STRATEGIES FOR IMPROVING THE QUALITY OF TRANSFERRED 3D MODELS IN THE CONTEXT OF THE TOOL INDUSTRY

Claudia KLEINSCHRODT, Reinhard HACKENSCHMIDT, Frank RIEG

University of Bayreuth, Chair of Engineering Design and CAD

Universitätsstraße 30, Bayreuth, Germany

Abstract

Due to the increasing digitalisation, the availability of high-quality data is gaining in importance. However, nowadays suppliers of technical products have a lot of work to do to provide all necessary information for electronic purchasing, technical documentation or as input for the digital factory of their customers. A fundamental problem is the exchange of 3D CAD data. Studies show that by crossing system borders with neutral data formats, information is often distorted or even lost. Starting from these findings the respective causes can be identified and strategies to increase data quality can be developed.

Keywords: data exchange, 3D model, STEP, tool industry

1. INTRODUCTION

In the middle of the 18th century the industrial age began. Since then, the world economy has been revolutionised several times by ground-breaking inventions such as the steam engine, the assembly line or the computer. These innovations lead not only to economic but also to social changes. In this historical context the current developments of digitisation and networking to intelligent value chains is often titled as the fourth industrial revolution or "Industry 4.0" [1]. This digital transformation shows great potential: flexible, individualised and optimised production, increased resource efficiency, new business models and modified work structures will determine the future. However, many challenges remain to be solved before this becomes reality [2].

In order to realise the vision of an end-to-end digital integration of engineering across the entire value chain, a consistency of the information generated throughout the life cycle of a product is necessary. A precondition for this is the error-free transfer of the relevant data. In consideration of the manufacturing industry, the exchange of tool models plays a crucial role. For instance, for the management of server-based catalogues or the virtual commissioning of machines it is important to transfer the developers' 3D models to the operators [3].

2. BACKROUND

Data exchange is the foundation of a networked world. Through the global operating range of companies, complex supplier structures, media or system breaks within processes, the topic also gains relevance. This applies to all sectors in which data is generated. In these investigations the example of the tooling industry is used. Due to the complexity caused by the large number of tools, countless involved companies and various software used, the exchange of tool data has enormous potential for optimisation within the manufacturing industry.

2.1 3D models in tool industry

Virtual commissioning of single machine tools, machining simulations for process design or the virtual planning of complete production systems requires the virtual images of the real components, the so-called digital twins. These digital twins accompany their real model through their life cycle and contain all the information that the real component includes [4,5].

Depending on the future use, various demands are placed on the 3D CAD model of a tool. Committees of experts try to determine the necessary requirements to define them in standards. In Germany, the series DIN 4000 [6] and DIN 4003 [7] have been developed. The international description of the features is given in the parts of ISO 13399 [8]. In these standards the criteria such as the structure of the models, different anchor points or colour assignments are defined. These regulations are intended to standardise crucial references for further use while protecting the company-internal know-how and enable the developer to work creatively. Figure 1 shows the example of a standard tool model according to DIN 4003-87 [9].

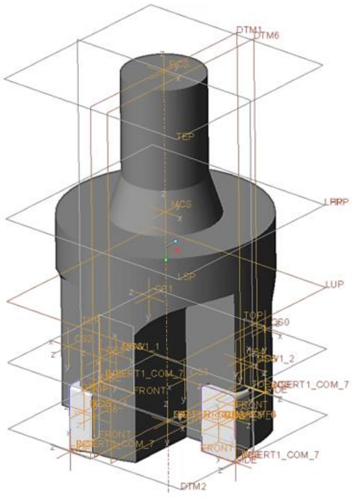

Figure 1 – End mills for indexable inserts according to DIN 4003-87 [9]

The 3D model, as its real model, will be sent to the customer, installed into virtual machine tools and integrated into digital processes. Therefore the 3D CAD model has to be transmitted to different departments [5].

2.2 Data transfer of a 3D model

In general there exist two ways to transfer data between two systems: By using native, system-specific data or through conversion into neutral, system-independent formats (figure 2) [10].

