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EVALUATION OF STANDARDIZATION LEVEL OF MECHANICAL SYSTEMS IN ENGINEERING DESIGN

Pavlos - Christoforos SINIGALIAS, Argyris DENTSORAS
University of Patras, Greece

ABSTRACT

The level of standardization of products and systems affects production process and the cost for their operation and maintenance. In reverse engineering and design, the systematic consideration of standards leads to better evaluation and efficient synthesis of parts and assemblies. Taking into account standardization during design leads to systems with better operational characteristics, high quality and low cost.
The establishment of metrics for estimating the standardization level of systems can provide valuable tools for analytic and synthetic engineering processes. The present study introduces such a metrics that is based on system analysis and decomposition into hierarchical structures of parts and assemblies. Procedures search exhaustively that structures and perform calculations of standardization indices. A PC-based platform implements the proposed method and provides estimations of standardization levels and multiple graphical outputs that visualize the obtained results. Then the designer may inspect the standardization level of parts, components and assemblies and proceed with necessary modifications. The method is exemplified with a study of a robot base subassembly.

Keywords: design for X, product structuring, standards, metrics

Contact:
Prof. Argyris Dentsoras
University of Patras
Mechanical Engineering and Aeronautics
Patras
26500
Greece
dentsora@mech.upatras.gr

1 INTRODUCTION

A standard, as defined by the National Standards Policy Advisory Committee 0, is "*a prescribed set of rules, conditions, or requirements concerning definitions of terms; classification of components; specification of materials, performance, or operations; delineation of procedures; or measurement of quantity and quality in describing materials, products, systems, services, or practices.*" (Maureen A. Breitenberg, 1997). Alternatively, a *standard* may be defined as a criterion, rule, principle, or description considered by an authority, or by general consent or usage and acceptance, as a basis for comparison or judgment or as an approved model. The terms *standards* and *specifications* are sometimes used interchangeably; however, *standards* refer to generalized situations, whereas *specifications* refer to specialized ones. For example, a standard might refer to mechanical power transmission equipment; a specification might refer to a particular gear drive (ASME, 2003). Engineering design is characterized by extensive use of standards; here the word 'standard' preserves its meaning as "*an accepted or approved example of something against which others are judged or measured" and as "an authorized model of a unit of measure or weight*". To achieve successful design appropriate standards are devised. According to Pat Toms, (1988), these include national standards framed within guidelines agreed through the International Organization for Standards (ISO).

In September 1994, the lack of standardization in the U.S. nuclear industry, in contrast to the French one, was discussed within the barriers of a standardization measuring study (Paul A. David, Geoffrey S. Rothwell, 1996). The problem of measuring the degree of standardization in an industry whose production facilities are as complex and multi-faceted as nuclear power stations was focused and analyzed, and performance-oriented measures were introduced based on operating downtime and the probability of shutdowns associated with reactor subsystems. Through focusing on operation performance and based on empirical measures of standardization, the problem of standards quantification was approached in three steps. First, the power plant subsystems were identified. Second, economic and safety-relevant performance factors were considered. Finally, performance weighted indexes that aggregate measures of standardization for each subsystem were computed. With suitable modifications, the degree of standardization of other technical systems could also be quantified.

Measuring and estimating standardization of already operating systems and products is one aspect of the problem. A second, equally important aspect refers to the design of new systems and products. In detailed design, problems such as the specification of thickness of a metal sheet, the selection of fasteners, the choice of power transmission belts, etc. require extensive consideration of standards and standardization processes. Usually, an engineer does not have to design a new cap screw to be used in a new machine. Instead, he/she must select an available standardized one that should always fulfill the corresponding design requirements regarding dimensions, material, finishing, cost, etc. The systematic consideration of standards while designing is a practice that provides more time for creative and innovative work and reduces cost by minimizing both the number of items to be designed from scratch and the number of types of manufacturing processes needed ASME, (2003).

According to the relevant technical literature and regarding machines and products where mechanical systems and structures play major functional roles, the categories of items and processes that are standardized (C. S. Sharma, Kamlesh Purohit, 2005) include: (1) Engineering materials (compositions, properties and testing methods), (2) Drawings and symbols, (3) Fits and tolerances for parts and assemblies, (4) Dimensions of various machine components (rivets, bolts, nuts, keys, couplings, bearings, etc.). The most significant value of industrial standards is the reduction of amount of information that should be handled during design. If there were no standards, for example, for screw threads, bolts, gears, materials, etc., huge and diverse information should be handled repeatedly and separately for the products being designed. This fact justifies to a large degree the past and current effort for developing standards in order to facilitate the design process and reduce design time and cost. A lot of work on standardization according to James G. Skakoon, (2000) still remains to be done for other domains. These domains, however, do not concern explicitly mechanical systems but other processes, systems and products.

