

*This paper reports an ontological approach to designing intelligent decision support to control the quality of multi-layered double-glazed windows within the framework of a virtual instrument-building enterprise (VIE) that produces solar energy complexes. It is shown that improving the efficiency in solving the tasks related to managing the quality of VIE products necessitates the application of an ontological engineering toolset to create a unified knowledge space that would cover the manufacturing phase of a product's life cycle. The methodical basis for making an ontological information-analytical system (OIAS) to manage product quality was the tool platform "TODOS" (Ukraine) whose means were used to synthesize a set of ontological models that make up the intelligent core of OIAS. The OIAS knowledge-based inference procedure has been described when making a decision about a deviation in the manufacturing process that led to the emergence of damage. This procedure implies the implementation of direct and reverse inference based on the knowledge in the ontological environment and makes it possible to identify the sources of defects and damage and generate a solution to eliminating these sources. Procedures have been devised to assess the effectiveness of the development and application of OIAS to automate the quality management of multi-layered double-glazed windows. These procedures employ a set of indicators that reflect both the technical and economic components of the quality control process. It has been shown that during 2019 a typical subcontractor enterprise that applied the developed system managed to reduce the number of defective products by about 73 %. Further research areas have been identified, including the development of methodical means and, based on them, the toolsets for the deployment of industrial ontological quality management systems*

**Keywords:** *solar energy complexes, multi-layered double-glazed windows, quality management, ontological approach, efficiency evaluation metrics*

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## 1. Introduction

Currently, in the Central and Southern European countries, in particular, in Ukraine, alternative energy complexes based on solar panels are becoming increasingly common [1]. At the same time, a relevant task is to improve the profitability of such complexes relative not only to conventional energy-generating technologies (nuclear, thermal, hydroelectric power plants) but also to advanced such as wind and tidal.

The task to ensure the operational efficiency of alternative energy systems using solar energy implies the implementation of a series of applied problems among which the cost of production of energy-generating units is important. Each of these units is a solar battery placed in a special airtight container whose outer part is glazed. The efficiency of unit operation depends to a large extent on the condition of the glazed part of the container (no raindrops, snow cover, and ice), as well as mechanical damage to the glass.

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# BUILDING AN ONTOLOGICAL INFORMATION-ANALYTICAL SYSTEM TO MANAGE QUALITY OF DOUBLE-GLAZED WINDOWS IN THE PRODUCTION OF SOLAR PANELS

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Based on the above circumstances, it is critical to ensure the quality of glazing containers for solar panels in an energy complex (EC).

The glazing of a solar cell container is a multi-layered double-glazed glass, made using the Triplex technology, with internal electric heating [2]. The manufacturing technology of such packages consists of many responsible stages, on each of which there may be defects and even damage to products. Analysis and timely identification of the causes of such deviations is a non-trivial task characterized by a high level of uncertainty and the need to process large amounts of information in real time. This explains the need to develop special computer tools to support decision-making to identify and address the causes of deviations in the manufacturing processes of multi-layered double-glazed windows.

The way production is organized significantly affects the cost of production of power generation units and solar energy complexes. The most advanced form of production organization today is a virtual instrument-building enterprise (VIE) [3]. The main feature of a VIE, distinguishing it from conventional enterprises, is the almost complete absence of fixed assets. The specificity of business processes at a VIE implies the assembly of goods in rented areas. Given this, the timing of manufacture and supply for the assembly of components at subcontractors is crucial for the successful operation of this type of enterprise. However, the concept of VIE organization outlined in work [3] does not reflect the key factor in determining the efficiency of such an enterprise, namely the level of quality of materials and components that are delivered to the assembly. The presence of defects and damage of assembly components inevitably leads to disrupting the “just-in-time” regime as the main principle of ensuring the VIE stable operation.

Based on the above, in order to improve the efficiency of VIE operation in producing solar energy complexes, it is advisable to create and deploy special computer systems for managing the quality of products, in particular, multi-layered double-glazed windows, at enterprises-subcontractors.

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## 2. Literature review and problem statement

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The ISO 9001:2015 certificate of quality is a testament to the existence of an effective quality management system at an enterprise-subcontractor producing multi-layered double-glazed windows. Such a system should include a series of organizational, technical, software, and other measures to ensure product quality. Paper [2] shows that most subcontractors experience a series of problems preventing product certification in accordance with ISO 9001:2015. These problems are due to the insufficient level of mechanization and automation of operations to produce multi-layered double-glazed windows; low manufacturability and small seriality of manufactured products; instability of the quality of parts and components.

The way to overcome these issues is discussed in works [2, 3]. In particular, it is shown that in order to organize the automated assembly of double-glazed windows, it is necessary to ensure the accuracy of the product’s matching parts, to ensure the required reliability and performance of the devices for automatic assembly, to choose the types of assembly design, etc. The authors of study [3] point out that the highest level of mechanization and automation of assembly processes is the comprehensive mechanization and

automation of all types of operations – preparatory, basic, auxiliary, and post-assembly. However, works [2, 3] do not offer a constructive approach to informationally maintain the quality management processes of assembly components during VIE, in particular, the authors do not address the problem of quality control of components at related enterprises-subcontractors.

The integrated mechanization and automation of the assembly process of multi-layered double-glazed windows at many enterprises that can act as VIE subcontractors currently employ assembly machines and automatic lines at which all types of assembly operations are carried out without the direct participation of workers in the assembly process. The functions of workers-fitters imply control over the proper operation of automatic assembly units, adjusting them when switching to the assembly of another type of product, etc. Since a multilayer glass unit is assembled manually, it should be taken into account that its design may not be suitable for transferring it to a complex mechanized or automated assembly. This should be taken into consideration when automating the task to manage the quality of such a product.

