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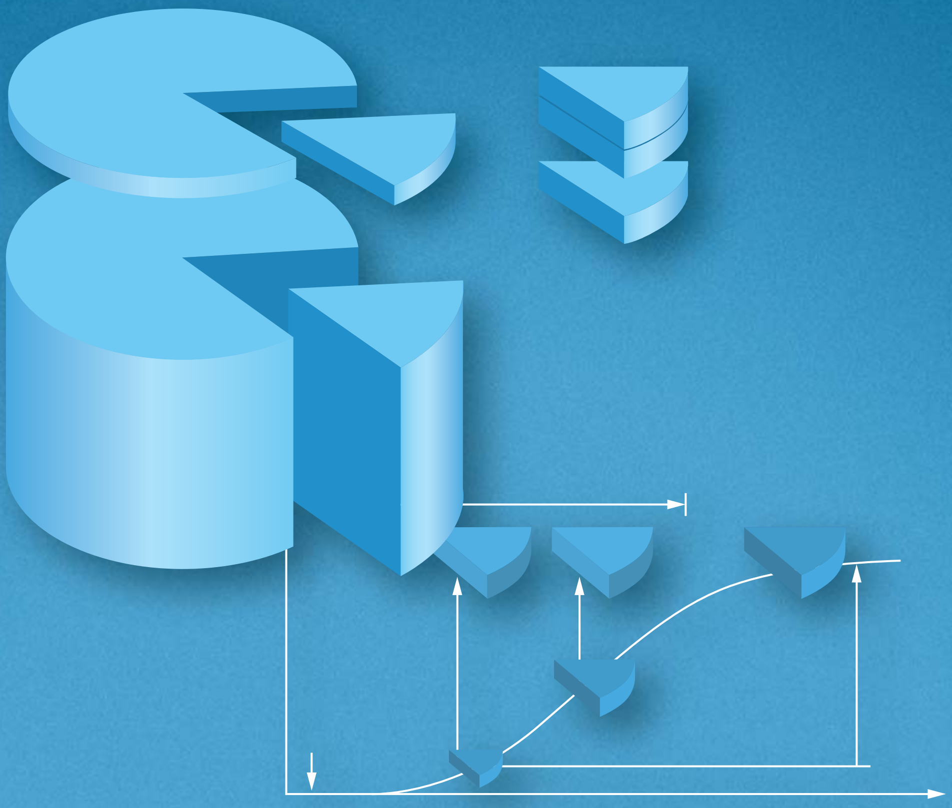

Quality Management in the Bosch Group | Technical Statistics

6. Evaluation of **Field Data**

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Edition 12.2001

Evaluation of Field Data

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1. Introduction

High product quality is one of our company's top priorities. Assuring product reliability, as an integral part of our quality effort, requires long-term planning. Quality targets, including reliability targets, are defined at the very beginning of the design process for new products and are often subject to binding agreements with automotive manufacturers.
The durability testing of our products, which is carried out in parallel with the design and manufacturing process, is defined in accordance with these targets. However, final proof that the quality targets have been achieved requires the observation of product quality in the field. This includes the collection and analysis of warranty data (see [1]). Automotive manufacturers and suppliers use statistics derived from this as control parameters in their overall quality control loop.
This publication describes procedures that yield suitable statistics for assessing product reliability in the field, which can be used for quality control and for comparative supplier assessments.

1.1 Access to Field Data

The products made by the automotive divisions are used by more than 100 million end users. For economic reasons, it does not make sense for us to track every single complaint related to one of our products. Instead, we try to have partial market agreements with the automotive manufacturers for the duration of the warranty period. Technical and business aspects of all complaints received in the appropriate partial market are reported to Bosch, and form the basis for statements about product quality in the total market. As a rule, all the Bosch products that were the subject of complaints in this partial market are available for fault analyses.
Bosch collects the partial market complaint and analysis data in computerized systems such as GATEK (database system for processing warranty complaints in the automotive divisions [2]).

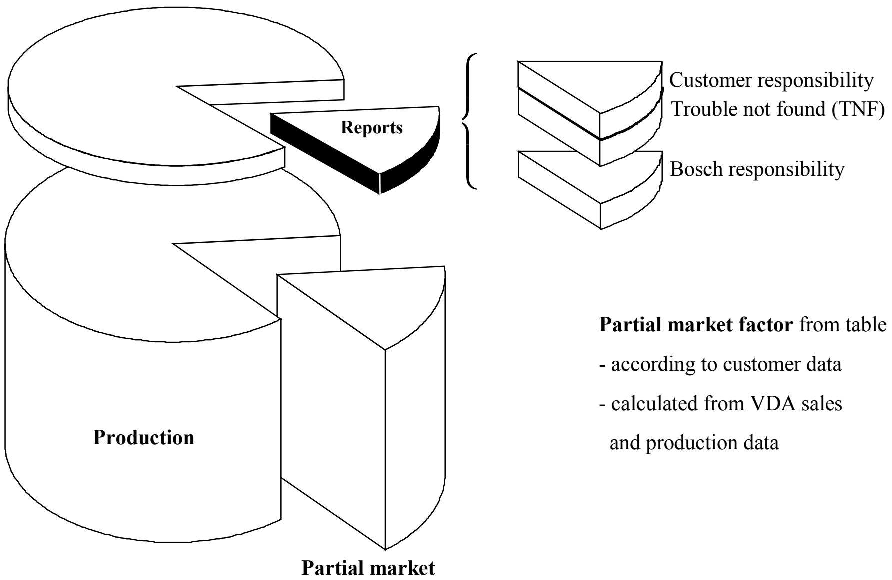


Fig. 1.1: Schematic of partial market approach
Observations always relate to a specific production period (year or quarter)

1.2 Basic Principles

The complaint rate during the warranty period is a key measure of product quality. The complaint rate is the ratio between the number of complaints reported and the total number of units used in the partial market concerned.

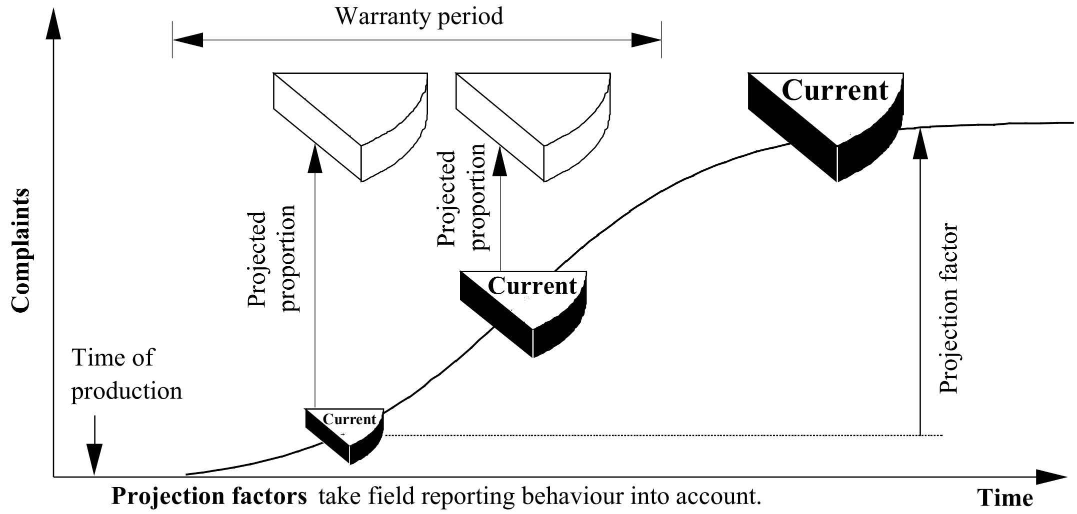
The complaint rate should be made available to those responsible in development, manufacturing, SE Teams and Distribution in a timely manner, so as to enable cause identification for any high rates as well as the definition and implementation of effective corrective action.

The following projection method is used during the warranty period to arrive at early estimates of the complaint rate to be expected by the end of the warranty period.

The partial market's complaint rate is calculated as follows:

Expected complaint rate = Current rate + Projected proportion

Here, the 'current rate' relates to the current complaint rate based on all complaints reported (known) at the time of the analysis.
The expected (projected) complaint rate is expressed in ppm (parts per million). It is always calculated for a defined production period. This provides a good basis for visualizing target deviations and for demonstrating the effectiveness of improvement actions.



Projection factors take field reporting behaviour into account.
Factors:
- Product age at the time of the observation
- Customer-specific reporting delay
- Product-specific delays
- Warranty period

Fig. 1.2: Schematic representation of the projection of field rates.
The continuous curve illustrates the increase in the number of complaints over time. Some time after the end of the warranty period, this settles down to a final value.

1.3 Complaint Rate vs. Failure Rate

The complaint rate shows the quality level from the point of view of the vehicle manufacturer. It also includes complaints attributable to unreliable dealer judgment, i.e. complaints revealed upon closer investigation to have been unfounded (TNF, trouble not found), as well as all parts damaged by customers or third parties.

Quality control within Bosch is based on the proportion of failures that are attributable to a Bosch error (henceforth called failure rate), especially when comparing against an upper limit.

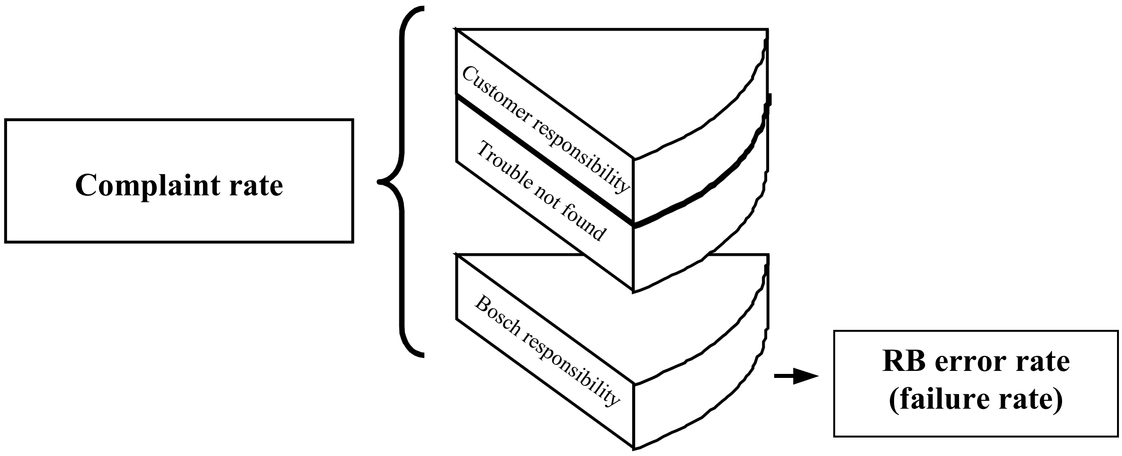


Fig. 1.3: Schematic representation of the relationship between complaint rate and failure rate.

