, ensure traceability and increase efficiency within engineering processes. However, this approach is not very suitable for LC management, because it focuses mainly on hardware management.

Unlike PLM, ALM was originally considered as an approach that can theoretically be used without the use of appropriate tools. ALM was mainly proposed to be used to integrate all processes, methods and data used and generated within software development [8]. The modern vision distinguishes three main aspects within ALM: governance, development and operations [9]. The governance aspect considers the tasks of conducting software business analysis, project portfolio management and program portfolio management. The development aspect considers the tasks of software generation (from requirements definition through design and source code development to testing and release). The operation aspect considers the tasks of software monitoring and management [12].

Modern research suggests understanding SLM as a technical and organizational basis for LC management of all system artifacts that are created or improved during the existence of this system, and the tools used to work with these artifacts. This basis provides clear tracking of all system elements. Thus, interdisciplinary SLM is considered the basis for complex digital engineering [13]. But IT products that are the results of this complex digital engineering differ significantly from each other. Examples of such IT products include:

- Microsoft products (Microsoft System Center 2016, Microsoft Azure Automation & Control in Microsoft Operations Management Suite);
- specialized products of individual IT companies (Cortex, ActiveBatch Workload Automation, Ignio, VMware Vrealize Orchestrator, etc.);
- products that are descendants of CASE systems and visual modeling environments (CA Process Automation).

As can be seen, the main difference between IT products designed to implement the SLM approach is caused mainly by the features and requirements of specific IT companies, on which orders these products were created. It should be noted that there is no fixed classification of IT products that can be used to implement the SLM approach.

But it should be recognized that these and similar IT products generally meet the requirements for service management systems defined in [3]. In general, the set of functions of such products is aimed at achieving the following goals:

- increasing the efficiency of the functioning of IT processes of the enterprise-consumer of IT services (technical and economic goal);
- reducing the operational risks of the enterprise-consumer of IT services (technical and economic goal);
- reducing the costs of IT processes of the enterprise-consumer of IT services throughout the entire LC (economic goal);
- compensation for the negative consequences of the complexity of managing the IT services system of the consumer enterprise, in particular, eliminating the effect of "IT blindness" (economic goal);
- increasing the level of compliance with standards, including to facilitate further certification (economic and organizational and methodological goal).

Unlike applied developments, most theoretical research in the field of PLM, ALM and SML is aimed at developing individual aspects of IT service management of large industrial systems based on the Internet of Things. For example, in [14] a description of the information layer of the reference architectural model RAMI 4.0 is proposed, which is supported by the Zachman Framework concept. The proposed description, according to the authors, should ensure the practical use of RAMI 4.0, allowing stakeholders to use model-based systems engineering, on the one hand, and include information engineering, on the other. However, the description proposed in [14] can be used to develop only individual aspects of industrial systems and does not cover the task of industrial IS management as a whole. Similar research is being conducted in the IT industry. Thus, in [15] the results of mixed modeling and modeling of continuous service delivery pipeline scenarios as a separate aspect of DevOps are described. But these studies also do not cover the overall task of managing IS and IT, which an IT company uses in its activities.

The formation of integral assessments of the progress and results of the functioning of individual IS services currently does not involve the use of formal models [16]. At the same time, studies have shown that the success of projects aimed at improving individual processes is not a coincidence, but a predictable result with clearly defined and measurable characteristics [17]. To solve various IT service management problems, approaches based on solving multi-criteria optimization problems are proposed in [18]. However, the difficulties of applying such approaches in managing real web-based IS force to look for other options for solving such problems. Thus, in [19] it is proposed to consider an approach to web service management based on knowledge. However, this approach is not yet fully developed and requires additional research.

A significant number of studies consider the problem of managing the IS LC mainly through the prism of tools for its solution. In this case, the multi-criteria decision-making process is usually proposed as the main tool. To implement this process, decision support systems based on multidimensional data warehouses are proposed. An example of such a platform designed to automate the management of the stages of the LC describing the development of modern software is considered in [20]. A significant part of the publications is devoted to describing the results of research into problems that arise when using tools for solving such multi-criteria optimization problems. Algorithms [21] and tools [22] for analyzing and optimizing hyperparameters are considered as similar tools in modern research. Studies devoted to the use of simulation modeling tools for LC management of individual aspects of IS [23] are not left without attention.

The following directions for further research on the development of SLM are indicated in [9]:

- improving the implementation of the knowledge management process in the business (in particular, ensuring the interconnection of business goals and indicators with current processes to identify awareness of complaints and the potential for business improvement [24]);
- developing an integrated or common ALM-PLM data model (in particular, to identify and minimize differences between the descriptions of the hardware and software development processes [25]);
- extending the requirements and use cases of the ALM-PLM system to other stages of the Life Cycle;
- further detailing and refining the SLM, PLM and ALM approaches, developing these approaches through new methods, ideas and processes to support the development of software and hardware;
- defining KPIs for ALM-PLM integration (in particular, to further evaluate and control the use of these approaches to assess their success or potential for improvement [26]).

But the SLM development is impossible without eliminating an important contradiction in the field of IT service management. The essence of this contradiction is as follows. A typical IT service management system, defined in [1], recognizes the goal of management as maintaining user satisfaction with existing IT services at the level desired by the Provider and Consumer of IT services. At the same time, the main quantitative criterion by which it is possible to determine the degree of achievement of this goal is the indicator of the number of incident reports that remain unresolved. But these incident reports arise as a result of the interaction of operators and users with existing IT services and the IT infrastructure that ensures the operation of these

IT services. Thus, the IT service management system defined in [3] and the IT products that are created on the basis of the requirements for this system are aimed at maintaining stable and time-invariant states of the software and hardware of the IT service system. Therefore, compliance with the requirements for a typical service management system defined in [3] does not allow optimizing the set of IT services taking into account the technical and economic features of changing business processes of individual consumers of IT services. Therefore, the study of the general formal formulation of the problem of managing the IS LC is relevant both from a theoretical and practical point of view.

The aim of the study is to develop the foundations of a methodology for effective management of the LC of an operated web-based IS as an IT service system taking into account the technical and economic features of business processes subject to automation. This will allow automating the solution of the tasks of managing the IS LC for enterprises and organizations, taking into account the features of SLM and ALM-PLM integration.

To achieve this aim, it is proposed to solve the following objectives:

- develop a concept for effective operation management of web-based IS;
- develop a set of models for effective operation of web-based IS;
- develop a formal statement of the problem of effective operation management of web-based IS;
- develop a model of the properties of the operated web-based IS.

### 1.3 Research concepts and assumptions

By analogy with the modern vision of ALM, the SLM approach in this study is proposed to be considered as a set of three main aspects: system governance, system development, and system operations. However, unlike the tasks considered in [9] and [12], which comprise the ALM aspects, it is proposed to present each SLM aspect as a set of typical processes of the system's LC, defined in [4]. Such a representation is shown in **Fig. 1.2**. The use of typical processes allowed, instead of defining individual management tasks characteristic of each individual aspect of the approach, to establish a set of works and activities, the implementation of which is most important for a specific aspect.

Based on the proposed aspect-process representation of the SLM approach, a conclusion was made about the significant differences in the methodologies for managing web-based IS under development and web-based IS under operation. Based on this conclusion, a decision was made on the feasibility of conducting research in

the field of developing the main elements of the methodology for managing the operation of web-based IS. This decision was also a consequence of the following reasons:

- the minimum (compared to other aspects) number of typical LC processes of the system, which in this aspect are the most important;
- recognition by modern IT companies of LC processes, which describe the operation of IT products, as critical business processes, the activities of which bring the main percentage of the IT company's profit;
- unlike the aspects of system management and development, the aspect of system operation remains the least studied from a theoretical and applied point of view.

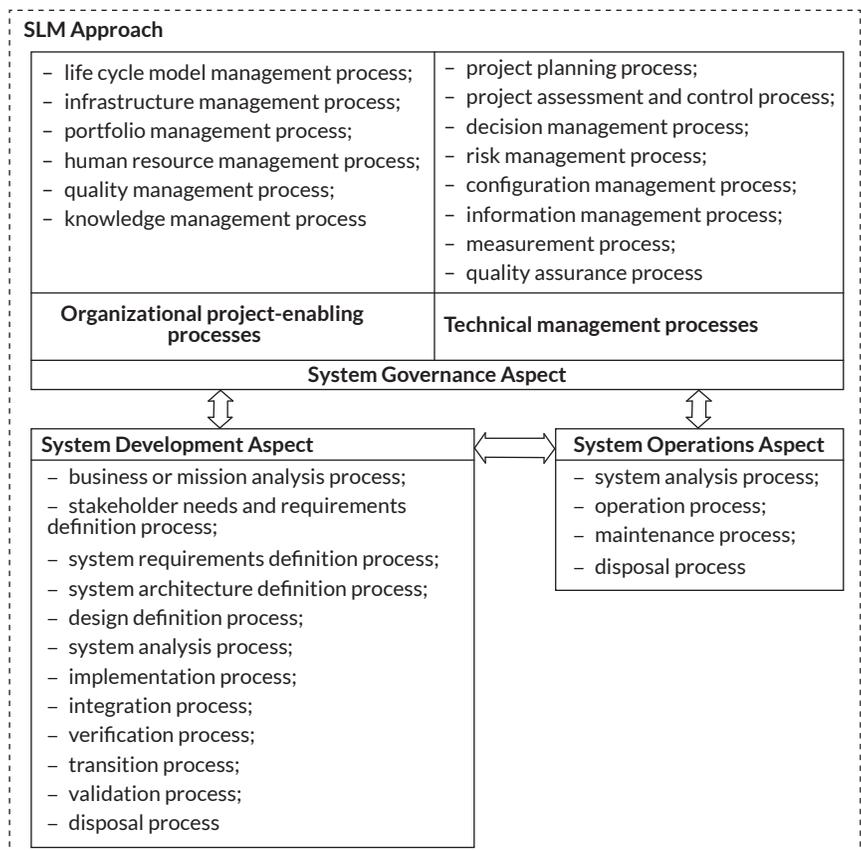


Fig. 1.2 Aspect-process representation of the System Lifecycle Management approach

Therefore, the object of this study was chosen to be the processes of functioning and maintenance of IS, which together determine the stage of operation of the IS LC. The subject of this study is the main methodological elements that allow formalizing the formulation and solution of the problem of managing the operation of web-based IS.