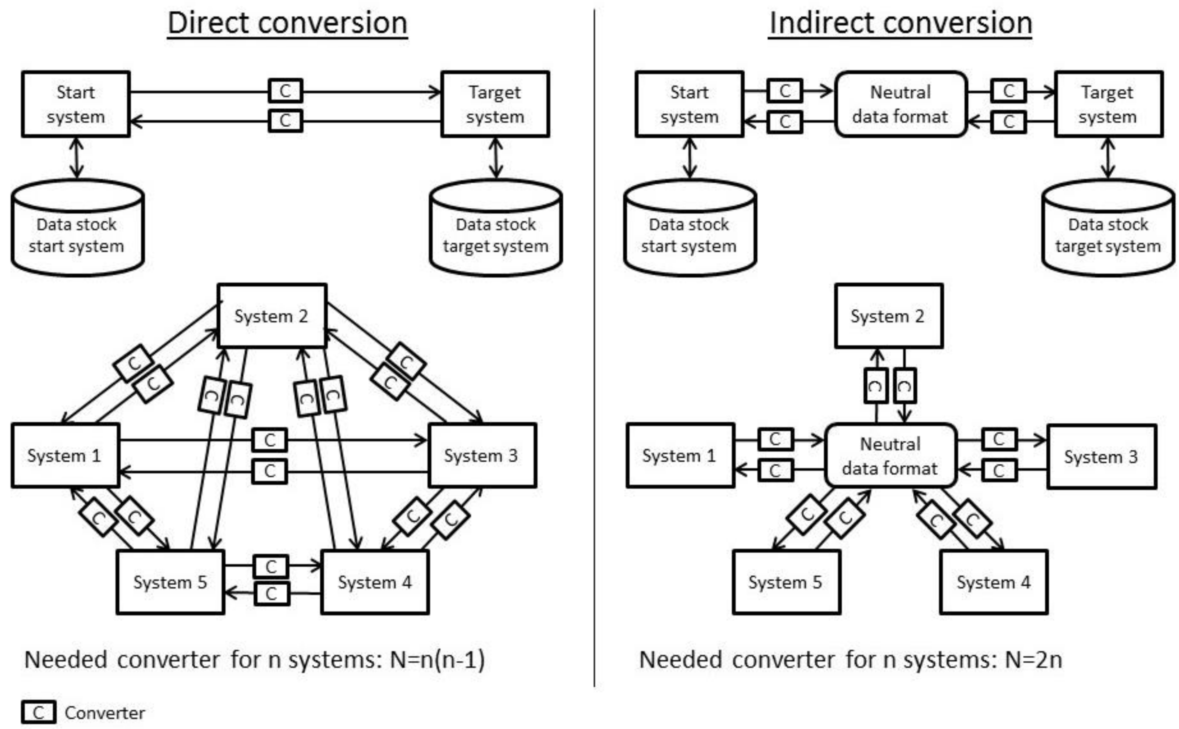

Figure 2 – data exchange via direct and indirect conversion [after 10,11]

Due to the enormous system diversity of CAx software used in the industry, the virtual tool will have to bridge several system boundaries. Every system break causes a conversion of data and means a critical point in data continuity and completeness of information [10]. In direct conversion, interfaces are used which allow a direct translation of the start system's native format into the native format of the target system. In this case a maximum of the information can be transmitted. For each pairing, two direct converters are required, which lead to a converter number of *n (n-1)* in the case of n systems. In view of the large number of systems used in the industry and the complexity of existing supplier structures, this approach is not intended. In practice, mostly neutral formats are used to exchange data. This method requires exactly two interfaces per system: one for importing and one for exporting the system-independent format. However, this type of data transfer often results in a corruption or even loss of data [10,11].

The STEP format (Standard for the Exchange of Product Model Data) takes a special value in the range of neutral formats for the transfer of 3D data. This format has existed as an ISO standard (ISO 10303) since 1992. From the outset it has been built as an extensive standard and nowadays it is implemented in almost every CAx program. The core of the STEP format is called Application Protocols (AP), which are responsible for the representation of various information in an exchange file. AP 203 (Configuration controlled 3D designs of mechanical parts and assemblies), AP 214 (Core data for automotive mechanical design processes) and AP 242 (Managed Model-based 3D Engineering) are the relevant application protocols to the tooling industry [10,12]. AP 214 is currently mainly used for data exchange because AP 203 is considered as obsolete and AP 242 has been published in 2014, so it is too recent to be comprehensively implemented. That is why the following investigations will consider the data exchange via the neutral format STEP AP 214.

These investigations are absolutely necessary because, in spite of the possibilities and the great potential of the STEP standard, studies show that there are often transfer problems in practice [3,13,14]. These errors result in manual multiple reworking of the virtual model and are preventing a development towards Industry 4.0.