The failure rate considers only those product failures that Bosch is responsible for. Like the complaint rate, it is made up of a current rate and a projected value to be added to this.

1.4 Failure Mode Distributions

To enable an effective response, the main failure areas must be established.

The projected numbers/rates for groups of similar failures are summed over the appropriate period and shown in order of magnitude.

1.5 Limitations of the Method

The projection method described in Section 1.2 uses empirical values for

- the reporting behavior of our customers and
- the failure behavior of our products.

The calculation method assumes that all complaints are registered in line with the requirements of the Warranty Manual [2]. Two particularly important requirements are regular receipt of warranty returns (hardware) from the customer and rapid fault analyses. Sudden changes in the process for dealing with warranty complaints (variation in reporting and processing behavior) will inevitably lead to erroneous assessments.

If there is a noticeable increase in the rate, an attempt should be made to analyze the failure behavior of the relevant product using Weibull methods (see e. g. [4]) and to determine an extrapolated value for the end of the warranty period.

Furthermore, care should be taken to ensure that ppm values are not given at a level of resolution that would represent less than a single failure. Hence, if delivery volumes are small, the period of observation should be increased, or quality control should be based on numbers of units rather than the calculation of rates.

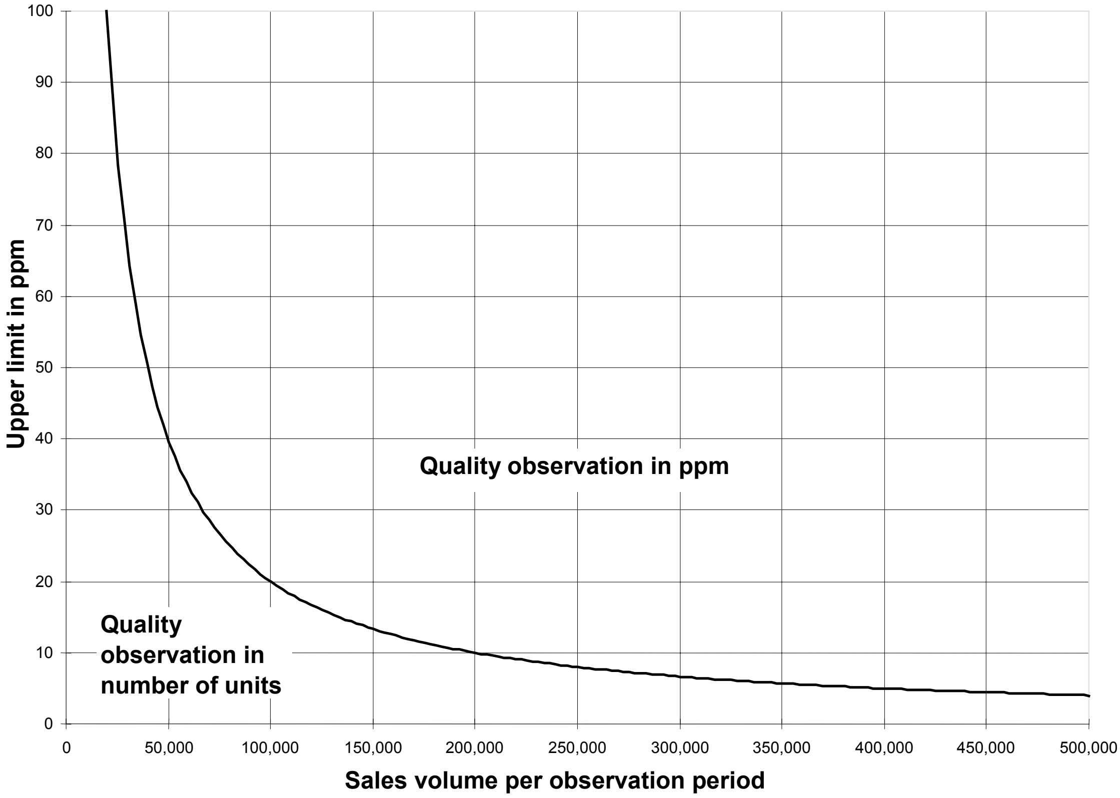


Fig. 1.5.1: Resolution as a function of sales volume (zero mileage)

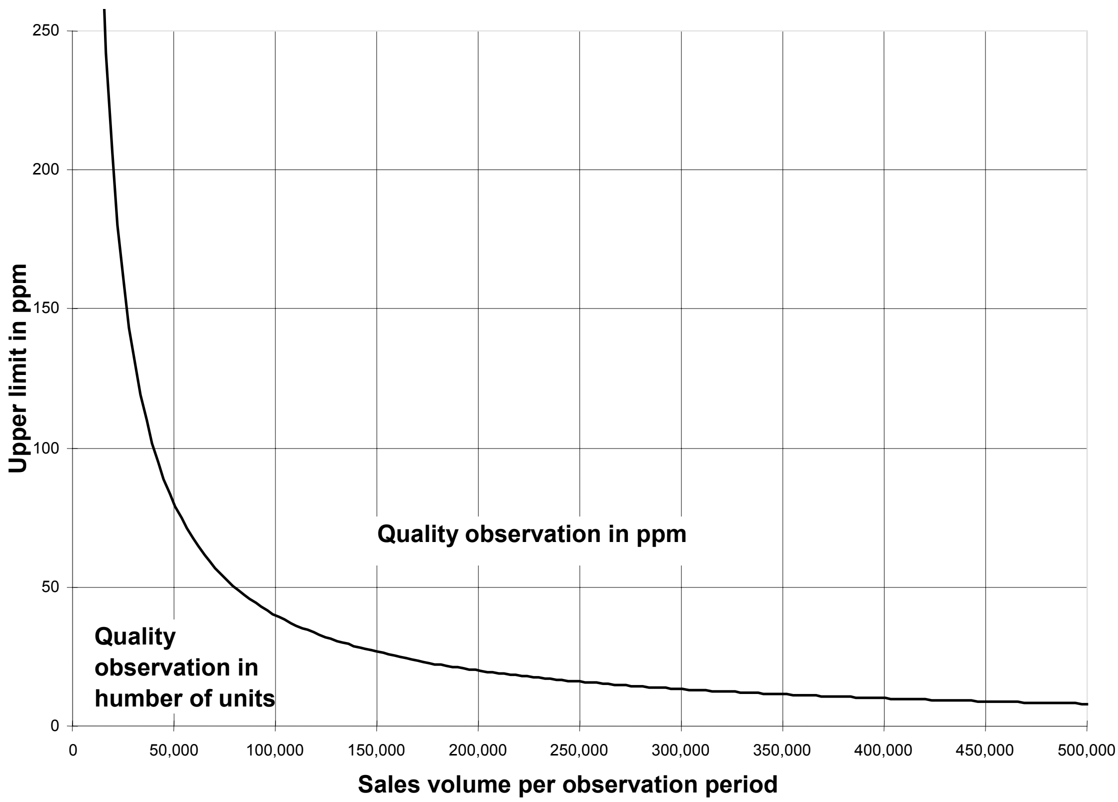


Fig. 1.5.2: Resolution as a function of sales volume (field)

1.6 Outlook

The passages above consider the current status of product quality in the field. This alone is not enough to satisfy today's quality requirements.

Systems for processing warranty data should offer the following facilities:

- Representation of error prevention measures, with implementation dates, for all major failure modes
- Failure rate projection/prognosis for future years, based upon the current failure rate and including the likely effect of planned measures and their implementation dates
- Visualizing these relationships.

2. Partial Market Factors

2.1 Purpose

To minimize the cost and effort involved in investigating field complaints and to streamline the business process for warranty matters, we have entered into contractually defined ‘partial market agreements’ with practically all our OEM customers.

The partial market is a part of the total market. All automotive products sold there that have been the subject of an end-customer complaint are returned to us via our OEM customer’s dealer network. The complaints are then logged and analyzed by us, and we establish whether or not there is a valid warranty claim. Usually, the partial market corresponds to one or more countries (e. g. Germany, US, …); these are referred to as ‘reporting’ countries.

Assuming that the failure pattern of our automotive products will also apply to the other, non-reporting countries or markets, we can then proceed to estimate the complaint or failure rate for the entire global market, using so-called partial market factors (PMF).

2.2 Determining Partial Market Factors

To obtain a first approximation, the partial market factor is determined as the ratio between the relevant automotive manufacturer’s production/registration total in the partial market concerned, and their total production/registration number over the relevant period.

$$\text{PMF} = \frac{\text{Number of vehicles registered/produced in/for partial market per period}}{\text{Total number of vehicles registered/produced per period}}$$

Manufacturers’ production totals are available to all areas at K/VMF. The number of partial market registrations as well as the proportions in the non-reporting markets are derived from business accounting factors, which are available from the relevant Technical Sales areas or regional subsidiaries. For technical rate calculation, these accounting factors are adjusted for those proportions that reflect additional payments for incidental expenditure (e. g. installation, disassembly, freight, handling charges).

Partial market factors used to calculate field failure rates are usually determined once per calendar year and are recorded in division- and customer-specific year-based reference tables.

2.3 Limitations of the Method

The comparatively simple determination of partial market factors using the above formula is only suitable where RB makes deliveries directly to the automotive manufacturers and there are no or only minor differences in product use due to market- or model-specific vehicle equipment variation.

For example, it may be that vehicles in non-reporting countries don't include certain products at all, or only in some cases, while 100% of the vehicles in the partial market are equipped with this product. In such cases, any partial market factor derived from vehicle registration statistics alone will need to be corrected or adjusted to reflect the actual situation. Equally, it does not make sense to define a partial market factor if an RB product is only intended for export to non-reporting countries. Since in such a case there would be a relative or complete lack of market information, given that logging and analysis of the relevant products would be lacking or incomplete, any rate calculated would not reflect actual product behavior in the field.

In any case, information on vehicle equipment and supply proportions in the relevant markets is of major importance in determining partial market factors. Partial market factors should always be calculated or estimated, as appropriate, in collaboration with the appropriate Technical Sales area or regional subsidiary.

A particular problem for the calculation of partial market factors arises where RB makes indirect supplies via third parties (e. g. systems suppliers) who have a warranty responsibility of their own to the OEM customers. Here it is not always known if or to what extent systems suppliers have agreed the same partial market procedures with the OEM customers as RB. This has to be ascertained on an individual basis, by consulting the systems supplier and the appropriate Technical Sales area or regional subsidiary, and taken into account accordingly.

So far, the scenarios we have considered have all been based on the calculation of a customer-focused field rate, taking into account the quantity sold to the OEM customers (sales volume).