The development of the main elements of the methodology for managing the operation of web-based IS was proposed to be carried out on the basis of the following initial assumptions and recommendations [27]:

- Assumption 1: the operated IS should be considered as a set of interconnected representations at different levels (business level, IT service level, IT service level, IT infrastructure level);

- Assumption 2: the main conditional "unit" of describing data processing actions in managed IS of any level of representation is a transaction;

- Assumption 3: the dimensionality of the problem of managing the functioning of the IS can be reduced provided that individual properties of the IS are identified, which characterize the manifestations of individual qualities of this system;

- Assumption 4: each individual property of the IS is determined by a set of requirements (functional and non-functional) and a set of requests for change (requests for change, RFC) of these requirements and individual elements of the system.

Assumption 1 arose from the need to eliminate one of the main shortcomings of the existing methodology for managing the operation of the system as a set of IT services. This methodology uses one level of representation to describe any IS – as a set of individual IT services and their heterogeneous components [3] without taking into account their belonging to the Supplier or Consumer of IT services. But for the Consumer and the Provider of IT services, the description of any IS implies the simultaneous existence of several levels of representation – as a single product, as a set of functions, and as a set of IT services that implement these functions and are at different stages of their LC. Therefore, to eliminate this contradiction, first of all, it is necessary to coordinate the descriptions of web-based IS at different levels of representation of this system. Similar levels were identified in [5] for the processes of forming and analyzing system requirements. Based on the solution proposed in [5], it is proposed to identify the following levels of representation of the operated IS:

- business level (combining the level of managed objects and/or processes proposed in [5] and the general system level);

- IT accommodation (or functional service) level;

- IT service level;

- IT infrastructure level.

The features of the representations of the concept of "operated IS" at each of the proposed levels are given in **Table 1.1** [27].

**Table 1.1 Definition of the "operated information system" concept at different levels of representation**

Presentation layer	Definition of the concept of "operated information system"
Business layer	IS – IT product, which: – has financial and legal value; – is one of the mechanisms of the managed object and/or process; – is simultaneously a system consisting of personnel and a complex of automation tools; – forms and reflects a single holistic information representation of this object and/or process in accordance with the goals set for this product
IT accommodation (or functional service) level	IS – a system of IT services (functional tasks, functions), which: – is operated on the basis of the Consumer's decisions on the economic or technical feasibility of this action; – is aimed at forming and reflecting a single holistic information representation of the managed object or process in accordance with the goals set for the system
IT service layer	IS – a system of IT services, which: – implements a set of operations for providing or processing data; – is aimed at forming and reflecting a single holistic information representation of the object or process in accordance with the goals set for the system
IT infrastructure layer	IS – a system of interconnected IT infrastructure elements necessary and sufficient for the operation of all IT services of IS, which: – consists of complexes of automation tools; – is aimed at the formation and display of a single holistic information representation of an object or process in accordance with the goals set for the system

Source: [27]

To harmonize the IS descriptions at the levels of representation considered in **Table 1.1**, it is necessary to introduce an additional concept that allows describing the behavior of IS and its elements during operation. For this purpose, Assumption 2 was formulated, according to which it was proposed to use the term "transaction" as such a concept. Each abstract transaction should have the following properties [28]:

- atomicity;
- correctness;
- isolation;
- durability.

These properties allow considering a transaction as the basis for a formal description of any possible action performed by a web-based IS and its individual elements during operation.

To describe the operated web-based IS and its elements at the levels of representation considered in **Table 1.1** levels of representation, it was proposed to distinguish the following types of transactions [27]:

- business transaction - an agreed change in the state of relations between two or more parties, where each party is ready for this change and knows that it will be agreed and approved by all parties [29];
- functional transaction - a logical unit of the scenario for performing an IS function (service), usually including several service transactions;
- service transaction (also transaction) - a logical unit of work, usually including several database operations [28];
- infrastructure transaction - a logical unit of work at the upper (application) levels of the network models used [30], usually including several operations of the lower levels of a specific network model.

Thus, any IS (including web-based IS) can be described at any level of representation using transactions that transfer the IS and its elements from the initial state to the final state. At the same time, to unify the descriptions of heterogeneous IS elements during its operation, it was proposed to use the concept of "configuration item" (CI) introduced in [3] - an element that must be controlled to provide one or more services.

However, such a representation of the operated IS seriously complicates its modeling during operation management. The application of the existing methodology for the operation management of IS leads to the fact that the growth rate of the number of indicators characterizing the IS and its CIs significantly exceeds the growth rate of the number of CIs in the IS. The consequence of this is the impossibility of scaling models and methods for solving management problems during the operation management of small, medium and large IS due to the sharp increase in the dimensionality of such problems. It should be noted that existing methods for solving large-dimensional problems are effective only in some cases and do not solve this problem radically.

To overcome this complication, it was proposed to apply elements of the theory of potential efficiency. This theory allows to assess the efficiency of a complex system by using relatively simple models that describe individual qualities of this system. In this case, the efficiency of the system is represented as the probability of a beneficial exchange between the system and the environment [31]. This definition does not contradict the definition of the concept of efficiency adopted in the existing methodology and allows to present the degree of implementation of planned activities and achievement of planned results in service management as the probability of a profitable exchange of CIs and resources necessary for their creation or modification between the IS, its Supplier and Consumer.

The proposed approach to organizing a formal solution to IS operation management tasks requires the introduction of an additional concept of "system property". At the same time, for solving IS operation management tasks, only those system properties that characterize the manifestations of individual qualities of this system are of interest. IS qualities, in turn, are determined by a set of requirements (functional and non-functional) put forward to the IS before the start of its operation, as well as by a set of RFCs of the IS and its individual CIs that are formed during the operation of the IS. In this case, the effectiveness of the operated IS will be determined as the degree of achievement of planned results for each individual IS property and its CIs [27].

The use of the theory of potential efficiency and Assumptions 3 and 4 formulated on its basis allowed to determine the main approach to the formal description of the operated web-based IS, its CIs, as well as the formulation of the problem of LC management of the operated web-based IS. To detail this approach, it was proposed to use the concept of "Digital Twin". This concept proposes to use their electronic representation – a digital analogue that is actually no different from such an object – to solve the problems of managing complex real-world objects [32]. Although the concept of "Digital Twin" is used mainly for managing material objects (aircraft, cars, power plants, industrial robots, etc.), a number of modern studies recognize the expediency of applying this concept in software engineering [33].

#### **1.4 Results of the development of the elements of the methodology for effective operation management of a web-based information system**

##### **1.4.1 Results of the development of the concept and ontology for effective operation management of a web-based information system**

The solution to the problem of managing the web-based IS operation largely depends on the Consumer and Supplier's point of view on the IS operation processes. Different data of the points of view are determined mainly by the difference in the global goals of the Consumer and Supplier, considered in [5, 34]. Therefore, it is necessary to recognize the simultaneous existence of two such points of view:

- an approach to managing the operation of web-based IS from the Consumer's point of view (an approach to managing operations within the framework of the web-based IS operation process);
- an approach to managing the operation of web-based IS from the Supplier's point of view (an approach to managing operations within the framework of the web-based IS maintenance process).

Recognition of these points of view allowed to formulate the basic concept of effective management of the operation of web-based IS as a set of the following provisions [27]:

- effective management of the operation of IS and its CIs from the consumer's point of view is considered as a set of design and/or operational measures, the result of which is the achievement of global IS efficiency from the point of view of all employees of the Consumer while maintaining the costs of these measures at the level desired by the Consumer;
- effective management of the operation of IS and its CIs from the Supplier's point of view is considered as a set of design and/or operational measures, the result of which is the achievement of global IS efficiency from the point of view of all employees of the Supplier while maintaining the costs of these measures at the level desired by the Supplier;
- effective management of the IS operation as a whole while respecting the interests of the Consumer and the Supplier of this IS is considered as a special case of the multi-criteria optimization problem, the solution of which will be Pareto-optimal IS;
- effective management of the operation of individual CIs of the IS while respecting the interests of the Consumer and the Supplier of this IS is considered as a set of design and/or operational measures to transform a set of current values of the indicators of the properties of the CIs of the IS (operational characteristics of individual CIs of the IS) into a set of planned values of these CIs, at which the IS as a whole will be Pareto-optimal.

In this study, the main attention is paid to the development of elements of the methodology for effective operation management of web-based IS precisely from the point of view of the Supplier. The role of such a Supplier can be any IT company that provides (sells or leases) its own web-based IS for operation by enterprises or organizations acting as Consumers.

Based on the developed concept of operation management of web-based IS, an ontology of the methodology for effective management of IT services of web-based IS was proposed. This ontology was obtained by improving the ontology of the existing service management methodology. The diagram of the relationships between the main concepts of the ontology of effective IT service management is shown in **Fig. 1.3** [27].

To improve perception, **Fig. 1.3** does not show the main slots of frames describing the main concepts. In red in **Fig. 1.3**, concepts that are introduced into the ontology as a result of improving the service management methodology are highlighted. In italics in **Fig. 1.3**, concepts that expand the service management methodology in the course of solving applied service management problems are highlighted.