2.3 State of the art

At the international level, organisations like the ProSTEP iViP association and the CAx Implementer Forum are focused on the general problem of data exchange of 3D models via different standards. Large-scale benchmark tests are used to identify the deficiencies of different interfaces and to develop solutions. In these studies, test objects from various systems were exported and then imported again, in order to assess the quality of the STEP processors. The criteria used in these test rounds change frequently and are for example a correct transfer of volume, surface content or certain display properties. The resulting documents, such as guidelines and recommendations, are then available to the members. ProSTEP iViP discontinued the studies on STEP AP 214 in 2003. The CAx Implementer Forum continues the investigations for AP 214 [13,14].

Due to the use of changing systems, different versions and varying requirements at different test rounds over a long period of time, the individual results are not systematically comparable with each other and thus cannot be checked against current studies. In order to establish a comprehensive comparability, it is important to use a uniform test method. Furthermore, changing factors, such as exact system versions, must be documented in a way that is accessible to all interested parties.

3. APPLIED METHOD

To address the problem of insufficient quality of the data transfer, the following steps are used:

1. Definition of data exchange requirements
2. Compatibility checks and exhaustive analysis of the exchange results
3. Classification of the problems by their cause
4. Development of solution strategies depending on the classification

3.1 Requirements for data exchange

Depending on the sector and the further use of the models, different requirements are placed on the exchange result. Just for the pure representation of the 3D model, for example for marketing purposes, the transfer of the external appearance is sufficient. For additional functional applications such as simulations or automated data storage, higher demands are placed on the models. The German tooling industry has agreed on common transfer characteristics in the series of standards DIN 4000 and DIN 4003. This standards define various anchor points such as the primary coordinate system (PCS) or the cutting reference point (CRP). In addition, colours with defined RGB (red green blue) values are used for the function assignment of individual components to allow an automated interpretation. For instance, the non-cutting part is coloured with a dark grey (RGB: 127/127/127), the cutting part with a light grey (RGB: 204/204/204) and the cutting edge line with blue (RGB: 0/0/255). Depending on the classification of a tool other attributes are claimed in the standard [6,7].

In order to generate universal results for the tooling industry as well as across all sectors, the characteristics required in the series of standards are abstracted. Coordinate systems, levels, points, axes, sketches and annotations serve as verification features. The colour values defined in the standards are used as controlled colours. The characteristics to check are selected depending on the demand and the models to be tested.

3.2 Compatibility checks – an example

In order to improve the quality of exchanged data, the second step is to identify the points of failure. An effective method for this is the implementation of compatibility checks in which files (exported from numerous systems) are reimported by several systems. This approach is based on existing methods of the ProSTEP iViP association and the CAx Implementer Forum. Nevertheless, a comparison with these studies is avoided because of the reasons mentioned in chapter 2.3.

Table 1 shows a resulting test matrix. In this case the components were created by four different companies in their standard system and exported as STEP-file. The CAD software systems used are CATIA V5 (Dassault Systèmes), Creo 3.0 (PTC) and NX 10 (Siemens). In this analysis, the colour values, which are defined in DIN 4003, were verified. When looking at the matrix, it is noticeable that the exported data of two companies (B and D) do not contain information about the colour blue. So it is logical that this colour does not appear in the imported models. However, company D uses the same software as company C and their file contains the necessary information. It can also be determined that software 3 swiches the RGB value of the dark grey from 127/127/127 to 125/125/125. The deviations of the colour values are still within the tolerance, nevertheless, a falsification took place.

Table 1 – Compatibility check of STEP-files, which were exported from different companies using different software systems (considering colour transfer)

Results of data transfer via STEP (characteristics according to DIN 4003)	EXPORT			Import								
				Software 1			Software 2			Software 3		
Software 1 (Company A)	+	+	+	+	+	+	+	+	-	+	●	-
Software 2 (Company B)	+	+	-	+	+	-	+	+	-	+	●	-
Software 3 (Company C)	+	+	+	+	+	+	+	+	+	+	●	+
Software 3 (Company D)	+	+	-	+	+	-	+	●	-	+	●	-

\+ transferred exactly ● transferred within the tolerance - transferred insufficiently

To validate the results of the compatibility tests by using original firm data the tests are repeated with a self-generated representative test object. The results of this study are shown in table 2. A lot of problems can be solved by using adjusted settings and a suitable model construction. However, the insufficient colour transfer of the colour blue from software 1 to the other two systems as well as an incorrect representation of the dark grey in software 3 remain.

