DOI: 10.2478/ijasitels-2024-0009

Conceptual Modelling of a Laboratory’s Products and Some Assisted Management Applications

Dragoș Iliescu [1,2]

[1]*National University of Science and Technology POLITEHNICA Bucharest, Romania*

[2]*SC Nuclear NDT Research and Services SRL, Bucharest, Romania*

Abstract

The research investigates by conceptual modelling tools the requirements needed for a proper definition of a laboratory's products or services. By using a high degree generalization modelling language, under the research scope we investigate the product/service as a material test and/or calibration for measuring equipment. The research results expressed in modelling language are later implemented in an Assisted Management Application.

Keywords: Conceptual Modelling, Laboratory, ISO 17025, Management Integrated System

1 Introduction

A laboratory of interest for the present paperwork is an organization that performs various tests and/or calibrations and extracts a set of interrelated data [1]. Gathered data later transformed into information, the laboratory issues a report stating the test or calibration results, and a declaration of conformity if such a request exists. The laboratory is expected to guard against data corruption by any means [2]. As a general perspective, a laboratory may act under accreditation as a degree of its testing and/or calibration competency and performance, accreditation being issued by the national accreditation body following the standard General requirements for the competence of testing and calibration laboratories - EN ISO/IEC 17025:2017 [3].

From another perspective, the laboratory, like any other organization, pursues financial health, and across different laboratories, different methods may be applied for the purpose. The fields to improve, according to American Productivity & Quality Centre (APQC), are Process Management, Continuous Improvement, Data and Measurement [4]. One may observe that intended improvements are also stated in the standard EN ISO/IEC 17025:2017 as requirements. It is the goal of this research to introduce a starting point for a management system application by modelling the products/services of a material testing and calibration laboratory.

2 Literature Review

2.1 The term of “eLIMS”

The term of “eLIMS” is broadly used over the Internet. Searching the terms of “eLIMS software” or “eLIMS laboratory” will return several results containing some exemplification, mostly having a commercial or marketing aspect. The term of “eLIMS” stands for “Laboratory Information Management System”, the e-particle indicating an electronic system as opposite to a classical, e.g. paper-based, system [5,6].

The “eLIMS” is approached by the literature as being a backbone of a laboratory [6] such that, from a management perspective, the importance of such a system is significant at least to say. Such a management system is currently described by literature in connection with other different systems, such as: i) Laboratory notebook, ii) Laboratory execution system, iii) Laboratory scientific data management, among other [1,5,6].

Despite its today importance, at the beginning, the interest in such a software system was low, but with the rapid growth of data volume and complexity, the eLIMS had become an important tool into the laboratory management [5]. Changing the perspective, i.e., the field in which the laboratory is acting, one may observe the implementations and solutions for the cases of medical or bio-medical laboratories [18], but for the cases of industrial material testing and calibration laboratories, the spread of eLIMS solutions are relatively low even nowadays.

2.2 Product versus Service

The general meaning of the term product refers to "something which is produced" with the specialization "something resulting from or necessarily following from a set of conditions" [7]. The general perspective over a product represents a physical object that poses a specific set of characteristics such as one may classify the product as "a product, a service, a process, a person, an organization, a system, a resource" [8,9,10,11]. In a special context, the product may be analysed as an abstract or a social object [10]. In the same direction, the term service is explained as of the product equivalence [9]. However, the term service returns more meanings [13,14,15] and compared with a physical object, the evaluation of its quality and/or effectiveness becomes difficult to evaluate as long the service is intangible [14].

For the cases of a management system complying in a unitary manner with a set of standards (known as a management integrated system), the definition of a product or a service can be even more complex [16,17,18,19].

2.3 Product modelling

The general perspective over a product represents a physical object but a larger perspective, including a service, or an abstract or social object, are possible objectives for modelling. The conceptual modelling represents the most general view [20] of a product for which it can be under study.

A conceptual model has two components according to DiSalvo cited by [12,21,22] - the inner and the outer models.