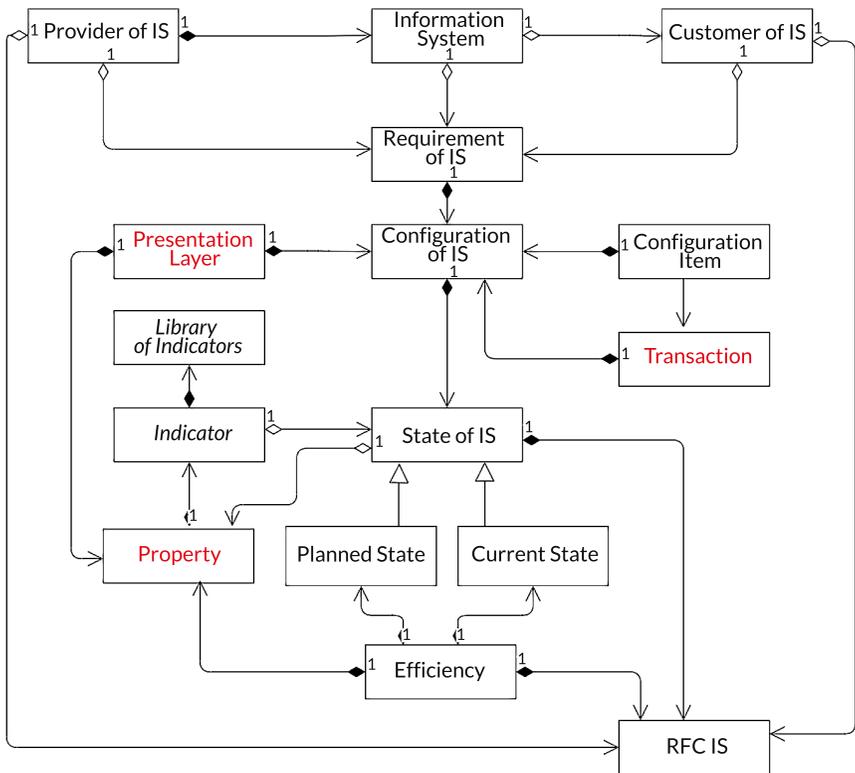


Fig. 1.3 Diagram of the relationships between the main concepts of the ontology of the methodology for managing IT services of web-based IS  
Source: [27]

The scheme shown in Fig. 1.3 allows to distinguish groups of main entities of the subject area, on the basis of which it is possible to form the following descriptions [27]:

- description of the operated IS at different levels of representation;
- description of the states of the operated IS;
- description of indicators that characterize the operated IS and its CIs;
- description of the efficiency of the operation of the IS by its individual properties and in general.

The description of the operated IS at different levels of representation will consist of the following concepts shown in Fig. 1.3 [27]:

- "Information System" concept;

- "Provider of IS" concept;
- "Customer of IS" concept;
- "Requirement of IS" concept;
- "RFC IS" concept;
- "Configuration of IS" concept;
- "Presentation Layer" concept;
- "Configuration Item" concept;
- "Transaction" concept.

These concepts define the main points of view that should be taken into account during a detailed formalized description of the operated IS at different levels of representation as a set of individual CIs and transactions created to meet the requirements of the IS Supplier and Consumer.

The description of the states of the operated IS will consist of the following concepts, shown in **Fig. 1.1** [27]:

- "Configuration of IS" concept;
- "Presentation Layer" concept;
- "Configuration Item" concept;
- "Transaction" concept;
- "State of IS" concept;
- "Planned state" concept;
- "Current state" concept.

These concepts define the main points of view that should be taken into account during a detailed formalized description of the operated IS at different levels of representation of both planned and current states of individual CIs and transactions.

The description of indicators that characterize the operated IS and its CIs will consist of the following concepts, shown in **Fig. 1.3** [27]:

- "State of IS" concept;
- "Indicator" concept;
- "Library of Indicators" concept.

These concepts define the main points of view that should be taken into account during a detailed formalized description of the operated IS by a set of individual indicators based on a specific library of indicators.

The description of the efficiency of the IS operation by its individual properties and as a whole will consist of the following concepts shown in **Fig. 1.3** [27]:

- "State of IS" concept;
- "Planned state" concept;
- "Current state" concept;
- "Indicator" concept;

- "Presentation Layer" concept;
- "Property" concept;
- "Efficiency" concept;
- "RFC IS" concept.

These concepts define the main points of view that should be taken into account during a detailed formalized description of the efficiency of the operated IS at different levels of representation.

Partial duplication of concepts in different descriptions is necessary to ensure the connections of these descriptions with each other.

#### 1.4.2 Results of development of a set of theoretical and categorical models of effective operation of a web-based information system

Based on the groups of concepts of the subject area identified in **Subsection 1.4.1**, it becomes possible to develop generalized mathematical models of effective management of the operation of web-based IS. Since these descriptions are sets of individual concepts defined in a different way, they can be formally represented in the form of the following categories [27]:

- description of the operated IS at different levels of representation will be represented by the  $L_{IS}$  category;
- description of the states of the operated IS will be represented by the  $L_{St}$  category;
- description of indicators characterizing the operated IS and its CIs will be represented by the  $L_{ind}$  category;
- description of the efficiency of the IS operation by its individual properties and in general will be represented by the  $L_{Eff}$  category.

The  $L_I$  category, taking into account the concepts of the ontology of web-based IS service management and the connections between these concepts, has the form

$$L_{IS} = \left[ \begin{array}{l} Ob_{IS}, Ob_{Pr}, Ob_{Cust}, Ob_{rec}, Ob_{RFC}, Ob_{Conf}, Ob_{P\_L}, Ob_{CI}, Ob_{Tr}, H_{Ob_{IS}}^{Ob_{Pr}}, H_{Ob_{Cust}}^{Ob_{IS}}, \\ H_{Ob_{rec}}^{Ob_{IS}}, H_{Ob_{rec}}^{Ob_{Pr}}, H_{Ob_{Cust}}^{Ob_{IS}}, H_{Ob_{rec}}^{Ob_{Conf}}, H_{Ob_{P\_L}}^{Ob_{Conf}}, H_{Ob_{CI}}^{Ob_{Conf}}, H_{Ob_{Tr}}^{Ob_{Conf}}, H_{Ob_{CI}}^{Ob_{Tr}}, H_{Ob_{RFC}}^{Ob_{Pr}}, H_{Ob_{RFC}}^{Ob_{Cust}}, H_{1_{Ob}} \end{array} \right], \quad (1.1)$$

where  $Ob_{IS}$  – a subset of  $L_{IS}$  category objects that describes the "Information System" concept;  $Ob_{Pr}$  – a subset of  $L_{IS}$  category objects that describes the "Provider of IS" concept;  $Ob_{Cust}$  – a subset of  $L_{IS}$  category objects that describes the "Customer of IS" concept;  $Ob_{rec}$  – a subset of  $L_{IS}$  category objects that describes the "Requirement of IS" concept;  $Ob_{RFC}$  – a subset of  $L_{IS}$  category objects that describes the "RFC IS" concept;  $Ob_{Conf}$  – a subset of  $L_{IS}$  category objects that describes the "Configuration of IS"

concept;  $Ob_{p\_L}$  – a subset of  $L_{IS}$  category objects that describes the "Presentation Layer" concept;  $Ob_{Cl}$  – a subset of  $L_{IS}$  category objects that describes the "Configuration Item" concept;  $Ob_{Tr}$  – a subset of  $L_{IS}$  category objects that describes the "Transaction" concept;  $H_{Ob_{IS}}^{Ob_{Pr}}$  – a subset of  $L_{IS}$  category morphisms defined between subsets  $Ob_{Pr}$  and  $Ob_{IS}$ ;  $H_{Ob_{Cust}}^{Ob_{IS}}$  – a subset of  $L_{IS}$  category morphisms defined between subsets  $Ob_{IS}$  and  $Ob_{Cust}$ ;  $H_{Ob_{rec}}^{Ob_{Pr}}$  – a subset of  $L_{IS}$  category morphisms defined between subsets  $Ob_{IS}$  and  $Ob_{rec}$ ;  $H_{Ob_{rec}}^{Ob_{Pr}}$  – a subset of  $L_{IS}$  category morphisms defined between subsets  $Ob_{Pr}$  and  $Ob_{rec}$ ;  $H_{Ob_{IS}}^{Ob_{Cust}}$  – subset of  $L_{IS}$  category morphisms defined between subsets  $Ob_{Cust}$  and  $Ob_{IS}$ ;  $H_{Ob_{Conf}}^{Ob_{rec}}$  – subset of  $L_{IS}$  category morphisms defined between subsets  $Ob_{rec}$  and  $Ob_{Conf}$ ;  $H_{Ob_{Conf}}^{Ob_{p\_L}}$  – subset of  $L_{IS}$  category morphisms defined between subsets  $Ob_{p\_L}$  and  $Ob_{Conf}$ ;  $H_{Ob_{Conf}}^{Ob_{Cl}}$  – subset of  $L_{IS}$  category morphisms defined between subsets  $Ob_{Cl}$  and  $Ob_{Conf}$ ;  $H_{Ob_{Conf}}^{Ob_{Tr}}$  – subset of  $L_{IS}$  category morphisms defined between subsets  $Ob_{Tr}$  and  $Ob_{Conf}$ ;  $H_{Ob_{Tr}}^{Ob_{Cl}}$  – subset  $L_{IS}$  category morphisms defined between subsets  $Ob_{Cl}$  and  $Ob_{Tr}$ ;  $H_{Ob_{RFC}}^{Ob_{Pr}}$  – a subset of morphisms of the  $L_{IS}$  category defined between the subsets  $Ob_{Pr}$  and  $Ob_{RFC}$ ;  $H_{Ob_{RFC}}^{Ob_{Cust}}$  – a subset of morphisms of the  $L_{IS}$  category defined between the subsets  $Ob_{Cust}$  and  $Ob_{RFC}$ ;  $H_{1_{ob}}$  – a subset of single morphisms defined on selected subsets of objects of the  $L_{IS}$  category.