A common characteristic of all modern products as Kevin N. Otto, Kristin L. Wood, (2000) indicate is that their structures involve mechanical, electrical and electronic components, control elements and software. Their design follows the steps and phases dictated by the established design methodologies and techniques which, nowadays, are characterized by high degree of collaboration and concurrency.

Design is always followed by manufacturing processes that realize the products so that the latter are finally brought into the market. When in market, user and/or consumer feedback plays an important role in locating design deficiencies that usually provoke redesign processes and consist of valuable reference points for future designs regarding overall quality and performance Wasim Ahmed Khan, Abdul Raouf, S.I., (2006).
Within this context and starting from the very early design phases and ending up to the stages of detailed ones, standardization data and information should be always taken concurrently into account so that maximum compliance of the product being designed is maintained and ensured. The consideration of standards during product design may be limited only by lack of information and/or unawareness of the members of design team.
This systematic partition of standards provides an easy way for efficiently applying "design-for-standardization" approaches in order to cover all major aspects related to product design, function and performance (Wasim Ahmed Khan, Abdul Raouf, S.I., 2006). The objective of this standard specification is to underline the quantity and diversity of the availability of design parameters as standard values0.
The basic model of VW Golf is made up of 4,786 different parts, with a total of 16,897 individual parts for one car. 4,219, almost a quarter of these, are standardized components. Standardized components are 20% to 60% cheaper than customized components, and this contributes greatly to reducing the cost of the product (Technical University Dresden and the Fraunhofer Institute for Systems and Innovations, 2000). Following a PLM-based approach, a company can systematically document, store and maintain standard parts. Then it can guaranty the final structural and functional quality of its products and fulfill the necessary legal requirements.
In the terms of component part standardization, commonality, i.e. using the same type of component in different locations of product structure trees, is frequently encountered in manufacturing industries (Wazed M.A., and Ahmed S., and Nukman Y., 2009). Dong, M., et al. state that the commonality index, (which though being inextricably related to component part standardization is out of the boundaries of this paper and therefore will not be discussed thoroughly), is a measure of how well the product design utilizes standardized components (Wu Yang-Dong, Xie Qing-Sheng, Qi Guo-Ning, Lu Yu-Jun, 2006)
Wazed, M. A., Ahmed, S. and Nukman, Y. consider the use of common components for different products in a company as an important factor for managing product variety and maintaining competitiveness in this age of mass customization and supply chain struggle. Numerous advantages of parts commonality in manufacturing systems including reduction of costs and lead times are reported in literatures. Despite these numerous advantages of mass production of standardized goods, customers nowadays are seeking for custom products with wider variety that will fulfill their constant changing demands which will furthermore be available to purchase at same low prices as mass-produced goods. Therefore a compromising decision among the product variety, customers demand and costs should be reached to cope up with the market trend and customers expectations, eventually for survival in business.
Although commonality might be a contributing factor for the augmentation of the standardization level of a product, designers should make allowances for the probable negative outcomes of such an approach. Hillier mentions that there should be a tradeoff between product performance and commonality within any product family (Hillier, M.S., 2002). Focusing solely on the maximization of the standardized parts of a product during design and adhering to quality standards (standards conformance) could affect drastically design creativity and innovation and may obstruct further suggestions and modifications. Therefore, great attention should be paid by the designers in order to resolve the tradeoff between too much commonality (i.e. lack of distinctiveness of the products) and not enough commonality (i.e. higher production costs).
In June 2006, the American Society of Mechanical Engineers (ASME) published the new *B18.24-2004* Part Identifying Number (PIN) Code System Standard for B18 Fastener Products. This standard defined PIN codes for over 630 different types of fasteners including screws, nuts, bolts, washers, pins/dowels, keys, retaining rings, rivets and SEMS (screw and washer assemblies). To better integrate the traditional paper standard with design software, ASME promoted a representation of the standard in a digital format as well (ASME International, 2006). This is the first such digital representation of a standard in ASME's 125-year history. The new B18 Digital Fastener Library (Doug Korneffel, 2006)

reduces several manual tasks to a few point-and-click selections. The library runs completely independently of any CAD system and can be used as a tool to describe an existing PIN number for anyone. On the other hand, it can also operate efficiently within the framework of a computer environment and is capable of producing – optionally - the 3D solid model of any fastener in virtually any CAD format. It is expected that in the future, similar new software tools will further encourage the use of standards and will help propagate their use, such as Cadenas PARTsolutions which is one of the leading software systems, helping engineers and purchasers manage and find company, supplier and standard parts. Another example is Solidworks Toolbox (Matt Lombard, 2010) which is Solidworks software add-in for automating tasks related to inserting and managing commonly used library type parts.