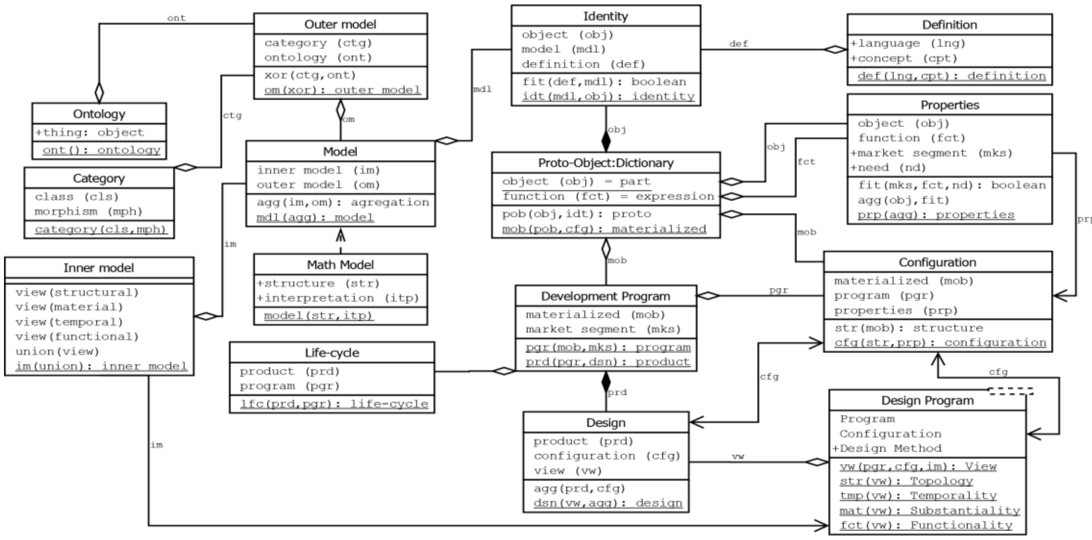


Figure 1. Conceptual model for product [10]

Regarding the outer, one may observe from the literature the category and the ontology theories [12]. For the inner model, there are four views to depict: (i) Topological, (ii) Substantial, (iii) Temporal, and (iv) Functional [12,21,22].
A specific aggregation of the enumerated views will supply in the end an identity to the object of which the model is under consideration [10,20].
A conceptual model can be formulated by a specific language, for exemplification in Fig. 1 the product conceptual model is graphically expressed by the Unified Modelling Language. Also, a formal language represents a possible formulation as in (1) [22].

$$P = \{S(O_k), O_0, \{\delta_k\}\}, \delta_k \in (h_s \circ h_t \circ h_m \circ h_f), 1 \leq k \leq (|c| - 1) \qquad (1)$$

With P as a generic product (1) and Ƥ as a category (P ∈ Ƥ), $S(O_k)$ is the structure of an object $O_k \in P$, O_0 is the root object (in particular, the null product [20]), |c| is the cardinal of P, and h_s, h_t, h_m, h_f are the functions defining the topological, temporal, substantial and functional views of δ_k.
With δ_k as a transitive transformation, then $U_k(P)$ is the orbit starting from P, and $O_k = O_0 + \delta_k$ [20].
The aggregation of the object, model, and definition results in the object's identity, and the proto-object implements it [12,23,24]. The proto-object is essentially a mental object and it can be further deployed by the concepts of potential components and null product [20]. The materialization of a proto-object is known as a prototype.

2.4 Product's orbit

Product modelling includes concepts of transformation, hypostases, and orbit [20]. The product model starts from a root object, named by different authors as "thing", "object", "artefact", "endurant", etc. The root object poses the most general and abstract meaning [10]. The root object lacks the identity, components and qualities, only the function may be, at least partial, known.
In Fig. 1 the root object is illustrated as “part”, defined by a dictionary (i.e., a restricted language).

To the root object, one may associate an identity by considering of a definition and a model combining outer and inner views. The object here is known also as a null product [20] and in association with a given identity the proto-object results (Fig. 1). It is to be noted that identity function may associate a function of fit (Fig. 1) which represents the evaluation of a knowledge space [21].
The proto-object represents the foundation of some other product's model components such as development program, design, and configuration (Fig. 1), each of these having a precise contribution in creating the complete product model.
The proto-object's components evolve by various transformations resulting in various hypostases of the product and later in a product orbit [20]. A product orbit represents a complete view, all perspectives included, of a product [25].