The  $L_{St}$  category, taking into account the concepts of the web-based IS service management ontology identified in [27] and the relationships between these concepts, has the form

$$L_{St} = \left[ \begin{array}{l} Ob_{Conf}, Ob_{p\_L}, Ob_{Cl}, Ob_{Tr}, Ob_{St}, Ob_{pl\_St}, Ob_{c\_St}, H_{Ob_{Conf}}^{Ob_{p\_L}}, H_{Ob_{Conf}}^{Ob_{Cl}} \\ H_{Ob_{Conf}}^{Ob_{Tr}}, H_{Ob_{Conf}}^{Ob_{Cl}}, H_{Ob_{Conf}}^{Ob_{St}}, H_{Ob_{St}}^{Ob_{pl\_St}}, H_{Ob_{c\_St}}^{Ob_{St}}, H_{1_{ob}} \end{array} \right], \quad (1.2)$$

where  $Ob_{St}$  – a subset of objects of the  $L_{St}$  category, which describes the concept of "State of IS" concept;  $Ob_{pl\_St}$  – a subset of objects of the  $L_{St}$  category, which describes the concept of "Planned State" concept;  $Ob_{c\_St}$  – a subset of objects of the  $L_{St}$  category, which describes the concept of "Current State" concept;  $H_{Ob_{Conf}}^{Ob_{p\_L}}$  – a subset of morphisms of the  $L_{St}$  category, defined between subsets  $Ob_{Conf}$  and  $Ob_{St}$ ;  $H_{Ob_{St}}^{Ob_{pl\_St}}$  – a subset of morphisms of the  $L_{St}$  category, defined between subsets  $Ob_{St}$  and  $Ob_{pl\_St}$ ;  $H_{Ob_{c\_St}}^{Ob_{St}}$  – a subset of morphisms of the  $L_{St}$  category, defined between subsets  $Ob_{St}$  and  $Ob_{c\_St}$ ;  $H_{1_{ob}}$  – a subset of single morphisms, defined on selected subsets of objects of the  $L_{St}$  category.

The  $L_{Ind}$  category, taking into account the concepts of the web-based IS service management ontology highlighted in [27] and the connections between these concepts, has the form

$$L_{Ind} = \left[ \begin{array}{l} Ob_{St}, Ob_{Ind}, Ob_{Lib}, H_{Ob_{St}}^{Ob_{Ind}}, H_{Ob_{Lib}}^{Ob_{Ind}}, H_{1_{ob}} \end{array} \right], \quad (1.3)$$

where  $Ob_{Ind}$  – a subset of objects of the  $L_{Ind}$  category, which describes the "Indicator" concept;  $Ob_{Lib}$  – a subset of objects of the  $L_{Ind}$  category, which describes the "Library of Indicators" concept;  $H_{Ob_{St}}^{Ob_{Ind}}$  – a subset of morphisms of the  $L_{Ind}$  category, defined between the  $Ob_{Ind}$  and  $Ob_{St}$  subsets;  $H_{Ob_{Lib}}^{Ob_{Ind}}$  – a subset of morphisms of the  $L_{Ind}$  category, defined between the  $Ob_{Ind}$  and  $Ob_{Lib}$  subsets;  $H_{1_{Ob}}$  – a subset of single morphisms, defined on selected subsets of objects of the  $L_{Ind}$  category.

The  $L_{Eff}$  category, taking into account the concepts of the web-based IS service management ontology highlighted in [27] and the connections between these concepts, has the form

$$L_{Eff} = \left[ \begin{array}{l} Ob_{St}, Ob_{Pl_{St}}, Ob_{C_{St}}, Ob_{Ind}, Ob_{P_{L}}, Ob_{Pr_{op}}, Ob_{Eff}, Ob_{RFC}, H_{Ob_{Pl_{St}}}^{Ob_{St}}, H_{Ob_{C_{St}}}^{Ob_{St}}, \\ H_{Ob_{St}}^{Ob_{Ind}}, H_{Ob_{Pr_{op}}}^{Ob_{St}}, H_{Ob_{Pr_{op}}}^{Ob_{P_{L}}}, H_{Ob_{Pr_{op}}}^{Ob_{Eff}}, H_{Ob_{Pl_{St}}}^{Ob_{Eff}}, H_{Ob_{C_{St}}}^{Ob_{Eff}}, H_{Ob_{RFC}}^{Ob_{St}}, H_{1_{Ob}} \end{array} \right], \quad (1.4)$$

where  $Ob_{Pr_{op}}$  – a subset of objects of the  $L_{Eff}$  category that describes the "Property" concept;  $Ob_{Eff}$  – a subset of objects of the  $L_{Eff}$  category that describes the "Efficiency" concept;  $H_{Ob_{Pr_{op}}}^{Ob_{St}}$  – a subset of morphisms of the  $L_{Eff}$  category defined between the  $Ob_{St}$  and  $Ob_{Pr_{op}}$  subsets;  $H_{Ob_{Pr_{op}}}^{Ob_{P_{L}}}$  – a subset of morphisms of the  $L_{Eff}$  category defined between the  $Ob_{P_{L}}$  and  $Ob_{Pr_{op}}$  subsets;  $H_{Ob_{Pl_{St}}}^{Ob_{Eff}}$  – a subset of morphisms of the  $L_{Eff}$  category defined between the  $Ob_{Eff}$  and  $Ob_{Pl_{St}}$  subsets;  $H_{Ob_{C_{St}}}^{Ob_{Eff}}$  – a subset of morphisms of the  $L_{Eff}$  category defined between the  $Ob_{Eff}$  and  $Ob_{Pl_{St}}$  subsets;  $H_{Ob_{RFC}}^{Ob_{St}}$  – a subset of morphisms of the  $L_{Eff}$  category defined between the  $Ob_{St}$  and  $Ob_{RFC}$  subsets;  $H_{1_{Ob}}$  – a subset of unit morphisms defined on selected subsets of objects of the  $L_{Eff}$  category.

According to the provisions of [3], the management of effective operation of web-based IS is based on the cycle "Plan – Do – Check – Act" (PDCA). In this management cycle:

- at the "Plan" stage, the development of web-based IS operation plans is carried out;
- at the "Do" stage, work is carried out to implement web-based IS operation plans;
- at the "Check" stage, work is carried out to verify the results of the implementation of web-based IS operation plans;
- at the "Act" stage, work is carried out to correct web-based IS operation plans.

Then the generalized model of effective management of web-based IS operation can be represented as a supercategory of the following form [27]

$$M_O = \left[ L_p, L_D, L_{Ch}, L_A, F_{L_D}^{L_p}, F_{L_{Ch}}^{L_D}, F_{L_D}^{L_{Ch}}, F_{L_A}^{L_{Ch}}, F_{L_p}^{L_A} \right], \quad (1.5)$$

where  $L_p$  – a supercategory that formally describes the "Plan" stage;  $L_D$  – a supercategory that formally describes the "Do" stage;  $L_{Ch}$  – a supercategory that formally describes the "Check" stage;  $L_A$  – a supercategory that formally describes the

"Act" stage;  $F_{L_D}^{L_P}$  – a single covariant functor that establishes a connection between the  $L_P$  and  $L_D$  supercategories;  $F_{L_{Ch}}^{L_D}$  – a single covariant functor that establishes a connection between the  $L_D$  and  $L_{Ch}$  supercategories;  $F_{L_D}^{L_{Ch}}$  – a single covariant functor that establishes a connection between the  $L_{Ch}$  and  $L_D$  supercategories;  $F_{L_A}^{L_{Ch}}$  – a single covariant functor that establishes a connection between the  $L_{Ch}$  and  $L_A$  supercategories;  $F_{L_P}^{L_A}$  – a single covariant functor that establishes a connection between the  $L_A$  and  $L_P$  supercategories.

The functors  $F_{L_D}^{L_P}$ ,  $F_{L_{Ch}}^{L_D}$ ,  $F_{L_A}^{L_{Ch}}$  and  $F_{L_P}^{L_A}$  connect the supercategories  $L_P$ ,  $L_D$ ,  $L_{Ch}$  and  $L_A$  according to the control cycle of the operated web-based IS. The functor  $F_{L_D}^{L_{Ch}}$  establishes a connection between the supercategories  $L_{Ch}$  and  $L_D$  to describe situations when the operation of the web-based IS is carried out according to the developed plans and there is no need to adjust these plans.

To detail the formal description of the supercategories  $L_P$ ,  $L_D$ ,  $L_{Ch}$  and  $L_A$ , the category of description of the states of the operated IS  $L_{St}$  (1.2) was divided into two subcategories: the subcategory of description of the planned state of the operated IS  $L_{St}^P$  and the subcategory of description of the current state of the operated IS  $L_{St}^C$ . The  $L_{St}^P$  subcategory has the form [6, 27]

$$L_{St}^P = \left[ \begin{array}{l} Ob_{Conf}, Ob_{P\_L}, Ob_{Cl}, Ob_{Tr}, Ob_{St}, Ob_{Pl\_St}, H_{Ob_{Conf}}^{Ob_{P\_L}}, H_{Ob_{Conf}}^{Ob_{Cl}}, \\ H_{Ob_{Conf}}^{Ob_{Tr}}, H_{Ob_{Conf}}^{Ob_{Cl}}, H_{Ob_{St}}^{Ob_{Conf}}, H_{Ob_{Pl\_St}}^{Ob_{St}}, H_{1_{Ob}} \end{array} \right], \quad (1.6)$$

and the subcategory  $L_{St}^C$  has the form [6, 27]

$$L_{St}^C = \left[ \begin{array}{l} Ob_{Conf}, Ob_{P\_L}, Ob_{Cl}, Ob_{Tr}, Ob_{St}, Ob_{C\_St}, H_{Ob_{Conf}}^{Ob_{P\_L}}, H_{Ob_{Conf}}^{Ob_{Cl}}, \\ H_{Ob_{Conf}}^{Ob_{Tr}}, H_{Ob_{Conf}}^{Ob_{Cl}}, H_{Ob_{St}}^{Ob_{Conf}}, H_{Ob_{C\_St}}^{Ob_{St}}, H_{1_{Ob}} \end{array} \right]. \quad (1.7)$$

Then, taking into account the previously developed categorical descriptions of the exploited ISS, the  $L_P$  supercategory is proposed to be described as follows [6, 27]

$$L_P = \left[ L_{IS}, L_{St}^P, L_{Ind}, F_{L_{St}^P}^{L_{IS}}, F_{L_{Ind}}^{L_{St}^P} \right], \quad (1.8)$$

where  $F_{L_{St}^P}^{L_{IS}}$  – a single covariant functor that establishes a connection between the LIS categories  $L_{IS}$  and  $L_{St}^P$ ;  $F_{L_{Ind}}^{L_{St}^P}$  – a single covariant functor that establishes a connection between the categories  $L_{St}^P$  and  $L_{Ind}$ .

