VDA

Quality Management in the Automotive Industry

Quality Assurance Part 2 before series production

System FMEA

1st Edition 1996
Quality assurance before series production

System FMEA
Failure Mode and Effects Analysis

1. Edition 1996

Verband der Automobilindustrie e.V. (VDA)
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Preface

The System FMEA, we are dealing with, is developed from the Design FMEA and the Process FMEA and consists of a risk analysis accompanying the development and project scheduling, which is integrated into the special fields. The System FMEA is an important methodical instrument for recognition and prevention of possible failures in a premature state, especially with new conceptions.

The System FMEA supports the team and project work, mainly by the consistent structuring of the failure potentials of the system.

The quality of development and project scheduling will be analysed and evaluated with the System FMEA during the stage of development and project scheduling. It represents in that way a possible "Monitor for the degree of maturity" and an important management instrument, which supports the interdisciplinary co-operation. The System FMEA demonstrates at all critical points of the project how the risk has already been reduced or has to be reduced in future, by using experience, estimations, proving and tests.

The structured documentation of the System FMEA can be used for subsequently added tasks, as for example for diagnosis and maintenance, as well as during the type approval tests and certification. The documentation supports the familiarisation with the system and the failure prevention for later advances and new developments.

The project flow diagram for the quality assurance activities (project plan, annex 11.5) shows when the System FMEA is required as a method of TQM during development and project scheduling and when their presence will be required by the quality management system (QM-system).

The System FMEA belongs to the range of methods indicated in the VDA publication volume 4, part 1 in the overview and in the main section 5.
We express our gratitude to all enterprises and to their collaborators, which have contributed to this working group:

BMW AG, München
Robert Bosch GmbH, Stuttgart
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Mercedes-Benz AG, Stuttgart
Mercedes-Benz Omnibusse, EvoBus GmbH, Mannheim
Dr.-Ing. h.c. F Porsche AG, Stuttgart
Volkswagen AG, Wolfsburg
WABCO Fahrzeugbremsen GmbH, Hannover

Our gratitude is also aimed to those which have given us suggestions for ameliorations.

Frankfurt/Main, July 1996

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1 GENERAL ABOUT FMEA and SYSTEM FMEA

Authors of the VDA publication volume 4, part 2:
Turecht Beltz, Berthold Edenhofer*, Jürgen Eilers, Detlef Gaide*, Andreas Krause, Guido Laschet, Hans-Joachim Pfeufer, Dietmar Zander

* Anchormen of the team of authors

1.1 Historical Evolution of the FMEA

The Failure Mode and Effects Analysis (FMEA) has been developed at the mid-sixties in the USA for the Apollo-project by the NASA. After applying that method in the aeronautics and the aerospace industry, as well as in the nuclear technology, its usage had been introduced soon in the automobile industry. The FMEA finds now globally a widespread application. The FMEA is nowadays a methodical component of quality management systems for many automobile manufactures and their suppliers.

1.2 Objectives of the System FMEA

The objectives of the FMEA derive from the influence factors, e.g. onto the automobile industry, which considerably changed in the past. Increased demands in quality from clients, as well as the necessary cost optimisation of the products and the product liability required by the framework of legislation have their own impact. The achievement of the following co-operate objectives itemised below are supported by the FMEA:

- Increase in performance reliability and dependability of products
- Reducing of guaranty cost and goodwill commitments
- Shorter development processes
- Minor susceptibility to failures during start-up of series production
- Improved faithfulness to deadlines
- More economical manufacturing
- Improved services
- Improved internal communication

The System FMEA as method for the failure prevention should be used in a very early stage of the product development process (e.g. at the stage of tender specification). It investigates the stage of development and project schedule, valid at that time, for possible failures, in order to take measures for prevention of those.
The System FMEA is a team-oriented method for minimising the risk of the development and project schedule processes and it stimulates the interdisciplinary co-operation between the affected areas already in a very early stage. Furthermore, it provides a documentation of knowledge within the company.

1.3 Advance of the System FMEA Method

During the previous application of the FMEA different disadvantages had become obvious:

- With the Design FMEA the failure examination had been effected on the component level. The functional context between all components had not been examined systematically.
- With the process FMEA the possible failures had been examined in individual process steps. A systematically structured analysis of the entire manufacturing process, if necessary, down to the layout of tools and machines, had not been effected.
- The drawing-up of a FMEA was carried out using the FMEA form and did not allow to describe structurally the functional context and the context between malfunctions within the system.

This made it necessary to develop further the method into direction Design potential FMEA and Process potential FMEA.

<table>
<thead>
<tr>
<th>Failure Mode and Effects Analysis</th>
<th>Page of</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type/Model/Production/Batch:</td>
<td></td>
</tr>
<tr>
<td>Part-Nr.: Revision date:</td>
<td>Responsible: Company</td>
</tr>
<tr>
<td>Part-No.: Revision date:</td>
<td>Responsible: Company</td>
</tr>
<tr>
<td>Comp./Charact. Potential failure</td>
<td>Potential failure effects</td>
</tr>
</tbody>
</table>

Establishing of FMEA using Form VDA '86
Entry into the system FMEA via the structure of the system to be considered, incl. the new form VDA'96

**Fig. 1.1:** Advance of the FMEA-Method
2 Fundamental Principles of the System FMEA for Products and Processes

The following chapter describes the proceedings of the System FMEA in principle.

2.1 Definition of the System FMEA

For drawing up the System FMEA for products and processes the following steps are required in addition to the previous Design FMEA or Process FMEA:

- The structuring of the system to be investigated into system elements and the revealing of possible functional correlation between these elements.

- The deduction of conceivable malfunctions (possible failures) of a system element from its functions described previously.

- The logical association following afterwards of the malfunctions of the different matching system elements to facilitate the description of the possible failure effects, failures and failure causes, which have to be analysed by the System FMEA.

Application fields of the System FMEA are the product development and the process planning. A Design potential FMEA regards possible malfunctions of product systems as possible failures. If necessary, the failure analyses go down to the design failures of individual components step by step.

The procedure in the System FMEA for products may also be transferred into the analysis of manufacturing processes. The Process potential FMEA regards the possible malfunctions of a production process (e.g. sequences for production, assembly, logistics or transport) as possible failures.
2.2 Design potential FMEA

The Design potential FMEA examines the possible functional faults of complete products (e.g. of a gearbox, or unit). The examination is only effected down to the failure potentials of the components, if this is required. The possible failure potentials of the individual components (e.g. of a gear) are examined by the conventional Design FMEA.

The failure analysis of the Design potential FMEA is methodically deduced from the contents of the previous Design FMEA (Fig. 2.1).

- **Failure (F) of the component**
  The component (e.g. the drive shaft of a gearbox) is regarded as system element. The physical component failures (e.g. wear of a bearing fit) under service conditions of production are considered as potential failures.

- **Failure causes (FC)**
  The failure causes are searched for every potential failure of a component by investigating its design data (e.g. dimension, surface hardness, material).

- **Failure effects (FE)**
  The failure effects, such as the effects of wear (restriction of the properties of a gearbox bearing), lead to malfunctions of the gearbox as examined product.
The failure analysis of a Design potential FMEA (e.g. for the complete system vehicle, fig. 2.2) is carried out as follows:

- **Failure (F) of the system**
  A limited system is examined (e.g. a gearbox), which consists of multiple components. This system does possibly not meet one of its functions under service conditions. The malfunctions are considered as possible failures (F) by the Design potential FMEA.

- **Failure causes (FC) of the system**
  The possible failure causes are searched in the malfunctions of the system elements (e.g. the failure of a drive shaft, of a gear, or of a bearing).

- **Failure effects (FE) within the system**
  The possible failure effects (FE) lead to the malfunctions of the superior system elements (e.g. functional disturbance of the drive train up to the malfunctions of the complete system (e.g. vehicle is faulty/"conked-out vehicle").)
Fig. 2.2: System structure Complete system Vehicle with malfunctions

By looking at that way the Design FMEA is part or the Design potential FMEA. It represents the more profound examination of a component down to its design data.
2.3 Process potential FMEA

The previous process FMEA examined failures in the process steps using the FMEA form (analogously to the previous Design FMEA, cf. chapter 1.3).

On the other hand, the manufacturing process is structured and described with the Process potential FMEA by means of the involved system elements Men, Machine, Material and Medium (the "4 M"), e.g. for a complete process, fig. 2.3. By looking at that way the process steps are understood as tasks/functions of these system elements.

The examinations of functions and failures are, as far as necessary, effected down to the design data of the manufacturing installations, step by step. Such examinations correspond to the proceedings for a Design potential FMEA depicted previously.

![System structure Complete Process with Malfunctions](image)

**Fig. 2.3:** System structure Complete Process with Malfunctions
The five Steps for Drawing up the System FMEA

The drawing-up of the System FMEA is structured into the "Five steps" of the System FMEA.

1. Step
   - System elements
   - System structure

2. Step
   - function
   - function structure

3. Step
   - Failure analysis

4. Step
   - Risk assessment

5. Step
   - Optimisation

Fig. 3.1: The five Steps of the System FMEA

These five steps convey the basic understanding for the proceedings with the FMEA in systems and are explained thoroughly as follows:
3.1 System elements and System structure (1. Step)

The system consists of individual system elements (SE) which are arranged hierarchically for the description of the structural correlation in a complete system within a system structure (e.g. hardware conception, organisational structure). The number of hierarchical levels is principally not established during drawing-up of the system structure. The unambiguously structured depiction of the complete system (fig. 3.2) is warranted by the fact that each SE exists only once. The structures arranged under each SE are independent substructures.