Representation and implementation of structural decompositions of mechanical systems in computers may be performed by hierarchical relations (M. Anastasopoulos, A. Dentsoras, ,2009) and can now be considered trivial tasks. However, measuring the standardization level of those systems is not so trivial. In a paper by Lee, Seung-Hwan, Park Myeong-Cheol, Lee Sang-Woo, Koo Kyoung-Cheol, (2003) that establishes a model for measuring standardization level of information and communication technology, a standardization index was proposed representing the degree of standardization of systems in the field of information and telecommunications. In this paper, the set of the most important determinants for that index was considered along with their weight factors. The concept of the weighted average was adopted and an analytical hierarchy process methodology (AHP) for determining factor weights by utilizing judgments of standardization experts and statistical data from the market. Within the context of the same work, an effort was also made to obtain objective data from several certified associations and institutions. After the normalization of the standardization data set and the development of the standardization index, the validity and the rationality of the applied model were verified by examining the rank consistency of standardization indexes using the research model with specialists' opinions.

The present paper copes with the problem of estimation of the standardization level of mechanical systems. The problem is methodological and belongs to a set of problems related to standardization issues that characterize the design and manufacturing of such systems; its solution could be the establishment of a systematic metric method for performing that estimation.

2 ESTIMATING THE STANDARDIZATION LEVEL OF A MECHANICAL SYSTEM

Figure 1 depicts the basic idea. A module decomposes recursively and iteratively the assemblies of a system into subassemblies and parts or composes them to subassemblies and assemblies, depending on whether a reverse engineering process or a design process takes place. These parts and assemblies may be new or may be extracted from or found in dynamically updated libraries. Irrespectively of whether analysis or synthesis is being performed, parts are considered as the most significant entities that should be evaluated for standardization through systematic comparison to available standardization data. The engineer always plays central role in providing and handling that data, as well any additional information and knowledge about them.

Data about standardized parts may be presented in a variety of forms and configurations and each such form or configuration may contain one or more discrete attributes. Then, if a certain standardization configuration is chosen, its attributes form a set of reference points for evaluating the considered part with respect to the standardized one (see Figure 2). This evaluation is performed with the help of evaluation module (see Figure 1). Once a new part is considered and a quantity of identity/standardization data is provided about it, an algorithm undertakes a full search for text matching them with part standards in the library of standards. Given the results of the search, the algorithm that calculates and returns a value for the standardization index I of the part and then propagates that value to all assemblies that the part belongs to in order to calculate their (I)s too. All calculations of (I)s for parts and assemblies are performed in the calculation module. An analysis about the search for text and the method for calculating I is given in the next section. It should be stressed out here that the value of I depends on the quantity and completeness of data and information about standards that have been provided by the engineers. The approach described above is intensively iterative and recursive in all modules.

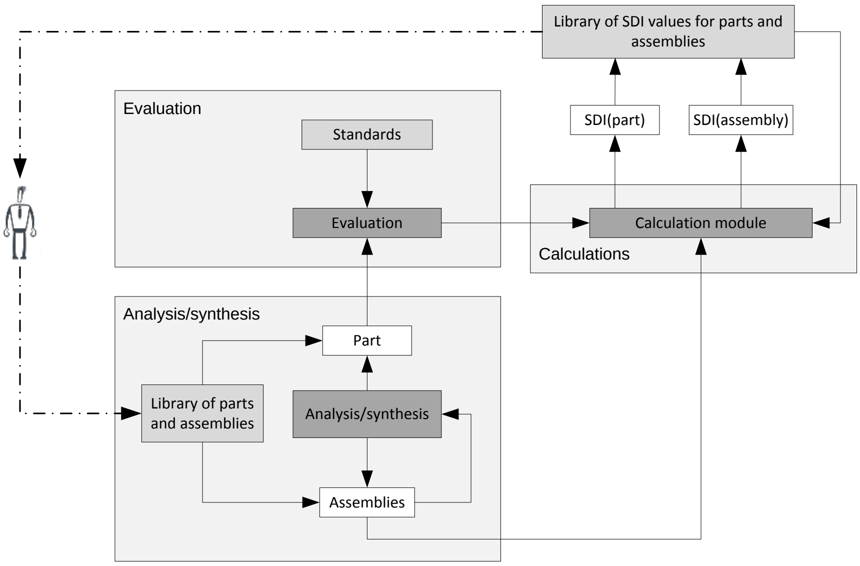

Figure 1. A general approach for estimating standardization levels and establishing metrics of standardization.

