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CONCEPTS, PRINCIPLES AND RULES IN THE ISO GPS SYSTEM – RELATIONS, COHERENCES AND INCOHERENCES

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Abstract: The ISO/TC 213 Technical Committee works on the coherent and systematic development of international standards covering the issues of dimensioning, geometrical tolerancing, surface texture, and metrology. The development of the ISO GPS standards has resulted in the publishing of almost 150 standards. The main task of the committee is to develop new standards with a strong emphasis on their unambiguity and consistency, however, the Committee has not always succeeded in preserving these goals. A brief review of the following set of standards: ISO 8015, ISO 17450 series, ISO 22432, ISO 25378 and ISO 14638, by ISO/TC 213 experts forced Working Group 14 (Vertical GPS Principles) to consider actions related to the in-depth revision of these standards' structure and content. Several inconsistencies were discovered, and the issue of the standards' incoherence has emerged as much more serious than it first appeared. To initiate the work, the authors were asked by WG 14 to find and determine relationships between such fundamental expressions as concept, principle, rule, and term, the usage of which in the standards seems to be inconsistent. However, due to the current standards' structure and content, the authors have encountered problems in clearly identifying these expressions, which make relationship analysis very difficult. This paper discusses the inconsistencies and findings mentioned above. Due to the wide application of the ISO geometrical product specification system (geometrical tolerancing system) in the automotive and aviation industries, this paper aims to highlight the problems experienced by practitioners. Finally, significant changes regarding the approach to the structure of standards are proposed and discussed.

Key words: Geometrical tolerancing, Geometrical Product Specifications, ISO GPS, ISO 17450

1. INTRODUCTION

Established almost 30 years ago, the ISO/TC 213 Technical Committee *Dimensional and geometrical product specifications and verification* works on the coherent and systematic development of international standards covering the issues of dimensioning, geometrical tolerancing, surface texture, and metrology of these quantities in the design, manufacturing, and verification phases [1]. The dynamic development of the ISO GPS standards has resulted in almost 150 standards being published over the years.

The work is performed by 11 *Working Groups* and 4 *Advisory Groups*, which results in the publication of more than 5 new or updated standards per year (some standards are revised 2 or even 3 times during this period). The committee's task is to develop new standards

with a strong emphasis on their unambiguity and consistency with other documents, however the committee has not always succeeded in preserving these goals. The core group in the ISO/TC 213 committee comprises about 25 long-term active members. Additionally, there are many short-term experts, who over the years, have made substantial contributions.

It should be mentioned that Paul Scott of the University of Huddersfield, chairman of ISO/TC 213 *Advisory Group 12 (Mathematical support group)*, has already started work on preparing the new future structure of the ISO GPS System suitable for Industry 4.0. One of the main goals is to have a mathematically sound basis for the ISO GPS standards to be ready for the increasing digitization occurring within the industry. Anticipated changes to the ISO GPS system require embracing the future in both the structure of the next generation of the ISO GPS system, as

well as making GPS a science and allowing smart documents to be usable by both Humans and Smart Systems (Cobots). This will require the application of a formal, logical and mathematical structure for the work of the ISO/TC 213 committee and the development of its standards. It will allow the ISO GPS system to be well founded, being based on rigorous scientific principles and provide an organized 'flow' to the way in which standards reference to each other.

A brief review of the following set of standards: ISO 8015, ISO 17450-1, ISO 17450-2, ISO 17450-3, ISO 17450-4, ISO 22432, ISO 25378 and ISO 14638 by ISO/TC 213 experts forced Working Group 14 (*Vertical GPS principles*) to consider actions related to an in-depth revision of these standards structure and content. Several inconsistencies were discovered, and the issue of the standards' incoherence has emerged as much more serious than it first appeared. To initiate the work, the authors were asked by WG 14 to find and determine relationships between such fundamental expressions as *concept*, *principle*, *rule*, and *term*, the usage of which in the standards seems to be inconsistent. It is worth emphasizing that expression as used in this paper is understood by us as a single word or as a set of words. However, due to the current standards' structure and content, the authors have encountered problems in clearly identifying these expressions, which makes relationship analysis very difficult. Notoriously, the expression *concept* turns out to be a rule or has a double meaning, resulting in concatenations. A further review of standards led the authors to discover additional expressions as *sub-concept*, *tenet* and *assumption*, giving new glaring inconsistencies. There are also some incoherences in the structures of standards.

