QUALITY MANAGEMENT MAINTENANCE OF AIR TRAFFIC

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The authors within the scientific contribution present the maintenance task to provide aircrafts ready for flight. Engineering standards and the framework of international and national air law are fundamental for efficient and reliable aircraft maintenance services. The present thesis provides an insight into general maintenance fundamentals, legal requirements and into actual organization of this business. The second step is to identify optimization potential in scientific-validated and condition-based maintenance, spare part logistics and in applied quality management systems. Due to this optimization potential a new quality management approach is created on a scientific basis, it considers the identified gaps of the present systems.

KEYWORDS

quality management systems, maintenance, logistics, optimization

1 INTRODUCTION

Comprehensive, carefully researched and up-to-date lifecycle information represent the basis for reliable maintenance strategies. Only a high quality and a sufficient extent of data lead to a realistic prediction of failure probabilities. In practice, warranty data from manufacturing organizations and inventory data from maintenance organizations are the only source of information–for statistical analysis not always perfect. The following are the major shortcomings that should be considered:

- Incompleteness: Parts which are away from supply of manufacturers tend to incomplete data. Losses of information occur mainly during the transfer of spare parts between the material-preservation systems,
- Uncleanliness: Less accuracy in failure reporting and incorrect part attribution distort warranty and inventory data for statistical analysis,
- Distortions: Soft failures which degrade performance, but the system is still operating; reporting of failures may be delayed and negative effects on data analysis arise,
- Maturing data phenomena: The values of warranty and maintenance performance indicators change with time. This phenomenon increases and impedes the forecasting of failure probabilities [Bharatendra 2009].

In most cases a sufficient extent of data to generate representative results is not realistic. In everyday life there is only a small extent of data. However, the Weibull distribution is able to generate valid results concerning part failure mechanisms for several states of the parts lifecycle; therefore, WaloddiWeibull derived a generalization of the exponential distribution. Special events of the operating state may affect the failure probability and need to be considered during data analysis. By using Bayesian networks, additional information are taken into consideration to generate condition-based failure probabilities [Daneshjo 2017].

Next to technical malfunctions also the human factor has also to be taken into account. Higher technical standards and improved quality are not able to impede system failures; human failures have a high impact on statistical analysis although they are not easy to handle. To stabilize the absolute number of operational incidents, quality and reliability need to be improved [Daneshjo 2016], [Daneshjo 2012].

2 THE WEIBULL DISTRIBUTION

For describing the typical lifecycle of products the bathtub curve draws the failure rate as a function of lifetime. But not all components have the same life and only in a few cases the extent of available data is large enough to derive reliable conclusions [Stephens 2010].

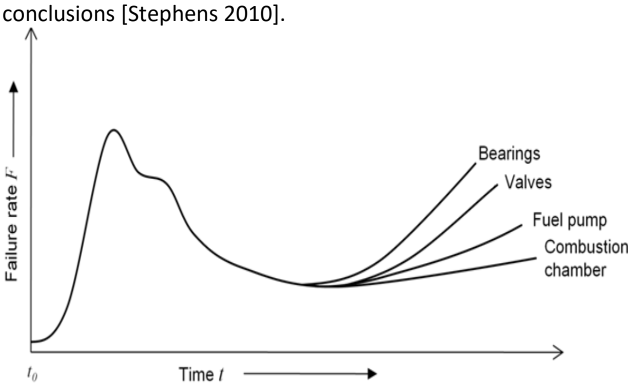

Figure 1: Composite failure rate/bathtub curve for jet engine components [Stephens 2010]

The Weibull distribution is a more general exponential probability distribution which was introduced to characterize constant, increasing and decreasing failure rates. The products do not exhibit constant failure rates. In statistics the Weibull distribution is a cumulative distribution function (CDF). It describes the probability distribution of a real-valued random variable x, for x≥0. For technical applications the variable x is replaced by t to describe the time-dependence. The Weibull CDF characterizes the failure probability at the time t; it is defined as follows:

$$F(t) = 1 - e^{-\left(\frac{t}{\alpha}\right)^{\beta}} \tag{1}$$

The Weibull CDF is defined by integration of the probability density function (PDF):

$$f(t) = \frac{\beta}{t}\left(\frac{t}{\alpha}\right)^{\beta} e^{-\left(\frac{t}{\alpha}\right)^{\beta}} \tag{2}$$

There are two Weibull parameters: *α* (alpha) is a scale parameter which is often called characteristic life, *β* (beta) is the shape parameter.