However, in some cases it is necessary to provide production volume-related field rates for a complete product group. This may involve a need to take various partial markets and/or warranty periods into account. For this reason, the calculation of partial market factors does not always boil down to a straightforward application of the above method. In such cases, a generic factor for a product group can only be estimated and determined by means of volume-weighted averaging.

3. Projection Factors

3.1 Introduction to the Capture and Analysis of Field Data

The failure behavior of products is investigated by means of durability studies carried out in parallel with development and manufacturing. These durability analyses are based on Weibull methods (see e. g. [4], [7]).

Where durability studies are based on testing a representative sample of (similar) products on test rigs, there are defined test conditions such as:

- Product parameters
- From what time stress is applied to product
- How much stress is applied to product
- Environmental conditions.

In particular, it is usually easy to determine times or other product-specific durability characteristics (e. g. number of load changes, operating/switching/duty cycles, revolutions) between start-up and (defined) failure.

In addition, since the mechanisms that result in failure can usually be analyzed in great detail, the application of Weibull methods in such situations does not generally pose any problems (apart from any problems caused by small sample sizes).

However, when trying to derive descriptions of the failure behavior of a product from analyses of field data, the situation is (at least from a statistical point of view) much more complicated.

A product’s service life does not begin as soon as it has been manufactured. Once it has been assembled into a vehicle by an OEM manufacturer, some time may elapse before the vehicle is sold, registered and in regular use by the end customer. This time, which we will call the storage period or storage delay, can be viewed as a failure-free period, i. e. the product is not subject to any wear or aging caused by usage-related stress.

However, the storage period is not the same for each individual product. Corresponding studies have shown that storage periods approximately follow the lognormal distribution.

The storage period is followed by the actual operating time. Operating time is not identical with calendar time. It depends both on calendar time and on the frequency of usage. The usage frequencies of vehicle parts have been the subject of many comprehensive studies. People have, for example, installed usage frequency counters in vehicles of a representative cross-section of vehicle owners and logged frequencies of usage. This has shown, among other things, that one has to make a distinction between various different user groups, such as commercial drivers, long-distance drivers, drivers of a second family car, and drivers that use their cars mainly for short journeys (taxi cabs, police patrol cars). Within such groups, frequencies of usage can be adequately represented by lognormal distribution models (see e.g. [4]).

When evaluating warranty data, a key issue is the ability to arrive at an early (i.e. before the end of the warranty period) projection of the total expected number of warranty cases. But if we bear in mind, e.g., that the distribution of reported miles-to-failure is theoretically the result of combining a Weibull distribution with the annual mileage distribution, it becomes clear that projections of this kind are not easy to arrive at.

Furthermore, there are a number of products (such as fuel pump, alternator, starter) whose life variable (e.g. number of revolutions) does not have a direct correlation with the vehicle's mileage, but is rather dependent on the operating time and the operating conditions (e.g. engine speed, load, vehicle speed) or the operating mode (e.g. cold start, short trip).

The following figures show histograms for annual mileage (measured in kilometers) and storage periods based on warranty data.

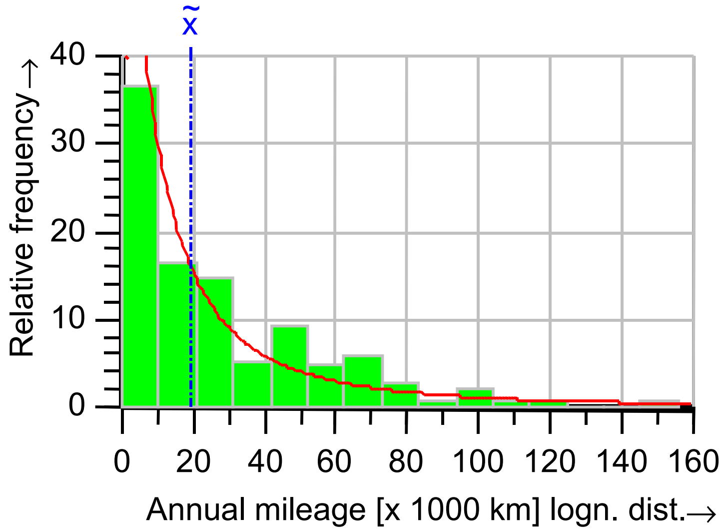


Fig. 3.1.1: Annual mileage (km/year). Approximation using a lognormal distribution model. $\tilde{x} = 19{,}300\ km$, $\bar{x} = 27{,}600\ km$.

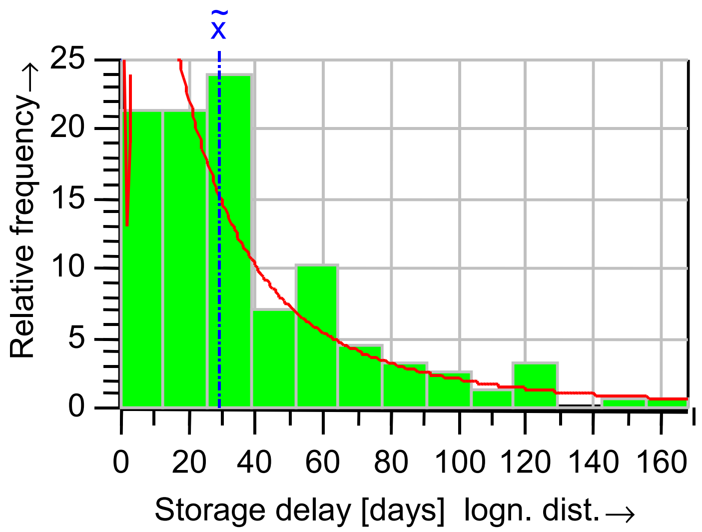


Fig. 3.1.2: Time lapse between manufacturing date and vehicle registration date. Approximation using a lognormal distribution model. $\tilde{x} = 29$ days.

In creating mathematical models, a particular problem arises from the fact that there may be a mixture of two or more separate distributions (bimodal/multimodal distribution) and/or competing failure mechanisms (see [4], [7]).

Warranty data represent a type of ‘negative selection’, since they comprise data of failed units only. This means that the histogram shown in Fig. 3.1.1 will not be representative of the population as a whole. A sample that was truly representative of the population would have to be defined prior to product delivery (usage). Only subsequent events would then show which of these products were destined to fail or not.

[4] describes a method for evaluating field failures according to the ‘sudden death’ method, which we shall return to in section 6.3.

Another method described in [4] uses a Weibull analysis that takes into account the mileage distribution of vehicles of identical age, assuming that this distribution is known. It should be noted that such a mileage distribution can not be gained from the warranty data themselves, due to the ‘negative selection’ problem that we touched on above.

Either method fails to address any of the problems related to the aspects raised above, such as lack of correlation between wear and mileage, incomplete data, customer usage patterns, reporting delays or competing failure mechanisms.

A prediction program developed by a Bosch division in the early eighties used the ‘storage distribution’ (time from production to vehicle registration) and the ‘usage distribution’ (annual mileage) to determine projection factors which were then used as multipliers for the failures that had been registered in a particular mileage class up to a particular point in time. This was meant to address the fact that, due to the storage period, a proportion of the products from a particular manufacturing date wouldn’t as yet have reached the mileage where a failure might occur.

This idea is revisited in [10] and [11], including the issues of practical implementation (see Section 6.6).

3.2 Representation of Field Data

3.2.1 Stair-step Table

Experience shows that zero-mileage failures and field failures of products can often be attributed to specific failure causes that occurred during a particular production period. One would therefore expect to find a systematic relationship between zero-mileage or field quality and the production date. As a rule, there is no systematic relationship between zero-mileage or field quality and the purchase date. Hence, the purchase date is not usually a relevant point of reference.

The stair-step table is a representation of product failures organized according to reporting period (month, quarter) and production period (production date, month, quarter). To generate this table, all the failures reported from the beginning of the production month to the end of the reporting month (complaints by end customers that have been accepted as warranted by RB) are summed and given in absolute terms and/or as a proportion (in ppm) of the total number produced during the relevant period.

	← Reporting month												
Prod.	8.99	7.99	6.99	5.99	4.99	3.99	2.99	1.99	12.98	11.98	10.98	9.98	8.98
month	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
8.98	2525	2310	2095	2041	1988	1934	1397	1289	1021	591	376	107	54
9.98	5091	4859	4744	4551	4281	3510	2584	1581	964	309	77	0	
10.98	2971	2710	2514	2449	2220	1894	1045	686	359	65	0		
11.98	6735	6591	6303	5799	4538	2989	2521	1513	396	216			
12.98	4600	4303	3895	3079	1818	927	445	74	37				
1.99	3539	3146	2500	1461	758	309	84	28					
2.99	2629	1920	1152	561	207	30	0						
3.99	2351	1312	629	219	55	27							
4.99	1639	862	402	115	0								
5.99	881	320	120	40									
6.99	320	58	29										
7.99	63	32											
8.99	0												

Stair-step table, status: end 8.99

3.2.2 Isochrone Chart

The failure proportions of products of equal age (same time gap between production and failure report) can be taken from this table and used to plot a so-called isochrone chart (contour plot). Isochrones are lines of equal product age. Failures are not shown against the reporting month, but against the production month.

Fig. 3.2.2 shows isochrones for product ages of 0, 1, 2, 3, ..., 12 months. The 0-months isochrone represents product failures at ages of less than one month. In this case, the production month and reporting month are identical, corresponding to the entries along the jagged lower edge of the stair-step table.

By following an isochrone to the right, changes in product quality over time are immediately apparent. It's very useful to make a note of any quality improvement actions, such as design changes or changes in manufacturing and assembly processes, along the time axis.

The effects of such measures will then, after a corresponding delay, be apparent from the subsequent development of the isochrones. Likewise, the behavior of the lowest isochrones enables early recognition of any critical developments concerning the product quality for a specific production quarter.

Since the failures of products from a particular production month are captured as cumulative totals at the end of each reporting month, the isochrones can never cross. The most that can happen is that no further failures of products from a given production month are observed. In this case, the failure proportion of this production month does not increase any further, and subsequent isochrones all run through the same point.

