RAPP: Method for risk prognosis on complex failure behaviour in automobile fleets within the use phase

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Abstract: The increasing complexity of product functionality and manufacturing process parameters often leads to complex failure modes during the product life cycle. These field information are the basis for risk analyses and damage case prognosis with the goal of an early risk detection and leads to the possibility of nearby interactions e.g. product and manufacturing optimisation or recall action. This paper outlines the essential procedure of the new developed method "Risk Analysis and Prognosis of complex Products (RAPP)". The main focus of the RAPP method is the detection, visualisation and prognosis of risks and damage cases depending on their life span variables regarding to a product fleet - based on a risky production batch - in field. The RAPP method contains multiple steps: First steps include the mapping/prognosis of the failure behaviour and the mapping of product field load profiles. Next step is focusing on the estimation of the critical area regarding the life span variable (e.g. critical kilometer range). Based on these steps, it is possible to perform the risk analysis and risk prognosis regarding the product fleet. Finally, the last step of the RAPP method is the verification of risk analysis and –prognosis. The theory and application of the RAPP method is explained within an automotive case study oil tube leakage.

Keywords: Product reliability, risk analysis, risk prognosis, product fleet risks, statistical methods

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1. INTRODUCTION

The development and manufacturing of technically complex products as well as capital goods are confronted to central challenges: The increasing complexity of product functionality and manufacturing process parameters often leads to complex product damage symptoms and failure modes during the product life cycle. In case of this paper technically complex products are meant to be electronic goods, home appliances, consumer electronics or automobiles. These products are manufactured in series with an amount of middle up to a high production batches (statistical population), for example $N \geq 100$ products per day. After the sales of such production batches the products are passed into the use phase. The term product fleet denotes each production batch with the same construction stage (same grade of upgrade/ innovation stage) of a component.

During the usage phase a huge amount of operational data (operating time, operating temperature, load characteristics etc.) regarding each product is generated. A special type of operational data collection can be found in case of failure occurrence during the usage phase of such components. For instance the time of damage appearance, the failure mode as well as the life span at the failure occurrence is recorded. These field informations are the basis for risk analysis and damage case prognosis with the goal of an early risk detection, visualisation and prognosis. Finally, it leads to the possibility of nearby interactions e.g. product and manufacturing optimisations or recall actions.

As part of the research work the RAPP approach (Risk Analysis and Prognosis of technical complex Products) has been already developed [1]: In this paper, the RAPP method is developed regarding an extended procedure. The overarching goal of the RAPP method is the analysis of product fleet risks in the use phase depending on their life span variables regarding to certain failure modes.

2. GOALS OF THE RAPP APPROACH

The challenges and requirements of a risk analysis and risk prognosis based on the RAPP method with regard to product fleets in the use phase are as follows:

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a) Detection of specific risks regarding to a product fleet in field, which is based on a risky production batch.
b) Prognosis of the future amount of units at risk depending on their life span variables (e.g.: operating/switching cycles, operation time or operation parameters).
c) Visualisation of the determined risk as a basis for further decisions (e.g.: recall actions, garage actions).

This paper demonstrates on the one hand the developed theoretical background of the RAPP method and on the other hand an application of the shown RAPP steps due to the automotive engineering case study oil tube leakage. The case study is based on a synthetic field data set. The creation of these data and information was based on characteristics with respect to real damage case data sets. The result of the RAPP method application is the estimation of the risk regarding the product fleet during the usage phase based on a detected failure mode. The data set includes e.g. field operating times, kilometrage and observation time based on the car-level.

3. RAPP APPROACH AND CASE STUDY OIL TUBE LEAKAGE: BASE OF OPERATIONS

The basis of every risk analysis constitutes two parts [4]: On the one hand the knowledge of the damage case at a certain observation period and on the other hand the empirical product use phase behaviour. The observation of both data base is independent from each other.

The knowledge of the damage case includes data and information regarding the amount of damaged components as well as data of the life span variables regarding the point of observation, when the damage of each component appeared in the use phase (e.g.: operating hours, operation cycles, start and shut down activities). In addition, external conditions (e.g.: temperature, air humidity) have to be analysed and documented [10].

The knowledge of the empirical product usage phase behaviour includes data and information regarding the determination and mapping of the products' life span variables. This data is based on independent observations regarding the damage cases: The data base is collected from the whole - not damaged - product fleet in the field during the usage phase. This means that the data are not censored.

The precondition with regard to the RAPP approach is the correlation between the progression of the analysed failure mode variable and the chosen life span variable. This can be verified with the help of the Spearman´s rank correlation coefficient [12].

An excerpt of the data and information of the case study oil tube leakage regarding the damage case and the empirical product use phase behaviour is shown in table 1.

