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ASSESSMENT OF RELIABILITY IMPLEMENTATION IN MANUFACTURING ENTERPRISES

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Abstract

Purpose: The increasing internationalization of markets make the creation of competitive advantages more difficult. Companies have to be faster, better and more economical than their competitors in order to survive. Reliable products offer the capability to develop competitive advantages. To achieve the reliability objectives, a systematic approach of reliability actions and supporting methods is necessary. The integration of reliability activities into companies with regard to company size and industry has not been quantitatively determined.
Methodology: An international survey drawing upon literature was applied. Evaluations are based on descriptive and inductive statistics.
Results: The empirical study reveals reasons for applying reliability management in industry, the extent of applied reliability methods and performed reliability actions to achieve reliability objectives and used reliability data. The results are differentiated according to company size and industry.
Research implications: The results of this study are applicable to companies which have already dealt with reliability issues. Further studies should consider a cross-section status of reliability implementation in industry, as well as they should contain extended actions and methods of reliability.
Value of paper: This research relates to the status of reliability management implementation in international industry. There are shown significant differences in industries and company size. The results show potentials in reliability management and can be used as benchmark.

Keywords
reliability management, reliability programs, reliability methods, manufacturing sector, reliability capability.

Introduction

The increasing internationalization of markets makes the creation of competitive advantage more difficult. Companies have to be faster, better and more economical than their competitors to survive in the market. Reliable products offer the capability to develop competitive advantages. When buying a new car, the reliability as a decision criterion is more important than design or price [1]. However, the high reliability requirements on motor vehicle do not conform to increasing vehicle recalls [2].

The reasons for unreliable products are versatile. On the one hand, products become more complex due to the increasing integration of mechanics, electronics and software [3]. On the other hand, development time and budget decline. Development faces conflicting objectives to realize high quality in less time and at low costs. An efficient deployment of reliability actions and methods are necessary to overcome this hurdles [4]. While superior reliability leads to competitive advantages, unreliable products result in extensive consequences for the company.

Defective products lead to direct costs, for instance warranty and goodwill or indirect costs, like loss of market share and damage to customer relationships. Furthermore, the public perception of the company can be affected and legal obligations may follow [5].

Previous research on the implementation of reliability program plans [6] or the validation of the reliability capability model [7] show important approaches of reliability and where weaknesses are. A general overview of the implementation of reliability activities, methods and data in industry as well as the determination of statistically significance does not exist.

Research objectives and methodology

Study objectives and design

The objective of the study is to determine to which extent actions and methods of reliability are implemented in manufacturing enterprises. Following sub-questions are derived to identify enterprise' awareness of reliability importance:

- Which objectives are pursued by companies?
- To what extent are reliability actions performed in product life cycle to achieve reliability objectives?
- What methods are applied in industry and which are rated as valuable?
- Which reliability data are used to analyze and determine the product reliability?
- Which differences exist with respect to company size and industry background.

To answer the questions a survey drawing upon literature was constructed [8–11]. The survey was conducted between December 2014 and February 2015. Content of the questionnaire is:

- classification of economic activity, quantity of employees and sales of the participant's company;
- classification of respondent's activities in departments and in product life cycle phases as well as specification of the region of the predominant field of respondent's activity;
- selection of reliability actions according to the respondent's field of activity, which are conducted by the respondent or by the company and description of further conducted reliability actions;
- selection of reliability methods which are conducted by the respondent or by the company and assessment of reliability methods applied by the respondent in terms of experience, efforts and benefit;
- selection of used reliability data, barriers for using reliability methods and reliability objectives, which are important to the company.

For this purpose, 166 reliability experts were directly consulted in business networks and in reliability symposia. With a response rate of 21.1% 35 data sets were used. The survey was distributed additionally into nine reliability engineering groups of a business networking portal. The potential range is 77,000 group members without consideration of multiple group memberships. 55 data sets are used. In total there are 90 data sets available. Since the participants are experts in the field of reliability engineering, the data have a high validity.

Composition of the respondents

The respondents are composed of international reliability experts. 36% come from North America, 33% from Europe, 17% from Asia and 9% from South America.

Figure 1 represents the industries of respondents regarding to the Statistical Classification of Economic Activities in the European Community. To keep the questionnaire lean, some industries have been summarized and some have been further detailed. The following analysis considers the seven most represented industries (A to G). The size of the company is classified as follows.