The  $L_D$  supercategory is proposed to be described as follows [6, 27]

$$L_D = \left[ L_{IS}, L_{St}^C, L_{Ind}, F_{L_{St}^C}^{L_{IS}}, F_{L_{Ind}}^{L_{St}^C} \right], \quad (1.9)$$

where  $F_{L_{St}^{L_{IS}}}^{L_{IS}}$  – a single covariant functor that establishes a connection between the LIS categories  $L_{IS}$  and  $L_{St}^P$ ;  $F_{L_{Ind}^{L_{St}}}^{L_{St}^P}$  – a single covariant functor that establishes a connection between the supercategories and  $L_{Ind}$ .

The  $L_{Ch}$  supercategory is proposed to be described as follows [6, 27]

$$L_{Ch} = \left[ L_{IS}, L_{St}^P, L_{St}^C, L_{Ind}, F_{L_{St}^P}^{L_{IS}}, F_{L_{St}^C}^{L_{IS}}, F_{L_{Ind}^{L_{St}}}^{L_{St}^P}, F_{L_{Ind}^{L_{St}}}^{L_{St}^C} \right]. \quad (1.10)$$

The  $L_A$  supercategory is proposed to be described as follows [27]

$$L_A = \left[ L_{IS}, L_{Eff}, F_{L_{Eff}}^{L_{IS}} \right], \quad (1.11)$$

where  $F_{L_{Eff}}^{L_{IS}}$  – a single covariant functor that establishes a connection between the supercategories  $L_{IS}$  and  $L_{Eff}$ .

The diagram of the relationships between the elements of the generalized model of effective management of the operation of web-based IS (1.5) is shown in Fig. 1.4 [6].

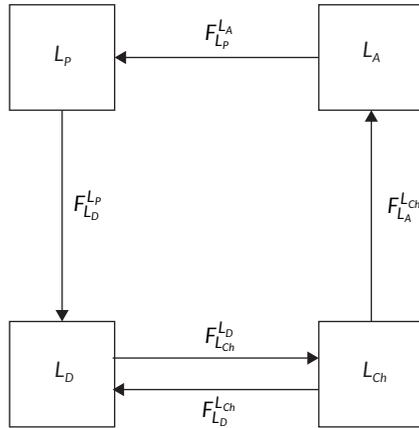


Fig. 1.4 Diagram of relationships between elements of a generalized model of effective management of the operation of a web-based information system

This diagram establishes transitions between the main states of the cycle "Plan – Do – Check – Act" of effective management of the operation of a web-based IS. In this diagram, states are defined as supercategories  $L_p$ ,  $L_D$ ,  $L_{Ch}$  and  $L_A$ , which describe the corresponding stages of the mentioned cycle. Transitions between these

states are shown as functors  $F_{L_D}^{L_p}$ ,  $F_{L_{Ch}}^{L_D}$ ,  $F_{L_D}^{L_{Ch}}$ ,  $F_{L_A}^{L_{Ch}}$  and  $F_{L_p}^{L_A}$ . Thus, model (1.5) can be represented as a finite state machine, transitions between the states of which are associated with changing the alphabets of the description of these states, although they retain their structural features.

### 1.4.3 Results of the development of a formal statement of the problem of effective management of the operation of a web-based information system

The use of the developed set of theoretical and categorical models (1.1)–(1.11) allowed to formally describe the global problem of managing the operation of a web-based IS as an IT service system. In doing so, it is possible to proceed from the following assumption.

Assumption 5: the main approach to managing an IT service system is the "Plan – Do – Check – Act" cycle.

As noted above, classical management of the operation of an IT service system is management aimed at minimizing the number of incident reports that remain unresolved. Therefore, it is proposed to consider the target state of the operated IT service system as a state in which the number of incident reports and RFC of the managed IT service system tends to 0. Let's call such a state of the operated IS as an IT service system stable.

The aspiration of the operated web-based IS to a stable state is proposed to be described by an objective function, which has the form [6]

$$\left| (Tr_i)_{i=1,n} \right| + \left| (RFC_j)_{j=1,m} \right| \rightarrow 0, \quad (1.12)$$

where  $Tr_i$  – the transaction, the execution of which generates the  $i$ -th incident;  $n$  is the number of incidents that occur during the operation of the web-based IS;  $RFC_j$  – the  $j$ -th RFC;  $m$  – the number of RFCs that occur during the operation of the web-based IS.

The objective function (1.12) of the classical (permanent) LC management  $r$  of the operation of a web-based IS is limited by the following conditions [6]:

– for each incident during its elimination, the planned and current states in which the operated IS may be during the control of its operation must be determined

$$\forall Tr_i \in Ob_{Tr} \in L_{IS} \in L_D \exists (L_{St}^P \in L_{Ch}, L_{St}^C \in L_{Ch}); \quad (1.13)$$

– for each RFC during its implementation, the planned and current states in which the operated IS may be during the control of its operation must be determined

$$\forall RFC_i \in Ob_{RFC} \in L_{IS} \in L_D \exists (L_{St}^P \in L_{Ch}, L_{St}^C \in L_{Ch}); \quad (1.14)$$

– the current state of the IS in the process of controlling its operation must fully correspond to its planned state (based on the features of the "Plan - Do - Check - Act" cycle and model (1.5))

$$|(L_{St}^P \in L_{Ch} - L_{St}^C \in L_{Ch}) \cap (L_{St}^C \in L_{Ch} - L_{St}^P \in L_{Ch})| = 0. \quad (1.15)$$

Such a formulation of the task of managing the operation of a web-based IS will allow obtaining an IS that will be best adapted to the requirements of its users. But such adaptability does not guarantee effective operation of the IS, because the set of requirements and RFC itself may not be aimed at achieving effective planned and current states of the operated IS. Therefore, an attempt to achieve goal (1.12) may lead to an increase in RFC. This increase is due to the fact that the number of RFCs that will arise during the operation of the IS can increase only because previous solutions to the management task will not give the desired coincidence of planned and current states. This situation will be especially pronounced in cases where the business processes of the automation object, the IS itself and the IT infrastructure in which the IS is operated are in a state of constant change. Unlike the considered concept of classical (constant) management, the proposed concept of effective management of the operation of web-based IS uses an additional concept of "system property" [31]. At the same time, the interest for the Consumer and the Supplier of IS is only those properties of the system that characterize the manifestations of individual qualities of the web-based IS. The qualities of the web-based IS, in turn, are determined by a set of requirements (functional and non-functional) that are imposed on the IS before the start of its operation, as well as a set of RFCs of the IS and its individual CIs formed during the operation of the IS. In this case, effective management of the operation of the web-based IS will be defined as actions to achieve the planned results for each individual property of the IS and its CIs.

Then the task of achieving the global goal of effective management of the operation of the web-based IS will be considered as the task of achieving optimal characteristics of this IS for each of its specific properties and the minimum probability of the existence of unsolved incidents and RFCs during the operation stage of this IS. The formal description of the objective function of this task will be as follows [6]

$$\begin{cases}
 f_{\text{Eff}}^1(\text{Ob}_{\text{Prop}}^1 \in L_{\text{Eff}}, \text{Ob}_{\text{Eff}} \in L_{\text{Eff}}) \rightarrow \text{opt}^1, \\
 f_{\text{Eff}}^2(\text{Ob}_{\text{Prop}}^2 \in L_{\text{Eff}}, \text{Ob}_{\text{Eff}} \in L_{\text{Eff}}) \rightarrow \text{opt}^2, \\
 \dots\dots\dots \\
 f_{\text{Eff}}^z(\text{Ob}_{\text{Prop}}^z \in L_{\text{Eff}}, \text{Ob}_{\text{Eff}} \in L_{\text{Eff}}) \rightarrow \text{opt}^z, \\
 \sum_{i=1}^n P(\text{Tr}_i) + \sum_{j=1}^m P(\text{RFC}_j) \rightarrow \min,
 \end{cases} \quad (1.16)$$

where 1, 2, ..., z – identifiers of individual properties of the operated IS;  $P(\text{Tr}_i)$  – probability of no beneficial exchange between the operated IS and its environment as a result of transaction  $\text{Tr}_i$ ;  $P(\text{RFC}_j)$  – probability of no beneficial exchange between the operated IS and its environment as a result of RFC  $\text{RFC}_j$  implementation.