3 Research Objectives and Methods

Under the research scope, we consider the laboratory of interest as an information-based organization. With the assumed laboratory typology, the laboratory's management system becomes the subject for research from the effectiveness perspective.
The research focuses on the laboratories acting on the field of material or product testing by destructive and/or non-destructive methods. A typical example represents a set of tests performed on metallic materials of any kind, e.g. – steels, iron, copper-alloys, aluminium-alloys, etc. The ultrasonic examination of tubes (i.e., tubular products), magnetic particle testing for forged, cast or rolled products, etc. may be considered as a typical example.
The research focuses also on the laboratories acting in the calibration of industrial measuring equipment, e.g. – gages, micrometres, temperature measurement systems, hardness testers, etc.
It is the goal of the present research to propose and to build a computer-based assisted management application with the goal of management system's effectiveness improvement in direct response to the ISO/IEC 17025:2017 requirements.
The research preliminaries count on the elements of conceptual modelling introduced in section 2 and intend as outputs to define the general framework for the laboratory's product definition, such that to model not only the product, but the product's orbit.
The research focuses on product definition and on the method to implement such a product definition into a laboratory's management integrated system. Under the scope of the present study, the term of product modelling refers to all the meanings the term of product poses (§2.3, §2.4).
For a finite set of abstract objects standing as laboratory's products, $P = \{p_i\}$, $i = 0 \dots n$, $n = |P|$, (2)-(4) define the characteristics of reflexivity, anti-symmetry, and transitivity, where · represents a relation of any kind between elements of P.

$$p_m = p_m \quad (2)$$

$$p_m \cdot p_r = p_r \cdot p_m \rightarrow p_m = p_r \quad (3)$$

$$p_m \cdot p_r \wedge p_r \cdot p_s \rightarrow p_m \cdot p_s \quad (4)$$

4 General Frameworks

With p as an abstract object ($p \in P$), considering (1) and the model depicted in Fig. 1 we will define the model of a laboratory's service (s) as in (5).

$$s \in p \qquad (5)$$

We define s as a function of category (C) and the views of topology, temporality, substantiality and functionality, i.e., δ_k as defined in (1). Then, C and δ_k classify s (6).

$$s = C \times \delta_k \qquad (6)$$

Following the model in Fig. 1, Table I (see §4.2) summarizes the parameters of service identity introduced by (6).

4.1 Outer identity implementation

The term of category introduces the theory of classes (objects and morphisms) into the laboratory's service model. A specific classification, i.e., a category-based classification, poses a high degree of generality. The current research focuses on identity morphisms, which by definition, is unique for every given object in the category, i.e., to every class. For exemplification, in Table 1 (see §4.2), one will expect that the designation of "Tensile tests" indicates a unique class of testing. A category has classes as elements (in this case the term of large categories is applied) or sets (small categories).
This specialization introduced a tree-like structure in which the research focuses on verifying the relations in (2) – (4).

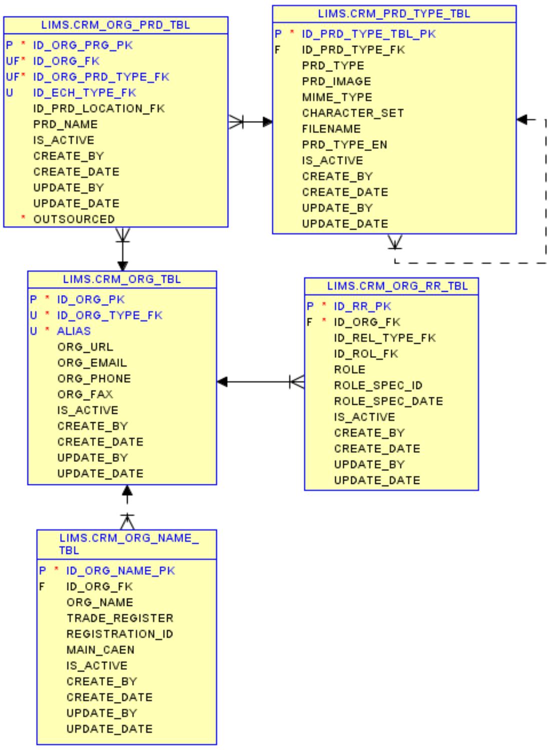


Figure 2. Database implementation of outer model (screen capture Oracle SQL Developer)