- 19 small and medium-sized enterprises (SME): employees < 250 or sales $<$ €50 million,
- 34 large enterprises (LE): $250 \leq$ employees $<$ 25,000 or €50 million $\leq$ sales $<$ €5 billion and
- 33 very large enterprises (VLE): employees $\geq$ 25,000 or sales $\geq$ €5 billion.

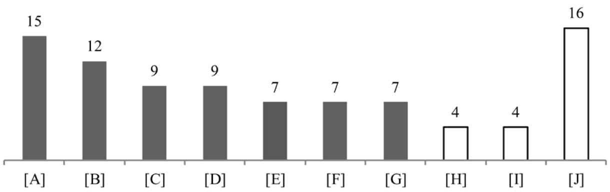

Fig. 1. Represented industries in the survey.

- A Manufacture of **comp**uter, electronic and optical products (Comp)
- B **Mech**anical Engineering (Mech)
- C **Rep**air and installation of machinery and equipment (Rep)
- D Manufacture of **mot**or vehicles and motor vehicle parts (Mot)
- E Manufacture of **elec**trical equipment (Elec)
- F Manufacture of **air**craft and spacecraft (Air)
- G Manufacture of **chem**icals and chemical products (Chem)
- H Manufacture of coke, refined petroleum products and nuclear fuel
- I Manufacture of glass and glass products, ceramics, processing mineral products
- J Miscellaneous

The main represented departments by the participants are research and development (24.4%), quality management (17.8%), asset management (17.1%), project management (12.2%) and production (5.7%). Other areas, like disposal, supply chain management or innovation management are less represented.

Reliability activities are implemented within the entire product life cycle, see Table 1. The product life cycle phases originate from [9]. The data show a focus on product development for taking early influence on product reliability and operation to analyze the field behavior as well as to improve future product developments. The information of the participants' allocation in product life cycle serves as a filter regarding the question of the reliability actions execution. There are only actions listed that correspond to the selected product life cycle phase to increase the significance of the answers.

Table 1
Represented product life cycle phases in the survey.

Product life cycle phase	Quantity	Percentage
Predevelopment	36	15.1
Detail development	42	17.6
Qualification and verification	42	17.6
Production planning	8	3.3
Production	20	8.4
Assembly	13	5.4
Operation planning	8	3.3
Operation	38	15.9
Aging	24	10.0
Decommissioning	8	3.3

The quantity of respondents is not sufficient to obtain a complete overview of implementation status of reliability activities in industry. However, the information density is higher than in a cross-section survey by interviewing reliability experts. Therefore, the following statements refer to those companies which have already implemented a reliability program in their company.

To determine the influence of industry or company size on reliability activities, objectives, methods and data significance tests are performed in 95.5% (bright orange*/bright green**) and 99.7% (dark orange****/dark green***) confidence intervals. Orange colored cells (*, ****) indicate a significant or high significant negative difference of the sample to the data set and green colored cells (**, ***) a significant or high significant positive difference.

Objectives of companies to ensure product reliability

The questionnaire includes reliability objectives of [8] and [10]. The IEC 60300-1 lists advantages of reliability management, for example to increase security, reduce impact on environment or reduce the life cycle costs [8]. According to LEVIN and KALAL, purchase decisions are not based on price or quality, but increasingly on perceived product reliability. The increase of reliability and the simultaneous reduction of life cycle costs are central objectives in introducing reliability within the entire product life cycle. The result is, for example, less scrap, rework and field failures [10].

In Table 2 the results about reliability objectives of the interviewed companies are summarized and are listed depending on company size and industry. Significant differences are highlighted. In contrast to *LEVIN* and *KALAL*, the industry does not attach the same importance to a high perceived reliability while minimizing costs. In the foreground, there are directly measurable objectives, as minimizing field errors, achieving the expected reliability objectives or ensuring product functionality. Other key objectives are related with financial obligations resulting from low reliability, such as product recalls or warranty and goodwill costs.

Depending on company size, the objectives are not significantly different with exception of the preservation or expansion of security. Very big companies attach more importance to product security than smaller companies. Companies manufacturing electrical equipment consider the listed targets more important than other industry. Safety, manufacturing, and environmental factors are subordinated pursued on average level. Preservation of production or manufacturing capacity is relevant for chemical industry, while the reduction of field failures or warranty costs due the character of chemical products play a minor role. Contrary to expectations, the reliability goals of aerospace are on average. The reduction and control of risks are even below.