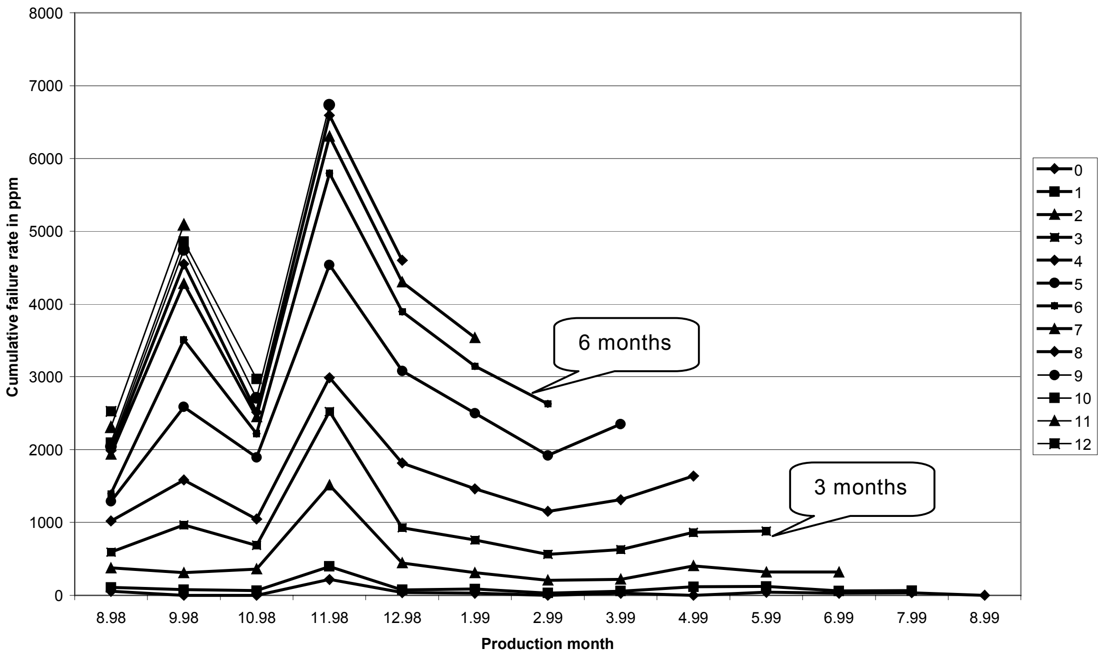


Fig. 3.2.2: Isochrone chart, status: end 8.99.

The isochrone values for a particular production month (read from the bottom up) correspond to the values in the row for that production month in the stair-step table (read from right to left). A given isochrone corresponds to one of the ‘diagonals’ in the stair-step table.

The stair-step table and the isochrone chart reflect the number of actual, reported and recognized failures. This figure may not be identical to the number of failures that have actually occurred, due to causes such as the following:

- The failure only occurs under certain operating conditions
- The driver does not notice the failure
- The driver does not feel the need to register a complaint, since the failure is felt to be insignificant
- The dealer workshop is unable to find the real cause of failure or just puts the vehicle owner off.

Of course, the vehicle manufacturer’s service behavior plays a role as well. The manufacturer may, for example:

- Initiate a recall campaign for all the affected vehicles
- Instruct workshops to look out for this type of fault whenever a vehicle is serviced
- Instruct workshops to ask vehicle owners whether they have ever observed this specific type of fault.

Whenever some of the products manufactured over a certain period of time are shipped to other countries or regions where data collection is less than complete, the reported proportion of failures will be smaller than the actual proportion by a certain factor. This so-called partial market factor must be taken into account when reimbursing the OEM customers for warranty costs.

Determining the necessary warranty budget requires a projection for the likely number of failure reports received by the end of the warranty period (and beyond, if the company pursues a good-will repair policy). However, due to the problems described above, such projections are subject to a fairly large degree of uncertainty.

Notes related to the reference literature:

[9] shows an isochrone chart where the isochrones have a slightly different labeling (i.e. <1, <2, ..., <n) from the one used in our example, even though their meaning is the same. Another slight difference is that the appropriate production quantity is noted at the top for each production quarter.

Clearly, the isochrone chart can be modified to suit individual practical requirements.

3.3 Purpose of Projection Factors

When observing product performance in the field, there is a need to establish as soon as possible what the final complaint rate is likely to be, based on the product's present failure behavior in the field.

Such projections are needed both for business management of warranty cases (including production planning and planning of final stock levels at the time manufacture of this product is discontinued) and for reporting.

If the current (actual) complaint rates for various production dates are analyzed at a particular point in time, this will always show a positive (downward) trend, at least for more recent production dates (see Fig. 3.3). In other words, the more recent the production date, the smaller the complaint rate.

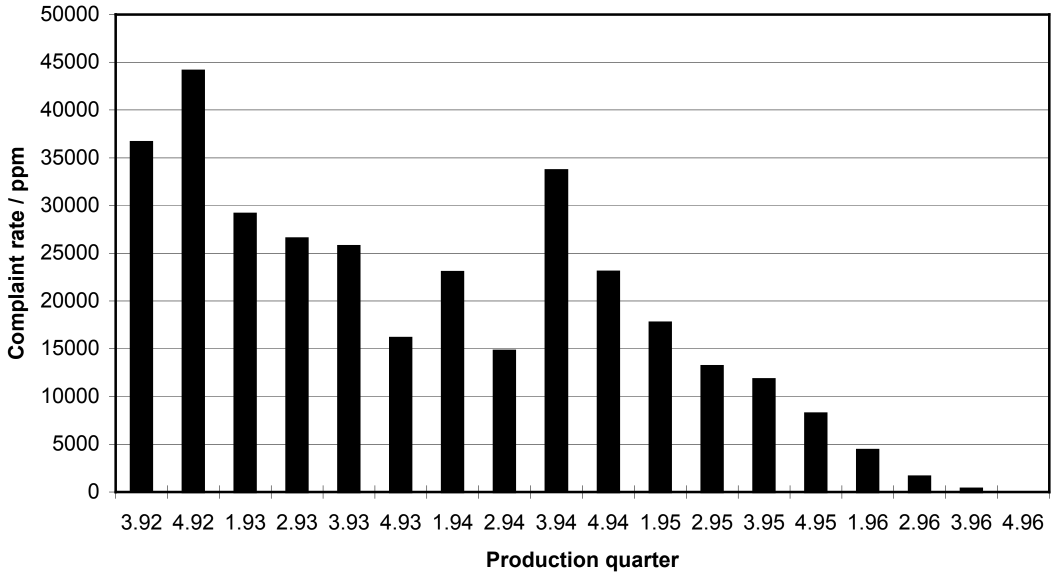


Fig. 3.3: Chart of current complaint rates for various production periods.

As discussed in section 3.1, the cause of this effect is the statistical distribution of time intervals between the products' manufacture and the reporting of failures. The factors impacting on this are summarized in section 3.4.4.

It's only after a certain amount of time, which considerably exceeds the warranty period (plus a limited goodwill period, where appropriate), that the cumulative total of complaints will asymptotically approach its final value. In the case of a one-year warranty period, the final value is typically only reached after three to four years (from production date).

The aim of the projection is to estimate the likely final complaint rate based on the current complaint rate. To determine this estimated final value, the current complaint rate must be multiplied by the projection factor.

3.4 Determining Projection Factors

Projection factors can be determined on the basis of the complaint rates known for a product (or comparable product) at a particular point in time. Monitoring the development of the complaint rates against time elapsed since the production date (product age) shows that the various production periods approach different final values (Fig. 3.4.1).

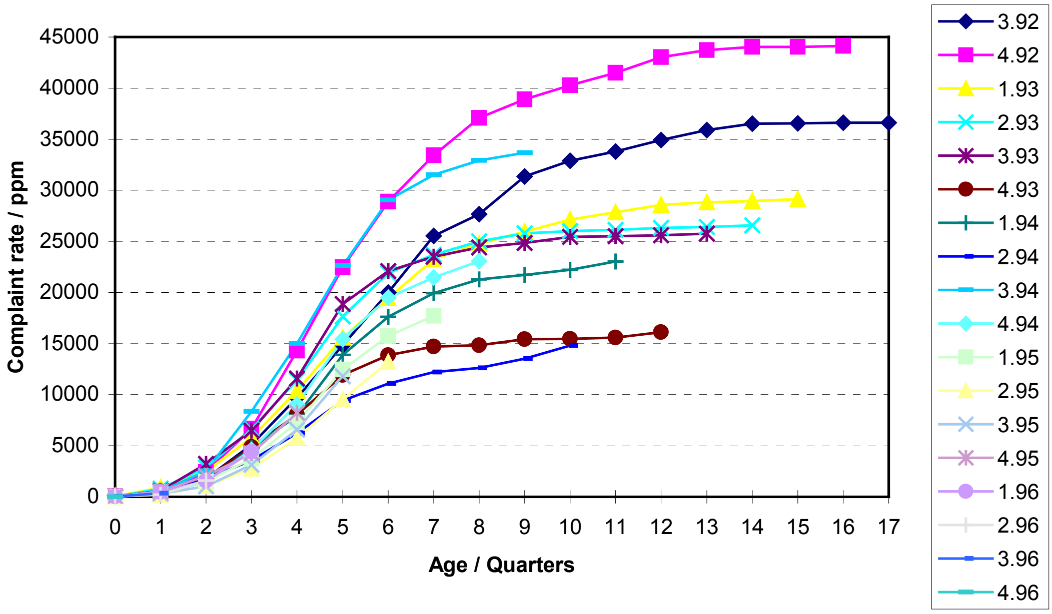


Fig. 3.4.1: Development of complaint rates over time
(in ppm, relative to the quantity produced)

Dividing the ppm values represented by the points on a curve (in Fig. 3.4.1) by the final value that the curve is approaching and plotting the percentages calculated in this manner against time yields a standardized plot as shown in Fig. 3.4.2.

If the curves all have a similar shape, i.e. if the standardized complaint rate behavior over time is independent of the production date, then an averaging process can be used to arrive at an average curve which may be assumed to be representative of this product's behavior. The projection factors then correspond to the reciprocals of the standardization factors.

The curve for the production quarter (PQ) 1.95 reaches 17,724 ppm after 7 quarters (Fig. 3.4.1). After 7 quarters, the complaint rates of the comparable quarters have on average reached about 79% of their final value (Fig. 3.4.2).

If the time pattern of the ppm numbers for the production quarter under consideration is similar to the pattern observed in the other quarters, then the complaint rate will reach a final value of approx. $\frac{17{,}724 \text{ ppm}}{0.79} \approx 22{,}435 \text{ ppm}$.

The projection factor thus has a value here of $\frac{1}{0.79} \approx 1.27$.