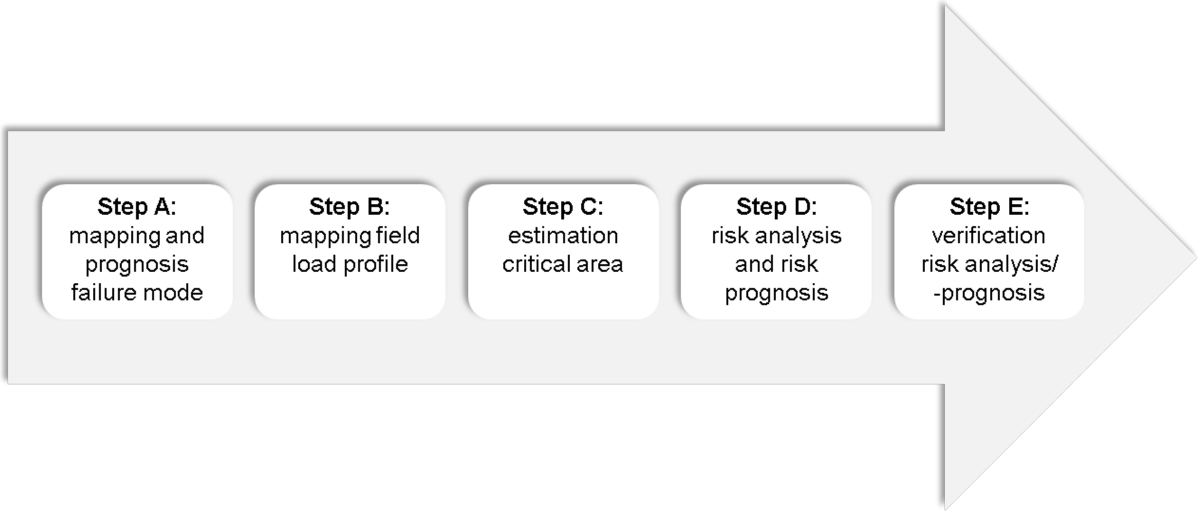
Table 1: Excerpt of data and information of the automotive case study oil tube leak regarding damage cases and product fleet (synthetic field data set)

Nr.	Data array	Format / content
	1. Information regarding the product fleet	
1.1	Production batch (automobile fleet)	$N_{PF} = 6{,}259$
1.2	Production period	01.2009 - 03.2009
1.3	Kilometrage profile of the product fleet regarding the life span of the product	Log-Normal distribution (parameters: $\mu; \sigma$)
	2. Field damage case information	
2.1	Observation time of concerned automobile fleet in field	11 months
2.2	Failed oil tube leaks up to observation time	n = 254

4. RAPP METHOD: OVERVIEW, PRINCIPALS AND STATISTICAL TOOLS

The essential procedure of the RAPP method (Risk Analysis and Prognosis of complex Products) includes five steps A – E, which are shown in figure 1 (cf. [1]). The single steps of the method and the used statistical tools are summarised in an overview in this chapter and explained in table 2. A detailed application of the RAPP method based on the theoretical steps is explained within the automotive case study oil leakage in chapter 5.

Figure 1: Overview of the RAPP method [1]



The main goal of step A is the detection of the failure mode related to the product life span variables and the statistical mapping and prognosis of the failure mode (FM). Base of operations is data out of the technical analysis of damaged components and field data (e.g. guarantee/goodwill database). The focus on step B is the empirical mapping of the product fleet (PF) behaviour based on the failure mode related life span variables (cf. step A). The goal of step C is the estimation of the critical area regarding the failure mode related life span variables by definition of a range using the borderlines of important quantiles of the failure mode and the product fleet distribution models. The step D of the RAPP method focuses on the determination of the risk in product fleets in terms of a detected failure mode. Furthermore, step D considers the estimation of the retrospective and the expected risk development within the product fleet. The last step E of the RAPP method is the verification of the risk analysis and prognosis (cf. step D) based on field observation and Monte Carlo simulation methods. The application of step E regarding the case study oil tube leak is part of future research works.

Table 2: Essential procedure of the RAPP method

	Step	Data Bases, statistical tools, procedure
Step A: Mapping and prognosis of the failure behaviour		
No.	**Action**	**Statistical tools and data bases**
A1	Analysis of failure mode related life span variables	Technical analysis of damaged components
A2	Determination of life span variable´s correlation	Spearmans ς; Kendalls τ
A3	Analysis of the behaviour development of the failure mode	Distribution models; e.g. Weibull distribution (parameters b, T)
A4	Prognosis of the parameters of the statistical model of the failure mode (FM)	Regression analysis; coefficient of determination r^2
A5	Analysis and mapping of clearing effects: e.g. replacement part operations	Consideration of market charging via distribution models
Step B: Mapping field load profile		
No.	**Action**	**Statistical tools**
B1	Analysis of the life span variables of the product fleet (PF)	Correlation analysis between technical analysis and product fleet
B2	Empirical mapping of the life span variable development	Distribution models; e.g. log-normal (parameters μ, σ)
B3	Analysis and mapping of clearing effects: e.g. product fleet reduction	Consideration of market scrap influences via distribution models
Step C: Estimation of the critical area		
No.	**Action**	**Statistical tools**
C1	Determination of critical areas (quantiles)	E.g.: 50%, 95% 99%-quantile of FM and PF models
C2	Mapping of life span variable quantiles regarding failure mode and product fleet	E.g.: $l_{CLL-CUL} = \lvert Q_{PF-LL;0.05} - Q_{FM-UL;0.95} \rvert$
Step D: Risk analysis and risk prognosis		
No.	**Action**	**Statistical tools**
	Risk analysis	
D1	Risk probability in product fleets regarding actual point of time, based on critical areas	Overlap of FM and PF distribution models results in risk probability P_{FM}
D2	Determination of function "damage appearance"	Overlap of FM and PF distribution models results in density function f_{DA}
D3	Analysis of risk probability and damage appearance peaks development [retrospective]	Regression analysis at different points of time t_x leads to damage appearance function
D4	Analysis of significant changes: risk in-/decrease	Significance tests (e.g.: Mann-Whitney U-Test; Siegel-Tukey-Test, Fisher-Test) and confidence intervals
	Risk Prognosis	
D5	Risk probability regarding future points of time [future]	$P_{Prog-PF}$
D6	Prognosis of risk probability and damage appearance peaks development [future]	f_{DA}
D7	Determination of clearing effects: e.g. product fleet reduction / replacement part operations	Consideration of market charging distribution models
Step E: verification of risk analysis and –prognosis		
No.	**Action**	**Statistical tools**
E1	Field observation regarding to the risk point of time	Determination of failure rate λ and products at risk n
E2	Simulation of the failure and the product fleet behaviour	Monte Carlo simulation