The authors discovered that the usage of the expressions as principle and rule is not limited only to the listed set of standards. In the course of the work, it has been decided to expand the scope of the work to also show some incoherences in the other standards from the ISO GPS matrix model.

The interesting analysis of the definitions and information given in the ISO GPS standards

is presented in [2]. The paper highlights the evolving nature of information in technical product documentation and is focused on the analysis of [11], which is also considered in this paper. It is underlined in [2] that the hierarchy and interconnectivity of the specification types are still open tasks for standardization.

2. INCOHERENCES IN STANDARD STRUCTURES AND EXPRESSIONS

2.1 Concept, Principle, Rule – three cardinal expressions

The first step to be taken in this paper is to determine what are the meanings and relations among expressions *concept*, *principle*, *rule*, and *term* that are used in the ISO GPS system. It is stated in the *Introduction* to [3] that *For the purpose of this standard, a concept is considered as an abstract idea, a principle is considered as a standardized truth based on concepts upon which rules are based, and a rule is considered as a standardized procedure (for action)*. However, these definitions are included in the non-normative part of the standard [3], which is one of the fundamental ISO GPS standards. Relations between the expressions listed above are not described explicitly anywhere in this standard body. Moreover, in Clause 4 of global standard [5], there is a statement which says that the foundation of the GPS philosophy can be expressed in the four basic GPS tenets, listed as A, B, C, and D. As an example: tenet A states that *It is possible to significantly control the functionality of a workpiece or feature using one or more GPS specifications in the technical product documentation*. Here a question arises: is the expression *tenet* absolutely necessary? There is no significant difference in the message conveyed by expressions *tenet* and *concept*, so *Tenets* A, B, C, and D shall be named as *Concepts* A, B, C, and D. It would be more beneficial to call them directly instead of using enumerations by letters. For example, *Tenet A* could be called *GPS specification concept*.

Besides that, *Clause 4* of [3] introduces an additional expression: *assumption*, without explaining what the logical relationship between the expression *assumption* and other expressions, especially *tenet* and *concept*, is. The expression *assumption* appears in the title of

the *Clause 4: Fundamental assumptions for the reading of specifications on drawings*. Analysing the title of *Clause 4* and considering the location of this *Clause* in the standard before *Clause 5: Fundamental principles*, the expression *assumption* shall be substituted with the expression *concept*. Therefore, this forces a change in the title of *Clause 4* to: *Fundamental concepts for reading specifications on drawings*. Such an improvement would make the [3] structure more concise, reducing redundant expressions. Consequently, in each subclause title, the expression *concept* shall be added. For example, *Subclause 4.3* shall be titled as *Tolerance limits concept*. With such a change, the statement of *Subclause 4.3* *It is assumed for interpretation that the tolerance limits are identical to the functional limits* would be more coherent and logical.

It seems that the occurrence of a particular expression depends on the year of standard release and the responsible task group that worked on development of the specific standard. It can be noticed that the content of the listed documents was not fully reviewed from a consistency point of view. Selected inconsistency examples are presented below. It is worth adding that the list of given examples is not exhaustive. Some inconsistencies can also be found in other standards.

The examples of tenets and assumptions discussed above show that it is not reasonable to introduce both expressions. So, the following initial scheme (Fig. 1) of connections between expressions (wordings) can be determined:

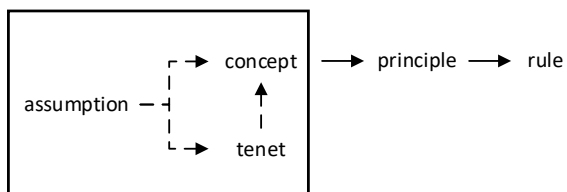


Fig. 1. Current relations between expressions used in the ISO GPS standards. Three framed expressions shall be substituted by one expression *concept*.

2.2 Occurrence of the expression: *Concept*

The titles of a few standards contain the expression *concept* which does not occur anywhere later in the standard body. Nevertheless, it can be said that some concepts appear implicitly in the content of the

documents. This means that the concepts without naming them as concepts are described in the body of the documents.

As an example: the title of [3] contains the word *concept* and it is used only once (as an expression) in *Clause 5.10.1*. Similarly, the title of [4] also contains the word *concept* (Fig. 2), but it is not used as an expression anywhere in the standard body.

INTERNATIONAL
STANDARD

ISO
17450-1

First edition
2011-12-15

**Geometrical product specifications
(GPS) — General concepts —**

Part 1:

**Model for geometrical specification and
verification**

*Spécification géométrique des produits — Concepts généraux —
Partie 1: Modèle pour la spécification et la vérification géométriques*

Fig. 2. Title page of ISO 17450-1 that contains the expression *concepts*.