The directive process of multi-layered double-glazed windows and their structure is the basis for the analysis of the flow of product quality data, the basis for assessing the current state of assembly machines and lines, including control and control systems [5]. The specificity of VIE operation as a new form of industrial organization implies a revision of the concept of the directive manufacturing process, in particular in terms of decentralization of the quality management system of assembly units.

Modern practice shows that the most effective means of organizing automated quality control of manufactured products are the information-analytical systems with an ontological component [6, 7]. The ontological approach provides an adequate representation of the certification process using computer tools [8]. At the same time, the existing tools for the development of such systems are focused on solving a rather narrow class of tasks [9] whose extension requires significant refinement of the software and, in some cases, the hardware platform. A common drawback of works [6–9] is the lack of theoretical justification and practical recommendations for applying an ontological approach to the design of industrial information-analytical systems.

The authors of [10, 11] examine in detail the issues of organizing virtual enterprises using an ontological approach; work [12] discusses the role of ontological engineering in the implementation of the Industry 4.0 concept in general, and, in particular, in the organization of manufacturing in the post-industrial period. The scientific results reported in the cited publications allow the authors to argue that under the current conditions the only way to improve the efficiency of industrial business processes is to move from data-oriented technologies to knowledge-oriented technologies, among which the most advanced one is the ontological approach. Study [13] describes the technology for the construction, deployment, and operational maintenance, within a VIE framework, of the ontological system of the ERP class, using intelligent agents. This approach seems redundant as ontological structures, by their very nature, make it possible for the implementation of the knowledge-based inference (KBI) procedure directly in the environment of ontologies themselves. For the organization of KBI directly in the ontologies themselves, the results describing such procedures have not

yet been published. Work [14] addresses the application of an ontological approach to modeling a VIE business structure but it does not tackle the quality management of assembly components manufactured by subcontractors.

Our analysis of the scientific literature has revealed that up to now there have not been any constructive approaches to the informational maintenance of quality management processes within the VIE concept.

Thus, in order to improve the efficiency when solving the tasks related to managing the quality of the production of multi-layered glass windows for the containers of solar panels in EC, produced at VIE, it is necessary to create, by the means of ontological engineering, a single, homogeneous knowledge space, enabling KBI, which would cover all the aspects and stages of a product’s life cycle.

Resolving this task could make it possible to fill the existing gap in research aimed at the informational maintenance of industrial processes, in terms of quality management, based on an ontological approach to the acquisition, representation, and manipulation of knowledge.

### 3. The aim and objectives of the study

The aim of this study is to develop, by the means of ontological engineering, a specialized information-analytical system to manage the quality of multi-layered double-glazed windows produced at an enterprise-subcontractor, in order to improve the efficiency of VIE operation when making solar energy complexes.

To achieve the set aim, the following tasks have been formulated and solved:

- to build a set of ontological models of knowledge about the implementation of an industrial phase in the life cycle of multi-layered double-glazed windows, as well as the regulatory framework and possible deviations from it during production;
- to devise a knowledge-based inference process in the environment of an ontological system as a mechanism of decision-making in managing the quality of multi-layered double-glazed windows;
- to justify an approach to assessing the effectiveness of ontological engineering tools to automate the process of solving the tasks related to managing the quality of multi-layered double-glazed windows.

### 4. Development of a set of ontological knowledge models to manage quality in the production of multi-layered double-glazed windows

In general, the model of product quality flow can be represented in the following form:

$$x_i(t) \rightarrow v_j(t) \rightarrow T_f(t),$$

where  $x_i(t)$  is the set of parameters for the original assembly compo-

nents (materials, parts, assembly units, blocks, components, etc.);  $v_j(t)$  is the set of intermediate parameters of assembly units formed by the implementation of the current operation;  $T_f(t)$  is the product’s initial parameters; a  $t$  index indicates the current value of the parameter, and arrows – the direction of the flow of parameters formation.

This model takes into consideration the assembly potential of products, which depends on the size, the physical parameters of the assembly components, and the assembly process. The size parameters of the assembly components and their matching surfaces are determined by the accuracy of manufacturing individual layers.

Obtaining the components that are to be assembled with increased variations in the size of the matching contours can disrupt their pairing, damage the product and assembly devices, break and fail the equipment. Therefore, in preparing the product for automated production, it is necessary to establish tolerances for the manufacture of assembly components and their connection, which could provide the set output parameters of the product. This is especially important when technical requirements impose special restrictions on the deviations of these parameters. The list of such restrictions is regulated by the DSTU standard BV. 2.7–107–2008 [15].

To ensure the system is operational in accordance with the ISO 9001:2015 requirements in terms of quality, an ontological model has been developed in the TODOS tool platform environment [16]. A given model (Fig. 1) makes it possible to control the availability of all the necessary components of the system, thereby forming a single space of knowledge for decision-making. The limitation of a given model when used in practice is the absence of requirements of the DSTU standard BV.2.7–107–2008. Although this standard is currently harmonized with the ISO 9001:2015 standard, it reflects a series of features inherent in domestic production. Due to this circumstance, in order to ensure the adequacy of the entire set of ontological models, it is advisable to further supplement the developed set with an ontological model for the requirements by the DSTU standard BV.2.7–107–2008.

