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ANALYSIS AND COMPARISON OF SYSTEMS ENGINEERING APPROACHES

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Abstract: *Objective of this contribution is to describe a method to compare and categorize existing as well as future Systems Engineering approaches in order to support the systematic derivation of suitable implementation within their company. The described method of comparison is applicable to many kinds of Systems Engineering approaches and helps to get a perception on how different organizations and people understand and use Systems Engineering.*
Key words: *comparison, systems, engineering, approaches*

1. INTRODUCTION

Starting with the first use during the development of the telephony at Bell Labs in 1940 thru the NASA Apollo programs until today, Systems Engineering (SE) has become more and more important. Along with technological progress technical products, production plants and any kinds of systems have gotten and are getting more and more complex (Blanchard, 2004). The purpose of SE is to help control this complexity during the entire lifecycle of a system.

Due to the fact that there is not one internationally accepted definition of SE, many organizations and engineers have a different understanding of what SE actually is and how it may be conducted. Purpose of this contribution is, to introduce a methodology that helps an engineering organization to evaluate SE approaches in order to find the best fitted one for their individual purposes and to serve as basis for discussions within the SE community.

2. DESIGN AND RESULT

In order to be able to assess the degree of support an engineering organization gets when applying a certain SE standard, a design research-based approach was used to develop a method to compare SE practices. This model consists of characteristics, which allow the comparison of SE approaches by using binary metrics. Each metric is associated with exactly one of four basic characteristics, that are sufficiently selective in order to differentiate the similarities and distinctions of competing SE approaches.

In order to identify these characteristics and their metrics, nine approaches were researched and analyzed in detail:

- VDI 4499 (VDI 4499, 2008)
- INCOSE Handbook (Haskins et al., 2007)
- VDI 3695 (VDI 3695, 2008)
- VDI 2206 (VDI 2206, 2004)
- Efficient Engineering (Fay, 2009)
- NA 35 (NA 35, 2003)
- ISO 15926 (ISO 15926, 2004)
- INCOSE Vision 2020 (Crisp, 2007)
- Space Engineering (ECSS-E-ST-10C, 2009)

In order to find significant characteristics, first of all the common parts of the approaches have been elaborated and classified by extracting their describing features, for example their lifecycle or project management aspects. Subsequently all those occurrences (for example common types of definitions, processes, activities, etc.) have been marked as *universal* or *generally accepted* by many approaches. Finally all remaining passages were extracted as binary metrics (allowing TRUE or FALSE answers) and analyzed in detail. They appear only in a few – sometimes just one – approach, and are therefore important for the characterization and highly selective in nature.

In order to structure the gathered findings, these metrics have been clustered into the following four groups called characteristics.

- Segments – The corresponding metrics verify that the most common, appellative parts of a SE approach (i.e. definitions, aim, methods, processes, activities, and trends) are available as part of the approach to be analyzed.
- Properties – contain all kinds of distinctive features, which can be found in an SE approach (for example: Is the approach plan driven? Is it iterative? Is it model based? Is it document based?).
- Processes – helps to determine if the analyzed approach covers certain parts of an universal lifecycle model and the occurring management processes (for example: Is the product development or product planning affected? Does the approach deal with Supply-Chain-Management?).
- Industries – helps to describe, to which industries the analyzed approach may be applied (for example: automation industry, process industry, healthcare industry, etc.).

It is important to point out, that the sum of characteristics mentioned above constitutes one of many possible engineering support models, which could be extracted from the analyzed approaches. Tab. 1 shows an overview of all characteristics as well as their associated metrics.

3. APPLICATION OF METHODOLOGY

The overall model, consisting of four characteristics and 46 associated metrics, has been applied to the approaches they have initially been extracted from. The results can be found in Tab. 2. After analyzing the result, the approaches can be assigned to one of three diffuse, not entirely and clearly defined groups:

The first group consists of *incomplete* approaches, in the sense that they don't define methods, processes or activities, but instead take a look into the future of Systems Engineering (e.g. INCOSE Vision 2020) or give an abstract and general overview about not just SE but the whole topic of engineering (e.g. Efficient Engineering).

The second group consists of approaches, which do have exact definitions of methods, processes and activities. They do however concentrate on *just one* method, process or model (e.g. ISO 15926), *just one* industry (NA 35 - process industry, Space Engineering - aerospace industry) or *just one* application area (VDI 2206 - product/plant development in order independent engineering).

Characteristic	Sub Characteristic / Metric
Segments	Are there… ▪ definitions in the approach? ▪ aims in the approach? ▪ methods described in the approach? ▪ processes described in the approach? ▪ activities described in the approach? ▪ trends described in the approach?
Properties	Are the processes iterative (with loops)? Are there standardizations in the approach? Does the approach contain the Life-Cycle aspect? Is it a… ▪ document based approach? ▪ model based approach? ▪ plan driven approach? Is the… ▪ approach based on a platform-concept? ▪ approach software based? ▪ V-model used in the approach? Is there a… ▪ leading subsection in the approach? ▪ process description / modeling? ▪ product or plant description / modeling? ▪ systems engineering organization? ▪ top-down concept in the approach?
Processes	Does the approach… ▪ handle project management? ▪ handle project implementation? ▪ handle non-project management? ▪ handle supply-chain-management? ▪ handle quality assurance / management? ▪ handle risk management? ▪ handle configuration management? ▪ handle change management? ▪ handle customer relationship management? ▪ handle knowledge management? ▪ handle enterprise environment management? ▪ handle investment management? ▪ handle resource management? ▪ deal with customer requirements? Is the… ▪ product development affected? ▪ production planning affected? ▪ production start-up affected? ▪ production operation affected? ▪ order processing affected?
Industries	Is the… ▪ automation industry affected? ▪ process industry affected? ▪ healthcare industry affected? ▪ mobility industry affected? ▪ aerospace industry affected? ▪ automobile industry affected? ▪ aircraft industry affected?

Tab. 1.Characteristics and associated sub characteristics for the comparison of systems engineering approaches

The remaining approaches (INCOSE Handbook, VDI 3694 and VDI 4499) constitute the third group. These approaches are defining methods, processes and activities not specifically for certain industry or applications. They are instead holistic in nature and can be used for many different engineering tasks and are applicable to many engineering organizations.

Approach	# of TRUE values per Characteristic				Total
	Segments	Properties	Processes	Industries	
VDI 4499	5	10	11	7	33
INCOSE Handbook	5	7	13	7	32
VDI 3695	5	6	14	2	27
VDI 2206	5	10	2	7	24
Efficient Engineering	4	6	5	7	22
NA 35	5	5	6	1	17
ISO 15926	2	4	9	1	16
INCOSE Vision 2020	3	2	2	7	14
Space Engineering	5	5	2	1	13

Tab. 2.Results of the systematic comparison of nine system engineering approaches

4. CONCLUSION AND OUTLOOK

The described methodology allows the evaluation of systems engineering approaches using an engineering support model consisting of 4 characteristics and 46 binary metrics. It helps engineering organizations to determine which SE approaches might be right for their individual targets and business needs; a problem which – to the authors knowledge – has not been covered in literature up until now.

In order to enhance the methodology further, the binary metrics will in the near future be associated with relative weights determined by quantitative research methods using a large, international expert sample.

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