Interfaces also originate from the structuring of physical connections present in the system, i.e. from the SE of a substructure to another substructure SE. Examples for these interfaces are:

- Two different SE contacting each other (contact surface/shaft sealing ring/forced-in press fit, screw/nut).
- A SE disassembled into multiple parts by the chosen system boundaries (e.g. components of cables, cords, screws, bolts, welding seams, oils and adhesives).

Fig. 3.2: System and System structure

All functional correlations between the SE of a system are described by functional structures (function tree/function network), even if stretched beyond the examined system structure interfaces.
3.2 Functions and Functional structures (2. Step)

The system structure (structure tree) described by SE is the base that allows analysing of each SE as differentiated as necessary with regard to its functions and malfunctions within the system.

Extensive knowledge about the system and about the environmental conditions of the system is required for this purpose; e.g. heat, cold, dust, splash water, salt, freezing-up, vibrations, electrical disturbances, etc.

Functions

Each SE has different functions or purposes, respectively, independently of its arrangement in the structure (fig. 3.3). For carrying out individual functions of a SE also the functions of the other SE are normally required. These can be differentiated into departing functions, arriving functions and internal functions:

- Departing functions are the functions, which act from a SE on its superior SE or via interfaces on the SE of other substructures.

- Arriving functions are the functions, which act on the examined SE from the subordinated SE or via interfaces.

- Internal functions of a SE are the functions of the examined SE substructure, which can be represented by functional structures without passing the structure interfaces (cf. also fig. 3.4)

![Fig. 3.3: System element with Functions](image)


**Functional structures**

The combined acting of the functions of several SE for a departing function can be represented as functional structure (function tree or function network). For drawing up the functional structure of a SE it is necessary to examine the involved arriving and internal functions. Substructures, which describe summarily a function, are logically linked together within the assigned functional structure.

Fig. 3.4: Functional structure for the Departing Function 1 of the System

Fig. 3.4 demonstrates that the function 1 of the system is only carried out if the contributions to function of SE 1 as well as of SE 2 are given. Moreover, the later contribution to function is only carried out if the contributions of SE 2.1, of SE 2.2 and of SE 3.5 (constitutes the interface to function 3 of the system) are given.

**3.3 Failure analysis (3. Step)**

A failure analysis can be carried out for each of the SE examined in the system description.

- Potential failures (F) of the examined SE are its malfunctions described and deducted from the well-known functions, e.g. non-performance of the function or restricted function.

- The potential failure causes (FC) are the conceivable malfunctions of the subordinated SE and of the SE assigned via interfaces.

- The potential failure effects (FE) are the resulting malfunctions of the superior SE and of the SE assigned via interfaces.
Structures of Malfunctions

For the failure analysis of the System FMEA the malfunctions will be deducted and the structures of malfunctions (failure trees, malfunction trees and failure net) drawn up, fig.3.5, both based on the well-known functions and structures of functions.

![Structure of Malfunction for the Malfunction 1](image)

The drawn-up structures of malfunctions (figure 3.6) will be transferred into the columns "Potential failure effects", "Potential failure" and "Potential failure causes" of the System-FMEA form (figure 5.1).

![The Structure of Malfunction as Base for the FMEA Form](image)

Depending on the deepness of the failure structure it is possible to draw up System-FMEA forms on different levels and to depict the contents of the structures of malfunctions in the three form columns. The execution of the failure analysis is followed by the risk assessment.
3.4 Risk assessment (4. Step)

The risk of each failure cause will be evaluated. For risk assessment of a given system preventive and detecting measures already existing in the development and planning stage will be enlisted. The criterion for this evaluation is the risk priority number (RPN), which consists of three single factors:

- **S** for the Severity of the failure effect,
- **O** for the Occurrence likelihood factor of the failure cause and
- **D** for the Detection likelihood of the occurred failure cause, failure or failure effect respectively.

For S, O and D evaluation numbers from 10 down to 1 will be used and the risk priority number (RPN) will be calculated in each case.

\[
RPN = S \times O \times D
\]

**Severity S**

The evaluation number S will be determined by the severity of a failure effect for the entire system and consequently for the end user (external customer).

In this way the "10" or "9" will be attributed for example, if a safety risk exists, the non-fulfilment of legal prescriptions is evident or the occurred failure leads to the "conked-out vehicle". The "1" will be attributed for example, if the failure effect has a very little severity for the end user.

Furthermore other criteria from the view of internal customers can be laid down for the evaluation ranking index of S than those of table 1 and 2 in this chapter. Internal customers are for example buyers in the production chain at the Process potential FMEA (see also examples in chapters 7 and 8).

**Preventive and detecting measures**

Evaluations for the occurrence and detection likelihood (O and D) are laid down corresponding to the effectiveness of executed preventive or detecting measures for the examined failure causes.
The more detailed the fault analysis of the System FMEA is carried out for the causes, the more subtly differentiated the evaluations O and D can be carried out.

In the System FMEA it is possible to fall back upon experimental values for the O- and S-evaluation of causes (e.g. upon reliability rates of similar systems). If already evaluated subsystems are integrated in a new system the evaluations have then to be checked due to possibly changed boundary conditions of the new system (see also examples in chapters 7 and 8).

**Occurrence likelihood O**

The evaluation of the occurrence likelihood of a failure cause is carried out under consideration of all listed preventive measures. The "10" will be allocated if the regarded failure cause arises with high probability at the O-evaluation. The "1" will be allocated if it is improbable that the regarded failure cause arises (see also examples in chapters 7 and 8).

**Detection likelihood D**

The evaluation of the detection likelihood of the arisen failure cause is carried out under consideration of all detecting measures listed for this. Detecting measures for failures and failure effects can be enlisted for D-evaluation of failure causes as well. Such detecting measures lead then to a common D-evaluation for all failure causes of the detected failure or of the failure effect. What makes sense is generally the earliest possible detection possibility in the cause/effect chain.

The evaluation number "10" will be allocated, if no detecting measures are planned, e.g. proving measures or checking measures. The evaluation number "1" will be allocated, for instance, if a considered failure cause will be determined as certain during the development by the amount of all proving measures, or if a production failure will be definitely detected in the process at the place of the failure formation.

**Statement about the O- and D-Evaluation**

While the O-evaluation describes the quantity of the expected faulty products, the D-evaluation states that only a part of these arising failures can be detected.

The product O x D describes the probability for the residual quantity of faulty parts (see also examples in chapters 7 and 8).
Examples for Evaluation tables

– please compare also the annex, chapter 11.3
### Table 1: Criteria for Evaluation ranking indices for the Design potential FMEA

<table>
<thead>
<tr>
<th>Evaluation ranking Index for the Severity S</th>
<th>Evaluation ranking Index for the Occurrence likelihood O</th>
<th>attributed failure quota in ppm</th>
<th>Evaluation ranking Index for the Occurrence likelihood O</th>
<th>Certainty of detection method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very large</td>
<td>Very large</td>
<td>500,000</td>
<td>Very low</td>
<td>90 %</td>
</tr>
<tr>
<td>10 Safety risk, non-compliance with statutory provisions, Conked-out vehicle.</td>
<td>10 Very frequent occurrence of failure cause, 9 unusable, unsuitable design conception.</td>
<td>100,000</td>
<td>10 Detection of occurred failure causes is 9 improbable, Reliability of design has not been or can not be proven. Detection methods are uncertain.</td>
<td>98 %</td>
</tr>
<tr>
<td>Large</td>
<td>Large</td>
<td>50,000</td>
<td>Low</td>
<td>99,7 %</td>
</tr>
<tr>
<td>8 Operability of vehicle considerably impaired, Immediate inspection at garage is urgently required. Restricted functioning of important subsystems.</td>
<td>8 Failure reason occurs again and again, 7 problematic construction, not matured red.</td>
<td>10,000</td>
<td>8 Detection of occurred failure causes is 7 less probable, Reliability of design can probably not be proven. Detection methods are uncertain.</td>
<td>99,9 %</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
<td>5,000</td>
<td>Moderate</td>
<td>99,9 %</td>
</tr>
<tr>
<td>6 Operability of vehicle impaired, 5 Immediate inspection at garage 4 is not urgently required. Restricted functioning of important comfort and convenience systems.</td>
<td>6 Occasionally occurring failure cause, 5 suitable construction advanced in degree 4 of maturity.</td>
<td>1,000</td>
<td>6 Detection of occurred failure causes is 5 probable, Reliability of design could 4 perhaps be proven. Detection methods are relatively certain.</td>
<td>99,9 %</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>100</td>
<td>Large</td>
<td>99,9 %</td>
</tr>
<tr>
<td>3 Minor restriction of operability of the 2 vehicle, Clearing at next scheduled inspection in garage, Minor restrictions of comfort and conveniences systems.</td>
<td>3 Occurrence likelihood of failure causes is 2 low, Proven design.</td>
<td>50</td>
<td>3 Detection of occurred failure causes is 2 very probable, examinations are certain, e.g. by several tests independent from each other.</td>
<td>99,9 %</td>
</tr>
<tr>
<td>Very low</td>
<td>Very low</td>
<td>1</td>
<td>Very low</td>
<td>99,9 %</td>
</tr>
<tr>
<td>1 Very minor restriction of operability, discernible only by the skilled personnel.</td>
<td>1 Occurrence of failure cause is improbable.</td>
<td></td>
<td>1 Occurrence failure cause will certainly be detected.</td>
<td>99,9 %</td>
</tr>
</tbody>
</table>