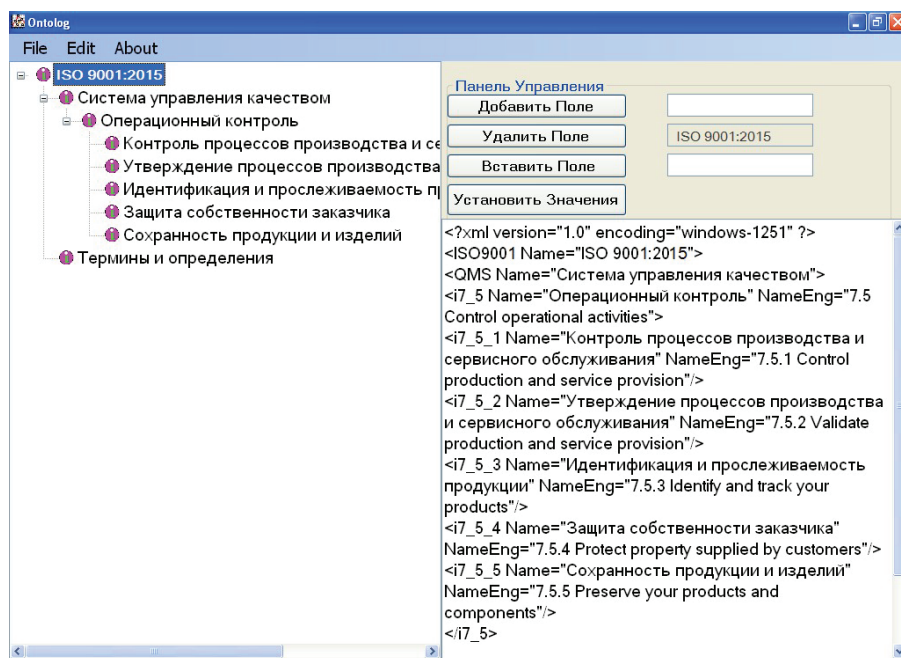


Fig. 1. The ISO 9001:2015 standard taxonomic tree in terms of manufacturing process quality management

The ontological model of the ISO 9001:2015 standard, shown in Fig. 1, is an ontology of the subject area in the developed quality management system to produce multi-layered double-glazed windows. Based on this model, a single dictionary of terms and definitions for the entire system (glossary) has been formed. This avoids situations of ambiguous interpretation of terms.

A set of objects in the domain for which quality is a relevant factor is set by the top-level ontological model (Fig. 3). This model includes the concepts “Resources”, as well as “Process,” “Operation”, and “Organization.” In the TODOS software package, the top-level ontological model is set by the following type of taxonomy (Fig. 2):

Attention must be paid to the fact that definitions of processes and products are given in terms of actions and resources. The ontological approach uses a single dictionary of terms (glossary). This has made it possible, in a given case, to ensure the unambiguous representation of the subject area “Production of multi-layered double-glazed windows for solar panels” and a model of quality in accordance with ISO 9001:2015. In addition, it is possible to formally represent the concept “Multi-layered double-glazed glass” using the concepts “Requirements” and “Specification”.

To access the quality parameter, one needs to establish the nature of the ontological “this” relationship, and what concepts from the set “Operations” must be available to obtain this relationship. Thus, the top-level ontological model formally describes the knowledge both about the nature of the product quality and the processes of its production.

The knowledge represented in the ontological system covers all activities that are part of the quality management system of multi-layered double-glazed windows produced by a subcontractor

and shows the relationship between them. Fig. 3 shows the ontological model of the directive manufacturing process of multi-layered double-glazed windows; Fig. 4 – a fragment of the ontological model “The range of materials for the production of multi-layered double-glazed windows.”

The ontological approach makes it possible to combine different manufacturing processes into a single knowledge base of the ontological information-analytical system (OIAS); when the monitoring database is updated in a dialogue mode, it notifies the chief technologist about deviations in the process implementation.

As part of constructing an OIAS to manage the manufacturing quality of multi-layered double-glazed windows, an ontological model “Equipment for the production of multi-layered double-glazed windows” was devised, shown in Fig. 5.

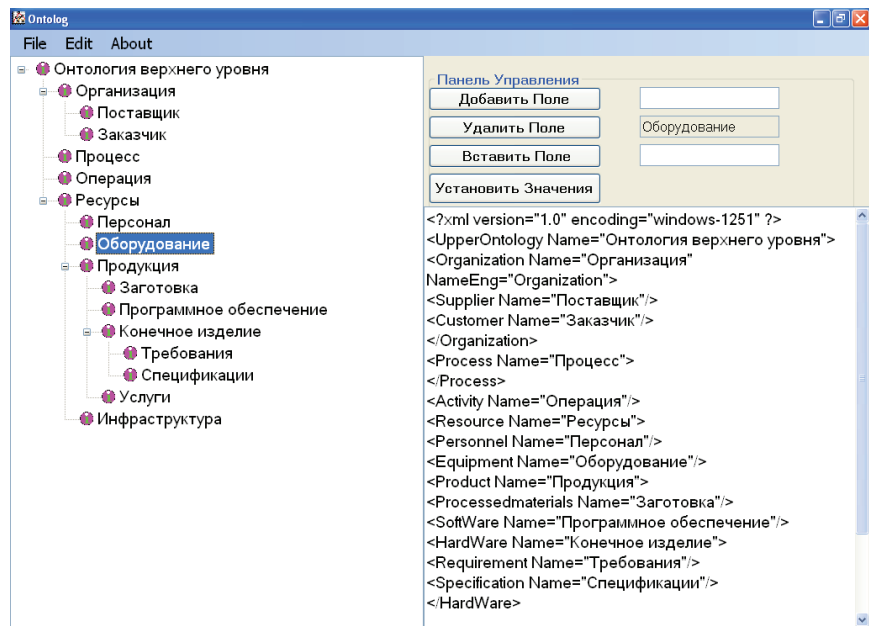


Fig. 2. A fragment of the ontology of the upper-level quality management system in the production of multi-layered double-glazed windows