5. RAPP: RISK-ANALYSIS AND -PROGNOSIS WITHIN THE CASE STUDY

5.1 Step A: Mapping and prognosis of the failure mode

Out of the field data base a density function is generated to represent the statistical area of the empirical failure mode (FM). A common distribution model to approximate such failure modes is the three parameter Weibull distribution (cf. density function (1)). An advantage to approximate such failure modes using a three parameter Weibull distribution is the interpretation of the utilised parameters (t_0 = failure-free time; T = characteristic lifetime; b = shape parameter; [2]). The estimation of the parameters is done by state of the art methods such as Trust-Region method [6] or Maximum-Likelihood-Estimator [9].

$$f(x)_{FM} = \frac{b}{T-t_0}\left(\frac{x-t_0}{T-t_0}\right)^{b-1} \cdot \exp\left(-\left(\frac{x-t_0}{T-t_0}\right)\right)^{b} \tag{1}$$

Regarding the case study, the point of time of field data analysis is early (11 month in service (MIS); cf. table 1), when the failure behaviour is not comprehensive known. Based on this special case, the use of an approach, which considers an additional prognosis of changing failure behaviour, is useful: The given damage cases within a limited observation period can be splitted into a certain number of classes (e.g. quarter division: 3, 6, 9, …, 24 months in service). With the use of each location parameter T, the mean value as well as the shape parameter b, the prospective parameters of the failure behaviour regarding the second year (24 month in service) can be calculated by using non-linear regression methods (cf. figure 2). A paradigmatic example is shown in figure 2. The abscissa represents the month in service (MIS) regarding to different field observation times, whereas the ordinate reflects the estimated values of the parameters regarding the Weibull distribution models. If the gradient of the regression functions converges to zero, the parameters are not changing and therefore it is assumed, that the failure behaviour is constant. According to the risk prognosis point of time (MIS point, cf. RAPP method step D), it is possible to choose the predicted parameters based on figure 2.

Figure 2: Estimation of Weibull parameters T, b, $t_0 = 0$ and arithmetic mean value x, using non-linear regression methods for prognosis of the comprehensive failure mode, product fleet field observation time 24 months in service; exemplified by the case study oil tube failure

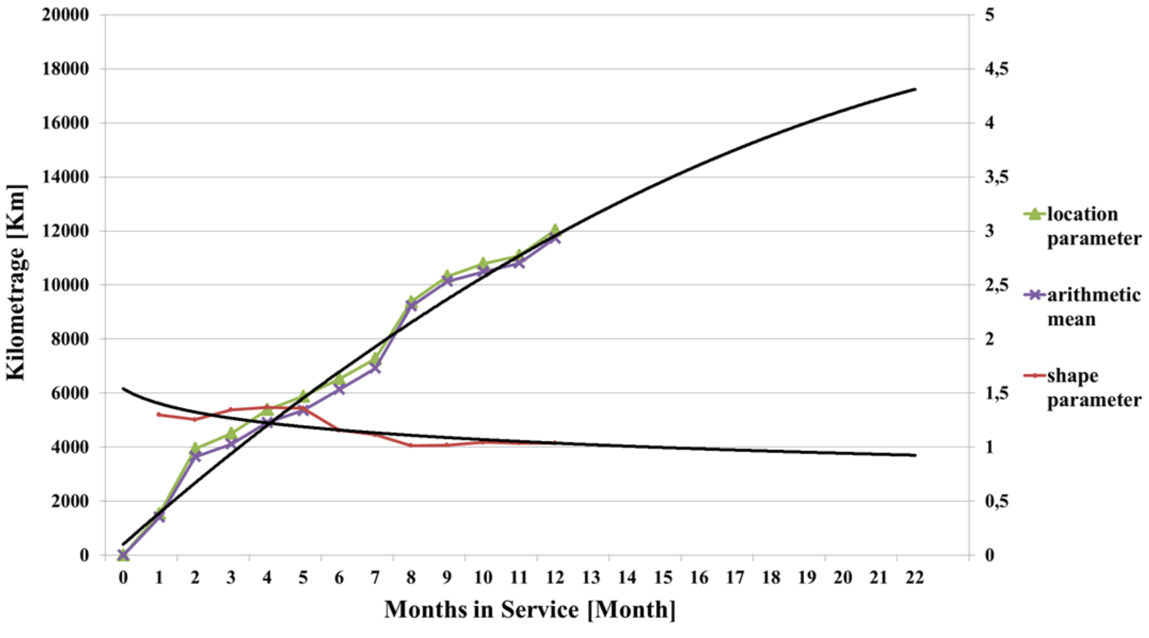
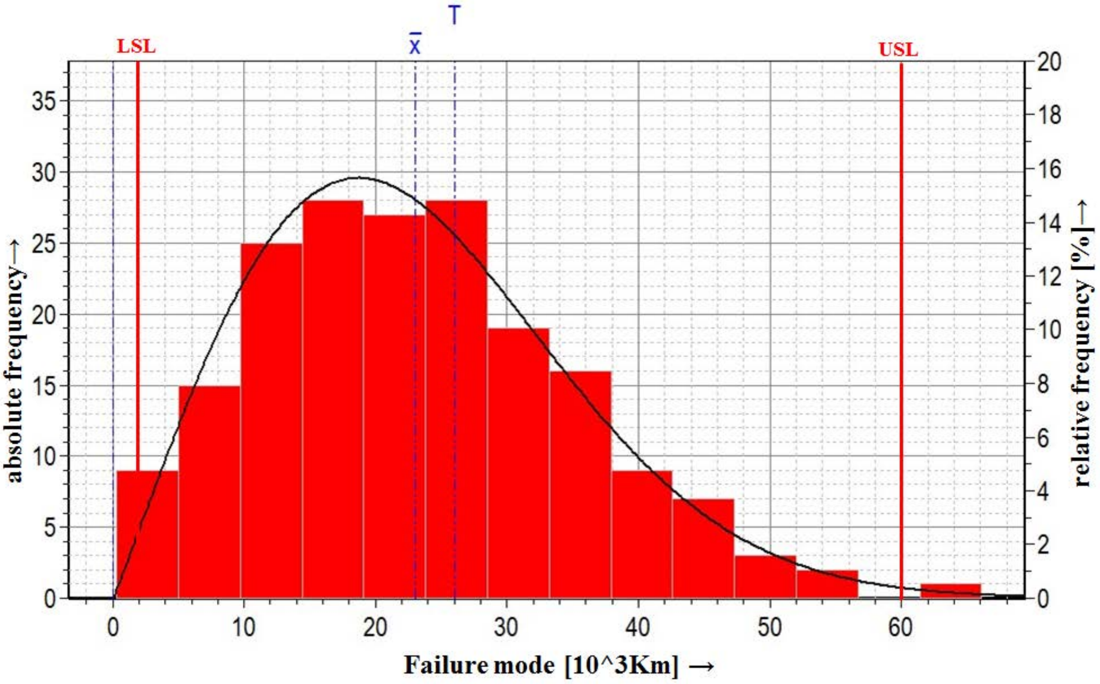