Both parameters must be greater than zero, the life distribution is defined only for positive times $0 \le t < \infty$ [Tobias 2012].

As a complementary value of the Weibull CDF the reliability function R(t) is defined (probability of surviving). The hazard rate is described by H(t).

$$R(t) = 1 - F(t) = e^{-\left(\frac{t}{\alpha}\right)^{\beta}} \quad (3)$$

$$h(t) = \frac{f(t)}{R(t)} = \frac{\beta}{t}\left(\frac{t}{\alpha}\right)^{\beta} \quad (4)$$

Flexibility is the major advantage of the Weibull distribution. The shape parameter determines the form of the Weibull and how it fits to different kinds of data:

0< β <1

If time approaches zero the probability density function (PDF) approaches infinity; for increasing time the PDF decreases rapidly towards zero. The hazard rate behaves identical; this type of Weibull is ideal for early failure mechanisms characterized by the front end of the bathtub curve [Tobias 2012].

β =1

The PDF reduces to a standard exponential function and a constant α.

β>1

Starting at zero the PDF increases to a peak at α[1-(1/ β)]^(1/ β). After the peak, it converges toward zero with increasing time. For increasing β the shape is skewed to the right. The hazard rate starts at zero and increases throughout life; the rate of increase depends on β. For β=2the hazard rate is linear (also known as Rayleigh distribution). A quadratic rate of increase is typical for β=3; useful model for wear-out failure mechanisms at the back end of the bathtub curve.
Fig. 2 shows examples of Weibull CDFs, Fig. 3 shows examples of Weibull PDFs and Figure 4 shows examples of Weibull hazard curves for the parameter β=0.5,1,2,4and α=1=constant. Tab. 1 summarizes the Weibull varieties for changing values of the shape parameter [Pham 2006], [Tobias 2012], [Jiang 2006].

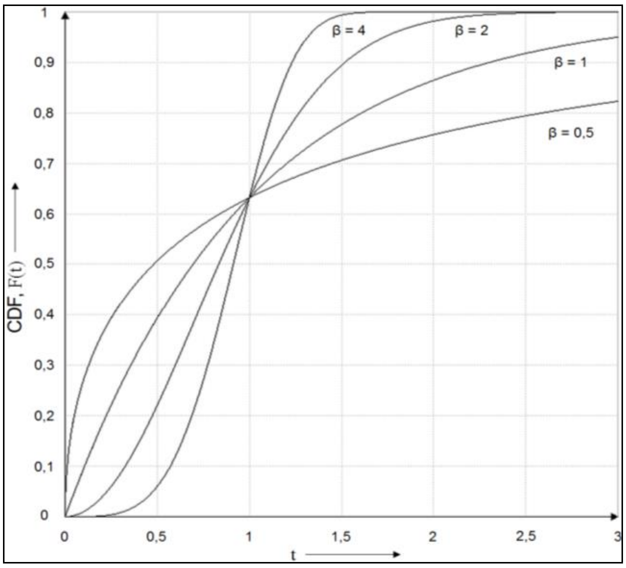

Figure 2: Weibull cumulative distribution function [Tobias 2012]