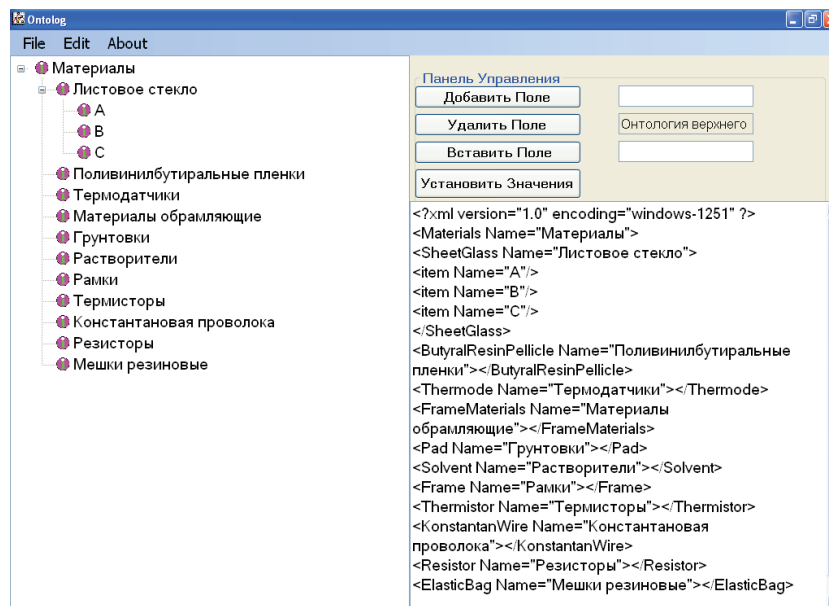


Fig. 3. The ontological model of the directive manufacturing process of multi-layered double-glazed windows

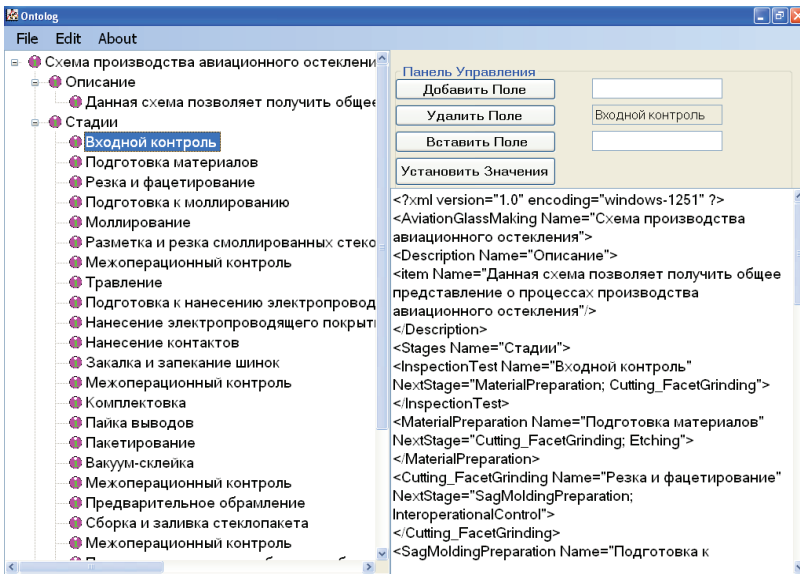


Fig. 4. Fragment of the ontological model “The range of materials used in the production of multi-layered double-glazed windows”

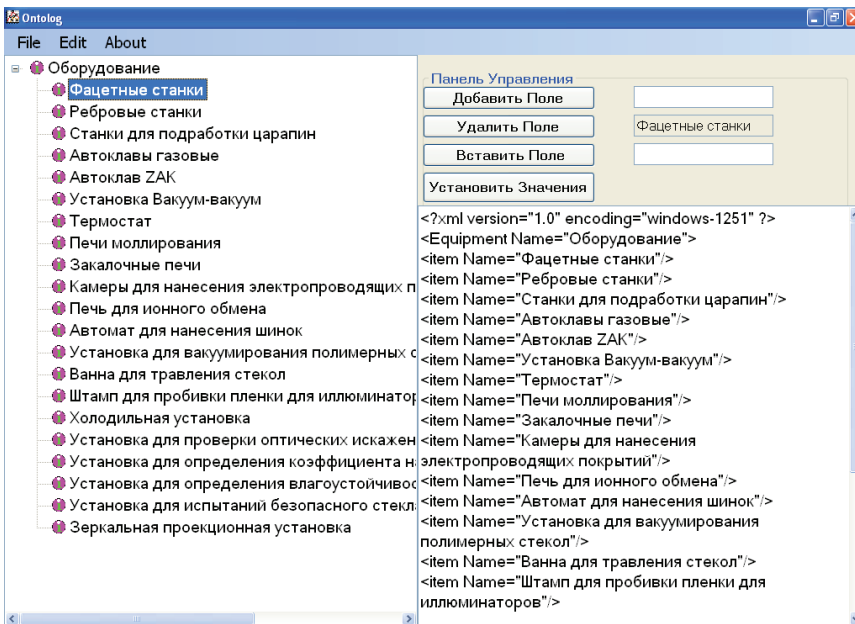


Fig. 5. Ontological model “Equipment for the production of multi-layered double-glazed windows”

The ontological models shown in Fig. 2–5 are only the fragments of taxonomies, which are invariant relative to production at a particular enterprise-subcontractor. In solving practical quality management tasks, complete versions of such models were used, reflecting the specificity of production organization at a typical plant for the production of multi-layered double-glazed windows.

### 5. Devising a procedure for manipulating knowledge in the environment of the ontological quality management system in the production of multi-layered double-glazed windows

Consider two standard tasks that arise during the evaluation of the quality of multi-layered double-glazed manufacturing processes: determining the causes of defects or damage of manufactured products, and predicting the dete-

rioration in the quality of products launched into production. The starting data for these tasks are:

- the ontological system, which includes the models described above “Equipment,” “Materials,” “Manufacturing,” “Product Characteristics Relationship,” “Directive Process for the Manufacture of Multilayered Glass”;
- a fragment of a database containing the results of measurements of the characteristics of products from four batches, during an inter-operative control, and at the Technical Control Department (TCD).