Figure 3: Example for a failure mode using the knowledge after two years of field observation of the product fleet (Weibull distribution fit), case study oil tube leakage



After two years of field observation time, a Weibull distribution model can be fitted based on field data: Figure 3 shows the field data and the fitted Weibull density function $f(x)_{FM}$ after two years of field observation (24 MIS). In this case study a comparison between the predicted parameters (cf. figure 2) and the estimated parameters based on the full data set is feasible and shows similar values. E.g. the location parameter at 24 MIS is predicted to $19*10^3$ km (based on 12 MIS knowledge) and the value of the estimated location parameter is $22.5*10^3$ km (based on 24 MIS knowledge).

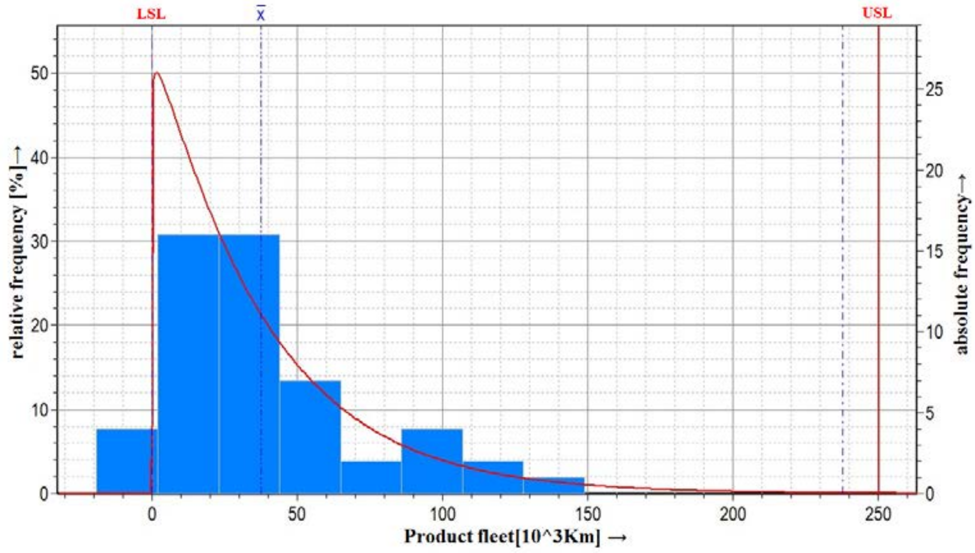
5.2 Step B: Mapping field load profile

A kilometrage profile can be generated (cf. table 1) out of the empirically known field data of the product fleet (*PF*). An important criterion is the timeframe between the product approval (e.g.: car registration) and the failure occurrence, the latter describes the risks observation point inside the RAPP method. In many cases distribution functions for mapping a product fleet kilometrage profile can be described with the help of a log-normal distribution (2) [12], normal distribution as well as the Weibull distribution model (1).

$$f(x)_{PF} = \frac{1}{x \cdot \sigma \cdot \sqrt{2 \cdot \pi}} \cdot e^{-\frac{(\lg(x)-\mu)^2}{2\sigma^2}} \tag{2}$$

An example for a approximated density function $f(x)_{PF,2}$ of the product fleet (observation time 2 years) is shown in figure 4. The estimated density function is a general log-normal distribution with two parameters [1].

Figure 4: An example of an empirical kilometrage function $f(x)_{PF}$ (log-normal destiny distribution) of the product fleet based on an observation period of two years (cf. [1])



5.3 Step C: Estimation of the critical area

The estimation of the critical area has to be evaluated by limiting the two density functions within the given one-sided quantile (Q) of each function. A typical one-sided quantile in case of the automotive industry (Lower Limit LL = 0.05 / Upper Limit UL = 0.95) is used in the constituted case study. Therefore, the left-sided failure mode distribution was limited by using a 0.05 quantile (Q_{LL}) and the kilometrage distribution by applying a right-sided 0.95 quantile (Q_{UL}). In case of a right-sided failure mode, the quantile borders have to be switched. The schematic visualisation of the critical area within the oil tube case study is shown in figure 5.