### Table 2: Criteria for Evaluation ranking indices for the Process potential FMEA

<table>
<thead>
<tr>
<th>Evaluation ranking Index for the Severity S</th>
<th>Evaluation ranking Index for the Occurrence likelihood O</th>
<th>attributed failure quota in ppm</th>
<th>Evaluation ranking Index for the Occurrence likelihood O</th>
<th>Certainty of detection method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very large</td>
<td>Very large</td>
<td>500,000</td>
<td>Very low</td>
<td>90 %</td>
</tr>
<tr>
<td>10 Safety risk, non-compliance with statutory provisions, Conked-out vehicle.</td>
<td>10 Very frequent occurrence of failure cause, 9 unusable, unsuitable process.</td>
<td>100,000</td>
<td>10 Detection of occurred failure causes is 9 improbable, the failure causes will or can not be proven.</td>
<td>98 %</td>
</tr>
<tr>
<td>Large</td>
<td>Large</td>
<td>50,000</td>
<td>Low</td>
<td>99,7 %</td>
</tr>
<tr>
<td>8 Operability of vehicle considerably impaired, Immediate inspection at garage is urgently required. Restricted functioning of important subsystems.</td>
<td>8 Failure reason occurs again and again, 7 Inaccurate process.</td>
<td>10,000</td>
<td>8 Detection of occurred failure causes is 7 less probable, Failure cause will probably not be detected, uncertain examinations.</td>
<td>99,9 %</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
<td>5,000</td>
<td>Moderate</td>
<td>99,9 %</td>
</tr>
<tr>
<td>6 Operability of vehicle impaired, 5 Immediate inspection at garage 4 is not urgently required. Restricted functioning of important comfort and convenience systems.</td>
<td>6 Occasionally occurring failure cause, 5 less accurate process.</td>
<td>1,000</td>
<td>6 Detection of occurred failure causes is 5 probable, Examinations are relatively certain.</td>
<td>99,9 %</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>100</td>
<td>Large</td>
<td>99,9 %</td>
</tr>
<tr>
<td>3 Minor restriction of operability of the 2 vehicle, Clearing at next scheduled inspection in garage, Minor restrictions of comfort and conveniences systems.</td>
<td>3 Occurrence likelihood of failure causes is 2 low, Accurate process.</td>
<td>50</td>
<td>3 Detection of occurred failure causes is 2 very probable, Examinations are certain, e.g. by several tests independent from each other.</td>
<td>99,9 %</td>
</tr>
<tr>
<td>Very low</td>
<td>Very low</td>
<td>1</td>
<td>Very low</td>
<td>99,9 %</td>
</tr>
<tr>
<td>1 Very minor restriction of operability, discernible only by the skilled personnel.</td>
<td>1 Occurrence of failure cause is improbable.</td>
<td></td>
<td>1 Occurrence failure cause will certainly be detected.</td>
<td>99,9 %</td>
</tr>
</tbody>
</table>
3.5 Optimisation (5. Step)

The RPN and the individual evaluations S, O and D clarify the system risks. Improving measures are necessary for high RPN or high individual evaluations.

The optimisations will be done according to following priorities:

1) Concept modification, in order to exclude the failure cause or to obtain a failure effect with a little severity, respectively

2) Enhancement of the concept reliability, in order to minimise the occurrence of the failure cause

3) More effective detection of the failure causes (to avoid additional examination as far as possible)

For measures the responsible (R) and the target completion date (T) are to be indicated in the FMEA form, respectively (figure 5.1). The determination of the measures for reliability enhancement or for more effective detection is followed by a new preliminary risk assessment. The definitive evaluation is effected after execution of the action and of the examination of its effectiveness by means of the RPN to be re-determined. All 5 steps of the System FMEA for the concerned sections will be run through again in case of far-reaching concept modifications.

Analysis of Risk priority numbers

In many cases the examination of the absolute value of a risk priority number is not sufficient to find starting-points for optimisation measures.

It does not make sense as well to define a "Rigid RPN" as action limit for all parts within the enterprise, because the evaluation criteria can possibly be different for each System FMEA.
4 Overlaps for the System FMEA

This chapter describes a form of interfaces, that can exist within an examined system as well as between different System FMEA.

4.1 Within a System

The determination of the overlaps between System FMEA on different system levels is the precondition for the constant dealing with complex systems, such as a vehicle gearbox for example. With the aid of these determinations a clear and useful division of labour will be achieved for extensive System FMEA. This means to the manufacturer of a component (ball bearing) that his System FMEA begins with a defined system extent, for example, at the seat of the ball bearing outer race in the boring of the gearbox housing. SE of the system description selected for that purpose serve therefore for determination of overlaps. The mutual delimitation and also the associations of System FMEA on different examination levels will be facilitated by the determination of overlaps.

Fig. 4.1: Overlaps of different System FMEA

Fig. 4.1 shows overlaps of System FMEA. The analysis of the malfunctions of a selected SE is integrated into three different deep System FMEA. In the System FMEA, level 1, the malfunctions of the SE examined at the interface are the failure causes (FC). In the further System FMEA, level 2 the same malfunctions of this SE will be considered as failure (F). In a System FMEA, level 3, the malfunctions of this SE are the failure effects (FE). For the System FMEA, level 3, failures (F) and also failure causes (FC) are located in further smaller SE of the system.
4.2 For different Systems

An overlapping of System FMEA exists also between a Design potential FMEA and a Process potential FMEA. With the Design potential FMEA and the Process potential FMEA the co-operation between development and manufacturing will be supported by the consideration of this association. Because of the complexity of the systems different degrees of overlapping are possible, as the figure 4.2 shows clearly.

Fig. 4.2: Overlapping of the Design potential FMEA and Process potential FMEA
5 System-FMEA Form

The form (fig. 5.1) of the System FMEA has been redesigned based on the failure analysis and risk assessment described in the chapter 3.

![Failure Mode and Effects Analysis](image)

<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>S</th>
<th>Potential failure</th>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>O</th>
<th>Detecting measures</th>
<th>D</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>6</td>
<td>3</td>
<td>4</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14</td>
<td>14</td>
<td>15</td>
</tr>
</tbody>
</table>

S = Severity ranking index
O = Occurrence ranking index
D = Detection ranking index
RPN = S * O * D
R = Responsibility
T = Target completion date

Fig. 5.1: System-FMEA Form VDA '96

5.1 Contents of the System-FMEA form VDA '96

1) **Master data**
   The data are to be entered into the form header or upon the cover of the System FMEA according to the requirements of the respective products and processes. The considered system has to be discernible from these data.

2) **System element (SE)/Function/Task**
   Description of the SE with the respectively considered function/task.

3) **Potential failure**
   Entering of the potential failures (malfunctions) of the considered SE from item 2.
4) **Potential Failure causes**
For each failure the potential failure causes will be examined and entered into a column.
For this purpose the following items can be used:
Quality system records, field experiences, longevity data, reliability data, application conditions, such as heat, cold, dust, fluctuations of mains voltage, etc.

5) **Potential Failure effects**
Description of the potential failure effects that these failures or malfunctions, respectively, may imply for the entire system, and how that effects are perceptible for the end user.

6) **Evaluation ranking index for the Severity (S)**
The evaluation ranking index S will be laid down for the severity of the failure effects for the entire system (see tables 1 and 2, chapter 3).

7) **Preventive Measures**
For each potential failure cause, the preventive measures already carried out at the time of examination will be revealed as basis for the risk assessment. Preventive measures, which have to be carried out in future, will be determined, however, only after effected risk assessment for the system optimisation. Preventive measures of the Design potential FMEA are constructional measures for example, which minimise the occurrence of failure causes during the development stage or serve for achievement of the technical reliability, respectively.

8) **Evaluation ranking index for the Occurrence likelihood (O)**
The evaluation ranking index O will be laid down for each failure cause in view of all effective preventive measures (see tables 1 and 2, chapter 3).

9) **Detecting Measures**
Detecting measures are measures, which detect failure causes, failures and failure effects. Detecting measures effective at the time of the examination are relevant for the risk assessment.
10) **Evaluation ranking index for the**
Detection likelihood (D)
The evaluation ranking index D will be laid down for each failure cause in view of all effective detecting measures (see tables 1 and 2, chapter 3).

11) **Risk priority number (RPN)**
The risk priority number results from the multiplication of the evaluation ranking indices S, O, and D. It weights the system risk for the system user and serves as a deciding factor for initiation of optimisation measures (RPN = S x O x D).

12) **Optimisation**
Optimisation measures are required for large RPN or large individual evaluation rankings (O, D). The evaluation ranking indices S, O, D and the RPN show clearly system risks and reveal the starting-points for optimisation of the system.

13) **R/T**
Responsible (R) for the execution and Target date for completion (T) of actions.