In order to achieve competitive advantage through reliable products, it is essential that customers as well perceive the reliability of the product on point of sale. Further research has to identify corresponding product characteristics which have to be considered in product development to get the objective and perceived reliability balanced.

Table 2
Represented product life cycle phases in the survey.

Quantity [%]			Reliability objectives	Quantity [%]							
SME	VE	VLE		All	Comp	Mech	Rep	Mot	Elec	Air	Chem
63	68	82	Reducing field error	69	80	83	67	78	100	71	29*
47	68	82	Achievement of the expected reliability	68	73	42	56	89	86	71	71
68	62	64	Ensuring product functionality	63	60	67	89	78	100**	57	29
47	59	70	Reduce and control risks	58	73	50	67	78	100**	14*	71
47	59	67	Improve product quality	57	80	58	33	89	100**	43	29
58	53	67	Reducing risk of product recalls	57	80	58	67	78	86	29	43
42	53	67	Reducing warranty and goodwill costs	54	73	58	56	78	86	57	14*
42	50	70	Minimize life-cycle costs	53	60	42	44	56	86	43	57
58	41	67	Reduction of scrap and rework	52	60	33	56	78	86	57	71
42	41	52	Preservation of production or manufacturing capacity	43	40	17	44	67	57	14	100***
32	35	55	Increase the perceived value of the product	40	47	17	33	89**	100***	29	14
42	38	42	Reduce the impact on the environment	39	33	25	56	56	57	14	57
0*	29	45***	Preservation or expansion of security	28	20	17	22	56	57	43	29

Reliability actions to achieve objectives

Implementing reliability programs support the achievements of the mentioned reliability objectives. A reliability program defines the organizational structure, responsibilities, procedures, processes, and resources. They are used to control reliability actions in all product life cycle phases. Implementing reliability programs by planning, executing and controlling documents of project or product-specific actions found on the reliability plan. Aim of the reliability plan is the description of the processes to ensure product reliability. Reliability actions, a part of a process, are performed throughout the product life cycle. The life cycle is divided into the four phases of development, production, operation and disposal, and further divided into the steps of planning, implementation and testing [9].

The Table 3 shows the product life cycle phases and a summary of the performed reliability actions recommended by [9]. The phases of pre-development, detailed development, qualification and verification, production, operation and ageing are considered in detail. The phases of production planning, operation planning and procurement as well as disposal are not subject to detailed consideration, since less than 20 participants are available. Therefore, significance is diminished. Differences in industry are not considered. The sample sizes are small, since only respondents were taken into account, which are involved in the phase and are attributable to the industry.

For example, the participation in market research and studies on reliability during pre-development show potential of extended performance. This includes the determination of reliability and warranty requirements of the customers, the determination of the actual product reliability situation and comparable products from competitors or the willingness of the market to pay for additional costs [9].

The results show a high implementation of recommended actions by industry, particularly in product development. These high values also result in the fact that the content of actions is described generally and the respondent rather agrees to questions than to decline them. Furthermore, the recommended actions do not constitute a general and complete character. A catalogue of potentially necessary and specifically described actions could be helpful for companies to implement reliability programs systematically.

There is a main focus on performed reliability actions in the three phases of product development. Since in early stages of development there can be largely taken influence on reliability. The high performance of actions in operation are due the required field data. There are no significant differences in the considered industries. In detailed development small and medium sized enterprises pay significantly less attention to reliability actions.

Table 3
Conducted reliability actions of interviewed companies in product development and product utilisation.