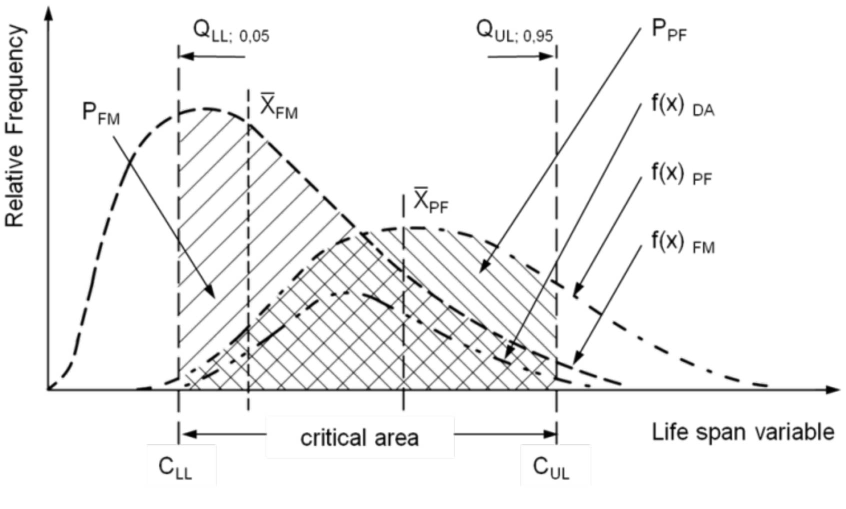
5.4 Step D: Risk analysis and risk prognosis

The RAPP method provides the calculation of three characteristics:

- P_{RPF}: Risk probability regarding the product fleet (Index: *RPF*),
- $f(x)_{DA}$: Probability function of damage appearance (Index: *DA*) and
- $P_{RPF\text{-}Prog}$: Prognosis of the future risk probability (Index: *RPF-Prog*).

Besides the kilometrage function $f(x)_{PF}$ and the failure mode function $f(x)_{FM}$, the introduced characteristics are visualised in figure 6.

Figure 5: Visualisation to determine the critical area [$c_{LL} = Q_{LL;0.05}$; $c_{UL} = Q_{UL;0.95}$] as well as the overlapping of $f(x)_{PF}$ and $f(x)_{FM}$ to determine the risk parameters P_{RPF} and $f(x)_{DA}$ (cf. [1])



The calculation of the RAPP characteristics is as follows: The risk probability of the critical product fleet P_{PF} can be estimated using the failure occurrence probability P_{FM} (Integral of $f(x)_{FM}$ (1) regarding to the critical area, cf. Step C) and the product fleet kilometrage probability P_{PF} (Integral of $f(x)_{PF}$ (2) regarding to the critical area, cf. Step C).

$$P_{RPF} = \mathrm{P_{FM}} \cdot \mathrm{P_{PF}} = \int_{C_{LL}}^{C_{UL}} \frac{b}{T-t_0}\left(\frac{x}{T}\right)^{b-1} \cdot \exp\left[-\left(\frac{x}{T}\right)^{b}\right] \cdot \int_{C_{LL}}^{C_{UL}} \frac{1}{x\cdot\sigma\cdot\sqrt{2\cdot\pi}} \cdot e^{\frac{(\lg(x)-\mu)^2}{2\sigma^2}} \tag{3}$$

The function $f(x)_{DA}$ describes the damage appearance probability of the product fleet in dependence on a life span variable (e.g.: kilometrage). With this specific characteristic the damage appearance probability can be determined (4) at any point of observation time with respect to an appropriate life span variable. Furthermore, the probability to find one unit at the point of observation can be easily calculated by finding the maximum of the failure occurrence function (5).

$$f(x)_{DA} = \frac{\mathrm{b}}{\mathrm{T}}\left(\frac{x}{T}\right)^{b-1} \cdot \exp\left[-\left(\frac{x}{T}\right)^{b}\right] \cdot \int_{C_{LL}}^{C_{UL}} \frac{1}{x\cdot\sigma\cdot\sqrt{2\cdot\pi}} \cdot e^{\frac{(\lg(x)-\mu)^2}{2\sigma^2}} \tag{4}$$

$$f'(x)_{DA} = 0 \tag{5}$$

The probability P_{RPF} maps the prognosis in the field of expected damage cases in the future at a specific point of observation time t_{RP}. The general procedure is identical to the determination of the first risk characteristic P_{RPF}. The difference is the adjustment of the product fleet's kilometrage function $f(x)_{PF}$ in relation to the prognosis point of time and thus the renewed determination of the left-sided lower quantile $Q_{LL(Prog);0.01}$. In case of additional changing failure behaviour, the adjusted failure mode function and its appropriate quantile have to be considered.
Referring to equation (3) the probability $P_{RPF\text{-}Prog}$ can be calculated as follows:

$$P_{RPF,\ Prog} = P_{FM,\ Prog} \cdot P_{PF,\ Prog} \tag{6}$$

In the presented oil tube case study the risk analysis and prognosis based on the RAPP method is using the field data set regarding the first eleven MIS. Afterwards, the results of the risk prognosis are compared to the real failure behavior at the points of time 15, 18 and 21 MIS. The results of the RAPP risk analysis and the respective risk prognosis (Step D; cf. Figure 7) are shown in Table 3.