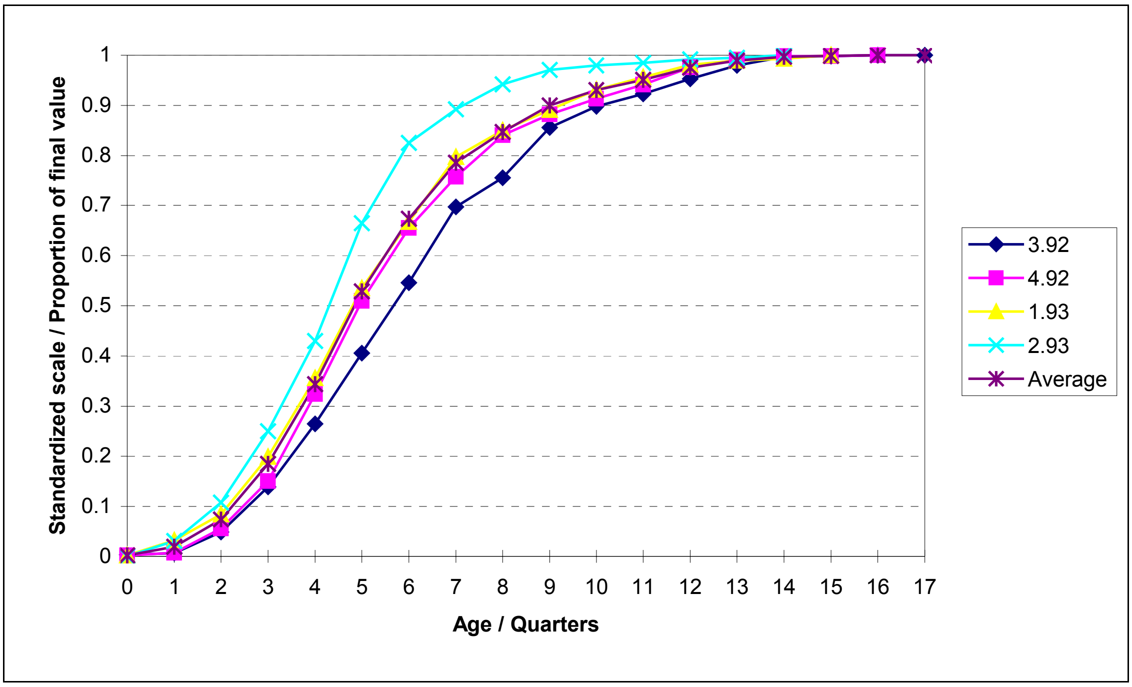


Fig. 3.4.2: Development of the standardized (expressed as proportion of the final value) complaint rate over time (for 4 production quarters).

3.4.1 Simple Calculation Method Based on the Stair-step Table

Below follows a description of a simple method for calculating projection factors based on the data contained in a stair-step table (see section 3.2.1).

We are looking for the expected final complaint rate for a specific production quarter. The complaint rate value for this production quarter, as known at the time of the analysis, can be found in the column for the most recent reporting quarter (RQ, third column from the left). It represents a certain product age. We now look for a comparable value relating to a production quarter that's very much 'older' and has a stable end value. Production quarters with an 'age' of more than 14 quarters can be assumed to have settled down to a stable end value.

Data (production quarters) of equal age can be found in fields lying on a diagonal running from bottom left to top right in the stair-step table. The final value for the older production quarter is again found in the column for the most recent reporting quarter. Dividing this final value by the comparable value yields a projection factor for this age, based on the data for the older production quarter. This can now be multiplied by the current value of the production quarter that interests us, to arrive at the expected end value for this production quarter (cf. the example on the following page).

This method assumes that the complaint rate for the quarter under consideration will develop in the same way as was the case for the earlier quarter some years ago that served as the basis for the projection. In other words, there is a tacit assumption that the general state of affairs concerning the factors summarized in Section 3.4.4 (e.g. manufacturing and development quality, reporting behavior) has not changed in any significant way.

Table 3.4.1

PQ	Basis	Reporting Quarter (RQ) 9604	9603	9602	9601	9504	9503	9502	9501	9404	9403	9402	9401	9304	9303	9302	9301	9204	9203
3.92	16299	36628	36628	36566	36505	35891	34910	33805	32885	31351	27670	25523	20001	14847	9693	5092	1779	245	122
4.92	13081	44109	44033	44033	43727	43039	41510	40287	38911	37076	33407	28896	22475	14295	6650	2446	305	76	
1.93	19494	29137	28931	28829	28572	27854	27136	25956	24776	23237	19441	15594	10362	5796	2462	923	51		
2.93	21993	26553	26417	26326	26144	26008	25780	25007	23689	21916	17641	11412	6638	2864	818	0			
3.93	13403	25740	25591	25516	25442	24845	24397	23502	22084	18876	11564	6491	3208	596	0				
4.93	18614	16116	15579	15472	15418	14827	14720	13860	11926	8058	4888	1826	537	53					
1.94	25929	23024	22214	21713	21288	19939	17625	13884	7944	4743	1465	385	0						
2.94	30625	14791	13518	12604	12212	11069	9404	6236	3559	1763	326	0							
3.94	27765	33675	32919	31514	29029	22618	14982	8355	2521	540	36								
4.94	26959	23072	21477	19511	15430	9050	4599	1446	408	74									
1.95	35600	17724	15730	12443	7247	3735	1488	449	28										
2.95	33857	13173	9540	5759	2746	1063	206	59											
3.95	36581	11809	6560	3143	1038	328	27												
4.95	34784	8222	4254	2041	546	28													
1.96	24983	4402	1561	480	40														
2.96	34330	1602	233	29															
3.96	31634	347	31																
4.96	24151	0																	

Example:

Sought: Final value for PQ 1.95
Current value: 17,724 ppm
Age: 7 quarters (4.96 – 1.95)
Comparable value: 23,237 ppm (intersection PQ 1.93/RQ 4.94) (same age, i.e. 7 quarters)
Final value (PQ 1.93): 29,137 ppm

Projection factor: $\frac{29{,}137 \text{ ppm}}{23{,}237 \text{ ppm}} = 1.25$

Projected final value for PQ 1.95 : $17{,}724 \text{ ppm} \cdot 1.25 = 22{,}155 \text{ ppm}$

3.4.2 Graphical Method

Following the basic approach outlined in section 3.4.1, final complaint rates can also be determined using contour lines (Fig. 3.4.2). To do this, one follows an isochrone (line of equal age) to find a comparative value in the past (relating to an earlier production quarter). According to the data available today, this value has led to a certain final value (uppermost isochrone for the corresponding production quarter). This yields the prediction factor to be applied to the quarter under consideration. The drawbacks of this method are as described above (section 3.4.1).

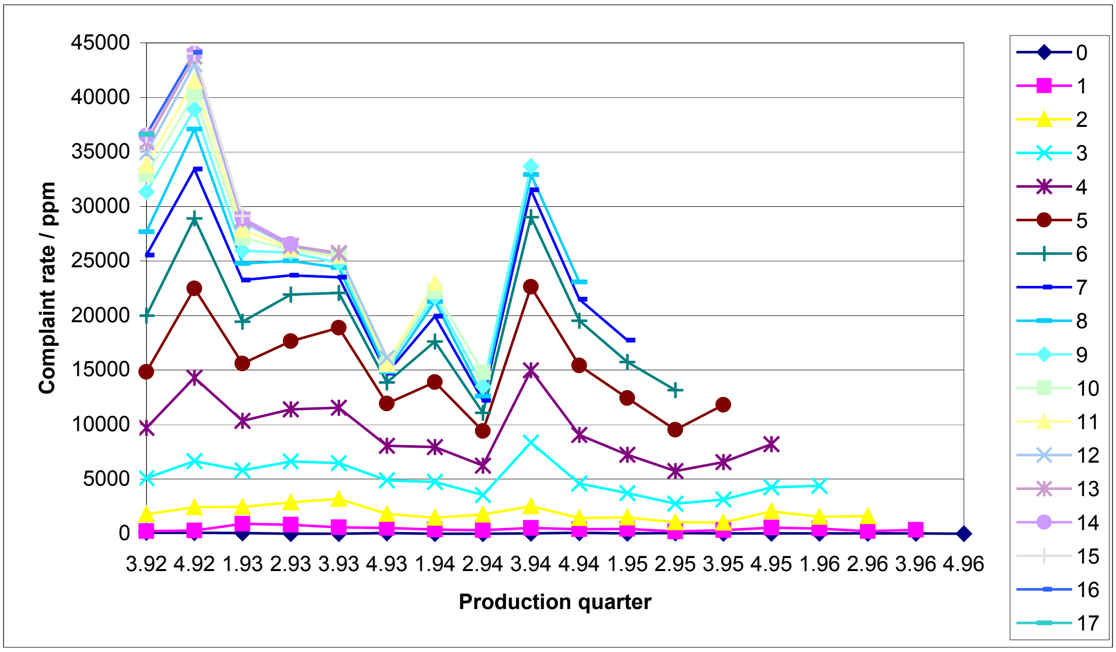


Figure 3.4.2: Isochrone chart based on the data in Table 3.4.1.

3.4.3 Computational Method

The following method is recommended in order to ensure that more recent data are also included in the determination of the prediction factors, thus putting the calculation on a broader footing.

Using a suitable software program (e.g. Excel), the stair-step table (Table 3.4.1) is converted to the format shown in Table 3.4.3.1. This shows the cumulative complaint rates for each production quarter against product age, measured in quarters elapsed since the production date. It can be seen that the values listed from right to left in each row (specific production date) of the stair-step table (Table 3.4.1) now appear in the corresponding column (relating to that same production date) of Table 3.4.3.1. The values found in these columns, read from top to bottom, correspond to the points of intersection of the isochrones (0, 1, 2, ...) with the vertical line representing the relevant PD in the isochrone chart (Fig. 3.4.2).

In each column (relating to a specific PQ) of Table 3.4.3.1, we divide each value by the one above it and enter the result in the lower of the two corresponding cells in Table 3.4.3.2. Each of these numbers indicates the factor by which the complaint rate has increased in comparison with the value of the preceding quarter. Of course, this only yields a useful result where the denominator is > 0.

The following example illustrates the procedure:

Of the products manufactured in the 3.92 production quarter, 1,779 ppm had given rise to a complaint by the time the first two quarters had elapsed (age = 2 quarters). The cumulative complaint rate reached 5,092 ppm by the end of the following quarter (age = 3 quarters). In other words, it rose by a factor of $\frac{5{,}092 \text{ ppm}}{1{,}779 \text{ ppm}} = 2.86$. This number thus corresponds to an 'instantaneous projection factor' and is entered in the appropriate cell of Table 3.4.3.2 (column: 3.92, row: age = 3).

The 'instantaneous projection factors' are then averaged for each age across all of the PQs (horizontally), and the averages are recorded in the average column on the right. Note that cells that contain the ∞ symbol are not taken into account in this.

The projection factors sought (PF column) are then calculated by multiplying together all the averages from that row downwards.

Thus the number 5.24 (in the PF column) results from multiplying all the averages together: $1.87 \cdot 1.61 \cdot 1.26 \cdot 1.13 \cdot \ldots \cdot 1.00 = 5.24$. This is the projection factor for the fourth quarter following the production date. Likewise, the projection factor for the fifth quarter is found by multiplying all of the averages from that row (age = 5 quarters) onwards: $1.61 \cdot 1.26 \cdot 1.13 \cdot \ldots \cdot 1.00 = 2.80$.