SME [%]	VE [%]	VLE [%]		Reliability actions in specific product life cycle phase	[%]
100	94	94	Predevelopment	plan reliability contributions to the studies in development	94
100	88	100		establish the responsibilities, interfaces, processes and methods	92
50	81	88		participate in all market analysis and studies	81
100	100	100		special reliability studies to establish weaknesses with respect to technology, feasibility and the necessary qualification	100
100	100	100		assess, coordinate and define reliability targets depending on the risks and availability requirements	100
100	94	100		classify the system functions and the hardware and software involved, and establish the type and scope of the analysis	97
100	88	94		break down the reliability targets and write down as performance specifications or similar documents	92
67****	100	100	Detail development	plan the reliability activities, describe the activities	95
67*	94	100		establish the work content, the costs and the deadlines	93
83	94	100		control the execution of the work packages	93
83*	100	100		qualitative reliability analysis to assess the failure possibilities and the combined failure statuses	98
83*	100	100		assess the main influencing parameters of the failure possibilities, compile the load ranges, assess failure rates and failure probabilities	98
83*	100	100		identify weak points and problem areas	98
67*	100	100		initiate design improvements to reduce fault possibilities, weak points and problem areas	93
83	94	100		carry out quantitative reliability analysis to assess the effectiveness of the design improvements and to verify the achieved reliability	95
100	100	100	Qualification & verification	plan the qualification	98
100	94	100		verify reliability targets	98
100	88	88		control the qualification and verification process considering the approval procedure with respect to reliability	86
100	100	100		synthesis of individual reliability analysis to form statements/verifications on a higher level or on the overall system or product level	100
86	94	100		initiate improvement or corrective measures if reliability is not achieved	93
100	88	100		compile verification documents regarding the achieved reliability and safety for authorities and customers	93
100	94	94		present and justify the verifications towards authorities and customers	93
100	100	94		execute reliability and qualification tests	95
80	90	100	Production	detailed planning of the reliability activities of this phase which are necessary to secure the process	90
80	80	100		control the reliability activities and initiate corrective measures if deviations are identified	85
80	80	100		assess trends of the defined characteristics for process optimisation	85
100	90	100		assess the main influencing parameters on the process faults or weak points of the process, carry out a cause analysis and evaluation,	95
100	90	100		initiate corrective measures for process improvement or elimination of the weak points	95
60	80	100		document the process and the products produced	80
88	88	85	Operation	plan, schedule, and control measures to maintain the reliability in detail	84
75	88	85		initiate changes/improvements if target specifications are not achieved	82
100	94	100		evaluate operation and fault data, assess operation reliability and identification of problem areas	95
100	81	85		adapt and revise the measures for the maintenance of reliability on the basis of operation experience	84
100	88	92		document the operation and the relevant reliability activities for the maintenance of safe operation	89
100	91	100	Aging	initiate measures to maintain the reliability and, in particular, the safety of the ageing product	92
100	82	100		product observation and documentation of all measures to maintain safe operation	88
100	91	100		evaluate operation and fault data, trend assessment, identify ageing areas	92
100	91	78		adapt the reliability activities to the ageing product characteristics	83
67	82	89		assess additional costs incurred due to increased maintenance work	79

Application of reliability methods

The application rate of reliability methods is listed in the Table 4. Most of the methods are listed in [9] as methods for reliability analysis and reliability testing. In addition, methods such as fuzzy logic or design of experiments from standard literature were included [12, 13]. There are further methods that are assigned to reliability.

In the survey, respondents could evaluate methods in terms of knowledge, effort and re-use of data when applying to ensure meaningful data. They could evaluate the methods in terms of methodological knowledge (1 basic knowledge to 5 expert), effort (1 low to 5 high) and re-use of knowledge and data generated (1 barely to 5 comprehensively).

The methods failure mode and effect analysis, fault tree analysis or block diagram are proven in the interviewed industries, see Table 4.

While Petri nets, fuzzy logic or neural networks are not widely used. The low application of sneak circuit analysis or zonal safety analysis could justify in the limited field of application. The usage of methods does not significantly differ depending on company size in general. The design of experiments, Monte Carlo simulation and status analysis increase with company size in contrast.

Computer, electronic and optical industries apply methods above average, especially burn-in or highly accelerated life tests. The electrical equipment industry is characterized by extended application of methods like failure reporting, analysis, and corrective action systems or production reliability acceptance tests. However, there is no statement about the frequency of application. The methods can be applied in company, for example from case to case or in all product developments. In the survey the method terminology of the standard is listed to avoid misunderstandings. Since the meaning of methods are different for everyone. Therefore, a clear definition is required.

Table 4
Applied reliability methods of interviewed companies.