Figure 6: Visualisation of the overlapping $\mathbf{f(x)_{PF}}$ and, $\mathbf{f(x)_{FM}}$ and the product of both to determine the risk parameters $\mathbf{f(x)_{DA}}$ after one MIS (left) and eleven MIS (right)

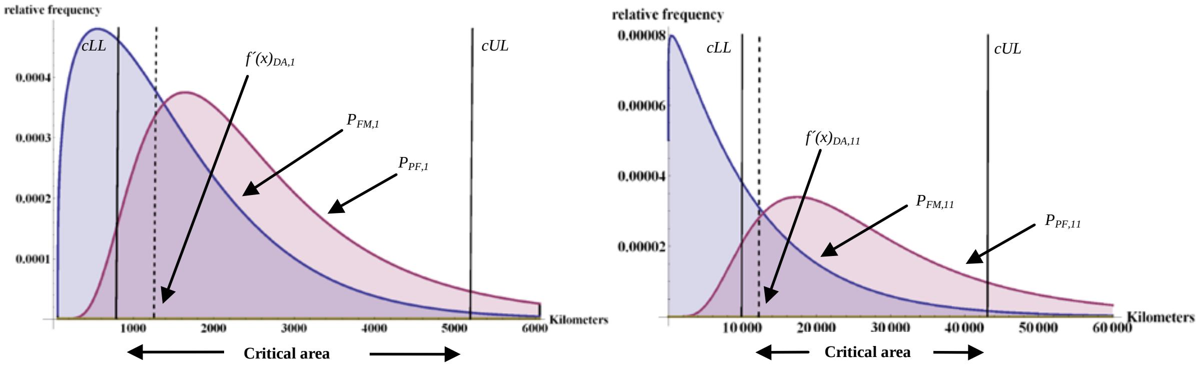


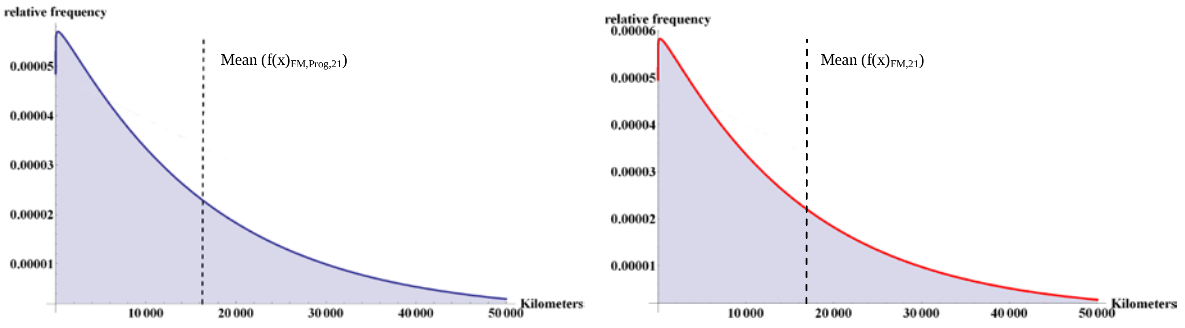
Figure 6 shows the overlapping of the density functions of cars based on the oil tube leak failure mode (Weibull distributed, (1)) and the associated product fleet (Lognormal distributed, (2)) after one and eleven MIS. After the one MIS the major section of the product fleet is moved in the range of cars with oil tube leak failure mode (84.52%). The extremum $f'(x)_{DA,1}$ is at 1,237 kilometres. At the beginning of 12 MIS regarding the product batch the fleet moved to a mean kilometrage of 11,927 kilometers. The risk analysis in product fleet (P_{RPF}) dropped from 44.02% to 15.83% by simultaneous increasing the range of the critical area (4,550 to 33,900 kilometers). Comparison of $f'(x)_{DA,1}$, $f(x)_{PF,1}$ and $f(x)_{FM,1}$ with $f'(x)_{DA,11}$, $f(x)_{PF,11}$ and $f(x)_{FM,11}$ shows a proportional process, therefore it can be assumed, that the failure mode is not completely developed. But it can be received that a short quantity of cars is in the critical area (max 15.83%) of the oil tube leak and could breakdown in higher kilometrage. The following table 2 resumes the results regarding risk analysis at 1 MIS and 11 MIS.

Table 3: Results of the RAPP risk analysis after one and eleven MIS; case study oil tube leakage

Risk characteristics	Results	Note
Results after one month in service		
$P_{PF,1}$	44.02 %	Risk analysis in product fleet; observation point of time: 1 MIS
$P_{PF,1}$: cLL / cUL	0.71 / 5.26 [10^3 km]	Critical area regarding to the life span variable within 1 MIS observation time
$f'(x)_{DA,1} = 0$	2.204 10^3 km	Damage appearance, 1 MIS
Results after eleven months in service		
$P_{PF,11}$	15.83 %	Risk analysis in product fleet; observation point of time: 11 MIS
$P_{PF,11}$: c_{LL} / c_{UL}	9.98 / 43.88 [10^3km]	Critical area regarding to the life span variable within 11 MIS observation time
$f'(x)_{DA,11} = 0$	16.538 10^3 km	Damage appearance, 11 MIS

The extrapolation of the Weibull distribution parameters of $f(x)_{FM,1-11}$ show a prognosis of the oil tube leak failure behaviour after 21 MIS based on the prognosis of the shape and location parameters (cf. figure 1). The following figure 7 shows the verification of the RAPP method: Risk prognosis regarding 21 MIS versus real field data regarding 21 MIS.