This method ensures that all the available data from the stair-step table are used to determine the projection factors.

One might think that it would make sense to use age-dependent weighting when calculating the averages. However, corresponding studies have shown that a broader base yields better results.

The values in the row that corresponds to an age of one quarter, as well as some of the values in the row for an age of two quarters, exhibit a great deal of variation. This applies both to the initial rate of complaints reported and the 'instantaneous projection factors' derived from them. This is due to the various factors covered in Section 3.4.4.

The first few age quarters in particular often yield projection factors that are significantly greater than 10.

Due to the evident uncertainty involved, it is recommended that practitioners should not normally try to calculate complaint rate projections on the basis of the two or three earliest quarters.

	Production Quarter																	
Age	3.92	4.92	1.93	2.93	3.93	4.93	1.94	2.94	3.94	4.94	1.95	2.95	3.95	4.95	1.96	2.96	3.96	4.96
0	122	76	51	0	0	53	0	0	36	74	28	59	27	28	40	29	31	0
1	245	305	923	818	596	537	385	326	540	408	449	206	328	546	480	233	347	
2	1779	2446	2462	2864	3208	1826	1465	1763	2521	1446	1488	1063	1038	2041	1561	1602		
3	5092	6650	5796	6638	6491	4888	4743	3559	8355	4599	3735	2746	3143	4254	4402			
4	9693	14295	10362	11412	11564	8058	7944	6236	14982	9050	7247	5759	6560	8222				
5	14847	22475	15594	17641	18876	11926	13884	9404	22618	15430	12443	9540	11809					
6	20001	28896	19441	21916	22084	13860	17625	11069	29029	19511	15730	13173						
7	25523	33407	23237	23689	23502	14720	19939	12212	31514	21477	17724							
8	27670	37076	24776	25007	24397	14827	21288	12604	32919	23072								
9	31351	38911	25956	25780	24845	15418	21713	13518	33675									
10	32885	40287	27136	26008	25442	15472	22214	14791										
11	33805	41510	27854	26144	25516	15579	23024											
12	34910	43039	28572	26326	25591	16116												
13	35891	43727	28829	26417	25740													
14	36505	44033	28931	26553														
15	36566	44033	29137															
16	36628	44109																
17	36628																	

	Production Quarter																			
Age	3.92	4.92	1.93	2.93	3.93	4.93	1.94	2.94	3.94	4.94	1.95	2.95	3.95	4.95	1.96	2.96	3.96	4.96	Average	PF
0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	2.01	4.01	18.10	∞	∞	10.13	∞	∞	15.00	5.51	16.04	3.49	12.15	19.50	12.00	8.03	11.19	-	10.55	670.50
2	7.26	8.02	2.67	3.50	5.38	3.40	3.81	5.41	4.67	3.54	3.31	5.16	3.16	3.74	3.25	6.88			4.57	63.50
3	2.86	2.72	2.35	2.32	2.02	2.68	3.24	2.02	3.31	3.18	2.51	2.58	3.03	2.08	2.82				2.65	13.89
4	1.90	2.15	1.79	1.72	1.78	1.65	1.67	1.75	1.79	1.97	1.94	2.10	2.09	1.93					1.87	5.24
5	1.53	1.57	1.50	1.55	1.63	1.48	1.75	1.51	1.51	1.70	1.72	1.66	1.80						1.61	2.80
6	1.35	1.29	1.25	1.24	1.17	1.16	1.27	1.18	1.28	1.26	1.26	1.38							1.26	1.74
7	1.28	1.16	1.20	1.08	1.06	1.06	1.13	1.10	1.09	1.10	1.13								1.13	1.38
8	1.08	1.11	1.07	1.06	1.04	1.01	1.07	1.03	1.04	1.07									1.06	1.23
9	1.13	1.05	1.05	1.03	1.02	1.04	1.02	1.07	1.02										1.05	1.16
10	1.05	1.04	1.05	1.01	1.02	1.00	1.02	1.09											1.04	1.11
11	1.03	1.03	1.03	1.01	1.00	1.01	1.04												1.02	1.07
12	1.03	1.04	1.03	1.01	1.00	1.03													1.02	1.05
13	1.03	1.02	1.01	1.00	1.01														1.01	1.03
14	1.02	1.01	1.00	1.01															1.01	1.01
15	1.00	1.00	1.01																1.00	1.00
16	1.00	1.00																	1.00	1.00
17	1.00																		1.00	1.00

Tables 3.4.3.1 (top) and 3.4.3.2 (bottom). For explanation see text.

3.4.4 Limitations of the Method

The ‘quality’ of the projection factors determined and thus the projection itself is limited by various factors. These include:

- Product-specific reporting behavior
- Sporadic batch reports made by OEM customers
- Long storage periods at RB or the customer’s premises
- Failure behavior of the products concerned
- Customer usage patterns
- Various warranty/goodwill periods.

The influence of these noise factors must be assessed in each individual case.

Experience shows that projections should only be made for quarters that go back at least 2–3 quarters (from the time of the analysis), since otherwise there won’t be a sufficient database for a reliable prediction.

4. Field Rate Calculation

4.1 Definitions

Annual average rate

This is calculated by averaging the values of the individual quarters, weighted according to the number of products. If the data for recent quarters are as yet unconfirmed, then the calculation basis for the year can be limited. Failure numbers and sales figures for such quarters do not enter into the calculations. Default setting in ISKB: The current and previous quarters are excluded.

Basis of calculation

This is one production quarter. Calculations are only ever performed for completed quarters. Failure numbers and reference totals of quarters as yet uncompleted are not taken into consideration.

Campaigns

Complaints are registered under warranty type 9 (WT 9, see [2]). Campaigns usually have a time limit. Hence, there are usually no projections for WT 9 complaints.

Current rate

This is the current complaint rate for a partial market.

Failure distributions

Failure distributions can be generated for failure causes or for failure locations/failure modes.

Field rate

Unless specified otherwise, this is always the projected figure for the warranty period.

Partial market

A partial market is a region agreed with a customer for which the customer will provide reports on any and all complaints received during the warranty period.

Partial market factor (PMF)

The partial market factor is the ratio between the number of products that are in use in a particular partial market and the number sold or manufactured by RB (over a specific period), i.e. a number between 0 and 1. They are listed in division- or customer-specific tables structured according to years. For more details see Section 2.

Projection factor (PF)

Multiplying the current rate by the projection factor yields the expected (projected) field rate for the end of the warranty period. There are product- and customer-specific reference tables with projection factors for various product ages, measured in quarters (cf. Section 3.4.3).

Reference total

The reference total for the calculation of field rates is the total number of products manufactured and sold, regardless of whether they were sold by the division or AA. The total number sold or the total number manufactured can be used as an alternative. ISKB uses the quantity sold as its default if the reporting group specifies a customer.

Reported rates

Figures are given to the nearest ppm (without decimal places).

Reporting delay
Time elapsed between failure (failure date) and reporting of a warranty complaint (reporting date).

Reporting group
Summary of complaint data according to specific selection criteria. The reporting group may, for example, describe one product/customer combination and establish a link to the appropriate partial market and projection factors that should be used.

Rounding
Figures ≤ 500 ppm are rounded to the nearest 10 ppm,
Figures > 500 ppm are rounded to the nearest 100 ppm.

Storage period
Time elapsed between production date (PD) and first use of a product (purchase/registration date).

TNF
Abbreviation of 'Trouble Not Found'

Usage
Mileage (measured in miles or kilometers) or operating time (measured in operating hours) from first use of the product to the time when the product failed (first occurrence of the fact that led to the complaint).

Warranty period
Calculations can be performed for the entire warranty period, or for the first, second, third, etc. warranty year, as desired. The appropriate projection factors have to be used.

4.2 General Requirements

- If the reference total is very small, no rates should be calculated.
  Default setting in ISKB: 300/quarter (cf. Fig. 1.5.1 and 1.5.2).

- If the number of complaints is very small, the projection factors used in any calculations should always be rounded to the nearest integer.

5. Calculation of Field Rates in the ISKB System

ISKB (German acronym for: Information System Customer Complaints) is a system for analyzing GATEK data. It does not include functions for editing data. This system provides access to reference data (OEM, divisions), production and sales data as well as data on aftermarket warranty cases (see [3]).

5.1 Process Steps

The following sections describe the steps for calculating field rates within the ISKB system (cf. also Fig. 1.3):

a) Calculating the complaint rate
b) Subdivision into ‘Bosch responsibility’ (failure rate), ‘Trouble not found’, ‘Customer responsibility’ and ‘Pending’.
c) Annual overview with failure mode distribution.

5.1.1 Calculating the Complaint Rate

The complaint rate shows the quality level of our products from the point of view of the customer. It is calculated by comparing all complaints originating from a specific partial market to the number of vehicle units sold in this market.

The calculation is usually performed for one customer product group and for the agreed warranty period.

The calculation determines the rate for a specific production quarter. In the annual summaries, the most recent quarters may be suppressed if it seems likely that the data for these quarters have not stabilized yet.

If the number of vehicle units sold in the relevant market is not available, the number supplied to the customer is used as the reference total and then corrected using the partial market factors (PMF) listed in the tables.

The projection factors (PF), which are also available from tables, are used to correct the number of field complaints.

No projections are made for complaints due to campaigns (WT 9), since these tend to be short-term effects, whose development over time does not really lend itself to the use of projection factors. Since all products that were the subject of a complaint within the campaign are captured on a global basis under WT 9, there is no need for any partial market factor either.

To limit the analysis to the warranty period agreed with the customer, any products that were the subject of a complaint, but whose operating time (time period elapsed between purchase/registration and failure) was greater than the warranty period, should be excluded from the calculation of the complaint rate.

Complaint rate in the quarter:

$$\text{Complaint rate / Q} = \text{Current rate} + \text{Projected proportion} + \text{Campaign proportion (WT 9)}$$

with:

$$\text{Current rate} = \frac{\text{Number of complaints from partial market}}{\text{Number sold} \cdot \text{PMF}}$$

$$\text{Projected proportion} = \frac{\text{Number of complaints from partial market}}{\text{Number sold} \cdot \text{PMF}} \cdot (\text{PF} - 1)$$

$$\text{Campaign proportion} = \frac{\text{Number of WT 9 complaints}}{\text{Number sold}}$$

Average complaint rate per year:

$$\text{Complaint rate / Y} = \frac{\sum_{j=1}^{4} (\text{ Failure rate in jth Q} \cdot \text{Reference total for jth Q})}{\text{Reference total (1st Q} + \text{2nd Q} + \text{3rd Q} + \text{4th Q)}}$$

5.1.2 Subdivision into 'Bosch Responsibility' (Failure Rate), 'TNF', 'Customer Responsibility' and 'Pending'

The complaint rate includes all complaint reports. As such, it comprises the following categories:

- Bosch reponsibility (failure rate):
  Any failures attributable to faults that Bosch (plant, development, application, distribution) is responsible for and which were recorded under warranty types 0, 3, 4, 7 and 9.