The objective function of effective management of web-based IS operation (1.16) is limited by the following conditions [6]:

– for any specified  $k$ -th property of the operated IS, there must be a set of states of this IS, being in which the operated IS will be considered effective for this property

$$\forall \text{Ob}_{\text{Eff}}^k \in \text{Ob}_{\text{Eff}} \in L_{\text{Eff}} \in L_A \rightarrow \text{opt}^k \exists (\text{Ob}_{\text{St}} \in L_{\text{IS}} \in L_D, \text{Ob}_{\text{Ind}} \in L_{\text{IS}} \in L_D), \quad (1.17)$$

where  $\text{Ob}_{\text{Ind}} \in L_{\text{IS}} \in L_D$  – a set of indicators by which the fact of this IS being in an effective state is established during the operation of the web-based IS;

– for each incident during its elimination, planned and current states must be determined, being in which the operated IS can be considered effective

$$\forall \text{Tr}_i \in \text{Ob}_{\text{Tr}} \in L_{\text{IS}} \in L_D \exists (L_{\text{St}}^p \in L_{\text{Ch}}, L_{\text{St}}^c \in L_{\text{Ch}}, L_{\text{Eff}} \in L_A); \quad (1.18)$$

– for each RFC during its implementation, planned and current states must be determined, being in which, the operated web-based IS can be considered effective

$$\forall \text{RFC}_j \in \text{Ob}_{\text{RFC}} \in L_{\text{IS}} \in L_D \exists (L_{\text{St}}^p \in L_{\text{Ch}}, L_{\text{St}}^c \in L_{\text{Ch}}, L_{\text{Eff}} \in L_A); \quad (1.19)$$

– the current state of the web-based IS in the process of controlling its operation must approach its planned state (based on the features of the "Plan – Do – Check – Act" cycle and model (1.5)) with some permissible small deviation

$$|(L_{\text{St}}^p \in L_{\text{Ch}} - L_{\text{St}}^c \in L_{\text{Ch}}) \cap (L_{\text{St}}^c \in L_{\text{Ch}} - L_{\text{St}}^p \in L_{\text{Ch}})| \leq \varepsilon. \quad (1.20)$$

The developed formulation of the problem of effective management of the operation of web-based IS allows to consider the problem of classical (permanent) management of the operation of web-based IS as a separate case of problem (1.16)–(1.20). For this case, the objective function (1.16) will have the form:

$$\left\{ \begin{array}{l} f_{Eff}^1 (Ob_{Prop}^1 \in L_{Eff}, Ob_{Eff} \in L_{Eff}) \rightarrow opt^1, \\ f_{Eff}^2 (Ob_{Prop}^2 \in L_{Eff}, Ob_{Eff} \in L_{Eff}) \rightarrow opt^2, \\ \dots\dots\dots \\ f_{Eff}^z (Ob_{Prop}^z \in L_{Eff}, Ob_{Eff} \in L_{Eff}) \rightarrow opt^z, \\ \sum_{i=1}^n P(Tr_i) + \sum_{j=1}^m P(RFC_j) \rightarrow 0. \end{array} \right. \quad (1.21)$$

The proposed formal description of the task of effective management of the operation of a web-based IS will allow obtaining an IS that will be during its operation:

- best adapted to the requirements of its users and the features of the IT infrastructure and business processes of the automation object existing during operation;
- be in those states that will be recognized as effective by both the Consumer and the Supplier (including, based on their strategies and goals within the IS LC [5]).

### 1.5 Results of the development of a theoretical and categorical model of the property of an information system

The proposed formal statement of the problem of effective management of the operation of web-based IS requires specifying the formal description of the concept "Property" and its possible connections with the "State of IS", "Indicator", "Presentation Layer" and "Efficiency" concepts.

Based on the formal description of the objective function (1.16), effective management of the operation of web-based IS requires the use of sets of parameters (or estimates of their values), which are elements of sets of objects of the categorical models of the concepts "Property" and "Efficiency". Therefore, to specify the formal model of the property of IS, it is proposed to use the following assumption.

Assumption 6: the main principles of effective management at individual stages of web-based IS LC should be identical to each other.

Using this assumption allows to formulate the main principle of effective management of the operation of web-based IS by analogy with the main principle of managing IS requirements described in [5]. This principle consists in the gradual

transformation of the set of initial values of attributes describing the requirement into the set of desired values of the same attributes. The desired value should be understood as the value that the attribute acquires when describing the implemented requirement, which is verified by the appropriate tests [5].

Based on the proposed concept of effective management of the operation of the IS, it was concluded that the main principle of managing the operation of individual CIs of the IS consists in the cyclical gradual transformation of the set of attribute values describing the property of the IS into the set of effective values of the same attributes. The effective value should be understood as the value that the attribute of the IS property acquires when describing the Pareto-optimal (desired) state of the process of the operated IS, provided that this state is agreed upon by the IS stakeholders.

From this principle it follows that to describe different properties of the operated web-based IS, the same set of property attributes should be used, as well as a universal model for evaluating the property of the IS and its processes by these attributes.

It should be noted that in general, the problem of assessing the studied processes is currently solved at the level of ISO 15504 and ISO 330XX standard groups (in particular, ISO 33001-33004, ISO 33021, etc.). However, these standards are focused on assessing the levels of capability of the LC processes of systems and software products. To solve the problem of assessing the processes occurring in the systems and IT products themselves, and the levels of capabilities of these processes in the specified standards, it is recommended to adapt the models proposed in them to the specifics of these processes [35, 36]. Modern IT companies recognized the need for practical application of the provisions of the standard [35] (in connection with the provisions of the ISO 20000 standard) almost immediately after its publication [37]. But modern research is mainly concerned with solving individual problems [38] that arise during the practical application of the provisions of standards [35, 36], or conceptual frameworks for assessing the maturity of individual IS and IT products [39]. Therefore, the problem of adapting the model for assessing process capability levels to the specifics of the task of assessing web-based IS processes by individual properties requires a separate study.

In the general case, the process assessment model should connect the basic model of the studied process and the measurement scheme, which consists of the following components [35]:

- a set of capability levels;
- a set of process attributes;
- a rating scale.

For such a connection, the process assessment model should establish a mapping of the measurement scheme into the process capability scale, which forms the ordinate axis. To form the abscissa axis, the process assessment model should determine the result of mapping the basic process model into a set of process categories. The ordered elements of this set form the abscissa axis. Then the evaluation model should establish the result of determining the correspondence of the studied process category and its specific base model to a specific quantitative value of the capability scale. Based on this value, the evaluation model provides the opportunity to establish quantitative values of process attributes and determine the current level of capabilities of the studied process [36]. In a generalized form, the model of the concept "Property" is proposed to be represented as a category  $L_{Prop} = [Ob_{Prop}; Mor_{Prop}]$ , the set of objects of which has the form

$$Ob_{Prop} = (Ob_{P\_G}, Ob_{PMF}, Ob_{AM}), \quad (1.22)$$

where  $Ob_{P\_G}$  – a subset of objects of the  $L_{Prop}$  category that describe the general characteristics of the IS property;  $Ob_{PMF}$  – a subset of objects of the  $L_{Prop}$  category that describe the process measurement scheme by the IS property;  $Ob_{AM}$  – a subset of objects of the  $L_{Prop}$  category that describe the process measurement model by the IS property.

For the formal description of subsets of objects  $Ob_{P\_G}$ ,  $Ob_{PMF}$  and  $Ob_{AM}$ , it is proposed to use the approach that was already used in [5] for the formal description of IS requirements design patterns. According to this approach, any subset of objects of the  $L_{Prop}$  category can be formally represented as a tuple consisting of such subsets

$$Ob_A = \langle M_A^B, M_A^{Add} \rangle, \quad (1.23)$$

where  $M_A^B$  – the basic attribute model that formally describes the tuple of attributes that characterize the mandatory elements of the  $Ob_A$  subset;  $M_A^{Add}$  – an additional attributive model that formally describes a tuple of attributes characterizing the elements of the subset  $Ob_A$ , the addition of which can improve the technological implementation of the developed methodology for effective management of the operation of web-based IS.

Then the subset of objects  $Ob_{P\_G}$  selected in (1.22) should be formally represented as follows

$$Ob_{P\_G} = \langle M_{P\_G}^B, M_{P\_G}^{Add} \rangle. \quad (1.24)$$

The basic attributive model of the general characteristics of the IS property is proposed to be represented by a tuple, which has the form

$$M_{P_G}^B = \langle P\_Name, P\_Des, P\_Date\_B, P\_Date\_E \rangle, \quad (1.25)$$

where  $P\_Name$  – an attribute that describes the name of the IS property;  $P\_Des$  – an attribute that describes the textual definition of the IS property;  $P\_Date\_B$  – an attribute that describes the start date of the application of this property for effective management of the operation of web-based IS;  $P\_Date\_E$  – an attribute that describes the end date of the application of this property for effective management of the operation of web-based IS.

For a detailed description of the process measurement scheme for the IS property, it is proposed to represent a subset of the  $Ob_{PMF}$  objects of the  $L_{Prop}$  category as a set of the following subsets

$$Ob_{PMF} = (Ob_{AbL}, Ob_{PA}, Ob_{RS}), \quad (1.26)$$

where  $Ob_{AbL}$  – a subset of the  $L_{Prop}$  category objects that describe the levels of possibilities of the IS property;  $Ob_{PA}$  – a subset of the  $L_{Prop}$  category objects that describe the process attributes used to measure the value of the level of possibilities of the IS property;  $Ob_{RS}$  – a subset of objects of the  $L_{Prop}$  category that describe the rating scale used to measure the value of the capability level of the IS property.

Detailed descriptions of these subsets are also determined by the approach formally described in (1.23).

Then, the basic attributive model of capability levels is proposed to be represented by a tuple that has the form

$$M_{AbL}^B = \left\langle \langle L\_Name, L\_M, L\_Des \rangle_i \right\rangle_{i=1, \dots, n}, \quad (1.27)$$

where  $\langle L\_Name, L\_Des \rangle_i$  – a tuple of attributes that describe the  $i$ -th capability level;  $n$  – the number of capability levels determined by the results of choosing a specific maturity model (Capable Maturity Model, SPICE, etc.);  $L\_Name$  – an attribute that describes the name of the capability level;  $L\_M$  – an attribute that describes the name of the maturity model selected as the source of describing the capability levels;  $L\_Des$  – an attribute that describes the textual definition of the capability level.