Size	Bore	OD	Thickness	Number of Balls	Display	Configuration Name
4TA12	4	16	8	6	Simplified	AFBMA 24.1.5 - 4TA12 - 6,SI,NC,668
4TA12	4	16	8	6	Detailed	AFBMA 24.1.5 - 4TA12 - 6,DE,NC,668
4TA12	4	16	8	6	Detailed	AFBMA 24.1.5 - 4TA12 - 6,DE,AC,668
4TA12	4	16	8	Full	Simplified	AFBMA 24.1.5 - 4TA12 - Full,SI,NC,Full68
4TA12	4	16	8	Full	Detailed	AFBMA 24.1.5 - 4TA12 - Full,DE,NC,Full68
4TA12	4	16	8	Full	Detailed	AFBMA 24.1.5 - 4TA12 - Full,DE,AC,Full68
6TA12	6	20	9	6	Simplified	AFBMA 24.1.5 - 6TA12 - 6,SI,NC,668
6TA12	6	20	9	6	Detailed	AFBMA 24.1.5 - 6TA12 - 6,DE,NC,668

Figure 2. Example of standard part configuration - Thrust Ball Bearing - AFBMA 24.1.5 Light Series (Solidworks Toolbox).

2.1 Calculation of standardization index

The proposed method is based on the fact that each mechanical system can be structurally decomposed into *assemblies*, *subassemblies* and individual *parts*. Subsequently, for each such part, considerations of its *standardization level* can be done with respect to one or more distinct predefined standardized *attributes*. Then, the standardization level of a higher-level structure (subassembly, assembly, system) may be achieved by estimating the standardization levels of its components. It is imperative, when analyzing or composing hierarchical relationships among parts and assemblies that the engineer provides as much as possible information about all factors that refer to standardization issues such as nomenclature, dimensions, tolerances, materials, machining processes etc. This will ensure that the calculated values of (I)s for parts and assemblies will reflect the real standardization level of the corresponding items. It is obvious that the process followed for measuring the standardization level of a part with respect to standardized attributes will be differentiated depending on the amount and the quality of the available data and information about standards.

Within the context of the present work, in order to attain the standardization data required for the indexes' calculations, the configurations of standard parts were extracted from the toolbox of Solidworks and were used as a point basis. The toolbox supports international standards, including ANSI, AS, GB, BSI, CISC, DIN, GB, ISO, IS, JIS, and KS. Each configuration of standards is described by specific standardized attributes with respect to the specific part. The set of these attributes

is a representation of information and is accompanied with all necessary mechanisms and definitions that enable data exchange, use and update.
The basic idea for a first estimation of standardization level of parts is based on the ratio of number of standardized attributes of the part currently under consideration to the total number of the attribute it refers to. In order to calculate that ratio, the (sub)-class (type) the part belongs to should be first identified. Class identification - through a similarity search algorithm influenced by the work of Wu Yang-Dong, Xie Qing-Sheng, Qi Guo-Ning, Lu Yu-Jun,(2006) - will lead to the attributes that pertain to that (sub)-class and which will be used for the calculation of index *I*.
Assume that the values of standardized attributes for a class of parts are represented by standardization tables (of different dimensions depending on the part and the standard under consideration). The classification algorithm will classify – after extended text search – the current part *p* to class c_p. If $A_c = \{a_{c.1}, a_{c.2}, ..., a_{c.n}\}$ is the set of all standardized attributes of class *c*, the comparison algorithm will compare all data and information inputted by the engineer for part *p* with those of A_c. If $A_p, A_p \subseteq A_c$ is the set of attributes of part *p*, then the ratio of the numbers of cardinality of these two sets is called the *standardization index for part p,* defined as:

$$I(p) @ |A_p| / |A_c|, I(p) \in [0,1] \qquad \text{(eq. 1)}$$

There may be cases where the deduction of the corresponding value will be facilitated by the fact that there are available standards for that attribute; then the process will be straight and simple. Nevertheless, during the design phase, the assembly composition cannot always consist of fully or partially standardized mechanical parts. If the classification algorithm for a part returns no results, then it is a non-standardized part, it is considered as a custom new part and the lowest value will be assigned to its index ($I(p) = 0$). On the contrary, for a fully standardized part, $I(p) = 1$.
The computations of standardization indexes for subassemblies, assemblies and systems are performed according to the structural hierarchical relationships, represented in the form of trees. Traversing such trees is a task that can be easily implemented through proper exhaustive search algorithms such as depth-first or breadth-first search (Daniel G. Bobrow, 1994), while the calculation of standardization indexes of parental nodes can be implemented by properly summing mean values of standardization indexes of children nodes in a recursive manner. While using simple averages appears to be a proper approach for the derivation of the standardization indexes, it does not take into account the different importance (weight) that each different part has for the calculation of the specific standardization index. On the other side, choosing the lowest part standardization index for representing the index of the assembly would be biased and unilateral and would not reflect reliably its standardization level. In future work, weighted averages will be used that will reflect the relative standardization importance of each part in an assembly (parent node) and provide a more balanced result. Given that the recursion will eventually reach leaf nodes of the tree, their standardization indexes should already be available.
As a conclusion and as far as calculation processes are concerned, the following comments should be made:

1. A standardization index can be assigned only to individual parts; assemblies acquire their standardization indexes via recursive calculations of standardization indexes of children parts and subassemblies
2. The method is capable of performing calculations even with missing assignments of standardization indices (custom parts). In that case, the standardization index being computed presents restricted validity.

2.2 Description of the platform

A platform was created – as a standalone Visual Studio application - for implementing the method. Its main interface holds the basic controls and is divided in 3 main sections. The first section depicts the structural tree of the system and provides extensive editing facilities for its components. The user has the ability to create a tree structure from scratch by adding and editing nodes, by forming the hyper and sub assemblies of the structure and by defining the final parts.
The second section is dedicated to standardization attributes. Once the structure of the system has been established and visualized, the user is able to proceed with calculations of standardization indexes for

every leaf node of the structural tree. Before any calculation is prompted for execution and after such a node has been selected, the user must update the standardization library with the appropriate standardization tables that contain the predefined standard values. Then the platform will attempt to extract the necessary data from the node's name and proceed to a certain classification. If the selected node belongs to a predefined class of standard parts, the calculation of standardization index will be initiated. Since the standardization attributes have values assigned, the standardization index is calculated and stored according to the calculation algorithm, otherwise the user is prompted to update first before calculating. If the selected part stands for a new custom part then the platform labels it as such and assigns the lowest permissible value for standardization index, that is $I(p)=0$. After the estimation of all standardization indices for the parts, the activation of calculation process for each assembly will automatically provide the values of their standardization indices and that of the overall assembly as well.
The third section of the platform presents standardization data and results obtained by calculations of standardization indexes of tree nodes. On-demand information can be always provided to the user regarding the selected node, its properties and its sub-tree within the overall tree structure.
The platform has been supplied with extended file I/O and printing operations and is capable of producing graphical visualization for the results in the form of pie chart diagrams (Evangelos Petroutsos, 2002). In these diagrams, the allocation percentage of the standardization index for the assemblies and the parts composing the selected hyper assembly can be viewed. This offers great versatility and permits direct and easy comprehension of the distribution of values of standardization indexes of assemblies and parts of the system. It also assists undertaking of proper actions in order to improve – either partially or totally - its standardization level.

3 A CASE STUDY: THE POLYMECHANON ROBOT – THE ASSEMBLY OF THE BASE

The polyMECHanon Robot (A. Synodinos, V. C. Moulianitis, 2011) is a tracked platform with a five degree of freedom manipulator and two extra degrees of freedom that connect the main body to the tracks (see Figure 3). The robot can function fully autonomously and is operated via remote wireless connections from the operator's station. It can overcome obstacles according to the rules of the competition and carry objects up to 500 grams with its manipulator. It can also function on real disaster sites, aiding in the location of victims and providing support where necessary.

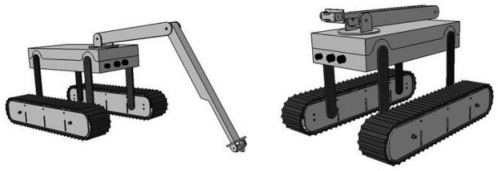

Figure 3. The CAD models of the mobile platform with the manipulator.