- Fault-free products (TNF rate):
  Products that were the subject of a complaint but where in fact no fault was found when the product was analyzed by Bosch. (TNF = trouble not found.)

- Customer responsibility:
  Parts with defects due to wrong application, or customer usage involving excessive stress.

- Pending:
  Parts that have been registered as faulty by the customer but have not yet been subjected to a functional test.

To calculate rates for each individual category, follow the method outlined for the complaint rate (Section 5.1.1).

5.1.3 Annual Overview with Failure Mode Distribution

For a quick determination of the main problem areas, the most frequent failure modes that were observed on products from a particular production period are shown in so-called annual overviews, with the various failure modes listed in order of frequency.

When showing data spanning several production years, the customary ISKB approach can be used to structure the print-out.

The calculation of failure mode distributions is based on all the products from the relevant production period that were subject to detailed analysis (e.g. failure mode/failure location) and exhibited defects falling within RB's responsibility. There is a separate calculation for each failure mode.

The failure mode distributions, given in number of units or ppm, are based on the analyzed and recognized failure totals. For warranty types 0, 1, 3, 4 and 7, these are multiplied by the partial market and projection factors. For campaigns, it is assumed that all products are captured globally under warranty type 9 and that there is a limited implementation period. For this reason, there is no need to take partial market and projection factors into account.

Failure mode distribution in number of units

Annual frequency of a failure mode (number of cases p.a.)

$$= \frac{\sum_{j=1}^{4}\left[(\text{Number of WT 0, 3, 4, 7 parts with same fault from jth Q})\cdot\text{PF for jth Q}\right]}{\text{PMF}}$$

$$+\text{Number of WT 9 parts with same fault from 1st, 2nd, 3rd and 4th Q}$$

Failure mode distribution in ppm

Relative annual frequency of a failure mode (number of cases p.a.)

$$= \frac{\sum_{j=1}^{4}\left[(\text{Number of WT 0, 3, 4, 7 parts with same fault from jth Q})\cdot\text{PF for jth Q}\right]}{(\text{Number sold in 1st, 2nd, 3rd and 4th Q})\cdot\text{PMF}}$$

$$+\frac{\text{Number of WT 9 parts with same fault from 1st, 2nd, 3rd and 4th Q}}{\text{Number sold in 1st, 2nd, 3rd and 4th Q}}$$

5.2 Presentation of Results

Complaint and failure rates and the most frequent failure modes are listed together on a report sheet. The tables below show examples of ISKB analyses (Lists 2.1 and 3.1). The total for each failure mode is the sum of the annual absolute frequency values, or the weighted average of the annual proportions. Each report sheet must include the warranty period, the analysis period and the status date of the failure data.

Subdivision of the complaints presented according to warranty decision

	Production year			
	1998	**1999**	**2000**	**Total**
Presented	59	675	172	906
during the last 30 days	-	28	28	56
during the last 90 days	4	325	157	486
RB responsibility	39	390	33	462
of which analyzed in detail	39	390	33	462
Customer responsibility	7	42	2	51
of which analyzed in detail	7	42	2	51
Trouble not found	12	63	8	83
of which analyzed in detail	12	63	8	83
Warranty decision pending	1	180	129	310

Failure mode frequency values for all products
Most frequent failure modes for the current production year and main failure modes for previous years (number of units)

	Production year			
	1998	**1999**	**2000**	**Total**
RB responsibility				
CP blocked	15	198	25	238
Particles in PCV	5	36	5	46
CP – other mech./hydr. failures	1	68	1	70
CP cylinder head leak	6	7	1	14
Particles under ceramic plate	-	5	1	6
Undesignated CP failure	7	34	-	41
CP casing damaged	-	24	-	24
Particles in HP pump	-	6	-	6
Overall PCV function not o.k.	3	3	-	6
Missing CP parts	1	1	-	2
Other	1	8	-	9
Total	39	390	33	462
Customer responsibility				
Unsuitable fuel	1	8	2	11
Corrosion damage	1	11	-	12
Dirt-induced failure	-	10	-	10
Product damaged	1	3	-	4
Other	4	10	-	14
Total	7	42	2	51

Table 5.2.2: Standard list 2.1 from ISKB; table entries represent number of units

Complaint rates in ppm (rounded)
Subdivision according to warranty decision
Current year only contains data up to production month 08.00
Rates may still be subject to change due to late reports.

	Production year		
	1998	**1999**	**2000**
Total number of complaints	4,498	8,677	1,897
RB responsibility	2,973	5,014	364
of which analyzed in detail	2,973	5,014	364
Customer responsibility	534	540	22
of which analyzed in detail	534	540	22
Trouble not found	915	810	88
of which analyzed in detail	915	810	88
Warranty decision pending	76	2,314	1,422
Target levels (max.) for RB responsibility	-	450	300

Failure rates in ppm for all products (rounded)
Most frequent failure modes for the current production year and main failure modes for previous years

	Production year		
	1998	**1999**	**2000**
RB responsibility			
CP blocked	1,143	2,545	276
Particles in PCV	381	463	55
CP – other mech./hydr. failures	76	874	11
CP cylinder head leak	457	90	11
Particles under ceramic plate	-	64	11
Undesignated CP failure	534	437	-
CP casing damaged	-	309	-
Particles in HP pump	-	77	-
Overall PCV function not o.k.	229	39	-
Missing CP parts	76	13	-
Other	76	103	-
Total	2,973	5,014	364
Customer responsibility			
Unsuitable fuel	76	103	22
Corrosion damage	76	141	-
Dirt-induced failure	-	129	-
Product damaged	76	39	-
Other	305	129	-
Total	534	540	22
Production total in 1000's	13	77	90

Table 5.2.2: Standard list 3.1 from ISKB; table entries in ppm unless stated otherwise (without projection and without inclusion of a partial market factor in the calculations)

6. Statistical Analysis Using Weibull Methods

6.1 Database

For each warranty case, the following data must be available:

- Production date (uncoded, i.e. simply DD.MM.YY) or at least the production month
- Production total at this production date
- Vehicle registration date
- Date of failure
- Vehicle mileage (at time of failure).

Data must not include zero-mileage cases, since such cases correspond to a life (mileage) of zero and as such cannot be modeled by the Weibull or lognormal distribution.

It helps to structure the data according to production date, starting with the earliest dates.

Problems in evaluating real-life data sets have shown that data may need to be edited to eliminate individual cases that would lead to illogical or nonsensical figures. Such cases usually won't even trigger an error message, making them a particular cause for concern.

The following table shows some examples, with suggested solutions:

Problem	Suggested solution
The purchase data is earlier than the production date, yielding a negative storage period.	Add 30 days to the (negative) storage period.
Mileage at the time of failure is zero.	Reset mileage to 0.5 miles or km.
When failure date and purchase date are the same, this results in an operating time of zero. In individual cases, this can lead to a very high annual mileage value, e.g. 352,000 miles.	Reset failure date to the 15th of the month or add two weeks to the failure date.
Individual data values do not seem plausible, e.g. 23,000 miles driven within one month or 30 miles over a period of 6 months.	Discard individual values.
In individual cases the storage period exceeds one year.	

6.2 Establishing the Annual Mileage Distribution

Where possible, the annual mileage distribution should be determined on the basis of independent representative data (e.g. manufacturer's data). From a statistical point of view, an estimation based on sample data would only be legitimate if a random (representative) sample had been defined prior to the first use of the vehicles, i.e. at a time when it was not yet known how many of the vehicles were going to fail.

The failures included in warranty data tend to be based on a large variety of failure mechanisms. Hence it seems justified to estimate the annual mileage distribution on the basis of the available data. However, the result might be biased, due to the fact that the exclusive consideration of warranty cases constitutes a negative selection principle, and should therefore be checked for plausibility.

For each individual case, it is possible to calculate an average annual mileage based on the difference between the registration date and the failure date and the vehicle's mileage at the time of failure.

$$\text{Annual mileage} = \frac{\text{Mileage at time of failure}}{\text{Failure date} - \text{Registration date}} \cdot 365\ \text{days} \quad \text{(production day known), or}$$

$$\text{Annual mileage} = \frac{\text{Mileage at time of failure}}{\text{Failure month} - \text{Registration month}} \cdot 12\ \text{months} \quad \text{(production month known)}$$

Experience has shown that the lognormal distribution represents a suitable model for this distribution (see e.g. [4] and [10]). Plotting the data on lognormal probability paper or performing a statistical goodness-of-fit test will show whether this assumption is justified in this particular case. Fig. 6.2.1 below shows an example of a good fit.

A random variable is said to follow the lognormal distribution if the logarithm of this variable follows the normal distribution. The statistics μ and σ of the underlying normal distribution can be calculated as the average and standard deviation of the logarithms of the data (see [5]).

Example:

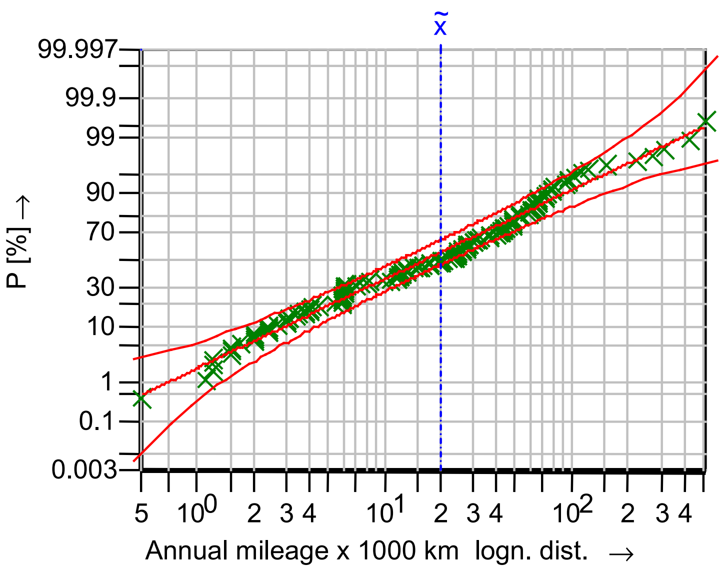


Fig. 6.2.1:
Plot of annual mileage data on lognormal probability data. All of the values lie within the 90%-confidence zone.

6.3 Sudden-Death Method for Field Failures

Sudden-death testing is a time-saving method used for investigating failure behavior in bench tests (cf. [4], [7]). The total number of test items is divided into a number of subgroups. Each subgroup is then tested until one item fails in each subgroup.