To illustrate the progress of problem-solving, we use a scheme of manufacturing multi-layered double-glazed windows in the form of an orderly set of blocks (Fig. 6). Using this scheme, we describe the scenario of the following production situation. Interoperative control after the operation of hardening of glass and baking (Block 13) indicated deviations from the specified quality indicators. There is non-equidistance in two sets of double-glazed windows exceeding 2 mm, and in three sets – not less than 1.8 mm.

It is necessary to establish the reasons for the tendency to deviate this product characteristic towards the limiting permissible value.

To manipulate knowledge in the MIAS environment, we used the methods of ascending and downward logical inference applying the language of operating semantics [17].

The situation described above activates the OIAS, in which the decision on the causes of product defects is formed on the basis of the following procedure:

1. The direct logical inference operation establishes an element of the ontological model “Production” directly related to the non-equidistance of the glass. This element is the “Interoperative Control” shown in Fig. 6 as Block 13.

2. Implementation of the inverse logical inference operation, which makes it possible to establish with the help

of the ontological model “Relationship of product characteristics” associated with the models “Material” and “Equipment” the factors that affect the non-equidistance of glass.

3. Construction of fish- and Pareto diagrams to present to the chief technologist a way to identify possible causes of the defect.

The application of the procedure described above is schematically shown in Fig. 7: it provides an opportunity to find a conflicting set of characteristics affecting the quality of multi-layered double-glazed windows.

Thus, the application of the ontological approach to the quality management of the production of multi-layered double-glazed windows provided the following opportunities. First, to establish the causes of deviations from the manufacturing process. Second, operative intervention in the manufacturing process to correct the deviations detected.