Id Org Prg Pk *Primary Key*	Acreditare *Accreditation*	Tip Produs *Product Type*	Referință *Refference*
1189	RENAR LI617/ 29-JAN-2024/ 1A Local Permanent *Permanent Location*	Încercarea la tracțiune la temperatura ambiantă: Îmbinări sudate *Tensile Test at Room Temperature: Welded Joints*	- NNDT-LIM-PL-01, Ed.: II; Rev.: 0; - SR EN ISO 4136, Ed.: 2022; - SR EN ISO 5178, Ed.: 2019; - AWS D1.1/D1.1M, Ed.: 2020; - AWS D1.5/D1.5M, Ed.: 2020; - AWS D1.6/D1.6M, Ed.: 2017; Rev.: AMD 1; - ASME Sect IX (Art. QW-150), Ed.: 2023;
1315	RENAR LI617/ 29-JAN-2024/ 1A Local Permanent *Permanent Location*	Încercarea la tracțiune la temperatura ambiantă: Produse din oțel *Tensile Test at Room Temperature: Steel products*	- NNDT-LIM-PL-01, Ed.: II; Rev.: 0; - ASTM A370, Ed.: 2023; - SR EN ISO 898-1, Ed.: 2013; - SR EN ISO 898-2, Ed.: 2022;
1317	RENAR LI617/ 29-JAN-2024/ 1A Local Permanent *Permanent Location*	Încercarea la tracțiune la temperatura ambiantă: Materiale metalice *Tensile Test at Room Temperature: Metallic Materials*	- NNDT-LIM-PL-01, Ed.: II; Rev.: 0; - SR EN ISO 6892-1 (Metoda B/*Method B*), Ed.: 2020; - ASTM E8/E8M, Ed.: 2022;
1318	RENAR LI617/ 29-JAN-2024/ 1A Local Permanent *Permanent Location*	Încercarea la tracțiune la temperatura ambiantă: Produse din Aliaje de Al și Mg *Tensile Test at Room Temperature:*	- NNDT-LIM-PL-01, Ed.: II; Rev.: 0; - ASTM B557, Ed.: 2015 (2023);

Figure 3. Application eLIMS (screen capture eLIMS application)

Continuing the exemplification, we can define the category of "Tensile tests" as being a small category (made by the sets of tensile tests at room temperature, and the set of tensile tests at elevated temperature), being part of a large category named, e.g., "Mechanical tests" (§4.2, Table 1). With a given large category, there should be a minimum of one large and one small, or at least two small categories. Along with the category, the location and the supplier (Table 1) will implement the outer model of a laboratory's service identity, with a possible implementation as illustrated in Fig. 2 and 3.

4.2 Inner identity implementation

Four views are under consideration (Table 1) for the inner identity. The structural view implements the identification of the test or calibration method, the accuracy and/or uncertainty, and the associated performance indicators.

The method and the work procedure are equipment-dependent. The collection data type means that the structural view may be optimally implemented by a relational database. Here the term of collection poses the characteristics of a configuration, with the specialization of configuration management (ISO 10007:2017 supplies more information on the topic). As a consequence, the laboratory's service structural identity is under construction by a unique collection (configuration) as illustrated in Fig. 4 and 5.

The configuration of a laboratory's service is under control with the help of the table ERP_PL_VER_TBL (Fig. 4 and 6). It controls the exact version of each standard or working procedure declared by the table of ERP_PRG_PL_TBL by edition, revision, and transaction type. Every document declared in association with a given service may have different versions, but only one may be an active document. This constraint is implemented with the help of a trigger attached to the table ERP_PL_VER_TBL.

A declared configuration is then kept under control by the tables CRM_PRD_ACRD_TBL and CRM_PRD_ACRD_POZ_TBL (Fig. 4).