The basic attributive model of process attributes is proposed to be represented by a tuple that has the form

$$M_{PA}^B = \left\langle \left\langle PA\_Name, PA\_Des, PA\_Date\_B, PA\_Date\_E \right\rangle_j \right\rangle_{j=1, \dots, m}, \quad (1.28)$$

where  $\langle PA\_Name, PA\_Des, PA\_Date\_B, PA\_Date\_E \rangle_j$  – a tuple of attributes that describe the  $j$ -th process attribute;  $m$  – the number of process attributes, which is determined by the results of choosing a specific maturity model (Capable Maturity Model, SPICE, etc.);  $L\_Name$  – an attribute that describes the name of the process attribute;  $L\_Des$  – an attribute that describes the textual definition of the process attribute.

The basic attributive model of the rating scale is proposed to be represented by a tuple that has the form

$$M_{RS}^B = \left\langle \left\langle RS\_Name, RS\_Des, RS\_Date\_B, RS\_Date\_E \right\rangle, \left\langle RS\_DB, RS\_DT, RS\_Ch \right\rangle_k \right\rangle_{k=1, \dots, p}, \quad (1.29)$$

where  $RS\_Name$  – attribute describing the name of the rating scale;  $RS\_Des$  – attribute describing the textual definition of the rating scale;  $RS\_Date\_B$  – attribute describing the date of the start of the rating scale application;  $RS\_Date\_E$  – attribute describing the date of the end of the rating scale application;  $\langle RS\_DB, RS\_DT, RS\_Ch \rangle_k$  – tuple of attributes describing the  $k$ -th range of the rating scale;  $p$  – number of ranges of the rating scale, determined by the results of the selection of a specific maturity model (for example, according to the ISO 15504 standard and the ISO 330XX group of standards  $p = 4$ );  $RS\_DT$  – attribute describing the minimum quantitative limit of the  $k$ -th range of the rating scale;  $RS\_DT$  – attribute describing the maximum quantitative limit of the  $k$ -th range of the rating scale;  $RS\_Ch$  – attribute describing the symbolic definition of the  $k$ -th range of the rating scale.

For a detailed description of the process measurement model by the IS property, it is proposed to represent a subset of  $Ob_{AM}$  objects of the  $L_{Prop}$  category as a set of the following subsets

$$Ob_{AM} = (Ob_{PAM}, Ob_{Tr}^{As}, Ob_{Ind}^{As}), \quad (1.30)$$

where  $Ob_{PAM}$  – a subset of  $L_{Prop}$  category objects that describe the attributes of processes used during measurement;  $Ob_{Tr}^{As}$  – a subset of  $L_{Prop}$  category objects that describe transactions as IS CIs, the state of which is measured;  $Ob_{Ind}^{As}$  – a subset of  $L_{Prop}$  category objects that describe indicators used to measure the state of a transaction as IS CIs.

Detailed descriptions of these subsets are also determined by the approach formally described in (1.23).

Then, it is proposed to represent the basic attributive model of process attributes used during measurement by a tuple that has the form

$$M_{PAM}^B = \left\langle \left\langle PA\_Name, \langle PA\_Val, PA\_DT\_As \rangle_i \right\rangle_j \right\rangle_{j=1, \dots, m; i=1, \dots, s}, \quad (1.31)$$

where  $\langle PA\_Name, \langle PA\_Val, PA\_DT\_As \rangle_i \rangle_j$  – a tuple of attributes that describe the  $j$ -th attribute of the process used in measurement;  $PA\_Name$  – an attribute that describes the name of the process attribute used in the measurement;  $\langle PA\_Val, PA\_DT\_As \rangle_i$  – a tuple of attributes that describe the result of the  $i$ -th measurement of the value of the  $j$ -th process attribute;  $PA\_Val$  – an attribute that describes the value of the  $j$ -th process attribute, which is the result of the  $i$ -th measurement;  $PA\_DT\_As$  – an attribute that describes the date and time of the  $i$ -th measurement of the  $j$ -th process attribute;  $s$  – the number of measurements planned within the implementation of the PDCA cycle iteration.

The basic attributive model of a transaction as a IS CI, the state of which is measured, is proposed to be represented by a tuple that has the form

$$M_{Tr}^{B,As} = \left\langle \left\langle Tr\_Name^{As}, Tr\_DT\_As, \langle CI\_Name^{As} \rangle_c \right\rangle_t \right\rangle_{t=1, \dots, t_{act}; c=1, \dots, c_{act}}, \quad (1.32)$$

where  $\langle Tr\_Name^{As}, Tr\_DT\_As, \langle CI\_Name^{As} \rangle_c \rangle_t$  – a tuple of attributes describing the  $t$ -th transaction as a IS CI participating in the measurement;  $Tr\_Name^{As}$  – an attribute describing the name of the transaction participating in the measurement;  $Tr\_DT\_As$  – an attribute describing the date and time of the transaction's participation in the measurement;  $\langle CI\_Name^{As} \rangle_c$  – a tuple of attributes describing the list of IS CIs as elements of the transaction participating in the measurement;  $CI\_Name^{As}$  – an attribute describing the name of the IS CI as an element of the transaction participating in the measurement;  $c$  – a designation of the IS CI that is an element of the  $t$ -th transaction;  $c_{act}$  – the maximum number of IS CIs that make up the  $t$ -th transaction on the date and time of the measurement;  $t$  – a designation of the transaction as a IS CI participating in the measurement;  $t_{act}$  – the maximum number of transactions as CIs that make up the IS configuration option that is current on the date and time of the measurement.

The basic attribute model of indicators used to measure the status of a transaction as an IS CI is proposed to be represented by a tuple, which has the form

$$M_{Ind}^{B,As} = \left\langle \left\langle CI\_Name^{As}, Ind\_Name^{As}, Ind\_DT\_M, Ind\_Val \right\rangle_q \right\rangle_{q=1, \dots, Ind_{act}}, \quad (1.33)$$

where  $\langle CI\_Name^{As}, Ind\_Name^{As}, Ind\_DT\_M, Ind\_Val \rangle_q$  – a tuple of attributes that describe the  $q$ -th indicator used to measure the status of a transaction as a IS CI;

$CI\_Name^{As}$  – an attribute that describes the name of the IS CI (transaction or its individual element) participating in the measurement;  $Ind\_Name^{As}$  – an attribute that describes the name of the  $q$ -th indicator used to measure the CI status;  $Ind\_DT\_M$  – an attribute that describes the date and time of measurement of the value of the  $q$ -th indicator;  $Ind_{act}$  – an attribute that describes the value of the  $q$ -th indicator as the result of the measurement,  $Ind_{act}$  – the maximum number of indicators used to measure the status of a transaction as a IS CI.

Based on the representations of the set of objects of the  $L_{Prop}$  category (1.22), (1.24), (1.26) and (1.30), it is proposed to represent the set of morphisms of the  $L_{Prop}$  category as a collection of the following subsets

$$Mor_{Prop} = (H_{P\_G}, H_{Abl}, H_{PAM}, H_{AM}^{PMF}), \quad (1.34)$$

where  $H_{P\_G}$  – a subset of morphisms that determine the subordination of descriptions of the process measurement scheme and model by the property of the IS to descriptions of the general characteristics of this property;  $H_{Abl}$  – a subset of morphisms that determine the subordination of descriptions of process attributes and rating scales to descriptions of the levels of capabilities of the IS property;  $H_{PAM}$  – a subset of morphisms that determine the subordination of descriptions of transactions as IS CIs, the state of which is measured, and indicators of these transactions to descriptions of process attributes used during measurement;  $H_{AM}^{PMF}$  – a subset of morphisms that determine the subordination of descriptions of the process measurement model to descriptions of the process measurement scheme.

The  $H_{P\_G}$  subset of morphisms generally consists of the following morphisms

$$H_{general} = (H_{PMF}^{P\_G}, H_{AM}^{P\_G}), \quad (1.35)$$

where  $H_{PMF}^{P\_G}$  – a morphism that determines the hierarchy of subordination of descriptions of the process measurement scheme by the IS property to descriptions of the general characteristics of this property;  $H_{AM}^{P\_G}$  – a morphism that defines the hierarchy of subordination of descriptions of the process measurement model by the IS property to descriptions of the general characteristics of this property.

$H_{Abl}$  morphisms subset in the general case consists of the following morphisms

$$H_{Abl} = (H_{PA}^{Abl}, H_{RS}^{Abl}), \quad (1.36)$$

where  $H_{PA}^{Abl}$  – a morphism that defines the hierarchy of subordination of descriptions of process attributes to descriptions of the corresponding capability level;

$H_{RS}^{ABL}$  – a morphism that defines the hierarchy of subordination of descriptions of the rating scale to descriptions of the corresponding capability level.

$H_{PAM}$  morphisms subset in the general case consists of the following morphisms

$$H_{PAM} = (H_{Tr}^{PAM}, H_{Ind}^{PAM}), \tag{1.37}$$

where  $H_{Tr}^{PAM}$  – a morphism that defines the hierarchy of subordination of descriptions of transactions as IS CIs, the state of which is measured, to descriptions of process attributes used during measurement;  $H_{Ind}^{PAM}$  – a morphism that defines the hierarchy of subordination of descriptions of indicators used to measure the state of a transaction as IS CI descriptions of process attributes used during measurement.

$H_{AM}^{PMF}$  morphisms subset in the general case consists of a  $H_{PAM}^{PA}$  morphism that defines the subordination of descriptions of process attributes used during measurement to descriptions of process attributes of the measurement scheme.

A diagram of the structure of the category-theoretic model  $L_{Prop}$ , which describes the "Property" concept, is shown in Fig. 1.5.