The title of [5] also contains the word *concept*, and again it is not used (as an expression) inside it, except in Annex A with concept diagrams, where all terms are called *concepts* or *subconcepts*. The absence of the word *concept* or single use of this word inside standards whose titles suggest that the standards contain concepts can be noted also in [5, 6, 7]. What is astonishing in [10] is that there is a *Clause 2* titled *Concepts*. It contains general information about the ISO GPS system, its connection with geometrical properties, and provides a base for the ISO GPS matrix given in [10]. The text in this clause seems to contain a few concepts supplemented by some principles or even rules, which are not directly identified as principles or rules.

2.3 Concepts vs Terms

Clause Terms may be used to present some concepts, and therefore certain concepts can be named identically as terms (by the same string of characters). The *Clause Terms* is compulsory in each ISO standard layout [11]. As an example: *characteristic* as a term is defined in *Clause 3.5* of [4] as *single property defined from one or more geometrical feature(s)*. On the other hand, *characteristic* as a concept is used in *Clause 5* of [9] as follows: *The GPS characteristics enable the definition of the deviations and the dimensions with regard to the ideal features*.

So, the expression *characteristic* is used with double meaning – as a term and as a concept. It would be easier to determine whether the *characteristic* is a concept or a term or both, if the titles of the clauses had contained the expression *concept*. As an example: the title of *Clause 5* in [9] shall be changed to *Concepts of GPS characteristics*. However, it is justified that the same expression, e.g. *characteristic*, with an additional adjective is used in the ISO GPS system as a separate term. The next clear example of such an approach can be found in [12] – *manufacturing specification* is defined as term 3.9 in the *Clause 3*, and it is used as a concept in *Subclause 4.3*. The comparison of standard [4] released in 2011 with standard [12] from 2018 shows how the titles of the clauses have been slightly improved by the committee experts gaining experience over time. Three detailed block diagrams (ISO 25378 Annex A) include nine expressions (*GPS characteristic*, *basic characteristic*, *condition*, *intrinsic characteristic*, *situation characteristic*, *location characteristic*, *orientation characteristic*, *population characteristic*, *individual characteristic*) that are included in *Clause 3* as terms, however the key to the diagrams with descriptions of the symbols (modified rectangle with two wavy edges instead of two longer straight edges/sides) used in the flowchart describes them as concepts. This confirms our statement, that a term can be a concept as well.

2.4 Contents page and naming of Clauses

The *Contents* page in every standard shall give the reader crucial information about the document, but in some cases the contents page is not written in a consistent way. This is the next

incoherence in a few of the standards developed by ISO/TC 213. The standards [13] and [14] are considered to show disorder in several standard structures. The *Clause 5* in [13] is titled *Principles* but it includes subclauses titled *Concepts* and subclauses titled *Rules*. This is contrary to the structure of the relationships between expressions presented in Fig. 1, where principles shall be based on concepts and not vice versa. The usage of *Subclause 5.2 Concepts* in *Clause 5 Principles* (Fig. 3) is not acceptable.

ISO 5458:2018(E)

Contents	Page
Foreword	iv
Introduction	v
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Symbols and specification modifiers	3
5 Principles	3
5.1 General	3
5.2 Concepts	4
5.3 Rule A: for position specification	4
5.4 Rules for pattern specification	5
5.4.1 General	5
5.4.2 Rule B: constraints	5
5.4.3 Rule C: indication of a single indicator pattern specification	6
5.4.4 Rule D: indication of a multiple indicator pattern specification	8
5.4.5 Rule E: indication of multi-level single indicator pattern specification	12
5.5 Pattern characteristic	17

ISO 1660:2017(E)

Contents	Page
Foreword	iv
Introduction	v
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Symbols	2
5 Rules for profile tolerancing	3
5.1 General	3
5.2 Default rules for profile tolerancing	4
5.2.1 Rule A: Definition of the theoretically exact feature (TEF)	4
5.2.2 Rule B: Type of tolerated feature	5
5.2.3 Rule C: Definition of the tolerance zone	5
5.3 Rules for profile tolerancing using additional specification elements	7
5.3.1 Rule D: Toleranced feature specification elements	7
5.3.2 Rule E: Unequally disposed tolerance zone	8
5.3.3 Rule F: Linear tolerance zone offset	8
5.3.4 Rule G: Angular tolerance zone offset	8
5.3.5 Rule H: Variable tolerance zone width	8
5.3.6 Rule I: Filtered feature specification elements	8
5.3.7 Rule J: Association and parameter specification elements	9
5.3.8 Rule K: Associated toleranced feature specification elements	9
5.3.9 Rule L: Non-rigid part	9

Fig. 3. Pages *Contents* in ISO 5458 (top) and ISO 1660 (bottom) – compare the titles of Clauses 5 and titles of Subclasses.