14) **Risk assessment after the Optimisation**
According to items 6, 8 and 10.

15) **New Risk priority number (RPN)**
According to item 11.
5.2 Advantages of the new Form VDA '96

1) Adaptation to Design potential FMEA and Process potential FMEA

2) Further entries per system element (SE) into the header (revision date, part-no., ...)

3) Inclusion of the functions and tasks into the form as line without need for additional columns

4) Concept modifying measures becoming apparent by means of additional headers

5) Modified columns arrangement for the system examination in order: Potential failure effects, Potential failure, Potential failure causes

6) Distinct description of the preventive and detecting measures

7) Assignment of the evaluation columns to the corresponding analysis columns

8) Wider columns, because the optimisation measures will be entered into the existing columns for measures.

9) EDP-sized form (A4 transversal, according to DIN 476)

10) Entries into the R/T-column show decided and open items of the FMEA (quick overview)

11) No limitation for the quantity of revision dates (vertical arrangement)

The FMEA drawn up according to the VDA-form ’86 keep their validity. This is valid for other forms as well, if the essential contents are contained.
6 Organisational sequences of a System FMEA

6.1 Drawing-up of System FMEA by Teamwork

System FMEA have to be drawn up by interdisciplinary working groups (fig. 6.1), consisting of system specialists for the responsible functional areas and of the method specialists, because

- the knowledge and the experience of several collaborators can be used,
- the acceptance of the drawn-up System FMEA increases,
- the communication and co-operation across the area boundaries will be supported, and
- the systematic and effective handling will be guaranteed by consulting the method specialists.

The Line-up of the System-FMEA team

The Line-up of the System-FMEA team

Fig. 6.1: The System-FMEA team

F: Special field (Initiator)
   Overall project manager

R: Responsible for the System FMEA Project
   (Developer, designer, planner, operator)

E: Experts
   (Developer, designer, experimental engineer, planner, producer, lab technician, operating resources planner, test planner, foreman, worker, further knowledge representatives)

M: Method specialist System FMEA
   (can also be the same as the expert or the responsible, respectively)
Task assignment within the System-FMEA team

The team members should perform the following tasks according to the requirements:

F: **Special field** (overall project management)
- Decision about the execution
- Supporting the collection of information
- Decision about introduction of actions
- Approval of the System FMEA
- Presentation of the System FMEA
- Checking of action implementation

R: **Responsible for the project System FMEA**
- Participation in the preparation of the System FMEA (subject delimitation, interface definition, team formation)
- Participation in the execution of system description, failure analysis and in the determination of optimisation measures
- Contribution of existing experience figures from already known processes
- Participation in the measure selection
- Presentation of the System FMEA

E: **Experts**
- Demonstration of the stages of development and planning within the System-FMEA team
- Contribution of existing experience figures from already known processes
- Participation in the execution of system description, failure analysis and in the determination of optimisation measures
- Incorporation of decided optimisation measures into the planning stage.

M: **Method specialist** (can also be identical with the expert or the responsible respectively).
- Provision of required data base
- Preparation of the System FMEA (subject delimitation, interface definition, team formation)
- Managing execution of system description, failure analysis, risk assessment and determination of optimisation measures
- Preparation or reworking of System-FMEA meetings, if required
- Presentation of the System-FMEA working group
- Evaluation of System FMEA, suggestion of measures
- Guarantee of the System FMEA documentation
- Co-ordination with all departments of the enterprise
6.2 Time sequence for the System FMEA

The drawing-up of a System FMEA should be effected at the earliest possible moment. Dates for beginning and end of the System-FMEA-drawn-up are described in the project plan (enclosure).

If updated regularly the System FMEA becomes a "Living document".

6.3 Co-operation during Execution

6.3.1 Design potential FMEA/Process potential FMEA

Descending from superior system levels the interfaces to subordinated system levels are defined. In this way a clear task assignment among several partners for System FMEA will be laid down.

System and method specialists from both system levels make the drawing-up of the System FMEA at the interface about system elements interesting both.

For the System FMEA the evaluation ranking indices for the severity of the failure effects, which will be determined in superior system levels, have to be taken into account for subordinated levels.

The System FMEA areas of suppliers beyond the interface will principally not be transferred to the customer. The essential results will be presented on request. In special cases the System FMEA can be handed over to the buyer, if this has been stipulated by contract beforehand.

6.3.2 Design FMEA/Process FMEA

In order to protect the know-how the Design and Process FMEA drawn up by suppliers will never be handed out to the customer. If detailed customised specifications exist in the tender specification and if the procedure is established by contract beforehand, excerpts from the Design FMEA can be exceptionally handed over to the buyer.

The customer can convince himself during inspections that pertinent FMEA have been drawn up for him. On this occasion it has to be proceeded in the same way as for the archived quality assurance documentation.
6.4 Reuse of the System FMEA

Existing System FMEA for known products and processes will be used in new analyses. This will reduce the expenditure for efforts. The transferred extents are to be critically checked with reference to the respective application case, particularly the evaluations.

6.5 EDP usage for the Drawing-up of a System FMEA

The System FMEA can be carried out more effectively by EDP usage:

- The systematic processing will be supported
- User guide and support are possible
- The execution of required preparations and analyses is simplified
- Support of the processing, e.g. for inserting, deleting, copying, etc.
- Access to FMEA previously drawn up is possible by networking of individual workplaces with systematic access protection.
- Managing of data bases with System FMEA previously drawn up

6.6 Introduction of System FMEA into the Enterprise

The participants in System-FMEA meetings must be informed about the fundamentals of the System-FMEA method and the sequences of the System-FMEA drawing-up.

According to the experience this means an expenditure of one up to two hours during the first meeting of the System-FMEA team. The method specialist gives an overview on the FMEA method and guarantees as presenter the methodically correct procedure during the execution of System FMEA. For wide use of the System FMEA in the enterprise it makes sense to train further collaborators at the locations to FMEA method specialists.
The drawing-up of System FMEA for products will be described with the example "Vehicle", for which the selected contents serve exclusively to demonstrate the procedure clearly.

Due to the system complexity the description is limited to the main contents.

A system description of the vehicle and its hierarchically different arranged system elements (SE) "Gearbox" and "Assembly (Ass.): Drive shaft" will be described. For the SE "Gearbox" the subordinated Design potential FMEA will be presented (compare chapter 4), where the FMEA for the component "Contact surface – Shaft sealing ring" will also be called Design FMEA.

7.1 System elements and System structure (1. Step)

The first system structure for the overall system "Vehicle", which does not go deeply into the subsystem, is shown in figure 7.1. The uppermost SE of the overall system to be described is the SE "Vehicle".

Figure 7.1: System structure Vehicle (Excerpt)

A more detailed system description of the SE "Gearbox" and of its SE "Ass. Drive shaft" is shown in figure 7.2. The figure 7.3 describes the fitting position of the drive shaft and the associated gearbox extent.
Figure 7.2: System structure "Gearbox"

Note: Corresponding to the methodical description the examination deepness can be different. The levels “characteristics” and “design data” can be described in one system element.

Figure 7.3: Detail from Ass. Gearbox drawing
7.2 Functions and Function structures (2. Step)

Functions will be assigned to the system elements of both system structures called "Vehicle" and "Gearbox" (fig. 7.4, 7.5). Function structures (function trees) can be drawn up for selected functions, for which the functions of the affected SE will be associated with each other and described in a corresponding function structure (fig. 7.6). The function "Warrants environment harmless and fail/safe operation" of the SE "Gearbox" will be selected as example for the function structure.

Figure 7.4: System structure "Vehicle" with Functions
Figure 7.5: System structure "Gearbox" with Functions
Figure 7.6: Function structure "Gearbox"

Functional Interfaces

One interface arising from the selected structure will be shown in figure 7.6. System elements, which must be examined mutually for the functional description of the sealing, have been arranged for the structuring into the substructures SE "Ass. Drive shaft", SE "Gearbox housing – Bearing cover" and SE "Shaft sealing ring" (fig. 7.2). These SE contribute functionally to the sealing of the overall system "Gearbox".

7.3 Failure analysis (3. Step)

A System FMEA can be drawn up for each SE independently of its arrangement in the system structure. Subsequently the failure analyses for both SE "Ass. Drive shaft" and "Contact surface – Shaft sealing ring" will be considered as example.
7.3.1  Failure analysis of the Design potential FMEA
"Ass. Drive shaft"

For each SE of the system examination a failure analysis can be carried out, for which several approaches are possible:

- Malfunctions can be derived from existing function structures (fig. 7.6), e.g. by negation and based on limited or faulty functions, and subsequently can be logically associated to a malfunction structure.