Table 2 – Compatibility check of STEP-files of a representative test object (considering colour transfer)

Results of data transfer via STEP (characteristics according to DIN 4003)	EXPORT			Import								
				Software 1			Software 2			Software 3		
Software 1	+	+	+	+	+	+	+	+	-	+	●	-
Software 2	+	+	+	+	+	+	+	+	+	+	●	+
Software 3	+	+	+	+	+	+	+	+	+	+	●	+

\+ transferred exactly ● transferred within the tolerance - transferred insufficiently

Another study considers the transfer of different structural elements by using a representative test object (figure 3). This 3D model in total contains 34 constructive attributes, like coordinate systems or planes, and eight colours for checking the quality of data transfer. The features are based on the requirements listed in DIN 4000/4003.

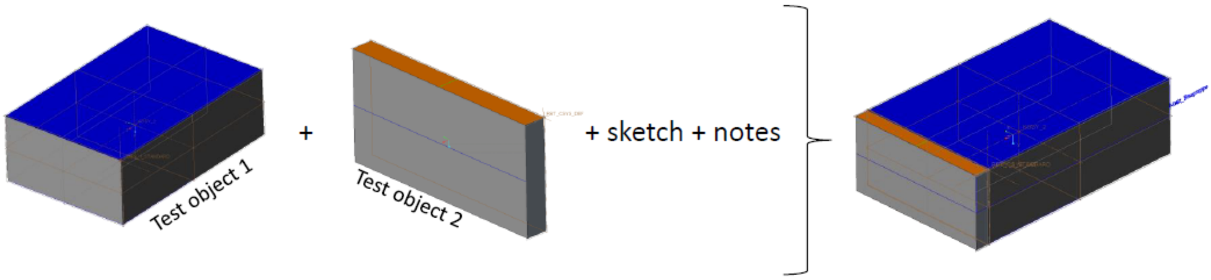

Figure 3 – representative test object with 34 constructive attributes and eight colours, based on the requirements listed in DIN 4000/4003

In this study CAD software systems used are CATIA V5 (Dassault Systèmes), Creo 3.0 (PTC), NX 10 (Siemens) and SOLIDWORKS 2015 (Dassault Systèmes). The test object is designed separately in all considered CAD systems. The import and export is performed with the previously determined optimal processor settings. Subsequently the result is regarded in the four CAD systems used and one viewing software. The evaluation of the data transfer of the constructive attributes is shown in table 3. In particular, the problems of individual software systems with transmitted information can be seen. For instance, software 3 is not capable of displaying any planes and software 4 ex- and imports only one coordinate system per component.

Table 3 – Compatibility check of STEP-files of a representative test object (considering construction characteristics)

		Test object 1																				Test object 2									Assembly				
		CS			PL								P		A						S	CS	PL						S		PL			S	N
		KOSY_1_STANDARD	KOSY_1	KOSY_2	E_YZ_STANDARD	E_ZX_STANDARD	E_XY_STANDARD	E_1	E_2	E_YZ	E_ZX	E_XY	P_1	P_2	A_X	A_Y	A_Z	A_X_STANDARD	A_Y_STANDARD	A_Z_STANDARD	Skizze CUTTERLINE	Standardkosy	Right	Top	Front	E_XY	E_YZ	E_ZX	IGNORECUTLINE	TACTILELINE	E_XY_BAUGRUPPE	E_YZ_BAUGRUPPE	E_ZX_BAUGRUPPE	Sketch (unnamed)	Notiz_Baugruppe
Compatibility to Software 1																																			
Start model out of	**Software 1**	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	+	+	+	+	+	+	+	+	+	-
	Software 2	-	+	+	-	-	-	+	-	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	+	+	+	+	+	-	-	-	-	-
	Software 3	-	+	+	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	+	+	-	-	-	-	-	-	+	+	-	-	-	+	+
	Software 4	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Compatibility to Software 2																																			
Start model out of	**Software 1**	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-
	Software 2	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	-	-	-	-	-
	Software 3	+	+	+	+	+	+	-	-	-	-	-	+	+	-	-	-	-	-	-	+	+	+	+	+	-	-	-	+	+	-	-	-	+	+
	Software 4	-	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-
Compatibility to Software 3																																			
Start model out of	**Software 1**	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	+	+	-	-	-	+	-
	Software 2	-	+	+	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	+	+	-	-	-	-	-
	Software 3	+	+	+	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	+	+	-	-	-	-	-	-	+	+	-	-	-	+	+
	Software 4	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Compatibility to Software 4																																			
Start model out of	**Software 1**	-- Import not possible--																																	
	Software 2	+	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	-	-	-	-	-	+	+	+	-	-
	Software 3	+	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	-	-	-	-	-	+	+	+	-	-
	Software 4	+	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	-	-	-	-	-	+	+	+	-	-
Compatibility to Viewer 1																																			
Start model out of	**Software 1**	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	+	+	-	-	-	+	-
	Software 2	-	+	+	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	+	+	-	-	-	-	-
	Software 3	+	+	+	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	+	+	-	-	-	-	-	-	+	+	-	-	-	+	+
	Software 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