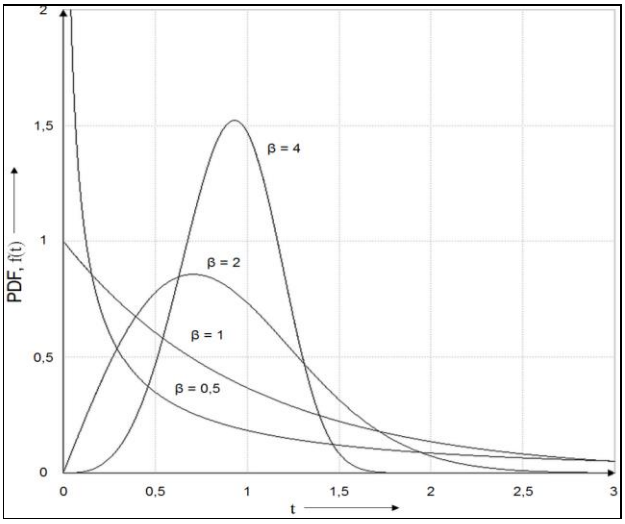

Figure 3: Weibullprobability density function, cf [Jiang 2006]

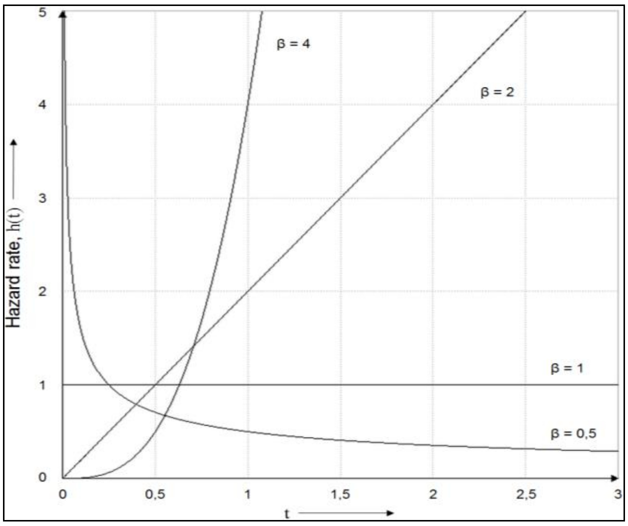

Figure 4: Weibull hazard/failure rate, cf [Pham 2006]

Shape parameter β	probability density function(PDF)	Failure rate h(t)
0< β<1	Exponentially decreasing from infinity	Same
β =1	Exponentially decreasing from 1/α	Constant
β >1	Rises to peak and then decreases	Increasing
β =2	Rayleigh distribution	Linearly increasing
3≤ β≤4	Has “normal” bell-shaped appearance	Rapidly increasing
β >10	Has “extreme” bell-shaped appearance	Very rapidly increasing

Table 1: Weibull distribution properties

2.1 BAYESIAN NETWORKS

With the aid of the Weibull distribution statistical evaluation can be performed for parts, components and systems. Provided that the extent of data generates sufficiently large and statistically appropriate results, the typical bathtub curve can be approximated. The reality can be prognosticated under normal conditions of usage.
If decisions have to be made under uncertainty the Bayesian theory proves to be helpful. For paying the price of making

more assumptions and generating results that might be more controversial to the point of being unacceptable to some specialists, more information can be derived from smaller sample sizes. All personal decisions made in daily life use intuitive process-based on experience and subjective judgments. Consequences of decisions with a high impact (financial or otherwise) necessitate decision support which is provided by the Bayesian theory [Tobias 2012].

Especially in aircraft maintenance engineering, there are many factors influencing the "normal" lifetime of parts, components and systems. Following some affecting incidents and determining forms of operation are listed:

- Number of pressure cycles (long distance or short distance aircraft),
- Strokes of lightning,
- Bird strikes,
- Duration of vibrations,
- Climatic conditions,
- Type of runway, etc.

The Bayesian theorem defines the likelihood P for the occurrence of Ai, from a complete set of events A, under the condition of the occurrence of event B, for all i =1,2,3,...,n [Czichos 2000].

$$P(A_i|B) = \frac{P(A_i)\cdot P(B|A_i)}{P(B)} \quad (5)$$

$$= \frac{P(A_i)\cdot P(B|A_i)}{\sum_{i=1}^{n} P(A_i)\cdot P(B|A_i)} \quad (6)$$

The Bayesian theorem describes how to calculate the probability distribution of the observed variable A when acquiring new information; an interference process is displayed (see Figure 5) [Borth 2004].