- Potential malfunctions will be described for the SE of the system structure (fig. 7.7), departing from the functions established in the system description (fig. 7.5), and subsequently logically associated. Malfunction structures arise in this way, which describe potential failure effects and failure causes (fig. 7.8) for all considered malfunctions – except the SE "Vehicle" (only failure effects) and the lowest SE "Design data" (only failure causes).
Fig. 7.7: Malfunctions of the System structure "Gearbox"

<table>
<thead>
<tr>
<th>Component</th>
<th>Malfunction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gearbox housing</td>
<td>does not seal the oil chamber to the environment, does not warrant stability of the gearbox</td>
</tr>
<tr>
<td>Gearbox housing-bearing cap</td>
<td>(drive side) does not receive shaft sealing ring leakage-free and suitable to function</td>
</tr>
<tr>
<td>Main/output drive shaft</td>
<td></td>
</tr>
<tr>
<td>Wheel set 5th speed</td>
<td></td>
</tr>
<tr>
<td>Gearbox</td>
<td>does not warrant environment harmless and fail/safe operation</td>
</tr>
<tr>
<td>Ass. Drive shaft</td>
<td>does not seal suitable to function against shaft sealing ring</td>
</tr>
<tr>
<td>Layshaft</td>
<td></td>
</tr>
<tr>
<td>Ball bearing-drive shaft (*)</td>
<td></td>
</tr>
<tr>
<td>Shaft sealing ring (*)</td>
<td>does not seal oil chamber leakage-free against environment</td>
</tr>
<tr>
<td>Lubricants (*)</td>
<td>chemical compatibility not given with all materials</td>
</tr>
<tr>
<td>Bearing fit-ball bearing</td>
<td>does not transmit forces from the tooth mesh (constant wheel) to ball bearing innerrace</td>
</tr>
<tr>
<td>Contact surface-shaft sealing ring</td>
<td>does not warrants building-up of oil film for shaft sealingring</td>
</tr>
<tr>
<td>Properties</td>
<td></td>
</tr>
<tr>
<td>Contact surface-shaft sealing ring</td>
<td>Contact surface worn Contact surface corroded</td>
</tr>
<tr>
<td>Properties</td>
<td></td>
</tr>
<tr>
<td>Design data Contact surface-shaft sealing ring (**)</td>
<td>Diameter not OK Rz not OK Hardness not sufficient chemically not resistant twisted</td>
</tr>
<tr>
<td>Design data</td>
<td></td>
</tr>
<tr>
<td>Wheel spider</td>
<td></td>
</tr>
<tr>
<td>Constantwheel (5th speed)</td>
<td></td>
</tr>
<tr>
<td>Splines</td>
<td>warrants torque transmission</td>
</tr>
<tr>
<td>Gear-tooth</td>
<td></td>
</tr>
</tbody>
</table>

(*) Design potential FMEA (supplied parts)
(**) Overlap to the process potential FMEA
Fig. 7.8: Malfunction structure "Gearbox"
This example of the System FMEA "Contact surface – Shaft sealing ring" deals with a Design FMEA within the substructure "Ass. Drive shaft". With the SE "Contact surface – Shaft sealing ring" (fig. 7.9) it will be shown, how potential malfunctions (wears, corrodes, etc.) of the SE "Characteristics Contact surface Shaft sealing ring" will be analysed. Design failures (e.g. Diameter not OK, Hardness not sufficient, ...) will always be indicated as potential failure causes for every property not complied and one of the malfunctions of the SE "Contact surface – Shaft sealing ring" will be considered as a potential failure effect. The malfunction structure is described in figure 7.9.

![Malfunction structure of the SE "Contact surface – Shaft sealing ring"

The malfunctions of the SE "Properties contact surface – Shaft sealing ring" will be entered into the FMEA form column "Potential failures" and the additional information from the failure structures will be transferred into the columns "Potential failure effects" and "Potential failure causes" (figure 7.13).
7.3.3 Overlaps

For the SE "Gearbox" the figure 7.10 shows overlaps of five systems FMEA with selected malfunctions.

The example describes the malfunction "does not warrant environment harmless/fail/safe operation" of the SE "Gearbox". This is a potential failure cause for the System FMEA "Drive train", a potential failure for the System FMEA "Gearbox" and a potential failure effect for the System FMEA "Ass. Drive shaft".

<table>
<thead>
<tr>
<th>System</th>
<th>FE</th>
<th>F</th>
<th>FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive train</td>
<td>F</td>
<td>Does not warrant trouble-free/ economical operation acc. tender specification</td>
<td>F</td>
</tr>
<tr>
<td>Gearbox</td>
<td>F</td>
<td>Does not warrant propulsion of the vehicle</td>
<td>FC</td>
</tr>
<tr>
<td>A: Drive shaft</td>
<td>F</td>
<td>Does not warrant environment harmless/fail/safe operation</td>
<td>F</td>
</tr>
<tr>
<td>Contact surface - Shaft sealing ring</td>
<td>F</td>
<td>Does not seal fail/safe against the shaft sealing ring</td>
<td>F</td>
</tr>
<tr>
<td>Properties Contact surface - Shaft sealing ring</td>
<td>F</td>
<td>Does not warrant building-up of oil film for shaft sealing ring</td>
<td>FC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contact surface worn</td>
<td>Design data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hardness not sufficient</td>
<td>Grinding process</td>
</tr>
</tbody>
</table>

Figure 7.10: Overlaps
The Design potential FMEA and Process potential FMEA overlap each other for example, as described in figure 7.11. For this, information from the Design potential FMEA will be considered in the Process potential FMEA. The reverse is also possible.

SE "Properties ..."

<table>
<thead>
<tr>
<th>FE</th>
<th>F</th>
<th>FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does not warrant building-up of oil film for shaft sealing ring</td>
<td>Contact surface worn</td>
<td>(Design data) Diameter not OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rz not OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hardness not sufficient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Grinding process) Peak-to-valley-height of shaft sealing ring not manufactures acc. drawing specification</td>
</tr>
</tbody>
</table>

SE "Grinding process ..."

<table>
<thead>
<tr>
<th>FE</th>
<th>F</th>
<th>FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Overall process) Ass. Drive shaft defectively manufactured (Properties) Contact surface worn</td>
<td>Peak-to-valley-height of Contact surface - Shaft sealing ring not manufactured acc. drawing specification</td>
<td>Circumferential speed of grinding machine too low</td>
</tr>
</tbody>
</table>

Fig. 7.11: Overlapping Design potential FMEA and Process potential FMEA
7.4 Risk assessment for both Examples
Design potential FMEA (4. Step)

The malfunctions of the SE "Ass. Drive shaft" will be described as a failure in the System FMEA "Ass. Drive shaft" and transferred into the form (figure 7.12).

The potential failure effects and the potential failure causes, both specified by the malfunction structures, will also be transferred into the form columns. The severity of the failure effects, the occurrence and detection likelihood of the failure causes will be evaluated for identification of the main risks in the system "Vehicle".

Severity S

Potential failure effects will be examined to the entire system "Vehicle" and their effects will be evaluated to the external customer (e.g. driver). The S-evaluation in the form is effected according to the table 1, chapter 3.4.

The selected example shows for the SE "Drive shaft", that an immediate inspection at garage is urgently required as a result of oil loss (restricted functioning of the substructure "Gearbox"). The potential failure effect will be evaluated with $S = 8$ for this reason.

<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>S</th>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>O</th>
<th>Detecting measures</th>
<th>D</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>does not warrant environment harmless/fail/safe operation</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Preventive Measures

For each potential failure cause the preventive measures obviously carried out at the examination time will be described. In the case of the Design potential FMEA these are constructional measures, which minimise the occurrence of potential failure causes in the development stage or guarantee the striven reliability respectively. In the form they will be entered into the column "Preventive Measure".

<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>Potential failure</th>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>O</th>
<th>Detecting measures</th>
<th>D</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>does not warrant oil film building-up for shaft sealing ring</td>
<td>Peak-to-valley-height acc. DIN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Note: Process potential FMEA &quot;Grinding&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Occurrence likelihood O

In view of all listed preventive measures the evaluation ranking index O for the occurrence likelihood will be determined for each potential failure cause with the aid of table 1, from chapter 3.4, and entered into the form.

In this example the evaluation is based on a design advanced in the degree of maturity (O = 4).
Detecting Measures

The Design potential FMEA knows in principle two types of detecting measures:

- **Detecting measures (development accompanying)**

  Detecting measures which will be carried out in a development accompanying way, and reveal potential failure causes already during the development on a concept or a prototype respectively,

<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>S</th>
<th>Potential failure</th>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>O</th>
<th>Detecting measures</th>
<th>D</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Detecting measures (during operation or in the field)**

  Detection possibilities, which inhere in the product (system) or will be recognised by the operator (customer). They point to the potential failures or the potential failure causes respectively, which have occurred during operation, so that further potential failure effects will be avoided.

The detecting measures will be entered into the identical form column.

<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>S</th>
<th>Potential failure</th>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>O</th>
<th>Detecting measures</th>
<th>D</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

50
Detection likelihood D

For each considered potential failure cause the detecting measures obviously carried out at the examination time will be listed. In view of all listed detecting measures the evaluation ranking index D for the detection likelihood will be defined for each potential failure cause with the table 1 from the chapter 3.4, and entered into the form. D is a criterion for the probability, which allows to detect the malfunctions occurred in spite of all preventive measures already during the development.

In the present example the potential failure cause "does not warrant oil film building-up for shaft sealing ring" will be recognised with high probability during the proving, i.e. D = 3.

<table>
<thead>
<tr>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>O Detecting measures</th>
<th>D</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement of Rz</td>
<td>Endurance test</td>
<td>4</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A second potential evaluation ranking index D can be referred to later failures of the product in the superior system. It differs from the preventive D evaluation mentioned above, which has already been effected in a development accompanying way.