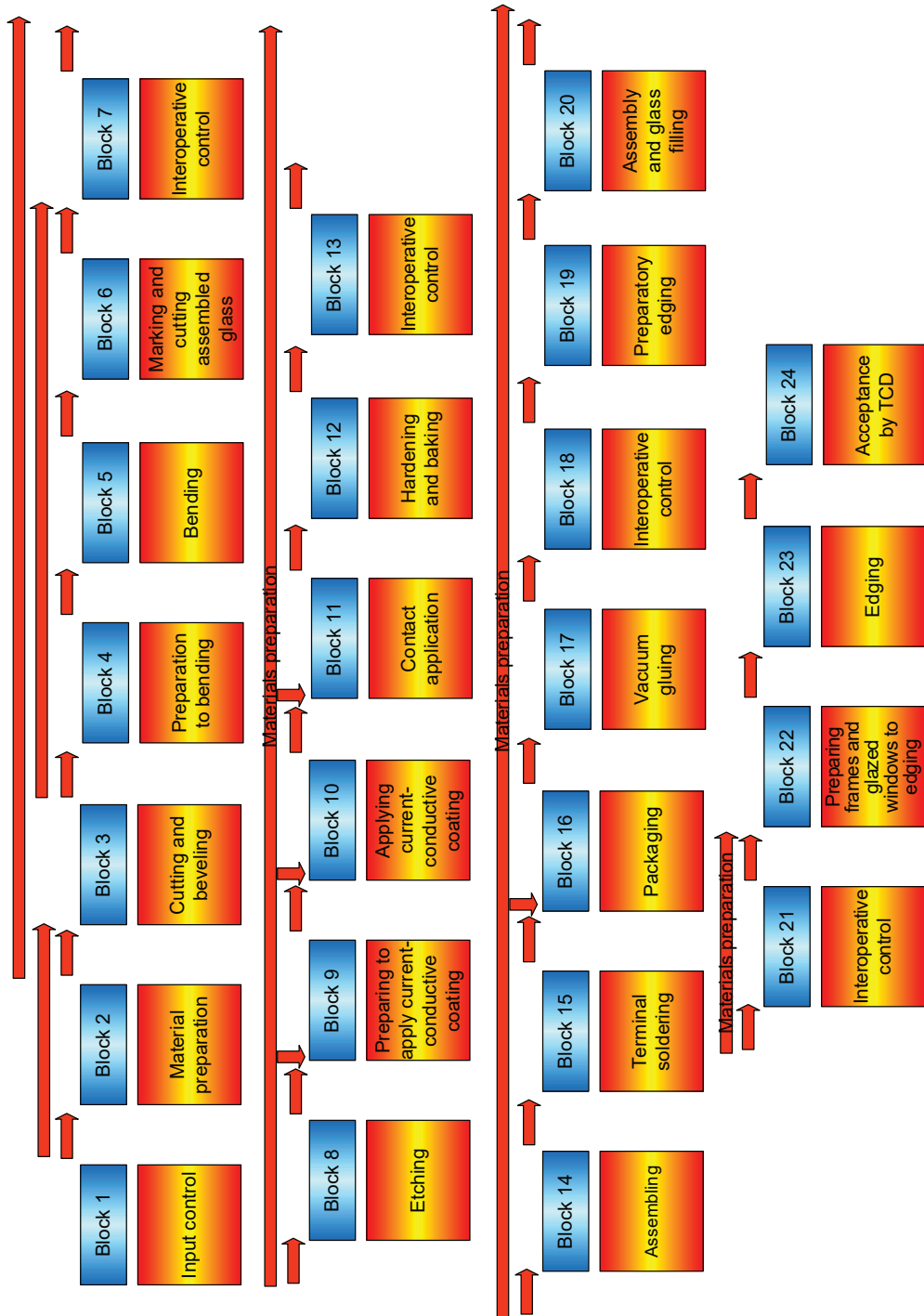


Fig. 6. Manufacturing scheme of multi-layered double-glazed windows

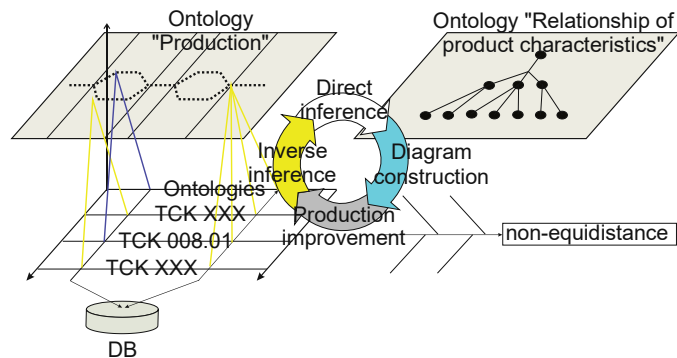


Fig. 7. The procedure for making decisions to manage the quality of multi-layered double-glazed windows production

**6. Substantiating the approach to assessing the effectiveness of using OIAS “TODOS” to manage the quality of multi-layered double-glazed windows**

The effectiveness of using OIAS in quality management tasks in the production of multi-layered double-glazed windows should be considered in two aspects – technical and economic. At the same time, the technical aspect is related to the evaluation of the effectiveness of information processing, mainly to the search for relevant knowledge within the intelligent core of OIAS “TODOS”.

Since the characteristic of the ontological approach to knowledge representation is the query-oriented hierarchy of records, the generalized structure of the intelligent core of OIAS “TODOS” takes the following form (Fig. 8).

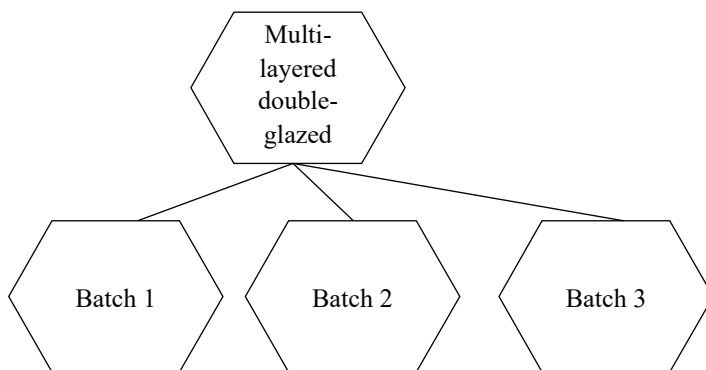


Fig. 8. Generalized ontological structure of knowledge about the subject area “Production of multi-layered double-glazed windows”

As the metrics that best reflect the process of implementing a request for an OIAS knowledge management system, it is appropriate to use the following: the number of items returned by request; density; selectivity; overhead.

The number of items returned by the query reflects in practice the number of unique values in the record. According to relational database theory, the presence of identical lines (tuples) in a relation (table) is prohibited. Thus, the number of items returned by the request corresponds to the number of tuples. This means that the SQL Server allows the same lines to exist in a table, so, in our case, the term “Number of elements” denotes the number of unique values in the dataset.

Density determines the uniqueness of values in the dataset. The density of the index is calculated by dividing the number of entries corresponding to a given key value by the number of entries in a table. For a unique index, this means dividing unity by the total number of entries in the table. The density varies from 0 to 1. The lower the density, the higher the efficiency of the process.

Selectivity is a measure of the number of entries that would be received for a particular request. It determines how the criterion of the query and the value of the index keys are related. Selectivity is calculated by dividing the number of keys requested by the number of records they correspond to. The selective query criterion (typically indicated in the WHERE part) most clearly reflects the effectiveness of the information search process as it indicates how many I/O operations would be required to make the request (Table 1).

As an illustrative example, consider a fragment of the intelligent OIAS core, under the mode of processing infor-

mation about the causes of damage during the process of production of multi-layered double-glazed windows. Suppose there is no clustered index in a table called Registration, which stores data on the results of the production process of 10,000 multi-layered double-glazed windows, and there is a no-cluster index for the Affiliation column (belonging to a batch). If the quality of three batches of multi-layered double-glazed windows is analyzed, and each batch has roughly the same number of discarded products, the Affiliation table would contain only three unique values. This means that the set index key value can determine 3,333 entries in the table. The result would be an index density value of 0.33 (3,333×10,000), and one can conclude that this index would not be used in the formation of a plan to execute requests not covered by the index.

To measure the effectiveness of the OIAS intelligent core operation, compare the cost of executing a simple query using an index and without using it. In fact, this example shows the superiority of the ontological approach to creating an information-analytical system over the conventional, based on the use of a relational database. If the request involves information about all defective multi-layered double-glazed windows in a particular batch, it is a matter of processing 3,333 entries, or a third of the table. If one uses the Affiliation index to access these records, one needs to implement 3,333 separate page-reading operations from the table. This fact means that every time one finds a key value in an index, one needs to use a tab to get columns that are not contained in the index. This in practice implies additional costs associated with logical (and possibly physical) I/O operations. For our example, there are 26MB of overheads associated with the search based on tabs (3,333 keys×8 K/page). Assuming an equal distribution of elements by batch, 3,333 records or 0.533 MB overheads are required to receive and execute the request.

The quantitative estimates obtained on the basis of selected metrics (Tables 1, 2) show that when implementing search tasks, the effectiveness of using an ontological model of knowledge is significantly higher than the effectiveness of the relational model.