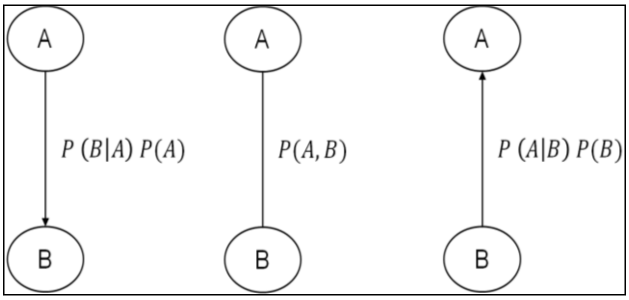

Figure 5: Bayesian interference displayed via inversion of arrows [Borth 2004]

Bayesian networks are mainly graphical models, which have their origin in statistical modeling. Directed and undirected graphs can be used for encoding relationships and assumptions, displaying dissections and supporting an efficient flow of information. Edges and knots are the elements of Bayesian networks; two knots are connected by an edge.

The edge connection may be directed or undirected. If there is no directed path A1→...→An, the directed graph is acyclic (DAG – directed acyclic graph). A DAG without undirected cycles is called "tree". DAGs represent qualitative information of uncertainty referring to conditional dependencies and independencies.

The type of connection is characteristic for the evidence of information and dependencies; Fig. 6 introduces three different types [Bramer 2007].

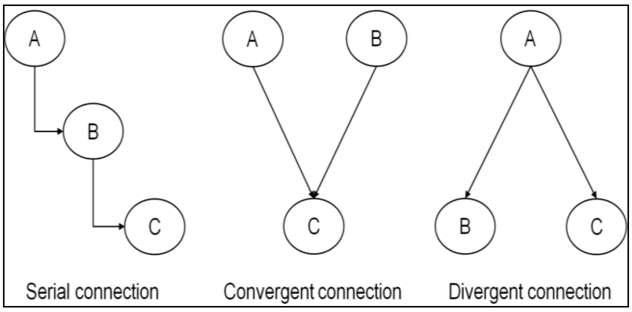

Figure 6: Types of connection in directed graphs [Bramer 2007]

Serial connection: All three knots are connected; knot A influences knot B which may have effect on knot C. Each evidence in knot C directly influences knot B and knot C, but only in case of a not instantiated knot B.

Convergent connection: Two parent knots are linked with a child knot. Evidence in one parent knot does not influence the other parent knot; evidence in the child knot has impact on both parent knots.

Divergent connection: The parent knot influences all child knots; it is instantiated and blocks communication between child knots.

Directly linked with the Bayesian networks are the conditional probabilities P(A|B1,...,Bn)=P(A|pa(A)) of each knot; pa(A)={B1,...,Bn} are the parents. For pa(A)=∅ the conditional probabilities reduce to P(A) [Borth 2004].

Bayesian networks are decompositions of a common distribution P(A) of an amount of variables A={A1,...,An}.P(A) can be calculated with the help of the chain rule, Fig. 7 shows an example with seven variables and the application of the chain rule:

$$P(A) = \prod_{i=1}^{n} P\big(A_i|pa(A_i)\big) \quad (7)$$

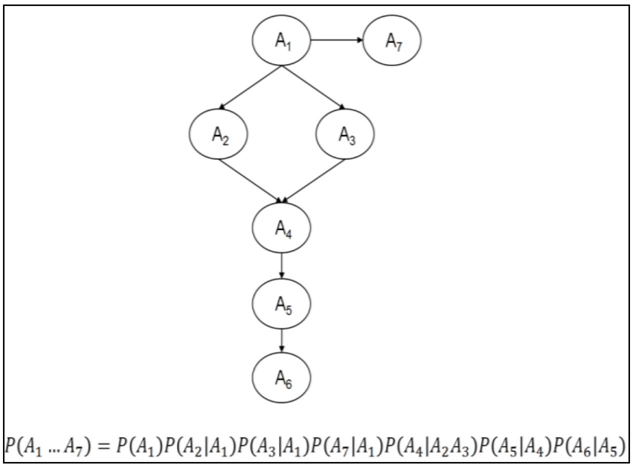

Figure 7: Decomposition of a distribution P(A) with a Bayesian network

3 FAILURES AND HUMAN FACTORS

The international airline business has reached a high level of flight safety, with a decreasing number of incidents caused by technical faults. In exchange the number of faults caused by non-technical skills increases. In the years 2012 to 2022, an annual growth rate of five percent in average is predicted. To keep the absolute number of safety incidents constant, in a growing market the relative number must decrease. For more than 70 percent of all aviation accidents and incidents the human error was identified as a primary contributor [Boeing 2012], [Cooper 2009], [Haas 2005].

Human factors in organizations are very complex; a variety of factors influences individual satisfaction, job attitudes and not least the number of accidents and incidents caused by human factors. Figure 8 gives an overview of factors affecting humans' satisfaction in maintenance organizations [Kelly 2006].

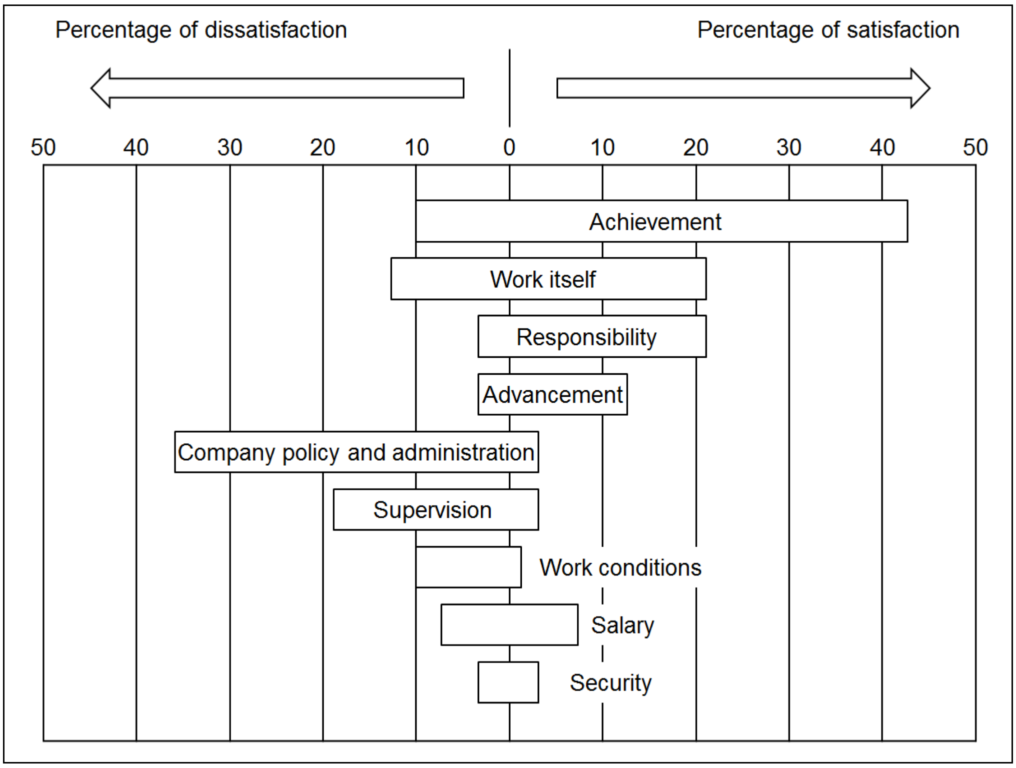

Figure 8: Affecting factors which lead to satisfaction/dissatisfaction

Humans' satisfaction is influenced by manifold variables, as shown in figure 16. There is an enormous expense for error avoidance resulting from an unfavorable constellation of variables. Programs need to be initiated which are able to improve the employees' inner attitude towards the job they are doing. The human performance effectiveness follows the curve shown in Figure 9, stress at a moderate level is necessary to achieve an individual maximum. Low stress activities as well as high stress activities lead to falling human performance effectiveness.