For example, the clutch slip will be complained about because of low acceleration of the vehicle (high detection likelihood, i.e. D = 2).
**Risk priority number RPN**

The RPN is the product from the evaluation ranking indices $S \times O \times D$ and appears also in the form.

For both different evaluation ranking indices $D$ two different RPN values result – under the assumption of an identical failure cause –, however, such a distinction for the Design FMEA has not yet been taken. But it is very helpful for the analysis of security requirements in complex systems and for the clear description of the system reactions for loss of functions (e.g. electronic systems).

---

### Form excerpt for the SE "Drive shaft"

<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>S</th>
<th>Potential failure</th>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>O</th>
<th>Detecting measures</th>
<th>D</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>does not warrant environment harmless fail/safe operation</td>
<td>8</td>
<td>does not seal against the shaft sealing-ring suitable to function</td>
<td>oil film building-up for shaft sealing-ring not warranted</td>
<td>Peak-to-valley-height acc. DIN</td>
<td>4</td>
<td>Measurement of Rz</td>
<td>3</td>
<td>96</td>
<td>Meier Dept. AB/D</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Note: Process potential FMEA &quot;Grinding&quot;</td>
<td></td>
<td>Endurance test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Clutch slip, ...</td>
<td>2</td>
<td>64</td>
<td></td>
</tr>
</tbody>
</table>
7.5 Optimisation for both Examples (5. Step)

At the contact surface for the shaft sealing ring further preventive measures (e.g. optimisation of the surface hardness and roughness) are provided for wear reduction with the aim to improve the surface quality. For example, a bench endurance test and a proving in the drive test with the optimised drive shaft will be proposed as detecting measure, and the planned measures will be entered into the form (fig. 7.13). These measures will be provisionally evaluated prior to their realisation. For measures still to be carried out a responsible office and the target completion date will be entered into the R/T-column. Due to this entering the status of settlement is clear at any time for those responsible of the System FMEA. After implementation of the planned measures a further risk assessment will be effected and the new RPN-values will be calculated.

Form excerpt for the SE "Drive shaft"

<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>S</th>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>O</th>
<th>Detecting measures</th>
<th>D</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td>Meier</td>
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<td>Dept.</td>
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<td></td>
<td></td>
<td></td>
<td>AB/D</td>
</tr>
</tbody>
</table>
### FMEA

<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>S</th>
<th>Potential failure</th>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>O</th>
<th>Detecting measures</th>
<th>D</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does not warrant</td>
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<td></td>
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<td></td>
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<td>environment harmless</td>
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<tr>
<td>and fail/safe operation</td>
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</tr>
<tr>
<td>[Gearbox]</td>
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<td>&gt;&gt; Does not warrant</td>
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<td>transmission/interruption</td>
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<tr>
<td>of drive power between</td>
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<tr>
<td>motor and gearbox</td>
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<tr>
<td>[Clutch(*)]</td>
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<td>&gt;&gt; Does not warrant</td>
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<tr>
<td>any trouble-free</td>
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<td></td>
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<tr>
<td>propulsion of the vehicle</td>
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<tr>
<td>[Drive train]</td>
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<tr>
<td>Does not warrant</td>
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<tr>
<td>any trouble-free/</td>
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<td></td>
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<tr>
<td>economical operation</td>
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<tr>
<td>acc, tender specification</td>
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<tr>
<td>[Vehicle]</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
| Structure element: Ass. Drive shaft | Function: warrants transmission of drive torque to the gearbox
| Does not warrant         |   |                  |                         |                     |   |                   |   |     |     |
| conversion of drive      |   |                  |                         |                     |   |                   |   |     |     |
| torque and speed in 5    |   |                  |                         |                     |   |                   |   |     |     |
| steps [Gearbox]          |   |                  |                         |                     |   |                   |   |     |     |
| >> Does not warrant      |   |                  |                         |                     |   |                   |   |     |     |
| any propulsion of the    |   |                  |                         |                     |   |                   |   |     |     |
| vehicle [Drive train]   |   |                  |                         |                     |   |                   |   |     |     |
| Structure element: Ass. Drive shaft | Function: warrants the fail/safe bearing in the housing
| does not warrant        |   |                  |                         |                     |   |                   |   |     |     |
| conversion of drive      |   |                  |                         |                     |   |                   |   |     |     |
| torque and speed in 5    |   |                  |                         |                     |   |                   |   |     |     |
| steps [Gearbox]          |   |                  |                         |                     |   |                   |   |     |     |
| >> Does not warrant      |   |                  |                         |                     |   |                   |   |     |     |
| any propulsion of the    |   |                  |                         |                     |   |                   |   |     |     |
| vehicle [Drive train]   |   |                  |                         |                     |   |                   |   |     |     |

---

**Figure 7.12:** Form of the System FMEA "Ass. Drive shaft"
Figure 7.13: Form of the System FMEA "Properties Contact surface – Shaft sealing ring"
Example: Process potential FMEA

For the manufacturing of the "Assembly (Ass.) Drive shaft" the proceeding with the Process potential FMEA for production and assembly will be described. The following example refers to the subprocesses "Grinding process Bearing fit ..." and "Assembly process Bearing onto shaft".

The system description and the Process potential FMEA will be drawn up for the selected SE.

8.1 System elements and System structure (1. Step)

The "4 M" (Men, Machine, Material and Medium) can be used as SE for the system description of manufacturing processes. In the following graphics the process sequence is represented vertically from top to bottom and the process penetration horizontally from the left to the right (figure 8.1).
The first structure path of the example (figure 8.2) selected in the SE "Overall process Manufacture Ass. Drive shaft" leads via the SE "Grinding process for Bearing fit – Ball bearing and Contact surface – Shaft sealing ring" to the SE "Toolsetter", "Operator", "Grinding machine" and "Surroundings". The more profound consideration leads for example via the SE "Grinding machine" to its components "Clamping system", "Drive", "Control", etc.

![Diagram](image)

Figure 8.2: Subsystem structure "Grinding process Bearing fit – Ball bearing ..."

**Functional Interfaces**

One interface, which has been arisen by separation of both SE "Process material feed grinding" and "Grinding process bearing fit ..." within the structure, will be shown in figure 8.3.

This interface between "Process Material feed grinding" and "Grinding process Bearing fit ..." is shown by the example "Workpiece transfer to the clamping system of the grinding machine by means of the handling device".
8.2 Functions (Tasks) and Function structures (2. Step)

The superior SE functions (tasks) for SE "Grinding process Bearing fit – Ball bearing and Contact surface – Shaft sealing ring" are:

- Work steps of the SE "Men"
- Work steps of the SE "Machine"
- Functions of the SE "Material"
- Requirements of the SE "Medium"

Selected functions will be described at first for all SE of the considered example path (figure 8.2).

A function structure will be shown for each of the SE, mentioned below, respectively. For the "Grinding process Bearing fit..." this is the structure "Contact surface – Shaft sealing ring to be ground according to specification" (figure 8.4). For this purpose the functions of the SE, which have to be considered, will be associated corresponding to their interrelations.
Figure 8.4: Function structure "Contact surface – Shaft sealing ring to be ground according to Specification"
8.3 Failure analysis (3. Step)

This example does not go down to the constructional design failures of production equipment (these will be represented as example in the failure analysis, however), but it considers potential failures of the SE "Toolsetter", "Operator", "Grinding machine" and "Medium" as failure causes.

The results of the production failures onto the functions for the "Ass. Drive shaft" will be shown. The further effects on the vehicle are represented in the Design potential FMEA (compare figure 7.12 from Design potential FMEA).

8.3.1 Failure analysis Process potential FMEA "Grinding process Bearing fit – Ball bearing and Contact surface – Shaft sealing ring"

Malfunctions and Malfunction structures

Potential malfunctions will be described for the example "Grinding process bearing fit – Ball bearing and contact surface – Shaft sealing ring" and for selected SE of this substructure. They are deducted from the functions of the SE.

A malfunction will be drawn up for a selected malfunction of the overall process manufacture "Ass. Drive shaft". This malfunction structure "Ass. Drive shaft defectively manufactured" follows from the association of the considered causal malfunctions of other system elements.

The following example shows the malfunction structure deducted from the function structure drawn up at the beginning (figure 8.5). In this malfunction structure an example for the constructional design failures mentioned before (denoted with [**]) can also be found again.
Figure 8.5: Malfunction structure "Ass. Drive shaft defectively manufactured"
Form

The SE "Grinding process bearing fit – Ball bearing and Contact surface – Shaft sealing ring" will be considered. Its malfunction "Peak-to-valley-height of the contact surface – Shaft sealing ring is not executed according to drawing specification" will be depicted in the column "Possible failures" of the System FMEA form (figure 8.6). The superior and subordinated malfunctions in the malfunction structure of the failures mentioned above will be transferred (from figure 8.5) into the form column for the failure effects or for the failure causes, respectively. The failure analysis of the System FMEA describes three differently deep specification levels (hierarchical levels) in the form.