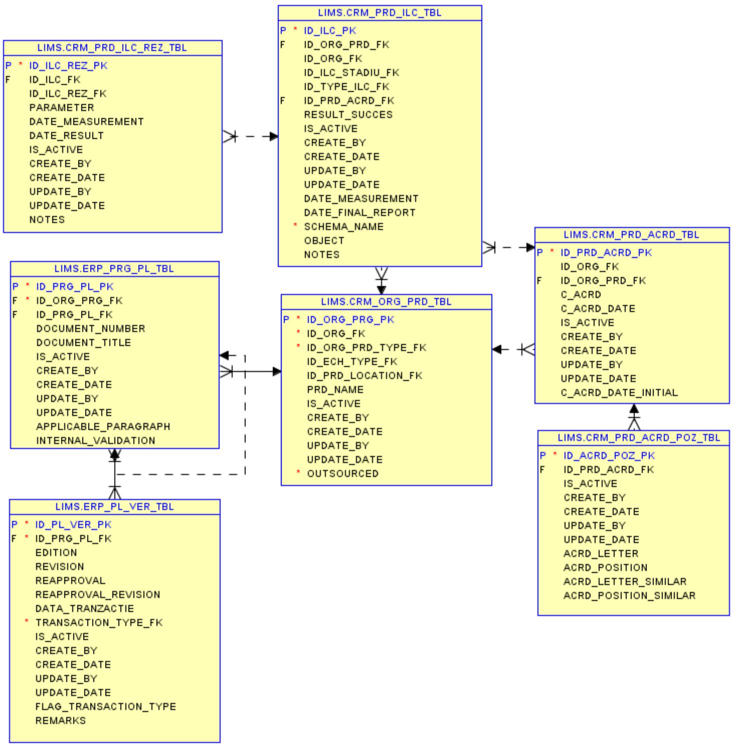


Figure 4. Database implementation of structural view
(screen capture Oracle SQL Developer v. 3.2, simplified view)

The material view classifies the measured values in primary and secondary data depending on whether the gathered data comes direct from the measurement process, or it is the result of a transformation. The material view operates with both primary and secondary data. It implements and controls the "Technical records" as per ISO/IEC 17025:2017. The material view also supplies the control of data transformation to information, i.e. supplying the unit of measure for both standard and reading values.

Id Prg Pl Pk *Primary Key*	Id Org Prg Fk *Forign Key*	Nr. Document *Document Number*	Validare Interna *Internal Validation*	Documente de referință *Refference Documents*	Versiune aplicabilă *Version*	Titlu Document *Document name*	Înregistrare activă *Active Record*
249	1317	NNDT-LIM-PL-01			Ed: II/Rev:0	Încercarea la tracțiune a materialelor metalice la temperatură ambiantă *Tensile testing at room temperature*	Y
250	1317	SR EN ISO 6892-1 (Metoda B/*Method B*)			Ed: 2020	Materiale metalice. Încercarea la tracțiune. Partea 1: Metodă de încercare la temperatura ambiantă *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*	Y
251	1317	ASTM E8/E8M			Ed: 2022	Standard Test Methods for Tension Testing of Metallic Materials	Y

Figure 5. Application NNDT-eLIMS
(screen capture NNDT-eLIMS application – structural view, reference documents)

Table 1. The laboratory's service identity

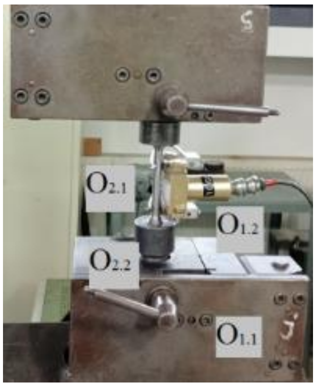
Model	Name	Type	Quale
Outer	Category	Natural/ Restricted language	Test designation (e.g., "Tensile tests")
			Calibration designation (e.g., "Calliper calibration")
	Location	Natural language	Laboratory premises
			Client premises
			Mobile premises
	Supplier	Natural/ Restricted language	Laboratory identification/name/address
Inner	Structure	Collection (Configuration)	Standards for tests or calibration methods (e.g., "ISO 13385-1:2019"
			Work procedures (e.g., "WP-04 Ed. 2019, Rev 4")
			Equipment/Domain/Range/ Accuracy/Uncertainty (e.g., "Calliper/0-300 mm/0.5%")
	Material	Information	primary data (e.g., "standard value"," reading value")
			secondary data (e.g., "transformed standard value"/"reading value")
	Temporal	Graph/ Partition	Version number (e.g. "Ed.2020, Rev. a")
	Function	k-Matrix[c]	$\{\{Ch^{a}_{j} \times r^{b}_{i}\}_{j}\}_{k}$ (e.g., "Testing/Calibration Report")
		Communication	Communication channel (e.g., e-mail, post, etc.)