Quantity [%]			Reliability methods	Quantity [%]							
SME	VE	VLE		All	Comp	Mech	Rep	Mot	Elec	Air	Chem
84	88	100	Failure mode and effect analysis	90	87	100	89	89	100	86	100
90	88	91	Risk analysis	88	93	92	78	78	100	86	100
74	85	91	Safety analysis	83	87	83	78	78	100	86	100
74	79	79	Fault tree analysis	77	80	92	56	89	71	100	71
74	71	73	Block diagram	70	87	50	78	78	100	100	71
63	65	82	System analysis	69	80	75	44	78	100	86	57
74	59	82	Life data analysis	69	87	83	56	78	100	71	57
74	68	64	Failure reporting, analysis, corrective action system	66	67	67	78	56	100	86	29*
47	62	76	Statistical process control	61	80	42	56	78	100**	43	57
47	50	82**	Design of experiments	59	87**	50	33	89	86	57	43
58	59	55	Reliability growth	56	67	50	67	67	71	71	57
53	68	49	Hazard analysis	56	40	50	44	44	57	71	86
58	47	61	Software reliability analysis	52	53	58	44	56	71	57	43
37	53	61	Highly accelerated life test	50	87**	42	22	67	86	57	29
47	32*	73**	Monte carlo simulation	50	73	67	0*	67	71	29	71
42	53	55	Event tree analysis	50	33	67	44	44	57	71	86
47	44	58	Reliability demonstration test	49	87**	33	22	56	86	100**	0*
37	41	58	Reliability determination test	44	73*	42	22	56	71	71	14
47	38	52	Production reliability acceptance test	43	67	25	22	44	86**	43	29
32	44	52	Burn-in test	42	93***	8*	11	56	71	57	29
26	27	49	Bayesian methods	34	47	33	22	56	71**	14	29
47	29	27	Human factor analysis	32	27	17	44	33	14	71**	29
5*	21	42**	Status analysis / Markov models	26	33	8	0	56**	57	29	43
26	24	15	Zonal safety analysis	20	0	17	33	11	29	43	14
16	18	24	Sneak circuit analysis	19	33	0	0	22	57**	29	0
5	15	30	Fuzzy logic	18	20	25	0	33	14	14	14
0	12	18	Neural network	11	13	25	0	11	14	14	14
0	3	18	Petri nets	9	7	8	0	11	14		14

In Fig. 2, methods depending on the benefit-effort-ratio and usage are shown. A distinction and interpretation can be made between the following quadrants.

I. Above-average method application and above-average method benefit-effort-ratio: Methods like design of experiments or risk analysis are perceived as efficient and are used. Due to the high application, the benefits should be further optimized.

II. Above-average method application and below-average method benefit-effort-ratio: System analysis or failure mode and effective analysis are widespread, but the efforts are estimated higher than the benefits. The use of the methods is to question, or benefits must be strengthened, for example data obtained from the FMEA have to be considered in following projects or are used in earlier stages of development.

III. Below-average method application and below-average method benefit-effort-ratio: Methods like fuzzy logic or status analysis are perceived as inefficient and also are slightly applied. Further fields of application have to be developed, benefits for industry have to be highlighted and efforts by developing software have to be reduced. Further education and training should be considered.

IV. Below-average method application and above-average method benefit-effort-ratio: Human factor analysis or Petri nets are efficient, but the application rate is low. The benefits have to be better advertised.

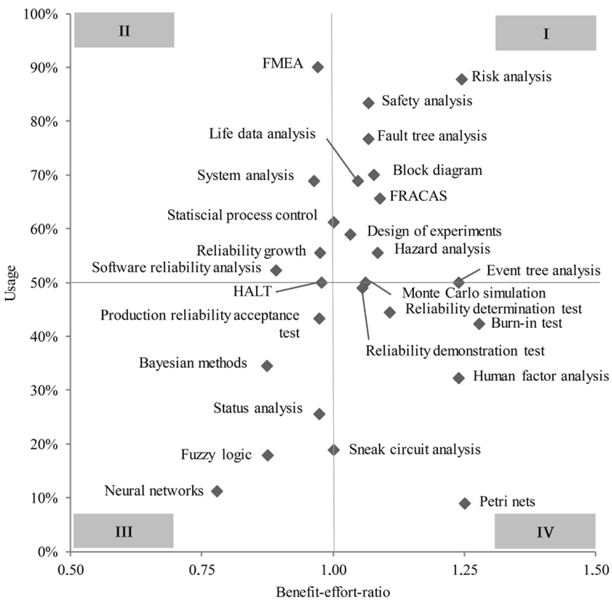

Fig. 2. Success and Usage of reliability methods.