On the other hand, it is worth underlining that in [14], specifications of rules are not mixed with descriptions of concepts because rules are given in completely separate clauses. The layout of the *Contents* in [13] is not based on the hierarchy between expressions (Concept -> Principle -> Rule, see Fig. 1) given in [3] in the *Clause Introduction*. Unfortunately, in [13], *concepts* are discussed in *Subclause 5.2 Concepts* of *Clause 5 Principles* and are on the same

hierarchy level as *Rules* (Subclauses 5.3 and 5.4).

Two possible solutions can be applied in this case. The relationships between expressions should be maintained in a hierarchical content layout (Fig. 4a) or each expression should be fully described in a separate clause in the content layout (Fig. 4b). It seems that the first approach (Fig. 4a) is better as it emphasises and enforces the ranked relationship between the different expressions established in [3].

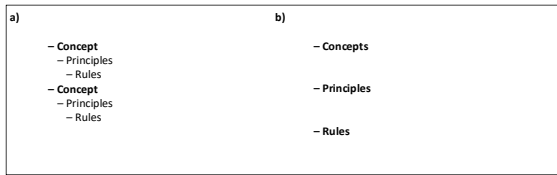


Fig. 4. Options for the correct layout of *Contents* in ISO GPS standards a) Hierarchical (ranked) layout b) Class layout.

2.5 Structure of terms related to the term *Geometrical Feature*

Another example that raises considerable ambiguities is the structure of the family of terms belonging to the expression *geometrical feature*. This family is listed in two standards published in the same year (2011) – [4] and [8]. The first contains twenty-one terms related to *geometrical feature* while the second one contains twenty-six terms. And it is not only the issue of the number of terms that raises ambiguities: the links (relations) between various types of *features* shown in both standards are in some cases significantly different (Fig. 5). An example can be seen in the substructure of the term *ideal feature*. This matter needs more detailed analysis. Therefore, it will be presented in another paper.

When terms defined in standards are considered, it is necessary to underline the problem of different definitions of the same term in different standards which belong to the ISO GPS system. In some cases, differences vary a lot, however, even minor changes in description cause confusion related to the reception of the definition. As an example: the term *integral feature* is defined in [4] as a *geometrical feature belonging to the real surface of the workpiece or to a surface model*. In [8] the same term is described as *surface or line on a surface*. Taking

into account the definition of geometrical feature (*point, line, surface, volume, or a set of these items*) given in [4] the definition of *integral feature* presented in [4] shall be rewritten

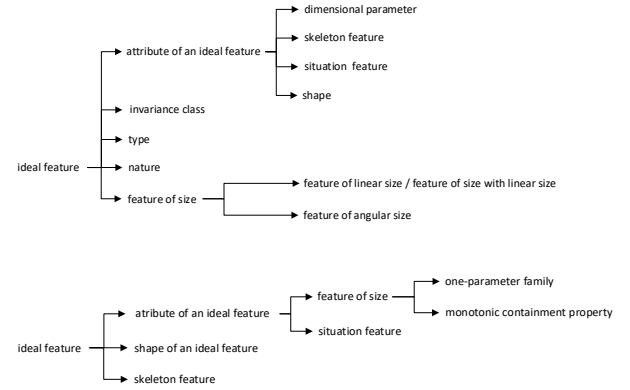


Fig. 5. Structure of terms related to the term *ideal feature* according to ISO 17450-1 (top) and ISO 22432:2011 (bottom).

as *point, line, surface, volume or a set of these items belonging to the real surface of the workpiece or to a surface model*. The definition of the term *integral feature* in [8] seems to be reduced and incomplete concerning the needs of the geometrical product specification system. Such inconsistency shall not occur in the standards.