[a]. Ch_j stands for the j^{th} characteristic (quality)
[b]. r_i stands for the i^{th} result (quale)
[c]. a k-dimension matrix

Id Pl Ver Pk *Primary Key*	Id Prg Pl Fk *Foreign Key*	Editie *Edition*	Revizie *Revision*	Reaprobare *Reapproval*	Revizie Reaprobare *Reapproval Revision*	Tip Tranzactie *Transation Type*	Data Tranzactie *Transation Date*	Obs Doc Retras *Withdran Document Details*	Înregistrare activă *Active Record*
290	251	2021				Document arhivat *Withdrawn Document*	06-NOV-2023		Y
1766	251	2022				Document aplicabil *Applicable Document*	06-NOV-2023		Y
4187	251	2024				Document indisponibil *Unavailable Document*	15-JUL-2024		Y

Figure 6. Application NNDT-eLIMS
(screen capture control of applicable Standard, ASTM E8/E8M)

As already introduced, the referenced method and the corresponding work procedure are equipment-dependent. With the tensile test exemplification, in Fig. 7 and 8 there are a possible implementation of the relation of dependability and Table 2 presents the specificity of this relation.



O_1 – Tensile - Compression testing machine;

$O_{1.1}$ – fixing vice;

$O_{1.2}$ – extensometer;

O_2 – tensile sample assembly;

$O_{2.1}$ – tensile sample;

$O_{2.2}$ – fixing adapter;

Figure 7. Tensile test machine and tensile sample fixing details for tensile test

Among the objects which are part in the process of tensile test at room temperature, a series of specific relations occur (Fig. 8) as detailed in Table 2.

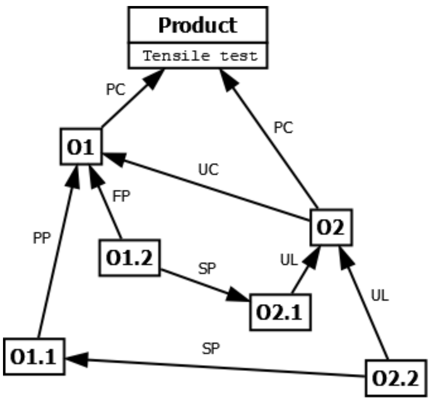


Figure 8. Topology analysis for tensile test at room temperature (simplified)

Table 2. Whole-part relations

Relation	Definition
PC (Participation)	One object participates in a process or in an event
PP (Proper part)	An object is part of a higher degree object as in assembly-subassembly
FP (Functional Part)	One object's function participates to a process/event or can be associated to the function of another object
SP (Spatial Part)	One object is located in another object but is not part nor proper part of it
UL (Underlap)	Two objects are parts, or proper-parts, of another object
UC (Under-cross)	Two UL objects that are not part nor proper-parts one another

5 A case study

The concepts expressed in this paper were tested by the creation of an information application called Nuclear NDT eLIMS and NNDT-eLIMS stands for its alias.
The goal of the NNDT-eLIMS application is to build an electronic computer-based information management system. In the pursuit of the goal, the research uses the following electronic infrastructure:

- Oracle XE database, version 11.2;
- Oracle SQL Developer, version 3.2;
- Oracle APEX, version 20.2;
- Oracle REST Data Services, version 20.4.

5.1 The case study construction

5.1.1 NNDT-eLIMS and management system effectiveness

With $R = \{r_i\}$, i = 1 … n, as the set of ISO/IEC 17025:2017 requirements, and $D = \{d_j\}$, j=1 … m, as the class of documents/records in response to R, the effectiveness of the management system, $E = \{0,1\}$, is defined as in (7):

$$E \leftrightarrow \forall r \in R, \exists \Gamma \rightarrow R \xrightarrow{\Gamma} D \qquad (7)$$

In (7), with Γ, we denote a morphism dependent to the actual management system implementation, i.e., it may vary from one organisation to another, but as Γ is a morphism, the R and D structures are preserved. It is the goal of NNDT-eLIMS application to materialise Γ as for the case of SC Nuclear NDT Research and Services SRL, and to maximise the effectiveness of the management system, i.e., $E = 1$.
For the case study of NNDT-eLIMS, we consider the product accredited by the National Accreditation Body - RENAR named as "Tensile test at room temperature" (original, "Încercarea la tracțiune la temperature ambiantă") as defined by [26], position 1A.