CS Coordinate systems   P Points   S Sketches   + Transferred exactly
PL Planes   A Axis   N Notes   - Transferred insufficiently

Even though the described studies are just examples, it is clear that there are a lot of problems which prevent an automatic data transfer. By considering other software systems and features described in the standards, the problems can be characterised more precisely and solutions can be identified.

3.3 Classification of the problem sources

These comparative tests allow a characterisation of the problems. When considering all conducted studies, the problems can be classified depending on their causes as follows:

- User-related problems
- Ambivalence of the standard interface STEP
- System specific inconsistency

The excessive demand of many users is shown for example in table 1: Although company C and D use the same software, they achieve other transfer results. The causes for this are not in the software or the interface, but due to individual decisions of the design engineers. This can be the construction of the 3D model or the used export settings. Depending on the program and configuration, various settings can be made during the export or import, which have a crucial influence on the transfer result. However, the user usually does not have the experience, the knowledge or the needed access rights to choose these settings properly.

The use of standard interfaces should allow the transfer of information over system boundaries. The format STEP for example is defined in international norms [10, 12]. Despite this uniform definition, the standard leaves enough scope for an ambiguous description of 3D models. Thus it is possible that STEP files, which are conform to the standard, are not compatible due to different interface implementations.

This can be clarified using table 2. Although optimal settings and a very simple test object have been used, correct transfer of the colour blue outgoing from system 1 is not possible. If some entities are added in the

STEP file (as shown in figure 4), a correct transferred display of the colour values is achieved. So this kind of problem is caused by the ambivalence of the standard interface STEP.

```
#75=COMPOSITE_CURVE('',(#47,#56,#65,#74),.F.);
#182=CURVE_STYLE('',#21,POSITIVE_LENGTH_MEASURE(2.E-2),#1);
#183=PRESENTATION_STYLE_ASSIGNMENT((#182));
#184=STYLED_ITEM('',(#183),#75);
#185=MECHANICAL_DESIGN_GEOMETRIC_PRESENTATION_REPRESENTATION('',(#38,#46,#55,#64,#73,#184),#90);
```

Figure 4 – modification of a STEP physical file by adding the blue entities to avoid compatibility problems

Problems that occur exclusively in one used software can often be attributed to system-specific properties. An example is the transfer of the dark grey colour into system 3 as it is shown in table 2. Although the colour values in the STEP file are correct, the colour is always displayed with slightly changed colour values. This occurs independently of the output system. The problem is caused by the standard colour settings of the target system. Instead of the transferred colour, the software uses the next standard colour of the system-specific colour palette.

3.4 Extractive solutions

Just as the causes of transfer problems are manifold, solutions also have to be implemented in different ways. User-specific problems can only be solved by supporting and training system users. Firstly, all users of CAx software must be sensitised to the problem of data exchange and the challenges of a digitised world. When this is achieved, recommendations for the respective settings for import and export depending on the used system combinations help to provide an overview. Company-internal configurations with fixed system settings can avoid problems in standardised processes. Furthermore, designers have to be trained on a standard-compliant design of their models. In order to be able to identify problems more easily by the system user, check routines are created, which check the STEP files for standard conformity and compatibility.

By skilful handling of the user, sometimes interface-related problems can be avoided. The remaining incompatibilities caused by the interfaces can be prevented, for example, by specifically manipulating the STEP physical file (as shown in figure 4).

The system-specific problems can only be solved by the software developers themselves. Only they have the possibility to implement changes in their software. Industry and research have the responsibility to get the developers’ attention for mistakes and possible solutions.