Figure 7: Comparison of the destiny functions $f(x)_{FM,Prog\ 21}$ (left) and $f(x)_{FM,21}$ (right)



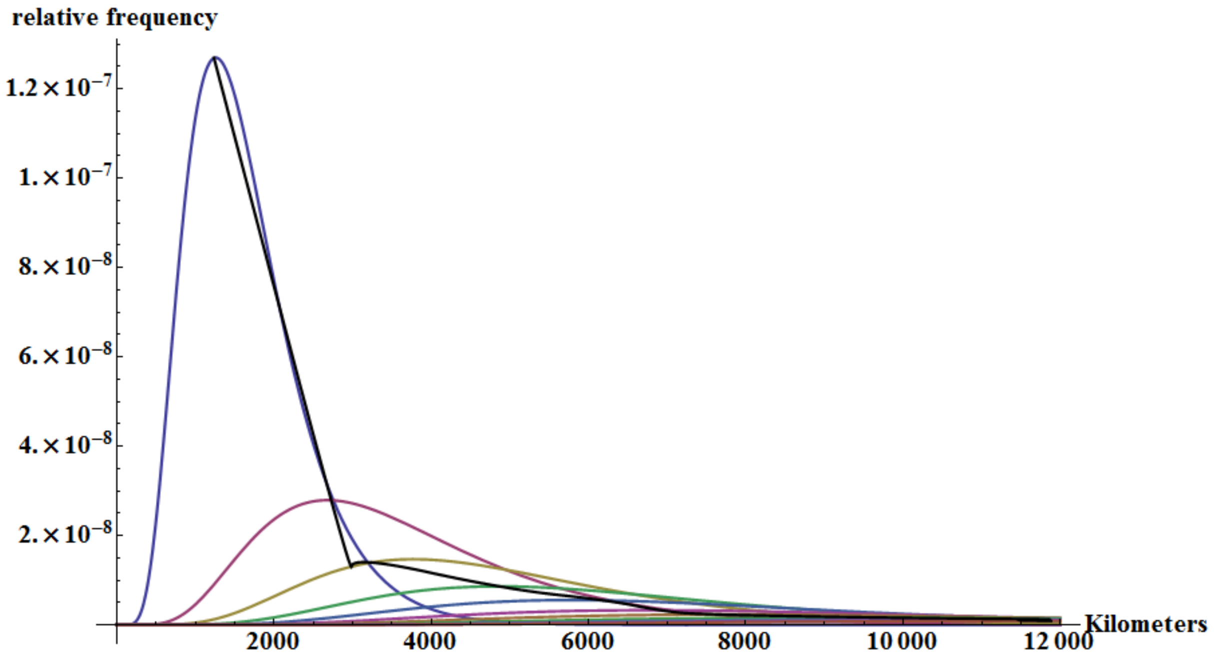
In figure 7 can be observed, that the results of the prognosis $f(x)_{FM,Prog,21}$ are close to the real occurrence of $f(x)_{FM,21}$. The following table 4 illustrates the parameters and results of both plots.

Table 4: Results of the $P_{FM,Prog\ 21}$ and $P_{FM,21}$

Risk characteristics	**Result**	**Note**
Parameters of the 21 months in service prognosis		
$\beta_{FM,Prog\ 21}$	0.988	Shape parameter of Weibull distributed prognosis for 21 MIS
$\alpha_{FM,Prog\ 21}$	19,540	Location parameter of Weibull distributed prognosis for 21 MIS
Mean($P_{FM,Prog\ 21}$)	19,450	Arithmetic mean of prognosis for 21 MIS
Values of parameters after 21 months in service		
$\beta_{FM,\ 21}$	1.0141	Shape parameter of Weibull distributed the real values after 21 MIS
$\alpha_{FM,21}$	19,720	Location parameter of Weibull distributed the real values after 21 MIS
Mean($P_{FM,21}$)	19,500	Arithmetic mean of the real values after 21 MIS

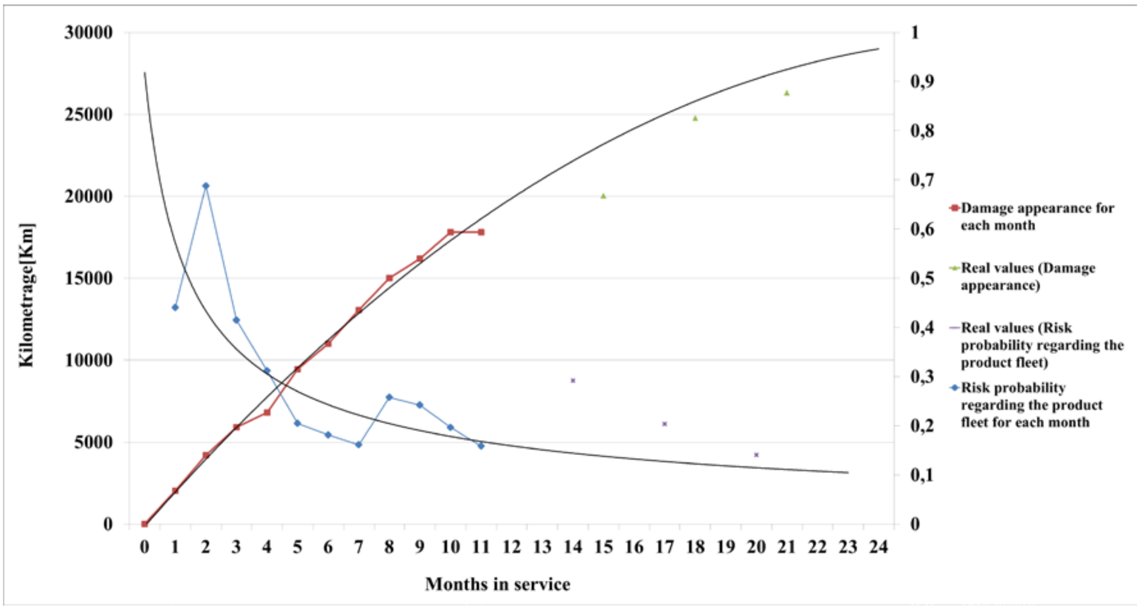
The determination of the function "damage appearance" (4) for each month in service $f(x)_{DA,1\text{-}11}$ shows the centered area of the $P_{RPF,1\text{-}11}$. After finding the maximum with (5) the x-value of $f'(x)_{DA,1\text{-}11} = 0$ expose the focus of kilometrage from the oil tube leak for each month. Figure 8 presents $f(x)_{DA,1}$ till $f(x)_{DA,11}$ and the course of the peaks (black line) $f'(x)_{DA,1} = 0$ till $f'(x)_{DA,11} = 0$