Table 3. Case study product definition

Parameter/definition	Setting for case study
Market	Destructive tests
Market segment	Mechanical tests
Specific need	Measure or determine the Ultimate Tensile Strength, Yield Strength, Reduction of Area, Elongation, and Modulus of elasticity for Metallic materials/ Products made in steel
Product function	Determine the metallic materials' behaviour under applied tensile force and a predetermined temperature
Object	Tensile test standard sample
Concept	ISO 6892-1, ASTM E8 (metallic materials) versus
	ISO 898-1, ISO 898-2, ASTM A370 (products made in steel)
Language	ISO 6892-1, ASTM E8 (metallic materials) versus
	ISO 898-1, ISO 898-2, ASTM A370 (products made in steel)
Topology	Fig. 7 and 8
Temporality	$t_{\mid M(o) \mid}$ = 2024-05
	Test rate → strain rate versus stress rate versus rate of separation
Substantiality	Type and dimensions of product versus type and dimensions of tensile sample
	Type of response → ISO 6892-1 Fig. 2 versus Fig. 3
	R_m, $R_p/R_{eH}/R_{eL}$ → [MPa]
	Elongation, Reduction of Area → [%]
	Modulus of elasticity (Young's) → [GPa]
Functionality	Out of scope

Expanding the definition of the selected product within the case study had resulted in the matrix illustrated in Table 3.
The matrix in Table 3 should be under consideration for every object in the product of interest, e.g., the objects illustrated in Fig. 7.
Finally, with all details settled, the product definition result as in Fig. 3, where the unique identity is represented by the column "ID_ORG_PRG_PK", i.e., the primary key. The primary keys were generated and queried later without errors as an evidence of success in the implementation of the concepts depicted within this research.

6 Conclusion

Within the present paperwork, we study the conceptual modelling technique as applied to the organizations, the scope of the study being with the material testing and calibration laboratory.
We investigate the conceptual modelling application starting with a general product model, with the help of different views introduced by the study – inner and outer views. By using the suggested procedure, we establish an information structure to determine the identity of a given service (tensile test at room temperature was

considered for exemplification) provided by our laboratory of interest. Keeping the traceability of records (the orbit concept) represents an objective of high interest as this is a requirement of the reference standard.
The proposed concepts, as defined in the general framework, and implemented into the NNDT-eLIMS application by the case study, validate the research's goal and results, in term of the management system effectiveness. A mathematical equation expressing the effectiveness of the information management system is proposed for this specific subject. The NNDT-eLIMS application implements and tests the concept of effectiveness expressed by (7).
The effectiveness was controlled by an information structure (the Γ set of relations) which was transformed into a database scheme to test the validity of the introduced concepts. The product identity in this case was substituted by a primary key ID as quale for $D = \{d_j\}$. The unity of $\{d_j\}$, i.e., the definition of a primary key, is the method to get the effectiveness of the management system.
Based on the database schema, an application (NNDT-eLIMS) was built to manage the information within the work scope. The NNDT-eLIMS is currently used within the SC Nuclear NDT Research and Services SRL management system to demonstrate that the necessary conditions for accreditation are preserved. The NNDT-eLIMS application is employed when RENAR evaluate SC Nuclear NDT Research and Services SRL for accreditation under the scope of ISO/IEC 17025:2017 requirements.
The utility of the present research goes in a better understanding of the work specificity of a material test and calibration laboratory as an information-based organization. The utility of the research goes further as the proposed framework can be extended to accommodate an electronic management of the information with specificity for the laboratory of interest, and even further, it permit extension of data and information management with new modules to connect the laboratory with its clients.

Acknowledgment

The present research is currently supported by SC Nuclear NDT Research and Services.