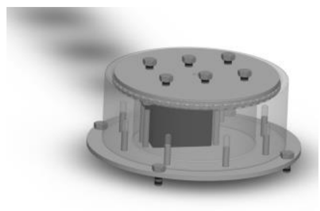

Figure 4. Structural analysis of the base of the robot

The robot was structurally decomposed and all its assemblies and parts were first distinguished (see Figure 4 as a reference for the base of the robot). Then all parts and assemblies were registered in the platform and the hierarchical tree was created. Twenty four (24) mechanical parts and five (5) system assemblies were recorded. After analysis, the process of calculation of standardization indexes for each part and assembly of the system was initiated. For each node element (part), the user inserted the available standardization data in the form of tables (see Figure 5). Finally the values of standardization indices for all participating parts as well as of their assemblies were calculated.
In order to conform to restrictions set regarding the length of the paper, a subset of the overall set of computations and results are shown. Particularly, for the assembly *Base Assembly System*, the standardization index was found equal to 0.585 with non-weighted values for the attributes (see Figure 6). All subassemblies of that system were thoroughly examined to distinguish the most important parts

that affect the resulted value. During the calculations, two (2) parts were detected that could not be classified. Therefore, they were considered as custom parts and for both of them a standardization index equal to 0 was assigned. These parts were considered the most crucial for further investigation regarding their possible standardization.

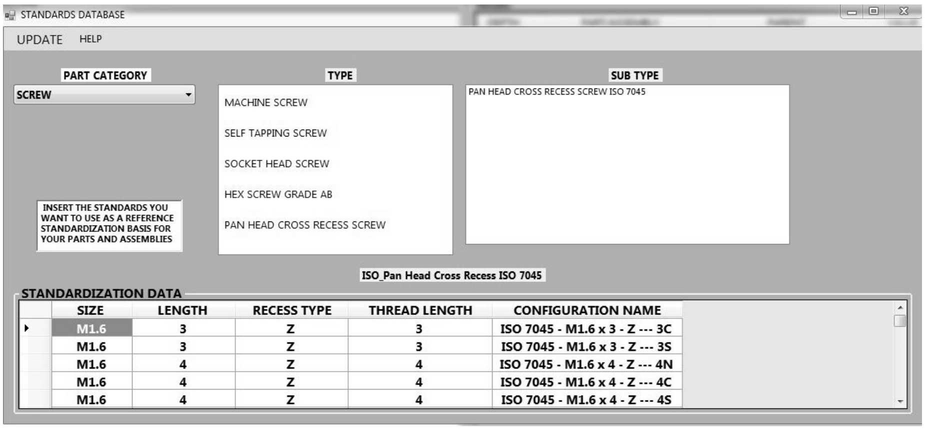

Figure 5. Base Assembly - Tree structure for manipulator gripper base system.