Performance of human operators is limited by a variety of factors. Violating them induces significantly increasing error rates. By reducing or avoiding the following negative operator conditions and characteristics during the system design, the error probability can be reduced drastically:

- Task steps performed at high speed,
- Poor feedback information in determining the correctness of activities,
- Need of prolonged monitoring,
- Only short decision-making time,
- Performance of tasks with a too long sequence of steps,
- Performing more than one task simultaneously at a high speed,
- Focusing two or more operating areas with time pressure,
- Decision-making with a lack of data [Dhillon 2009].

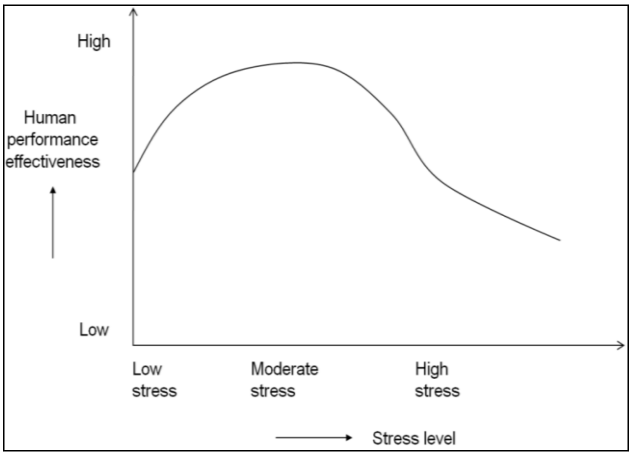

Figure 9: Human performance effectiveness/stress curve [Dhillon 2009]

Next to the consideration during the design of systems, the mentioned points also need to be regarded as central contents of training programs; the most effective way to reach the people and to initiate a process of reflecting daily activities. Special training programs were created to raise the participants' problem awareness, for improving communication and reducing errors – the maintenance resource management (MRM) program was born. It is defined as an interactive process for improving maintenance technicians' opportunity to perform work at a higher level of safety and effectiveness [Patankar 2004].

Measuring the improvement of safety is a difficult venture. Events which shall be avoided and which have not occurred yet are difficultly to quantify. The only way to analyze the effect of MRM and human factors training programs on safety is the statistic investigation of inventory data. Actual safety information have to be evaluated in contrast to safety information before and while introducing the programs.

4 MANAGEMENT ENSURING RELIABILITY

According to EN ISO 9000:2005, quality is defined as a degree to which a set of inherent distinguishing features fulfills needs or expectations. The grade of quality depends on these levels of features meeting the requirements, which are defined by customers, providers and the public interest. For aircraft maintenance business the customers are represented by airlines; their needs are aircrafts prepared for flight, safety and reliability. Aircraft maintenance providers are also interested in high quality by reducing failures, additional rework and to protect themselves against image losses. Furthermore, it should be noted that there is a public interest in quality to ensure safety, trust and environmental protection.
Introducing a quality management means to implement coordinated activities to steer an organization with regard to quality. Reasons for implementing quality management systems are listed below:
- Reduction of failure costs and internal friction losses by improved process control,
- Customers abstain from own audits; improvement of mutual trust between customer and provider,
- Successful marketing instrument,
- Better product quality,
- Improvement of customer satisfaction [DIN 2005], [Hinsch 2010], [Patankar 2004].

The first step is the written formulation of a common quality policy. As a shining example the management board has to live this policy; here the sole responsibility for quality orientation is located. Through a sustainable monitoring concept for all areas of the business, a quality management system can be established best. For the employees, the quality consciousness is increased and a stronger consideration of internal processes is encouraged. By enhancing the awareness for the business the responsibility readiness of each individual gets improved.
Constituting a quality management system is highly individual and very complex. Nevertheless, there are cross-industry commonalities – illustrated in Fig. 10.