Figure 8: Visualisation of $f(x)_{DA,1\text{-}11}$ as well as the course of $f'(x)_{DA,1\text{-}11}$ (Damage appearance peaks) from one till eleven months in service



Primarily, it can be observed that the y-value of the $f'(x)_{DA,1\text{-}11}$ is very small, therefore it is not possible to show $f(x)_{FM,,1\text{-}11}$ $f(x)_{PF,1\text{-}11}$ and $f(x)_{DA,\ 1\text{-}11.}$ in one plot. In the first month the focus of the failure mode ($f'(x)_{DA,1} = 0$) can be located at 1,237 kilometers. In the following months the dispersion regarding $f(x)_{DA,2\text{-}11}$ gets higher. With the increase of the range of $f'(x)_{DA,1\text{-}11}$ the validity of focus of the failure mode gets lower. The black line describes $f(x)_{DA,1\text{-}11}$. The following figure 9 compares the failure mode focus (damage appearance, cf. (5)) with the proportion of cars from P_{PF} in the critical area of P_{FM} for each month.

Figure 9: Prognosis of the damage appearance focus ($f'(x)_{DA}=0$) and the proportion of cars from P_{PF} in the critical area P_{FM} based on eleven months in service knowledge compared with the real values after 15, 18 and 21 months in service



According to figure 9 it can be observed, that the damage appearance (red line) is changing to a higher kilometrage. The prognosis shows the increase trend of failure mode focus regarding the kilometrage for the next 11 MIS (Total: 22 MIS). Comparison of the prognosis with the real values of 15th, 18th and 21st MIS based on field data shows a related behaviour, but overrates the real occurrence. The reason is the increase of the dispersion after eleven month in service.

The critical area of the risk probability regarding the product fleet (blue line) has a regressive course. Comparing the prognosis with real values after 15, 18 and 21 months in service the risk probability will be underrated, that implies outliers after the period of observation. While the damage appearance gets higher simultaneously the proportion of cars at risk gets lower which is an indicator that the overlapping of P_{FM} and P_{PF} gets smaller. The following table summarizes the important values of the figure 9.

Table 5: Results of prognosis from focus of failure mode and proportion of cars at risk compared with the fair values after 15, 18 and 21 MIS

Risk characteristics	Result	Note
Prognosis of the damage appearance		
$f'(x)_{DA,Prog,15}$	16,410 Km	Damage appearance prognosis: 15 MIS
$f'(x)_{DA,Prog,18}$	18,180 Km	Damage appearance prognosis: 18 MIS
$f'(x)_{DA,,Prog,21}$	21,040 Km	Damage appearance prognosis: 21 MIS
Real values of Damage appearance		
$f'(x)_{DA},_{15}$	14,890 Km	Damage appearance 15 MIS
$f'(x)_{DA},_{18}$	17,280 Km	Damage appearance 18 MIS
$f'(x)_{DA\ 21}$	20,450 Km	Damage appearance 21 MIS
Risk probability prognosis		
$P_{RPF,Prog,15}$	9.13%	Risk probability prognosis: 15 MIS
$P_{RPF,Prog,18}$	8.80%	Risk probability prognosis: 18 MIS
$P_{RPF,\ Prog,21}$	8.31%	Risk probability prognosis: 21 MIS
Real values proportion of the risk probability		
$P_{RPF,15}$	17.82%	Risk probability 15 MIS
$P_{RPF,18}$	11.31%	Risk probability 18 MIS
$P_{RPF,21}$	8.52%	Risk probability 21 MIS

6. CONCLUSION

This paper outlines the RAPP method and its application within the oil tube leak case study for determination of risks in product fleets within the usage phase. The focus is the analysis and prognosis of the field failure behaviour of a defect oil tube unit based on product field data. The results lead to a visualised risk analysis and prognosis on the basis of the existing failure mode and the product fleets life span variables at a certain point of observation. Furthermore, the estimation of the risk prognosis with respect to the expected damage cases within the product fleet is feasible. The comparison of the RAPP method and industrial state-of-the-art methods [7] has not been verified yet and is an inherent part of future research work.

The advantages of the present procedure are: The RAPP method, in comparison to the industrial standards of risk prognosis methods, considers a direct link of different dimensions (e.g. operating time, switching cycles) causing a specific damage case and the product's life span variables without a mathematical conversion. Thus, the method generates the possibility of direct visualisation of damage cases (failure behaviour) and life span areas at a specific point of observation time to estimate the existing risk potential. The visualisation includes the critical area between a product's life span variable and a present failure mode, which can be calculated by using p-quantiles of the failure behaviour probability function and the empirical life span variables. Furthermore, the adjusting empirical life span variable as related to the failure behaviour can be visualised properly and analysed subsequently. Finally the developing of the damage appearance regarding the predicted behaviour of the failure mode and the product fleet is calculable.

The disadvantages of the shown procedure are: The fitted density functions of the empirical failure modes and the product fleet's life span variables are fundamental for the presented method. Thus the deviation due to different probability functions and the fitted model itself can lead to different results of the risk analysis. The current research results due to different probability functions show a marginal influence in the result. However, some case studies led to adverse risk prognosis based on small critical areas, which is also a part of the future research work.

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