<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>S</th>
<th>Possible failure</th>
<th>Potential failure causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ass.- drive shaft defectively manufactured</td>
<td></td>
<td>Peak-to-valley-height of the contact surface – Shaft sealing ring not executed according to drawing specification</td>
<td>Circumferential speed too low [Grinding machine]</td>
</tr>
</tbody>
</table>

Figure 8.6: Excerpt from FMEA form

A more profound representation is obtained if the malfunction of the SE "Grinding machine" will be considered as potential failure for example. In the form resulting from this the lowest malfunction structure level (here the components of the SE grinding machine) will be depicted in the column "Potential failure causes" (malfunctions from: SE "Drive", SE "Control", SE "Clamping system"). FMEA forms can also arise on different levels of the examined process and overlap each other.
8.3.2 Overlaps

The overlaps of different Design potential FMEA, which are mentioned in the chapter 7.3.3, will be led into the Process potential FMEA in figure 8.7. The gearbox malfunction can be retraced, using such overlaps, to the malfunction of the manufacturing process of an individual component or assembly. With the itemised example the potential failure causes are to be found at last in the drive speed of the grinding machine.
8.4 Risk assessment (4. Step)

In the following example the risk assessment will be drawn up on the basis of an initial process planning stage. It evaluates the effectiveness of already effected or planned measures.

For high RPN an optimisation (5. Step) is necessary. The effectiveness of all optimisation measures will be determined by a repeated risk assessment. The result of the repeated risk assessment should lead to fewer risky process sequences.

The proceedings for the optimisation correspond methodically to the risk assessment of the initial stage. For this reason it will not be represented.

Severity S

The failure effect considered in the example is called:

"Ass. Drive shaft executed defectively".

To determine the severity S it will be assessed, which potential failure effects will arise for the vehicle and subsequently for the external customer (end user). In this case the evaluation value $S = 8$ of the "Potential top-failure effect" has been transferred from the Design potential FMEA for evaluating the severity, as it provides the potential failure effects for the vehicle (figure 7.12 and figure 7.13).

Evaluations of the severity of process failures for internal customers (e.g. next processing station in the factory) will be considered as well. The evaluation criteria, according to table 2, chapter 3.4, are not absolutely valid for this, because other severity criteria can be more important for internal customers than for the end user. Such evaluation criteria are to be internally determined.
Preventive measures

For the considered failure causes

- Toolsetter had loaded wrong processing program
- Toolsetter applies too small grinding wheel
- Operator does not determine tool wear
- Circumferential speed too low
- Finishing operation will not be carried out correctly
- Grinding machine will be influenced by vibrations from adjacent machines

the preventive measures will be described, which have been already carried out at the examination date or are integral part of the planning. These can also be preventive measures from the affiliated Design potential FMEA of the corresponding machine manufacturer, e.g. for the grinding machine.
The preventive measures are measures which minimise the occurrence of potential failure causes during the process. For the aforementioned potential failure causes, preventive measures are itemised in the corresponding column of form as example (figure 8.9).

<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>S</th>
<th>Potential failure</th>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>O</th>
<th>Detecting measures</th>
<th>D</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
<td></td>
<td>circumferential speed too low</td>
<td>Application well-established driving units planned</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Occurrence likelihood O**

In view of all listed preventive measures for each potential failure cause the evaluation ranking index O for the occurrence likelihood will be determined from table 2 and entered into the form (figure 8.9).

Potential failure causes without any preventive measures planned at the time of examination will be assigned with a higher O-evaluation.
Detecting measures

Detecting measures are the effective examination measures for safeguarding a manufacturing process. For the potential failure causes, detecting measures will be described, which are planned or already carried out at the examination date. Detecting measures are measures, which detect occurred potential failure causes. The earliest possible detection in the cause/effect chain is useful.

Excerpt of form to the SE "Grinding process bearing fit – Ball bearing ..."

<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>S</th>
<th>Potential failure</th>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>O</th>
<th>Detecting measures</th>
<th>D</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>On-line rotational speed supervision</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circumferential speed too low</td>
<td></td>
<td>Application well-established driving units planned</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Detection likelihood D

The evaluation will be carried out for each potential failure cause in view of all detecting measures listed for this. For each potential failure cause the evaluation ranking index D for the detection likelihood will be determined from table 2, chapter 3.4, and entered into the form.

Excerpt of form to the SE "Grinding process bearing fit – Ball bearing ..."

<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>S</th>
<th>Potential failure</th>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>O</th>
<th>Detecting measures</th>
<th>D</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>On-line rotational speed supervision</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
Risk priority number RPN

The RPN will be calculated as the product $S \times O \times E$ and represented in the form. With the aid of the RPN the weak points of the process will be revealed. They serve as deciding criteria about the introduction of optimisation measures up to concept modifications.

<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>S</th>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>O</th>
<th>Detecting measures</th>
<th>D</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ass.-Drive shaft defectively manufactured [Overall process Manufacture “Ass. Drive shaft”]</td>
<td>8</td>
<td>Peak-to-valley-height of the contact surface – shaft sealing ring not executed according to drawing specification</td>
<td>Application well-established driving units planned</td>
<td>2</td>
<td>On-line rotational speed supervision</td>
<td>2</td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>
8.5 Process optimisation (5. Step)

The basis of the process optimisation is the risk assessment in the FMEA form. The figure 8.9 shows such a form for the function "Contact surface – Shaft sealing ring to be ground according to specification".

<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>S</th>
<th>Potential failure</th>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>D</th>
<th>Detecting measures</th>
<th>O</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure element:</td>
<td></td>
<td>Bearing fit of Ball bearing and</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Function:</td>
<td></td>
<td>Contact surface of Shaft sealing ring</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ass.-Drive shaft</td>
<td>8</td>
<td>Peak-to-valley-height</td>
<td></td>
<td>Initial stage: 22.11.1994</td>
<td>10</td>
<td>Opto-electronic diameter monitoring of the unworked part</td>
<td>2</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>defectively manufactured</td>
<td></td>
<td>of the Contact surface – Shaft sealing ring not execu according to drawing specification</td>
<td></td>
<td>Initial stage: 22.12.1994</td>
<td>2</td>
<td>Opto-electronic diameter monitoring of the unworked part</td>
<td>2</td>
<td>32</td>
<td>Meier, terminated on 10.02.1995</td>
</tr>
<tr>
<td>[Overall process Manufacture “Ass. Drive shaft”]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tool-setter uses too small grinding wheel</td>
<td>Initial stage: 22.11.1994</td>
<td></td>
<td>not yet provided</td>
<td>10</td>
<td>Regular manual grinding wheel diameter check</td>
<td>4</td>
<td>320</td>
<td>Bauer</td>
<td></td>
</tr>
<tr>
<td>Diameter Contact surface of Shaft sealing ring &lt; Drawing specification</td>
<td>Initial stage: 22.11.1994</td>
<td></td>
<td>not yet provided</td>
<td>10</td>
<td>Opto-electronic diameter monitoring of the unworked part</td>
<td>2</td>
<td>160</td>
<td>Meier</td>
<td></td>
</tr>
<tr>
<td>Circumferential speed too low [Grinding machine]</td>
<td>Initial stage: 22.11.1994</td>
<td>Application of well established driving units scheduled</td>
<td></td>
<td>2</td>
<td>Online speed monitoring</td>
<td>2</td>
<td>32</td>
<td>Meier</td>
<td></td>
</tr>
<tr>
<td>finishing operation is not executed in order [Grinding machine]</td>
<td>Initial stage: 22.11.1994</td>
<td>scheduled control already introduced trouble-free into series production</td>
<td></td>
<td>2</td>
<td>test run at the machine manufacturer</td>
<td>3</td>
<td>48</td>
<td>Meier</td>
<td></td>
</tr>
<tr>
<td>Grinding machine is influenced by vibrations from adjacent machines [Medium]</td>
<td>Initial stage: 22.11.1994</td>
<td></td>
<td>not yet provided</td>
<td>10</td>
<td>not yet provided</td>
<td>10</td>
<td>800</td>
<td>Müller</td>
<td></td>
</tr>
<tr>
<td>Corresponding design of foundation [*]</td>
<td>Initial stage: 30.11.1994</td>
<td>Vibration Measurements effected at the foundation</td>
<td></td>
<td>1</td>
<td>Müller terminated on 15.03.1995</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ass.-Drive shaft</td>
<td>8</td>
<td>Diameter Contact surface of Shaft sealing ring &lt; Drawing specification</td>
<td></td>
<td>Initial stage: 22.11.1994</td>
<td>10</td>
<td>Opto-electronic diameter monitoring of the unworked part</td>
<td>2</td>
<td>160</td>
<td>Meier</td>
</tr>
<tr>
<td>defectively manufactured</td>
<td></td>
<td>[Overall process Ass. Drive shaft]</td>
<td></td>
<td>Initial stage: 30.11.1994</td>
<td>10</td>
<td>Opto-electronic diameter monitoring of the unworked part</td>
<td>2</td>
<td>32</td>
<td>Meier, terminated on 15.03.1995</td>
</tr>
<tr>
<td>Part-number-related program call</td>
<td>Initial stage: 22.11.1994</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finishing operation executed at too high erosion speed [Grinding machine]</td>
<td>Initial stage: 22.11.1994</td>
<td>scheduled control already introduced trouble-free into series production</td>
<td></td>
<td>2</td>
<td>test run at the machine manufacturer</td>
<td>3</td>
<td>48</td>
<td>Meier</td>
<td></td>
</tr>
</tbody>
</table>

Figure 8.9: Form with failure analysis
The consideration of the potential failure causes from the FMEA-form results in the following table, sorted according to the values of the RPN, given in excerpts:

<table>
<thead>
<tr>
<th>Potential failure cause</th>
<th>RPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grinding machine will be influenced by vibrations of adjacent machines</td>
<td>800</td>
</tr>
<tr>
<td>Toolsetter applies too small grinding wheel</td>
<td>320</td>
</tr>
<tr>
<td>Toolsetter loads wrong processing program</td>
<td>160</td>
</tr>
<tr>
<td>Operator has not determined tool wear</td>
<td>160</td>
</tr>
</tbody>
</table>

In order to minimise the risks determined with the RPN in the grinding process, the planning stage has been optimised by means of effective preventive and detecting measures and the risk priority numbers have been reduced consequently.