Application of reliability data

Reliability data can differ in raw and derived data depending on degree of processing. Raw data include, for example identification data, loads or failure data. They are correspondent to the objective of reliability study and subject matter. Derived data are aggregated information from raw data as failure rates or failure probabilities [14]. Results of reliability analysis are not included. In the survey the following reliability data sources throughout the product life cycle are considered [15, 16]:

Reliability data sources in product development

- Failure rates catalogues: contain failure rates for different parts and components and are based on very large data collections.
- Expertise: is an important source for assessing the reliability of products. In particular, interdisciplinary teams enable effective compression of acquired knowledge into an overall picture of the product reliability.
- Lifetime calculations: assume an estimation of the external load and the material properties. The results of lifetime calculations provide estimates of product reliability.
- Testing: is the experimental evidence of product reliability and is understood as an additional testing effort.

Reliability data sources in manufacturing

- In-process product testing: is performed as reliability tests in addition to functional testing in the context of quality assurance. The objective of these tests is to fulfil requirements. Known methods are highly accelerated stress screening or audit.

Reliability data sources in operation

- Customer surveys and technical hotlines: In customer surveys, information are often collected to improve reliability. Technical hotlines are used to support service center when these have questions for repair or failure of products. Thus, particularly, complex fault patterns and previously unknown fault patterns can be recorded.
- Public statistics: are especially used for measuring customer satisfaction, but can contain information about the failure probability at system level. Thus, potential failure modes and weaknesses of products can be determined.
- Warranty and goodwill data: provide relevant reliability data due to the fulfilment of legal claims.
- Extended warranty and goodwill data: provide failure causes that occur after the statutory warranty period due to a longer period of product observation.

Table 5
Used reliability data of interviewed companies.

Quantity [%]			Reliability methods	Quantity [%]							
SME	VE	VLE		All	Comp	Mech	Rep	Mot	Elec	Air	Chem
63	71	82	Expertise	70	73	75	56	78	71	57	100
53	65	79	Lifetime calculation	64	73	75	67	89	100	57	43
58	77	64	Testing	64	87	75	44	67	100	71	57
63	56	64	Maintenance data collection	58	27*	75	89	22*	57	57	71
58	53	42	Failure rates Catalogs	50	47	75	56	33	71	86	29
47	47	61	Warranty and goodwill data	50	60	58	56	78	100**	43	14
42	50	52	In-process product testing	47	67	50	11*	78	100**	29	14
21	32	61**	Direct data collection at the product	40	47	42	33	33	57	14	57
32	29	58**	Extended warranty and goodwill data collection	39	40	58	22	78**	100***	29	14
26	21	36	Customer surveys and technical hotlines	27	40	33	11	22	57	14	29
32	35	15	Public Statistics	27	40	25	11	22	43	29	29
5	9	18	Social media (forums, networks, blogs, etc.)	11	7	25	11	11	43**	0	0

- Maintenance data: are collected during operation throughout the product life and offer the opportunity to collect reliability data on unusual and intact products throughout the entire product life cycle.
- Direct data gathering at the product: means that reliability data as well as key data items are detected automatically by the product itself or by the aid of other components.
- Social media: provide a platform in which users exchange information about the characteristics and defects of products.

In Table 5 the used reliability data are summarized. The companies use particular reliability data sources from product development as testing, lifetime calculation or expertise. Advanced sources in operation as social media, direct data gathering at the product or extended warranty and goodwill data offer further potential for reliability analysis. Customer surveys or public statistics are rarely used, which is may due to the low data quality.

Companies that produce electrical equipment, are characterized by an above-average use of available reliable data sources. Furthermore, very large companies are more likely to handle necessary investment than smaller companies, for example to collect data directly on the product.

The use of reliability data shows areas to unlock potential for further reliability analysis. [16] show opportunities to collect and analyze field data from the internet. Data from forums are similar to real data sets. This makes it possible to obtain field data at product level to detect field failure priorities outside the warranty period.

Conclusions

The study builds on the results of an international survey of reliability experts from various industries. Objective of the study is to assess the status of implementation of reliability in enterprises in terms of objectives, actions, methods and data depending on company size and industries. Results of the study are summarized as follows:

1. The industry do attach the importance to directly measurable reliability objectives such as minimizing field errors, achieving the expected reliability or ensuring product functionality. Other key objectives are related with financial obligations resulting from low reliability, such as product recalls or warranty and goodwill costs. The objectives differ significantly in the industry for electrical equipment and chemical industry, but not in company size.