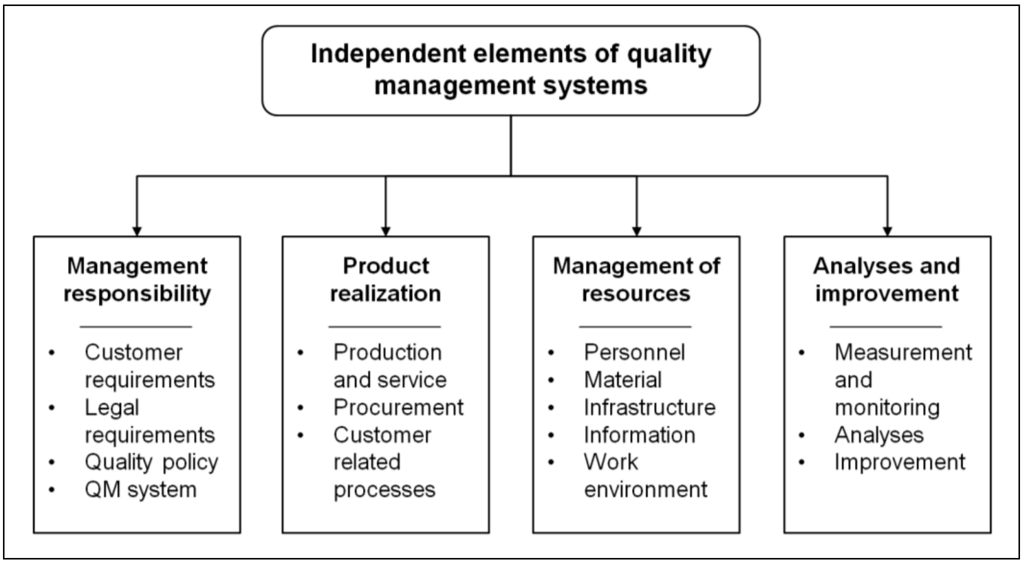

Figure 10: **Independent elements of a quality management** system [Zollondz 2002]

Strengthening the focus on safety, the quality management in aircraft maintenance is amended by additional aircraft maintenance-specific regulations. For the European Union the aspects of aviation law regarding aircraft maintenance. There are also included regulations concerning the quality management:
- Occurrence reporting systems (145A.60 and 21.A.165),
- Every employee is obliged to report incidents, failures, constructive deficits, etc. So the risk of common cause failures can be minimized,
- Design assurance system (21.A.239),
- Design organization approvals are bound to implementing a continuing monitoring system for verification of compliance.
- Production/design organization-arrangement (21.A.4).

Principles of communication are stated for the interaction of production and design organization approvals. They are obliged to transmit all their knowledge relating to common products [Hinsch 2010].
The area of aircraft maintenance contains much stricter regulations for quality management systems than defined in EN ISO 9000:2005; these are not only recommendations, they have a mandatory character concerning their implementation. This is the only way to implement quality management systems that ensure such a high level safety standard based on quality and reliability.

6 CONCLUSIONS

Preventive maintenance activities are planned nearly optimal, but a problem of particular importance remains - reactive maintenance in case of unforeseen failures. Depending on time and place of demand the supply chain management in combination with the applied quality management system plays a key role. The substantial treatment of the theoretical basics starts with typical engineering standards to provide reliability and to ensure safety. There are also introduced fundamental principles and general issues to organize maintenance operations. Due to the focus on aircraft maintenance the comprehensive legal framework with its hierarchical structure is analyzed. Starting with international air law, European air law and national air law a legal system is provided that covers all areas of air traffic, air transportation and aircraft maintenance. Responsibilities for monitoring the compliance with relevant regulations are assigned to international and national aviation agencies (NAA). A special focus is on maintenance organization approvals.

Strengthening the focus on safety, the quality management in aircraft maintenance is amended by additional aircraft maintenance-specific regulations. The area of aircraft maintenance contains much stricter regulations for quality management systems than defined in EN ISO 9000:2005; these are not only recommendations, they have a mandatory character concerning their implementation. This is the only way to implement quality management systems that ensure such a high level safety standard based on quality and reliability.

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