As outlined in [4], this method can also be applied to field failures. To facilitate this, the failures reported are viewed as the first failures occurring within artificial subgroups of 'test items'. In forming these artificial subgroups, the n_f failures reported are distributed evenly across the total number of items, n, produced during the reference period. Each subgroup comprises approximately $k = \frac{n - n_f}{n_f + 1} + 1$ products. The $k - 1$ items within a subgroup that did not fail are treated as suspended units.

Example:

PD: 10/98 Number of failures: $n_f = 24$ Production total: n = 7,902

Subgroup size $k = \frac{n - n_f}{n_f + 1} + 1 = \frac{7{,}902 - 24}{24 + 1} + 1 \approx 316$

Failure No.	Mileage in km	Failure No.	Mileage in km
1	500	13	4100
2	600	14	4500
3	900	15	5000
4	930	16	5100
5	1000	17	6000
6	1500	18	6900
7	1800	19	9800
8	2900	20	10400
9	3000	21	11500
10	3050	22	12000
11	3300	23	14000
12	4000	24	20000

[4] describes a graphical method for analyzing such data on Weibull paper. After plotting the points corresponding to the failures, a line of best fit is drawn which represents the 'first failures'. Parallel shifting of this 'line of first failures' to make it pass through a calculated point then yields the required line for the Weibull distribution of the population (see Fig. 6.3.1).

However, some software programs for life data analysis allow users to enter both the failed and non-failed items and enable direct analysis of such subgrouped data (Fig. 6.3.2) by means of the maximum-likelihood method (see [4], [13]).

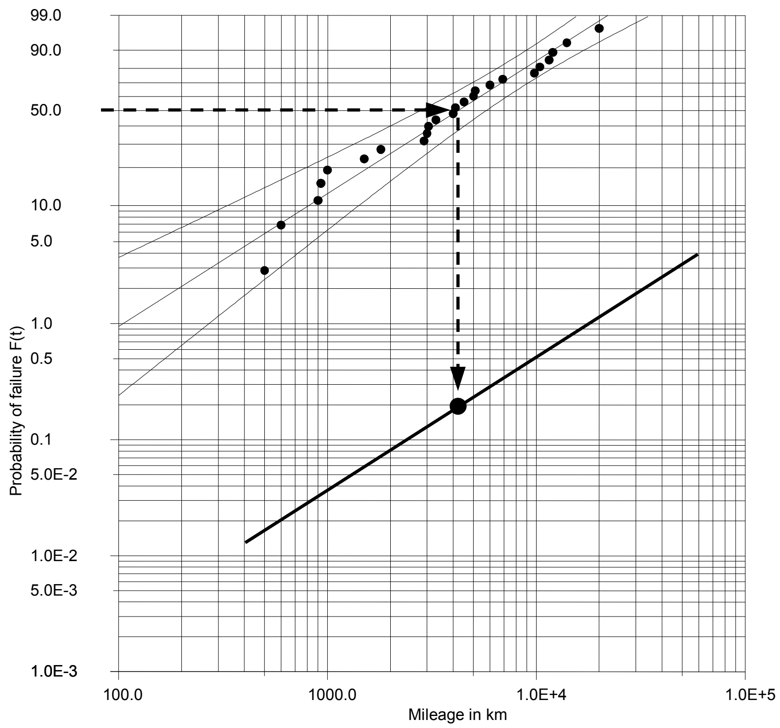


Fig. 6.3.1: Graphical analysis on Weibull paper, as described in [4]

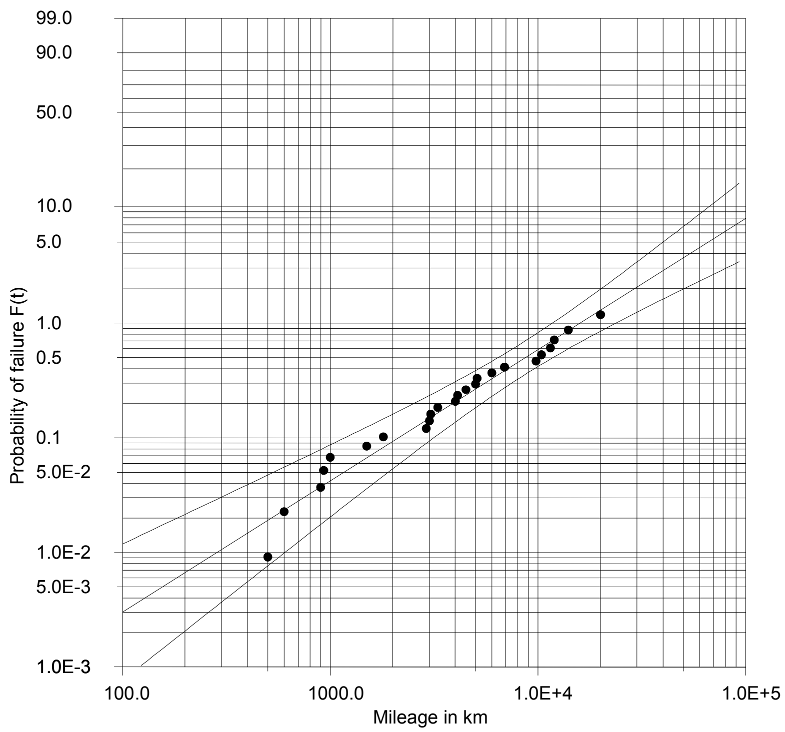


Fig. 6.3.2: Result of analysis using the maximum-likelihood method

Numerical results should of course be independent of the analysis method.

In this example, they are in agreement, within the degree of uncertainty inherent in the graphical method.

b	T	B_1	B_5	B_{10}
1,1	885,000 km	≈ 26,000 km	≈ 66,000 km	124,000 km

Note:
This method assumes that all the ‘suspended’ units of a group have exactly the same mileage as the unit that has failed. Since all groups have the same size (here, k = 316), an assumption is made that the number of parts that have performed a mileage of 4,000 km is the same as the number of parts that ran 20,000 km. In other words, the annual mileage distribution (cf. 6.2) is not taken into account.
Mixed distributions do not yield a straight line with constant b, but yield instead a curve. The graphical procedure described in [4] then no longer applies.

6.4 Possible Analysis for Constant Failure Rates

The preceding example with data from 10/98 yields a value of b = 1.1 for the shape parameter. Since the confidence range for b includes b = 1, the following deliberations assume that this case corresponds to the random failure scenario (b = 1), meaning that the failures are independent of the mileage. Similar analyses performed for other production months have shown this assumption to be justified.

The difference between the purchase date and the complaint date corresponds to the vehicle’s ‘operating time’ (of course, this does not, in this case, imply round-the-clock operation). Using the mileage shown on the vehicle’s odometer, it is then possible to calculate the average annual mileage of this vehicle. This can yield very high annual mileage projections (far in excess of 100,000 km/60,000 miles) which do not appear realistic. Since the median is much less sensitive to such outliers than the arithmetic mean, use of the median, rather than the mean, is recommended.

The median for the data set used in Sections 6.3 and 6.4 is approximately 20,100 km p.a. Division by twelve yields an estimate for the average mileage per month, in this case approximately 1,675 km/month.

For each production date from July 1997, the age in months as of September 1999 was determined, e.g. 9/99 – 7/97 = 26 months. By 9/99, a vehicle with a production date of 7/97 will thus have an expected mileage of approximately 26 · 1,675 km = 43,550 km. Multiplying this mileage figure by the production total for this month yields the total mileage covered by all the vehicles manufactured in 7/97, as of 9/99.

This calculation was performed for each production date, to calculate the total mileage of all the manufactured parts (cf. table below).

Remembering that there is a time gap of approximately 1 month between the production and purchase dates (see e.g. Fig. 3.1.2), the true operating time of the parts will actually be one month less. Hence the calculation was repeated, with each age reduced by one month.

Calculation for each PD and summation of total mileage for all the manufactured units, e.g.:

PD	Prod. Total	Age (months)	PT*Age*1,675	PT*(Age – 1)*1,675
...	...	...	...	...
1/99	13,190	8	1.8E8 km	1.5E8 km
2/99	12,903	7	1.5E8 km	1.3E8 km
3/99	21,576	6	2.2E8 km	1.8E8 km
...	...	...	...	...
8/99	15,343	1	2.8E7 km	0 km
			Σ $1,94 \cdot 10^9$ km	Σ $1.61 \cdot 10^9$ km

Result: $1,94 \cdot 10^9$ km. Since 5/98, there have been 102 failures.

Failure rate: $\lambda = \frac{102 \text{ failures}}{1.94 \cdot 10^9 \text{ km}} \approx \frac{53 \text{ ppm}}{1{,}000 \text{ km}}$

Taking into account the storage delay, the operating time will be reduced by one month, i.e. the age of each unit will be one month less.

Failure rate: $\lambda = \frac{102 \text{ failures}}{1.61 \cdot 10^9 \text{ km}} = \frac{63 \text{ ppm}}{1{,}000 \text{ km}}$

6.5 Analysis Using the Mileage Distribution

Prerequisites:

- All failures are known, no partial market.
- The period under analysis should be so long ago that all vehicles have a fairly similar operating time.
- The mileage distribution is known (probability plot or histogram).

The first step consists in defining appropriate classes for the mileage data.

The reported failures are then allocated to the various classes. In addition, the mileage distribution is used to determine how many of the non-failed parts are likely to belong to each of the various classes. This means that we will have a figure for both the number of failed parts and the number of non-failed parts in each mileage class.

[4] presents an example with a median-rank analysis based on the Johnson method. Using appropriate software, an analysis according to the maximum-likelihood method is equally possible.

In analyses performed during the warranty period, the prerequisite of the cars having fairly similar operating times is not fulfilled. The following section describes some alternatives for this case.

6.6 Projections During the Warranty Period

[11] describes a method that can be used for an approximate calculation of short-term prognoses, provided that the Weibull parameter b is known for the product in question. The method takes both the storage time and the reporting delay into account. This paper presents two possible ways to estimate the failure rate to be expected by the end of the warranty period, by weighting the known failure totals or by weighting the production quantities. Creating suitable EXCEL spreadsheets makes the practical implementation of these methods very much easier.

A simple projection model which also takes the annual mileage distribution into account is described in [10]. If the distribution L(s) of the annual mileage is known (cf. 6.2), then it is possible to calculate, for each mileage s at which a failure occurred, the proportion 1 – L(s) of vehicles from the relevant population which have not yet reached this mileage and can still fail. The reciprocal value $\frac{1}{1-L(s)}$ of this proportion is the projection factor by which the reported number of failures at mileage s has to be multiplied in order to obtain the corrected (projected) figure.

7. Literature

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Robert Bosch GmbH
C/QMM
Postfach 30 02 20
D-70442 Stuttgart
Germany
Phone +49 711 811-4 47 88
Fax +49 711 811-2 31 26
www.bosch.com