References

[1] Gerlach B., Untucht C., Stefan A.: Electronic Lab Notebooks and Experimental Design Assistants. In Good Research Practice in Non-Clinical Pharmacology and Biomedicine: Bespalov A., Martin C.M., and Steckler T. (eds.): Springer International Publishing, vol. 257, pp. 257-275, 2019.
[2] EN ISO/IEC 17025:2017 General requirements for the competence of testing and calibration laboratories. ISO, Geneve, 2017.
[3] RENAR, https://www.renar.ro/index.php/acreditarea, last accessed 2024/03/20.
[4] APQC: 2024 Process & Performance Management. APQC, Houston, 2024.
[5] Sun D., Wu L., Guomei Fan. Laboratory information management system for biosafety laboratory, Journal of Biosafety and Biosecurity, no. 3, pp. 28 – 34, 2021.
[6] Schmieder F. et al. Universal LIMS based platform for the automated processing of cell-based assays, Current Directions in Biomedical Engineering, no. 5(1), pp. 437 – 440, 2019.
[7] Merriam-Webster Dictionary, https://www.merriam-webster.com/dictionary/product, last accessed 2024/03/20.
[8] Tsimillis K.C.: Eurachem Training Programme - Data and information management, Pancyprian Union of Chemists, Nicosia, 2019.
[9] ISO 9000:2015 Quality management systems -- Fundamentals and vocabulary. ISO, Geneve, 2015.
[10] Borgo S., Vieu L.: From Physical Artefacts to Products. http://www.loa.istc.cnr.it/old/Papers/ProductFomi06-CR.pdf, last accessed 2006/11/15.

[11]Vernadat F.: Enterprise Modelling: Research review and outlook. Computers in Industry, vol. 122, p. 103265, 2020.
[12]Iliescu D.: Some Considerations on Universal Product Model (2) - Toward the Universal Product Model by UML. https:/dx.doi.org/10.13140/RG.2.2.30297.88162, last accessed 2024.02.18.
[13]Merriam-Webster Dictionary, https://www.merriam-webster.com/dictionary/service, last accessed 2023/03/10.
[14]Liu X.X., Chen Z.Y.: Service quality evaluation and service improvement using online reviews: A framework combining deep learning with a hierarchical service quality model. Electronic Commerce Research and Applications, vol. 54, p. 101174, 2022.
[15]Jaekel F.W., Zelm M., Chen D.: Service Modelling Language Applied for Hyper Connected Ecosystem. In Proceedings of the 2nd International Conference on Innovative Intelligent Industrial Production and Logistics 2021, pp. 209-215, 2021.
[16]Barbosa A.S., da Silva L.B., Morioka S. N., da Silva J.M.N, de Souza V.F.: Item response theory-based validation of an integrated management system. Journal of Cleaner Production, vol. 328, 2021.
[17]Biggeri M., Borsacchi L., Braito L., Ferrannini A.: Measuring the compliance of management system in manufacturing SMEs. Journal of Cleaner Production, vol. 382, 2023.
[18]Khalifa A. et al.: A qualitative study of prevalent laboratory information. Genetics in Medicine, vol. 23, pp. 2171-2177, 2021.
[19]Tomlinson E. et. al.: A Model for Design and Implementation of a Laboratory Information-Management System Specific for Molecular Pathology Laboratory Operations. The Journal of Molecular Diagnostics, vol. 24, no. 5, pp. 503-514, 2022.
[20]Gheorghe M. and Iliescu D.: Mathematical Modelling of Product Representations. U.P.B. Sci. Bull., Series A, vol. 81, no. 4, pp. 189-200, 2019.
[21]Iliescu D.: Toward the Universal Product Model by Knowledge Space. http:/dx.doi.org/10.13140/RG.2.2.33101.79840, last accessed 2019/10/10.
[22]Iliescu D.: Some Considerations on Universal Product Model. https://dx.doi.org/10.13140/RG.2.2.10165.22243, last accessed 2019/10/10.
[23]Dirk W., Christof K.: Modelling attention to salient proto-objects. Neural Networks, vol. 19, p. 1395–1407, 2006.
[24]Rensink A. R.: Seeing, sensing, and scrutinizing. Vision Research, vol. 40, p. 1469–1487, 2000.
[25]ISO 19440:2020 Enterprise modelling and architecture — Constructs for enterprise modelling. ISO, Geneve, 2020.
[26]Certificat de Acreditare LI 617/29.01.2024, RENAR, 2024. https://www.renar.ro/index.php/oec/get_oec_details/42927, last accessed 2024/05/10.