Table 1

Query efficiency metrics in the relational database management system (DBMS)

Metric	Value
Number of elements	10,000
Density	0.33
Selectivity	0.0003
Overhead	26 MB

Table 2

Query efficiency metrics in the environment of an ontological information-analytical system (OIAS)

Metric	Value
Number of elements	10,000
Density	0
Selectivity	1
Overhead	0.6 MB

Getting additional profit by improving quality is the basis for the economic justification of production in gener-

al, and multi-layered double-glazed windows in particular. Taking into consideration the nature of production and its specificity, we shall calculate additional investments related to the introduction of OIAS “TODOS” at an enterprise that produces multi-layered double-glazed windows, according to the following formula

$$K = K1 + K2 + K3 + K4 + \dots, \tag{1}$$

where  $K1$  is the cost of developing OIAS “TODOS”;  $K2$  is the testing and implementation of OIAS “TODOS” at an enterprise that produces multi-layered double-glazed windows;  $K3$  is the cost of staff training;  $K4$  is the cost of additional technical support.

Calculating the annual additional running costs associated with the operation of OIAS “TODOS” at an enterprise that produces multi-layered double-glazed windows

$$Cadd = Csl + Cdd + Cel + Ccs, \tag{2}$$

where  $Csl$  is the salary of a cognitive engineer who operates OIAS “TODOS” at an enterprise that produces multi-layered double-glazed windows;

$$Csl = (Smn + Sd)(1 + Kd) = (Smn + Sd) * 1.375;$$

$Cdd$  is the depreciation deductions;  $Ccs$  is the additional costs of maintaining the Cascade software complex and repairing the materials;  $Cel$  is the additional cost of electricity, etc.,  $Kd$  – single social entry.

The calculation of the annual additional profit from the introduction of OIAS “TODOS” at an enterprise that produces multi-layered double-glazed windows was carried out using the following formula:

$$\Delta P = \Delta Sdp + \Delta Sp - Cadd, \tag{3}$$

where  $\Delta Sdp$  is the savings from reducing the percentage of defective products;  $\Delta Sp$  is the additional profit from the increase in the sale price, due to the increase in the product quality

$$\Delta Sdp = \sum_{i=1}^n \frac{(\alpha_i^b + \alpha_i^n)}{100} Qi, \tag{4}$$

where  $\alpha_i^b$ ,  $\alpha_i^n$  are the percentage of discarded products in the basic and new version of manufacturing the  $i$ -th type of product;  $Qi$  is the average annual output of the  $i$ -th type of product;  $n$  is the product range;

$$\Delta Sp = \sum_{i=1}^n (P_i^n + P_i^b) \cdot Ni, \tag{5}$$

where  $P_i^n$ ,  $P_i^b$  are the price, new and basic, for the  $i$ -th product, UAH;  $Ni$  is the annual program of manufacturing the  $i$ -th product.

Calculating the efficiency of investments when implementing OIAS “TODOS” at an enterprise that produces multi-layered double-glazed windows

$$E = \frac{\Delta P}{I}, \tag{6}$$

where  $\Delta P$  is the annual additional profit from the introduction of OIAS “TODOS” at an enterprise that produces multi-layered double-glazed windows;  $I$  is the amount of additional investment associated with the introduction of OIAS “TODOS” at an enterprise that produces multi-layered double-glazed windows.

The 2019 sample from the database of a standard enterprise on the results of inter-operational control of the batches of double-glazed windows is given in Table 3.

Charts in Fig. 9 show a decrease in the number of defective double-glazed windows, indicating the technological operation at which the damage originated when using OIAS “TODOS” in the process of managing the quality of the production of multi-layered double-glazed windows at a typical glass factory.

Table 3

Causes of damage identified during interoperative control of multi-layered double-glazed windows

Year	Month	Stage	Double-glazed window No.	Code	Cause
2019	September	Hardening	26, 8, 21	5	Destroyed in furnace
2019	September	Hardening	39	10	Destroyed in furnace
2019	October	Hardening	37, 38	5	Destroyed in furnace
2019	November	Hardening	64	10	Destroyed in furnace
2019	September	Current-conductive coating	18	5	Field R less than tolerance
2019	October	Current-conductive coating	36, 39, 7	5	Field R less than tolerance
2019	October	Current-conductive coating	26, 40, 34	10	Field R less than tolerance
2019	January	Assembling	1, 99, 59	5	Dirt on the electric-conducting coating that arose when it was applied
2019	February	Pressing	340020205	10	No readings from sensor 2
2019	September	Pressing	25, 27, 28, 29	5	Aerosol glass destroyed at vacuum gluing
2019	October	Pressing	240111005	5	Inclusions in gluing joint (hair 1=60 mm)
2019	October	Pressing	240161005	10	Translucent spot in the gluing joint in the center exceeds the tolerance set by DSTU BV. 2.7-10 –2008
2019	December	Pressing	340201205	10	Aerosol glass destroyed during autoclave pressing
2019	December	Pressing	240221205	10	Aerosol glass destroyed at vacuum gluing
2019	December	Pressing	240231205	10	No readings from sensor 2
2019	February	Pressing	240030206	5	Chips along the chamfer with glass tearing in a gluing joint on aerosol glass
2019	March	Pressing	340050306	10	Aerosol glass destroyed at vacuum gluing in a thermostat
2019	March	Pressing	340060306	10	Aerosol glass destroyed at vacuum gluing in a thermostat
2019	November	Framing	240151005	5	No readings from sensor 2 after repeated pressing



Thus, an economic justification has been made for the effectiveness of the introduction of OIAS to manage the quality of the production of multi-layered double-glazed windows.