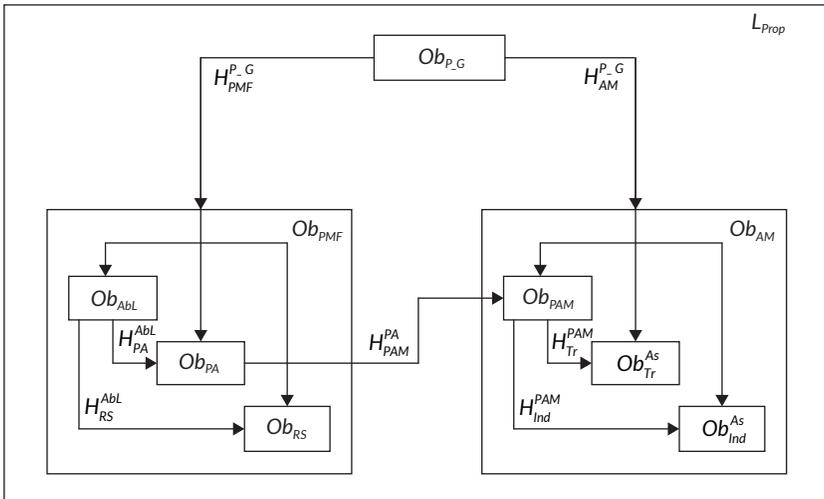


Fig. 1.5 Structure diagram of the theoretical-categorical model  $L_{Prop}$ , which describes the concept of "Property"

Modern standards and IT are focused on solving the problem of classical (permanent) management of IS operations, in which deviations between the planned and

current values of state indicators of individual IS CIs are measured. The application of the  $L_{Prop}$  model in the process of solving the problem of effective management of the operation of web-based IS made it possible to formulate and formally solve the following variants of this problem:

- the problem of minimizing deviations in the values of the levels of capabilities of IS transactions at any of the levels of representation of this IS (the problem of optimizing the levels of maturity of IS and its elements);
- the problem of minimizing deviations in the values of the attributes of IS transaction processes at any of the levels of capabilities and levels of representation of this IS (the problem of optimizing the states of IS and its elements within the selected maturity levels);
- the task of minimizing deviations in the values of IS transaction indicators and their CI within individual process attributes at any of the levels of capabilities and levels of representation of this IS (the task of classical (constant) IS operation management).

## 1.6 Discussion of the research results

In the process of the research, a concept of effective management of the LC of an operated web-based IS was proposed. The proposed concept consists in a multi-level representation of a web-based IS as a product with a set of individual properties. In this case, each property of the IS is considered as a manifestation of the individual qualities of this system. Each quality, in turn, is proposed to be considered as the result of fulfilling a set of requirements and RFCs of the IS and its SI. This concept allows to formally describe the task of effective management of the LC of an operated IS as a task of achieving optimal characteristics of this IS for each of its specific properties and the minimum probability of the existence of unresolved incidents and RFCs during the operation stage of this IS.

For a formal description of the proposed concept, a generalized model of effective management of the operation of web-based IS (1.5)-(1.11) and a complex of theoretical and categorical models (1.1)-(1.4) were developed, which detail the description of the elements of this model. The use of the apparatus of category theory allows to further present the generalized model (1.5)-(1.11) as a finite state machine, the transitions between the states of which are associated with the change of the alphabets of the description of these states, although they retain their structural features. Such a representation allows to consider the developed models (1.1)-(1.11) in further studies as the basis for a formal description of the

automated effective management of the operation of web-based IS based on the "Plan – Do – Check – Act" cycle. This description can exist provided that it is possible to prove the possibility of transforming the corresponding finite state machine into a consistent set of simpler finite state machines that describe IT processing of data structures at each stage of the cycle [6].

Based on the developed generalized model (1.5)–(1.11), a formal description (1.12) of the purpose of classical (permanent) LC management of the operated IS and limitations (1.13)–(1.15) was developed. Taking into account these formal descriptions and the results of the development of the concept of effective LC management of an operated web-based IS, a formal description of the objective function of effective management of the LC of an operated IS (1.16) and systems of constraints (1.17)–(1.20) was developed. The obtained results allow to define the problem of classical (permanent) LC management of an operated IS (1.21) as a special case of the problem of effective management.

To clarify the formal statement of the problem of effective LC management of an operated web-based IS, a theoretical-categorical model of the properties of an operated web-based IS (1.22)–(1.37) was developed. The use of the developed theoretical-categorical model  $L_{Prop}$  allowed to significantly change the features of the statement and solution of the problem of effective management of the operation of a web-based IS. Solving this problem using the developed model (1.22)–(1.37) will allow not only to maintain the operated IS in a stable state, but also to determine the optimal levels of maturity of the IS and its individual transactions from the point of view of the Consumer and the Provider of IT services. This allows stakeholders to plan and manage the recognition of the feasibility and implementation of the following measures during the operation of a web-based IS:

- standardization (typification) of individual IS transactions and IS as a whole at any of the representation levels;
- to ensure the manageability of individual transactions of the IS and the IS as a whole (in real time or time close to real);
- to ensure the optimal operation of individual transactions of the IS and the IS as a whole.

It should be noted that a significant number of modern studies in the field of PLM, ALM and SLM use the mathematical apparatus of graph theory for the formal description of the tasks to be solved. Examples of such studies are [40, 41]. In contrast, in this study, the mathematical apparatus of category theory was used for the formal description of the tasks of LC management of the operated IS. The theoretical and categorical models of the operated IS and the tasks of LC management of this IS used and developed in this study are based on the ontology of web-based

IS services management proposed by one of the authors of the study in [27] and allow to establish:

- the boundaries of domains and data structures used to describe individual concepts of the ontology;
- the rules for transforming domains and data structures when creating connections between different concepts of the ontology.

The applied application of the models developed in this study makes it possible to transition to effective LC management of an operated IS without global reengineering of systems and technologies for data storage and processing. The vast majority of IT products for LC management of an operated IS are highly specialized and relatively new products that occupy a small market segment. Therefore, systems for LC management of an operated IS are most often the result of integrating a large number of such highly specialized products. The proposed theoretical and categorical models allow in such cases [6]:

- to determine domains and data structures for technologies for integrating heterogeneous IT products into a single system;
- to ensure the transition from classical to effective LC management of an IT service system without serious changes in the list of highly specialized products in operation.

Also important from an applied point of view is the proposed presentation of the existing problem of classical (permanent) LC management of an operated IS as a separate case of the problem of effective management. This representation allows to consider the design and implementation of an effective LC management system of operated IS as a gradual evolutionary development of the previously created and already operating system for the classical LC management of IT services.

The main limitation of this study is the need to use complete descriptions of all elements of this IS to solve the problem of effective LC management of an operated IS. This means that during at least one iteration of the "Plan - Do - Check - Act" cycle, IS administrators must interact with a complete digital model of this IS at all levels of representation to solve individual tasks of LC management. The development and maintenance of such a model is a complex and costly task. But this limitation is methodological in nature and is valid for any work in the field of change management of developed or operated IS (which is confirmed, for example, by studies [42, 43]).

Another feature of the obtained results is their orientation on the LC management of the operated IS in conditions of constant changes in business processes, functions and elements of IT infrastructure. This feature is a consequence of the generalization of applied experience in supporting and ensuring the functioning of IS management of enterprises and organizations in conditions of martial law, which is in force in Ukraine [6].

Although the obtained research results are methodological in nature, they should be recognized as important for further theoretical and applied research in the field of creating PLM-, ALM- and SLM-IS and IT. The main further directions of development of this research are [6]:

- determination of the set of properties of the operated IS and efficiency indicators for these properties;
- development of new and improvement of existing models, detailing the formal description of the task of effective management;
- development and implementation of methods and algorithms for solving problems of effective management of various IS and IT options.

## 1.7 Conclusions

The concept of the task of effective LC management of an operated IS as an IT service system is formulated. The formulated concept allows to formally describe the task of effective LC management of an operated IS as the task of achieving optimal characteristics of this IS for each of its specific properties and the minimum probability of the existence of unresolved incidents and RFCs during the operation stage of this IS. The result obtained takes into account the points of view of the Supplier and Consumer of IT services as the main stakeholders of web-based IS. During further research, the main attention was paid to the development of elements of the methodology for effective management of the operation of web-based IS precisely from the point of view of the Supplier as an IT company that provides (sells or leases) its own web-based IS for operation by enterprises or organizations acting as Consumers.

A generalized model of effective management of web-based IS operation (1.5)–(1.11) and a set of theoretical and categorical models (1.1)–(1.4) that detail the description of the elements of this model have been developed. The developed models are a formal basis for creating IS and IT for effective management of web-based IS operation without global reengineering of systems and technologies for data storage and processing. Unlike existing models of a similar purpose, the developed models allow establishing the boundaries of domains and data structures used to describe the elements of the generalized model (1.5)–(1.11), as well as the rules for transforming domains and data structures when creating connections between different elements of this model.

A formal statement of the problem of classical (permanent) LC management of operated IS as an IT service system has been developed. A formal description of

the objective function (1.12) and constraints (1.13)–(1.15) of this problem is proposed using the apparatus of category theory and set theory. The developed formal formulation is based on the existing definition of the goal of such management as maximizing the satisfaction of IS users based on the results of each iteration of the "Plan – Do – Check – Act" cycle of LC management of the operated IS. It is proposed to consider the IS state as a formal sign of such satisfaction as the number of incident reports and RFCs of the operated IS tending to 0. The results obtained allow to formally describe the task of LC management of the operated IS in conditions of stable (unchangeable) business processes and IT infrastructure of enterprises and organizations as objects of automation.

A formal description of the objective function (1.16) and constraints (1.17)–(1.20) of the task of effective LC management of the operated IS is proposed using the apparatus of category theory, set theory and elements of probability theory. It is determined that the task of classical (permanent) LC management of the operated IS is a special case of the proposed task of effective management. Practical application of the proposed formal description of the task of effective LC management of an operated IS allows improving SLM-systems for LC management of an operated IS without global reengineering of existing systems and technologies for data storage and processing.

A theoretical and categorical model of the IS property (1.22)–(1.37) has been developed. This model allows formally describing any IS property taking into account the current requirements set by modern standards for the implementation of the processes of assessing the LC of the system. Using the developed model (1.22)–(1.37) allows solving tasks for automating effective planning and management of the operation of web-based IS.

### **Conflict of interest statement**

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

### **Use of artificial intelligence statement**

The authors declare that they did not use artificial intelligence tools in preparing this manuscript.

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