2. Achieving the objectives requires a structured approach. The results show a high implementation of recommended reliability actions by industry, particularly in product development. However, gaps are recognizable as the lack of participation in market analysis and studies.

3. There are many methods like failure mode and effect analysis or fault tree analysis which are proven and not significantly differ depending on company size or industries, while Petri nets, fuzzy logic or neural networks are not widely used. The low application of sneak circuit analysis or zonal safety analysis is justified in the limited field of application.

4. The matrix of method application level and benefit-effort-ratio shows potentials and deficits of reliability methods. For example, widely applied

methods like systems analysis or failure mode and effective analysis, are rated as inefficient. There are deficits in the further use of the generated knowledge. While the human factor analysis is considered to be efficient, it is not reflected in a corresponding application level.

5. The companies particularly use reliability data sources from product development as testing, lifetime calculation or expertise. Advanced sources in operation as social media, direct data gathering at the product or extended warranty and goodwill data offer further potential for reliability analysis.

In summary the status of the implementation of reliability in business is high. However, there is shown a lot of potential for improvements. Since the study is limited to companies that are already familiar with reliability, no statement about the general distribution of reliability management is possible. Impact of the results may be the adaptation of reliability methods and activities with regard to the industry and company size to increase the benefits. The available data have to be better integrated and linked to reduce efforts.

References

[1] Deutsche Automobil Treuhand GmbH, *DAT Report 2014*, 2014.

[2] Kraftfahrt-Bundesamt, *Annual Report 2012 – Federal Motor Transport Authority* [in German: *Jahresbericht 2012 – Kraftfahrt-Bundesamt*], 2012.

[3] Ehrlenspiel K., Meerkamm H., *Integrated product development: thought processes, application of methodologies, cooperation* [in German: *Integrierte Produktentwicklung: Denkabläufe, Methodeneinsatz, Zusammenarbeit*], München: Carl Hanser, 2013.

[4] Kopp M., *Modularization and synthesis of reliability methods* [in German: *Modularisierung und Synthese von Zuverlässigkeitsmethoden*], Stuttgart: Berichte aus dem Institut für Maschinenelemente, Antriebstechnik, CAD, Dichtungen, Zuverlässigkeit, 2013.

[5] Kapur K.C., Pecht M., *Reliability engineering*, Hoboken: John Wiley & Sons, 2014.

[6] Carlson C., Sarakakis G., Groebel D.J, Mettas A., *Best practices for effective reliability program plans*, Reliability and Maintainability Symposium (RAMS), pp. 1–7, January 2010.

[7] Tiku S., Pecht M., *Validation of reliability capability evaluation model using a quantitative assessment process*, International Journal of Quality & Reliability Management, 27 (8), 938–952, 2010.

[8] IEC 60300-1, *Dependability management – Part 1: Guidance for management and application*, Genf: International Electrotechnical Commission, 2014.

[9] VDI 4003:2007-03, *Reliability management*, Berlin: Beuth, 2007.

[10] Levin M.A., Kalal T.T., *Improving product reliability*, Chichester: Wiley, 2003.

[11] Delonga M., *Reliability management process based on field data* [in German: *Zuverlässigkeitsmanagementsystem auf Basis von Felddaten*], Stuttgart: Institut für Maschinenelemente, 2007.

[12] O'Connor P.D.T., Kleyner A., *Practical reliability engineering*, Chichester: John Wiley & Sons, 2012.

[13] Meyna A., Pauli B., *Handbook of Reliability Engineering* [in German: *Taschenbuch der Zuverlässigkeitstechnik*], München: Hanser, 2010.

[14] VDI 4010 Sheet 1:1997-03, *General concept of reliability data systems*, Berlin: Beuth 1997.

[15] Leopold T., *Holistic data collection for improved reliability analysis* [in German: *Ganzheitliche Datenerfassung für verbesserte Zuverlässigkeitsanalysen*], Stuttgart: Berichte aus dem Institut für Maschinenelemente, Antriebstechnik, CAD, Dichtungen, Zuverlässigkeit, 2012.

[16] Bracke S., Temminghoff P., Tursch P., Woll R., *Contribution for detection of long-time product reliability problems in the use phase based on analysis of data gathered in online communities*, Proceedings of the ESREL 2015, pp. 2033–2039, September 2015.