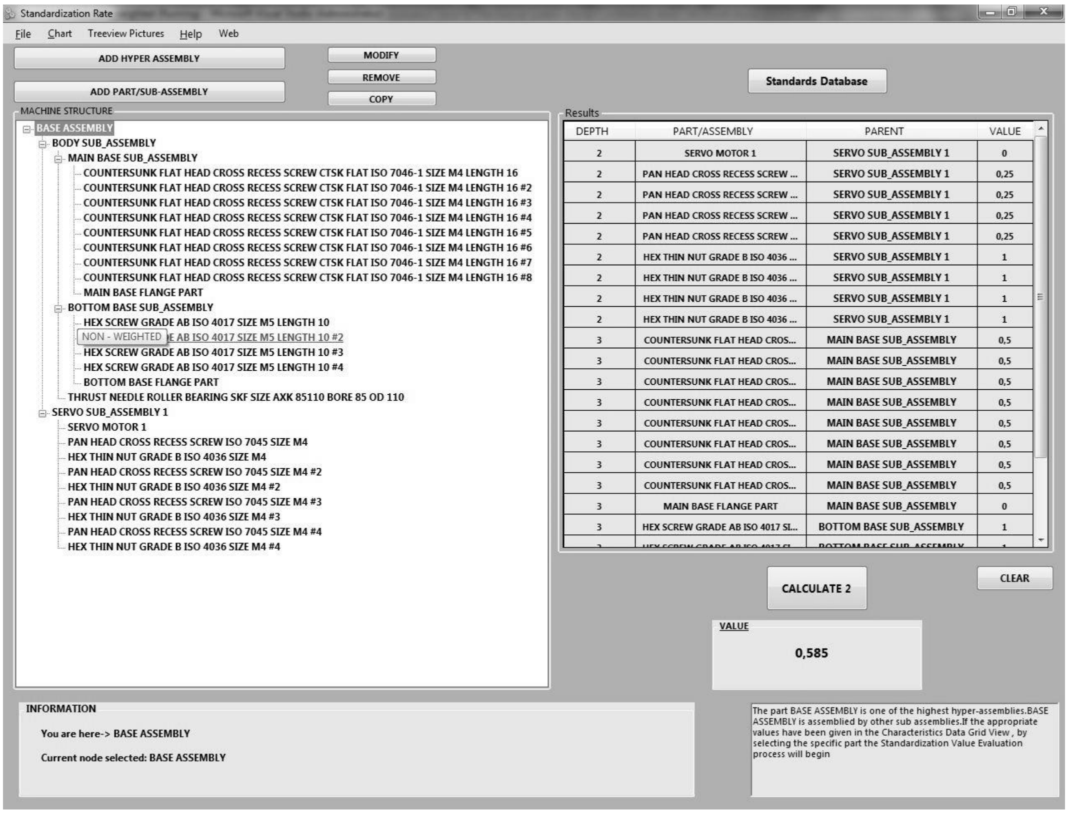

Figure 6. Base Assembly - Calculation of standardization index (non - weighted values).

As already mentioned, the performance of the platform basically relies on a similarity text search based on keywords. Through this search conclusions can be deduced for a selected part of system tree. A low standardization level may be possible due to the insufficient standardization data provision by the engineer during part declaration and assembly formation. This is expected to affect the calculations of the indices. Furthermore, the engineer, during the design phase, may introduce to the system a part that is so poorly standardized that will have to be considered as a new custom part for which standardization information is totally absent. In order to improve design efficiency, the use of standard parts – whenever this is possible - is encouraged. For already existing and operating systems, low

index values of parts and/or assemblies show the need to proceed with proper actions that will improve the standardization level of the system.
The platform can also provide graphical output in the form of pie charts. Then for each assembly of a system – at any level within the tree - a pie may be formed, with each piece of the pie representing either a part or a lower-level assembly (subassembly) (see Figure 7). The pie chart describes the distribution of each of these entities in forming the value of the standardization index of the assembly under consideration. The pie chart provides a simple and quick way of pointing out the elements that require attention due to their lowest standardization classification. For the present case study, custom parts *Main Base Flange Part* and *Bottom Flange Part* present the lowest standardization indexes in the assembly External Towing System (value = 0) (see Figures 6 and 7).

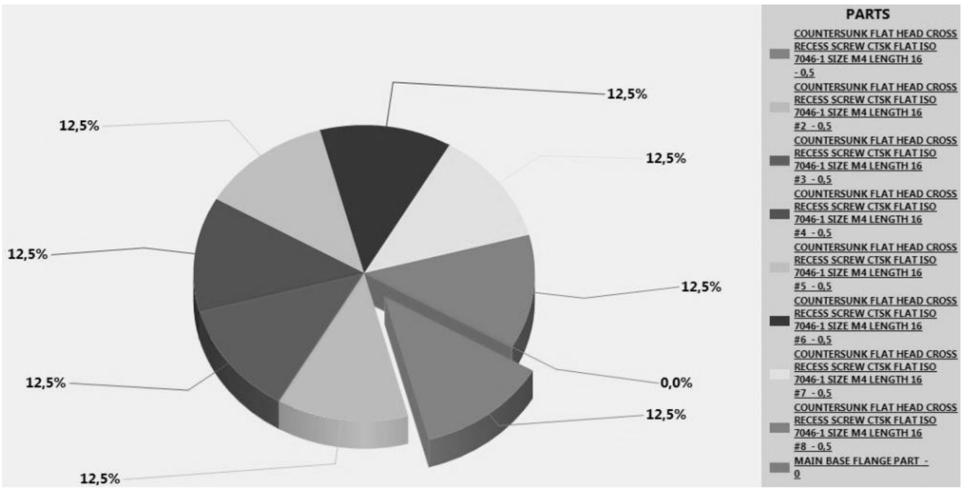

Figure 7. Pie chart for Main Base Sub - Assembly. The existence of custom parts (Main Base Flange Part) diminished the standardization level affecting the overall standardization of the assembly