4. CONCLUSION

Data exchange is a key requirement for the development of the industry in the direction of digitisation and Industry 4.0. Frequently, however, the significance of this topic and the consequences of the prevailing problems are underestimated. In order to create awareness of the subject´s matter and as a basis for solution strategies the problem diversity has to be documented at first. Compatibility tests and the resulting problem matrices as described in chapter 3.2 are used for this purpose. The test criteria to be examined are previously determined in accordance with existing standards (chapter 3.1). The investigations have been used to classify the problems according to their causes into three categories: User-related problems, ambivalence of the standard interface STEP and system specific inconsistency (chapter 3.3). Depending on the nature of the problem, other solution strategies have to be applied (chapter 3.4).

The shown results are insights of the public project CoCoDeal - Content Collection and Data Delivery Standards. The project CoCoDeal is part of the funding initiative "eStandards: Standardizing Business Processes, Securing Success", which is funded by the German Federal Ministry of Economics and Energy (BMWi) within the framework of the promotion "SME Digital - Strategies for the Digital Transformation of Business Processes". The main focus is on small and medium-sized enterprises (SMEs) as well as on the craft of digital transformation and the development and use of modern information and communication technologies (ICT). "Mittelstand-Digital" is composed of the promotion initiatives "Mittelstand 4.0 - Digital Production and

Work Processes", "eStandards: Standardizing Business Processes, Securing Success" and "Easy Intuitive - Usability for SMEs".

Even if the investigations refer to the requirements of the tooling industry, the results can be applied to all industries using the 3D modelling software. Thus the strategies for improving the quality of transferred 3D models presented here are of great importance for the global industry as a whole.

5. REFERENCES

[1] Bauernhansl, T., ten Hompel, M., Vogel-Heuser, B., eds.: *Industrie 4.0 in Produktion, Automatisierung und Logistik*, Springer, Wiesbaden, 2014

[2] Promotorengruppe Kommunikation der Forschungsunion Wirtschaft-Wissenschaft, ed.: *Deutschlands Zukunft als Produktionsstandort sichern. Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0. Abschlussbericht des Arbeitskreises Industrie 4.0*, www.bmbf.de/files/ Umsetzungsempfehlungen_Industrie4_0.pdf, 2016-12-13

[3] Kleinschrodt, C., Hackenschmidt, R., Rieg, F.: *Evaluierung des 3D-Datenaustauschs von Präzisionswerkzeugen*, Produktentwicklung zur Qualitätssicherung, 13. Gemeinsames Kolloquium Konstruktionstechnik. Clausthal, October 2015, 79-88

[4] Siemens AG: *Digitalisierung im Maschinenbau*. Advance. Digital Enterprise – auf dem Weg zu Industrie 4.0. 2 (2015), 4-13

[5] Strsk, R., Damerau, T., Lindow, K.: *Industrie 4.0 – Digitale Neugestaltung der Produktentstehung und Produktion am Standort Berlin. Herausforderungen und Lösungsansätze für die digitale Transformation und Innovation* Springer, Berlin Heidelberg, 2016, 169-184

[6] Deutsches Institut für Normung: *DIN 4000-1:2012-09: Tabular layouts of properties - Part 1: Concepts and principles*, Beuth, Berlin, 2012

[7] Deutsches Institut für Normung: *DIN 4003 -1:2014-02: Concept for the design of 3D models based on properties according to DIN 4000 - Part 1: Overview and fundamental principles*, Beuth, Berlin, 2014

[8] International Organization for Standardization: *ISO 13399-1:2006-02: Cutting tool data representation and exchange – Part 1: Overview, fundamental principles and general information model*, Beuth, Berlin, 2006

[9] Deutsches Institut für Normung: *DIN 4003 -87:2013-02: Concept for the design of 3D models based on properties according to DIN 4000 - Part 87: End mills for indexable inserts*, Beuth, Berlin, 2013

[10] Troll, A.: *CAx-Datenaustausch mit neutralen Datenformaten: Prozessgetriebene Konzeption eines Assistenzsystems für die Produktentwicklung*, Shaker, Aachen, 2011

[11] Vajna, S., Weber, C., Bley, H., Zeman, K.: *CAx für Ingenieure. Eine praxisbezogene Einführung*, Springer, Berlin Heidelberg, 2009

[12] Anderl, R., Trippner, D.: *STEP STandard for the Exchange of Product Model Data, Eine Einführung in die Entwicklung, Implementierung und industrielle Nutzung der Normenreihe ISO 10303 (STEP)*, Teubner, Stuttgart, 2000

[13] ProSTEP iViP: www.prostep.org, 2017-03-06.

[14] CAx Implementer Forum: www.cax-if.org, 2017-03-06.