2.6 Formulation of Principles and unexpected occurrence of additional Principles

The list and content of the principles set given in [3] are at least disputable. It appears that the importance and meaning of some principles are not equally useful (relevant). Some principles address general approaches (e.g. *Feature principle*), while others focus on specific issues (e.g. *Decimal principle*). What is very important in the principles formulation is that they all shall be described concisely. They shall be defined briefly, and complementary information shall be given only in the *Notes*. As an example of a principle that is too long, the *Definitive drawing principle* can be considered. It contains three descriptive paragraphs. Authors believe that the essence of this principle can be summed up in the following sentence: *The drawing is definitive, therefore requirements not specified on the drawing cannot be enforced*. The rest of the paragraphs included in the original standard text shall be moved to the *Notes*.

During the standards review, two more inconsistencies have been discovered. *Subclauses 4.1 and 4.2 of [9] contain two new principles, called General principles of the specifications and General principle of the characteristics.* The content of these two principles is similar to the *Feature principle (Subclause 5.4 of [3])*. So, actually, those principles from [9] are superfluous because they do not contain any new statements.

3. APPROACHES AND POSSIBLE SOLUTIONS

Taking into account all the inconsistencies presented above, the relationships among expressions (*concept, principle, and rule*) shall be moved from introduction into a normative Clause in 8015 [3]. The expressions as such shall be stated explicitly in the relevant ISO GPS standards. The amount of findings shows that a proper systematic revision of the ISO GPS fundamental standards is needed.

The important part of this paper is a proposal which can be used as a reference for actions planned in the ISO/TC 213 Working Group 14. The authors have identified usage, meaning, and relation between the expressions *concept, principle, and rule*. To facilitate understanding of the issues discussed, an example based on the everyday experience of each car driver and unrelated to the geometrical product specification is presented in Fig. 6.

a)

5. C1 *Road traffic safety concept*. Road traffic shall be organized in a way that minimizes the risk of accidents.
[The following principles and respective rules are derived from this concept:]
5.1. P1 *Separate roads principle*. Cars, bicycles and pedestrians should move on their designated roads.
5.1.1. R1 *Priority rule*. When the roads used by cars, bicycles, or pedestrians cross, the pedestrians have priority.
5.1.2. R2 *Right-side rule*. Cars, bicycles, and pedestrians shall keep as close as possible to the right side of their road/track.
5.1.3. etc.
5.2. P2 *Priority order principle*. The movement order is determined by: the police officer, traffic lights, road signs, and the right-hand rule.
5.2.1. R1 *Police officer hand signal rule*. The meaning of police officer hand signals is given in the table of police officer hand signals.

5.2.2. R2 *Traffic lights rule*. A green light means: you can drive/go, a red light means: stop and wait for the green light.
5.2.3. R3 *Road signs rule*. The meaning of road signs is given in the table of road signs.
5.2.4. R4 *Right-hand rule*. Priority is given to those approaching from the right side.
5.2.5. etc.
6. C2 etc.

b)

5 Concepts
5.1 C1. *Road traffic safety concept*. Road traffic shall be organized in a way that minimizes the risk of accidents.
5.2 C2. etc.
[From these concepts the following principles are derived:]
6 Principles
6.1 P1. *Separate roads principle*. Cars, bicycles and pedestrians should move on their designated roads.
6.2 P2. *Priority order principle*. The movement order is determined by: the police officer, traffic lights, road signs, and the right-hand rule.
6.3 P3. *Emergency vehicles principle*. Emergency vehicles always have priority.
6.4 P4. etc.
[From the listed principles, the following rules are derived:]
7 Rules
7.1 R1. *Priority rule*. When the roads used by cars, bicycles or pedestrians cross, the pedestrians have priority.
7.2 R2. *Right-side rule*. Cars, bicycles and pedestrians shall keep as close as possible to the right side of their road/track.
7.3 R3 *Police officer hand signal rule*. The meaning of police officer hand signals is given in the table of police officer hand signals.
7.4 R4. *Traffic lights rule*. A green light means: you can drive/go, a red light means: stop and wait for the green light.
7.5 R5. *Road signs rule*. The meaning of road signs is given in the table of road signs.
7.6 R6. *Right-hand rule*. The priority is given to those approaching from the right side.
7.7 R7. etc.

Fig. 6. Illustration of the conceptual relations between expressions *concept, principle* and *rule*.

a) Hierarchical (ranked) layout b) Class layout. Compare with Fig. 4.

(C1 denotes Concept No 1; P1... denotes principle No1, ...; R1... denotes rule No1, ...).