4 CONCLUSIONS

In the present paper a method is proposed and an interactive environment (platform) is presented for analyzing or composing mechanical assemblies and systems and for providing – for either the whole system or for any of its parts - estimations of standardization level in the form of quantitative standardization indexes. The method uses available standardization data for classes of parts for performing calculations of these indices.
There is a critical mass of available digital standards for mechanical parts. In the present paper and for the case study, some tables of standards from the toolbox of SolidWorks were used and all calculations of standardization indices were performed with respect to these tables.
In order to illustrate the method, a mechanical subsystem of a mobile manipulator base assembly was analyzed. The analysis of the system resulted to a structural tree consisting of 24 parts and 5 assemblies. Each part was examined and its standardization values were estimated and then the standardization index for every assembly was calculated. The results so obtained revealed the most problematic parts that the engineer(s) should focus on and reexamine.
The proposed method may function effectively in reverse engineering processes as an assisting tool for examining the standardization levels of existing mechanical systems and can also contribute in applications aiming at improving the standardization of parts and assemblies during design. It is also expected that its extension will enhance it further by providing: a. a reasoning mechanism for knowledge-based estimation of the standardization levels and b. a second mechanism capable of providing - more or less automatically – advices about the steps that should be followed towards a direction of increasing the standardization levels of the system or of one or more of its parts.
Future work is expected to consider the present contribution as part of a framework for establishing a new “design-for-standardization” consideration of design process. More specifically, a platform could dynamically provide all the necessary information about standardization from early design phases. At

the same time, this platform could validate the relevant decisions and provide advice about how to increase the standardization level of the product being designed.

REFERENCES

ASME International, (2006) ASME B18.24A: Part Identifying Number (PIN) Code System Standard for B18 Fastener Products. New York, USA: The American Society of Mechanical Engineers

ASME, (2003) *ASME Codes and Standards Examples of Use for Mechanical Engineering Students.* Three Park Avenue, New York: The American Society of Mechanical Engineers

C. S. Sharma, Kamlesh Purohit, (2005) *Design Of Machine Elements*. New Delhi: Prentice-Hall of India Private Limited.

Daniel G. Bobrow, (1994) *Artificial Intelligence in Perspective*. 55 Hayward St, Cambridge, MA, United States : MIT Press

Doug Korneffel, (2006), Digital Fastener Library Simplifies New Fastener Standard, *Fastener Technology International*,

Evangelos Petroutsos, (2002) *Mastering Visual Basic.NET*. Alameda,CA:SYBEX Inc.

Hillier, M.S., (2002) Using commonality as backup safety stock, European Journal of Operational Research, vol 136, no 2, pp. 353 - 365

James G. Skakoon, (2000) *Detailed Mechanical Design: A Practical Guide.*New York USA: ASME Press

Kevin N. Otto, Kristin L. Wood, (2000), *Product design: techniques in reverse engineering and new product development*, New Jersey, USA:Prentice Hall

Lee, Seung-Hwan, Park Myeong-Cheol, Lee Sang-Woo, Koo Kyoung-Cheol, (2003) A Model for Measuring Standardization Level of Information and Communication Technology: Korean Case, *Korea Institute of Science and Technology Information.*

M. Anastasopoulos, A. Dentsoras, (2009) Knowledge-based Hierarchical Decompositions of Mechanical Assemblies, *International Symposium on Methods of Artificial Intelligence (AI-METH 2009*), Gliwice, Poland, November 18-20

Matt Lombard, (2010) *SolidWorks 2010 Bible*. Indianapolis, Indiana: Wiley Publishing, Inc.

Maureen A. Breitenberg, (1997) *The Abc's of The U.S. Conformity Assessment System, Office of Standards Services*. Gaithersburg: National Institute of Standards and Technology.

Pat Toms , (1988) Standards and the design process, *DESIGN STUDIES*, Vol 9, No 2, pp 115-122

Paul A. David, Geoffrey S. Rothwell, (1996) Measuring standardization: An application to the American and French nuclear power industries, *European Journal of Political Economy*, Vol. 12 (1996), 291-308

Synodinos, V. C. Moulianitis, RoboCupRescue 2011 - Robot League Team polyMECHanon (Greece)

Technical University Dresden and the Fraunhofer Institute for Systems and Innovations, (2000) , *Economic benefits of standardization Economic benefits of standardization*. Dresden and Karlsruhe: Beuth Verlag.

Wasim Ahmed Khan, Abdul Raouf, S.I., (2006), *Standards for Engineering Design and Manufacturing*. USA: Taylor & Francis Group LLC.

Wazed M.A., and Ahmed S., and Nukman Y., (2009) Commonality Indices in Design and Production Planning. *Journal of Advanced Manufacturing Technology*, Vol.3, No. 1

Wu Yang-Dong, Xie Qing-Sheng, Qi Guo-Ning, Lu Yu-Jun,(2006) Study and Development of Mechanical 3D Standard Parts Library, *5th International Conference on e-Engineering & Digital Enterprise Technology*, Guiyang, China, 16th -18th August, 2006, China: Beijing International Academic Publishers Ltd., pp 437-441