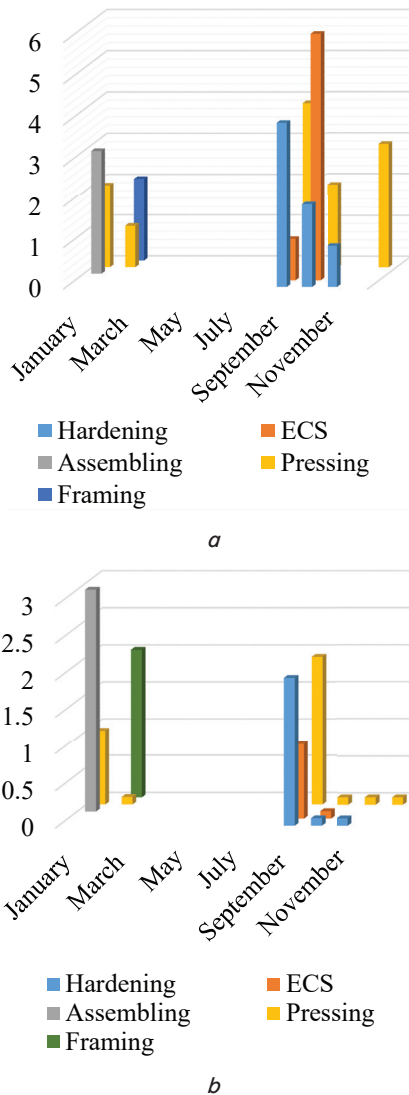


Fig. 9. A quantitative assessment of discarded products at each stage of interoperative control of multi-layered double-glazed windows production during 2019: *a* – using conventional computer decision-making tools; *b* – applying an ontological component

The proposed approach has shown that the efficiency of using OIAS in the quality management tasks related to the production of multi-layered glass windows at a standard glass factory would improve both technically and economically. In the first case, through the rational use of the computing resource; in the second – by reducing the cost of fixing defects and compensate for damage.

The source data for assessing the effectiveness of the developed approach, in the technical aspect, were the number of records that are analyzed by the system when maintaining a request to the information structure. In this case, the comparison with the conventional relational database, which is employed by most industrial information-analytical systems, has revealed that only one-third of records are required in the ontological system to ensure the same level of relevance and pertinence of the request. In the economic aspect, the

calculation of the effectiveness of the ontological information-analytical system is based on the comparison of statistics on the discarded products at a standard enterprise that produces multi-layered double-glazed windows over the first half of 2019. The calculation has demonstrated that the use of an ontological information-analytical system for quality management would reduce the volume of discarded products by 73 % on average.

### 7. Discussion of results of using the ontological approach to informationally maintain quality management processes

The main result of this study is the procedure for identifying the causes of defects and damage in products, as well as forming solutions to eliminate these causes. Its peculiarity is to activate the content of the ontological models whose fragments are shown in Fig. 1–5 in order to infer based on knowledge. Until now, ontologies have been treated only as static repositories of structured information; the activation of KBI process in ontological systems has been carried out by external mechanisms, for example, using the algebra of ontologies or intelligent agents.

The devised models of ontologies could be used to automate the process of solving quality management tasks within the VIE concept; the proposed procedure for calculating efficiency implies a comprehensive assessment of the achieved effect in two aspects – scientific-technical, and economic. In the scientific-technical aspect, the use of ontological engineering tools in the development of basic information technology to manage product quality at enterprises-sub-contractors, which are part of VIE, has made it possible to reduce the cost of finding relevant information in the data store, as evidenced by the indicators given in Table 2. The basis for comparison here was the calculation of such costs for the conventional way of organizing data used by industrial information-analytical systems – in the form of relational-type DBMS (Table 1). Regarding the economic impact of the implementation of OIAS, this paper reports a procedure of calculating the annual profit of an enterprise from the introduction of automation (1) to (6). The main difference between this procedure and the standard one is to take into consideration the additional costs associated with the support in the proper state of the ontological component of OIAS (2), as well as the calculation of additional profit from the improvement of product quality (4). Since the value of an additional profit indicator due to the increase in the sale price, given the improved product quality (4), is directly related to the identification of the causes of damage, this study at a typical glass factory involved an analysis of production events associated with the emergence of damage in the manufacture of multi-layered double-glazed windows during 2019 (Table 3). The findings provided an opportunity to compare the effectiveness of quality management processes for the considered type of enterprises using OIAS and by using standard methods and information support tools for non-destructive product control (Fig. 9).

The main limitation for the widespread use of the proposed approach is the relatively high cost of developing appropriate ontological models as this process implies the involvement of a team of highly paid cognitive specialists to extract knowledge from text sources and electronic resources.

Overcoming this caveat in further research involves two main phases. In the first stage, it is necessary to create a methodical basis for the automated acquisition of knowledge during the formation of an intelligent core of the ontological information-analytical system. The second phase involves the development of OIAS deployment tools that would address a wide range of quality management tasks at respective enterprises.

The introduction of the theoretical and applied research results in these areas could significantly reduce the cost of developing and operating OIAS.

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## 8. Conclusions

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1. We have built a set of ontological models of knowledge about the implementation of the production stage in the life cycle of multi-layered double-glazed windows, as well as about the regulatory framework and possible deviations from it during production. Unlike conventional means of representing information in computerized systems, the devised models adequately reflect the associative connections between the subject matter entities, which ensures the effec-

tiveness of quality management solutions generated in the computer environment.

2. An inference process based on knowledge in the environment of an ontological system has been developed, as a decision-making mechanism, employing the application of direct and inverse logical inference operations directly on ontological models. The use of the developed procedure makes it possible to implement both deductive and inductive methods when making decisions to manage the quality of multi-layered double-glazed windows.

3. We have substantiated an approach to assessing the effectiveness of using ontological engineering tools to automate the process of solving the tasks related to managing the quality of multi-layered double-glazed windows. This approach employs a set of specialized metrics. This set of metrics makes it possible to take into consideration both the technical and economic aspects of creating, deploying, supporting the operation of the ontological information-analytical system to manage the quality of multi-layered double-glazed windows. Our calculations have shown that over the analyzed period (2019) the number of discarded products decreased by 73 % on average.

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