Similarly, to the given example of *Road traffic safety concept*, the concept of the ISO GPS system is to provide the tools used to define how far the actual geometry of a manufactured workpiece can be different from the nominal geometry. Based on the authors' finding both expressions, those of *tenet* and *assumption*, can

be merged and unified through the expression *concept* (Fig. 1) which leads to the improvement that is illustrated by the following example.

Firstly, the basic concept (currently called as *tenet B* [5]) shall be applied. It states: *A GPS specification for a GPS characteristic shall be stated in the technical product documentation. The workpiece or feature is to be considered acceptable/good when the specification is fulfilled. Only that which is explicitly required in the technical product documentation shall be taken into account. The actual GPS specification stated in the technical product documentation defines the measurand.* This concept underscores the necessity for precise and unambiguous specifications, particularly when applied to critical function features. Any subsequent operations, such as further fabrication or assembly, cannot be performed without meeting the requirements of this concept. So according to this concept, a GPS characteristics shall be indicated for the top surfaces of the workpiece (Fig. 7).

Secondly, the *Feature principle* [3] shall be employed. It states: *A workpiece shall be considered as made up of a number of features limited by natural boundaries. By default, every GPS specification for a feature or relation between features applies to the entire feature or features; and each GPS specification applies only to one feature or one relation between features* (Fig. 7a). This default can only be overridden by explicit indications on the drawing (Fig. 7b). In the given example, the flatness of the indicated surfaces will be specified following more detailed instructions (rules).

Finally, rules which can be found in [15] provide strict guidelines on the application of particular specifications. The relevant rules are described in *Clause 8 (Geometrical specification indication)* and *Subclause 17.3 (Flatness specification)*. *Clause 8* defines the correct usage of standardized symbols and their appropriate indications in technical drawings. These rules are applied in Fig. 7a and respectively in Fig. 7b.

Subclause 17.3 provides the definition of geometrical specification of flatness: *The tolerated feature can be an integral feature or*

derived feature. The nature and shape of the nominal tolerated feature is explicitly given as a flat surface, which is an areal feature. The tolerance zone defined by the specification is limited by two parallel planes a distance t apart. This definition describes the design intent when the flatness tolerance is specified.

The design intent in Fig. 7b is to apply the flatness tolerance for two top surfaces simultaneously (not independently). Therefore the last sentence of *Feature principle* [3] cited above is supplemented by the rule provided in *Subclause 8.2.2.1.2 Combination specification element* that states: *Where one combined tolerance zone is applied to several separate features, ..., the requirement shall be indicated by the symbol CZ for combined zone.*

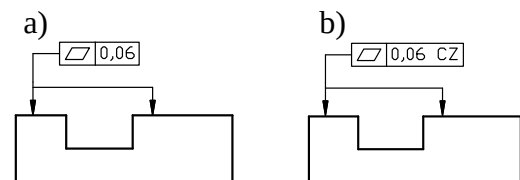


Fig. 7. a) The flatness tolerance is by default applied independently to each surface. Two individual requirements are specified. b) Due to modifier CZ, one combined flatness tolerance zone is applied to two separate features. One requirement is simultaneously applied to two surfaces (The workpiece is not fully tolerated, only tolerances relevant to illustrate the practical application of expressions *concept*, *principle* and *rule* are indicated).

4. SUMMARY

This paper presents discovered ambiguities in the current versions of some standards developed by the ISO/TC 213. This includes standard structures and expression vagueness (*concept*, *principle*, *rule*, *tenet*, etc.), the meaning and relations between these expressions as well as other inconsistencies between discussed documents.

The inconsistencies were found when verifying only 8 standards, which is about 5% of all the ISO GPS standards. The similar analysis of all standards would likely lead to the identification of more ambiguities. This shows the potential scale of inconsistencies in the ISO GPS system standards. The progress of the ISO/TC 213 work is not always systematic because the experts are contributing voluntarily

and do not always have enough time to spend on the development of particular standards. On the other hand, new computer tools enable the creation of databases with expressions and their definitions as well as systematic searches in the body of many standards that can help to detect potential inconsistencies and eliminate them.

Combining all ISO 17450 series and other standards analysed in this paper into fewer documents may help to remove the indicated ambiguities. This will produce more consistency in the ISO GPS system's fundamental standards. Naturally, it would require a huge work including clarification and systematization of all documents.

Research in the field of understanding ISO GPS standards [16] shows that users of the standards need a comprehensive set of well phrased information included in concise documents which allow for much easier overview of contents. It is also worth noting that research carried out on the terminology used in standards developed by other ISO technical committees has also revealed many inconsistencies [17].

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