For the potential failure cause "Grinding machine will be influenced by vibrations from adjacent machines" these are for example the corresponding machine foundation layout as preventive measure and a vibration measurement at the machine foundation as detecting measure. The repetition of a risk assessment carried out leads to a RPN of 40.

All other potential failure causes will be treated in the same way, where the need for action depends on the individual consideration of the different RPN (compare chapter 3.5).

The person responsible for each measure will be entered into the R/T column with the corresponding target completion date.
8.6 System FMEA "Assembly Bearing onto shaft"

This second System FMEA serves as example for the proceeding during an "Assembly process".

8.6.1 System elements and System structure (1. Step)

The second structure path selected in the SE "Overall process Manufacture Ass. Drive shaft" (figure 8.1) leads via the SE "Assembly process Bearing onto shaft" to the SE "Assembler", "Assembly fixture", "Bearing", "Grease", etc. (figure 8.10).

![Figure 8.10: Subsystem structure "Assembly process Bearing onto shaft"

8.6.2 Functions (Tasks) and Function structures (2. Step)

Analogously to the first System FMEA example with the SE "Assembly process bearing onto shaft" the superior functions are:

- Work steps of the SE "Men"
- Work steps of the SE "Machine"
- Functions of the SE "Material"
- Requirements of the SE "Medium".

At first the selected functions for all SE of the considered example path (figure 8.10) will be described, like in the first example.

For each of the SE mentioned below, a function structure is shown, e.g. the structure "Assemble Ball bearing onto Bearing fit Drive shaft suitable to function" for the "Assembly process bearing onto shaft" (figure 8.11). For this purpose the functions to be considered of the SE are associated corresponding to its interrelations as well as in the first example.
8.6.3 Failure analysis (3. Step),
Risk assessment (4. Step)
and Optimisation (5. Step)

Malfunctions are described for the SE "Assembly process Bearing onto shaft" and additionally selected SE. They have been deducted from the known functions of the SE (figure 8.10). For a selected malfunction of the assembly process "Bearing onto shaft" a malfunction structure will be drawn up. As shown in the previous example, this malfunction structure results from the causal malfunctions to be considered of other system elements.
The following example (figure 8.12) shows the malfunction structure deducted from the function structure drawn up at the beginning (figure 8.11).

![Diagram of System FMEA process]

<table>
<thead>
<tr>
<th>Overall process Manufacture</th>
<th>Ass. Drive shaft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacture</td>
<td>Ass. Drive manufacture defectively</td>
</tr>
</tbody>
</table>

![Diagram of Assambly process Ball bearing on shaft]

<table>
<thead>
<tr>
<th>Assambly process Ball bearing on shaft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball bearing will not be pushed onto the bearing fit completely</td>
</tr>
</tbody>
</table>

- [Assamblener] Clamps ball bearing inclined into assembly fixture
- [Assamblener] Does not apply grease
- [Assamblener] Does not apply enough grease
- [Assamblener] Positioning accuracy from drive shaft to ball bearing is not warranted
- [Assamblener] Joining process will not be executes suitable to function
- [Assamblener] Joining process will not be executes completely

Figure 8.12: Malfunctions of System elements for "Assembly Bearing onto shaft"

The further steps of the System FMEA are carried out analogously to the proceedings for the already shown examples:

- Transference of the malfunction of the SE "Assembly process Bearing onto shaft" into the column "Possible failure" of the System-FMEA form.
- Depiction of results and causes of the potential failures into the column "Failure effects and failure caused" of the FMEA form.

The subsequent risk analysis (4. Step) and the following optimisation (5. Step) proceed methodically in the same way as in the example "Grinding process bearing fit – Ball bearing and Contact surface – Shaft sealing ring“.

- Evaluation of the failure causes in view of the occurrence and detection likelihood; the evaluation of the failure effects in view of the severity for the (internal or external) customer and the creation of the risk priority numbers.
- Optimisation of the assembly process for failure causes with high risk potential.
9 Representation of Results and Management information

9.1 Frequency distribution of the RPN

After effected risk assessment a data compression is useful for management information. The frequency distribution of the RPN can serve as aid for this purpose, see figure 9.1 and chapter 3.5, analysis of risk priority numbers.

![Frequency distribution of the RPN](image)

**Figure 9.1:** Frequency distribution of the RPN

9.2 Follow-up of Measures

Different optimisation measures corresponding to the revealed risks are recommended for the drawing-up of the System FMEA. If the main points for treatment and findings of measures are established by above-mentioned considerations, the new risks resulting from the proposed measures for minimising the risks could be determined in a RPN in advance.

The determined remedial efforts are represented in a form "Follow-up of Measures" (Figure 9.2), responsible and deadline (R/T) are determined and monitored.
Example for a form for the "Follow-up of Measures":

<table>
<thead>
<tr>
<th>Follow-up of Measures Failure Mode and Effect Analysis</th>
<th>FMEA-No.:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type/Model/Production/Batch:</td>
<td></td>
</tr>
<tr>
<td>System-No./System element:</td>
<td></td>
</tr>
<tr>
<td>Function/Task:</td>
<td></td>
</tr>
<tr>
<td>Potential failure causes; with associated failure and failure effects</td>
<td>RPN</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 9.2: Form for the "Follow-up of Measures"

9.3 **Representation of Objectives for the Optimisation measures**

Depending on the determined ranking and on the settlement period for the optimisation measures, a defined goal and objective for the settlement status of all measures is resulting, e.g. corresponding to the following graphical representation (Figure 9.3):

Figure 9.3: Graphical representation of the Status of Settlement
10 Relationships to other methods

The different scopes of the System FMEA are related among other things to the following methods:

- Quality Function Deployment (QFD)
- Fault-Tree Analysis (FTA)
- Event Tree Analysis (ETA)
- Statistical Process Control (SPC)
- Value Analysis (VA)
- Design of Experiments (DoE)

The system structure, the functions and the function structures can already emerge during the course of a QFD and be transferred to the System FMEA. The FTA, ETA, SPC, VA and DoE could be based on the structured proceedings of the System FMEA failure analysis, as the following common structures exist:

During the analysis a delimited system is considered, for which the following is valid:

- The system is structured into different units for examination (system elements). Functions and malfunctions are assigned to each of these system elements.
- The effects/the causes for each of these malfunctions can be depicted in form of malfunction structures following the system classification.
- There are probability statements made for the potential malfunctions.
- RPN and action proposals from the System FMEA are important information for the design of experiments and for inspection planning.
- The System FMEA lead into the failure statistics and are an ideal prerequisite for diagnosis and maintenance.
- The System FMEA provide approaches for work assignments (production schedules).
As already the conventional design and process FMEA the System FMEA confines itself to the analysis of individually occurring failures. The FTA examines additionally the possible simultaneous failure occurrence and can therefore supplement the System FMEA, e.g. for safety analyses.

RPN and action proposals from the System FMEA are important information for design of experiments and inspection plannings. The System FMEA lead into the failure statistics and provide thus ideal prerequisites for diagnosis and maintenance.

Further approaches for the process planning may be found in the System FMEA, e.g. production schedules and work assignments from the Process potential FMEA.
11  Annex

11.1  User support for the Form System FMEA VDA ‘96

11.2  Form System FMEA VDA ‘96

11.3  Examples for Evaluation tables

11.4  Form for Follow-up of Measures

11.5  Flow chart

VDA-publication series
"Quality management within the Automobile industry“

Forms
11.1  User support for the Form System FMEA VDA '96

**Preparation**

Supply of

Drawings, tests reports, tender specification, quality regulations, failure lists and field experience of comparable system elements, wordings of law, ordinances, safety rules, standardising documents, schedules for process, assembly and inspection

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**The 5 steps of the system FMEA**

1st step **Drawing-up of system elements and system structure**

The system consists of individual system elements (SE), which serve for the description and structuring of the hardware concept and are arranged in the system structure. The system structure orders the individual SE up to down into different hierarchical levels. Further to this all existing connections from any SE are to be described as interfaces to each other SE.

2nd step **Representation of functions and functional structures**

System elements have different functions or tasks in the system. The acting in combination of the functions of several SE can be described as a functional structure (function tree/functional network). For the drawing-up of functional structures the involved arriving and internal functions have to be considered.

3rd step **Carrying out of failure analysis**

For each SE considered in the system description a failure analysis has to be carried out. Potential failures (F) of this SE are its malfunctions described and deducted from the known functions acc. to step 2. The potential failure causes (FC) are the conceivable malfunctions of the subordinated SE and the SE assigned via the interfaces. The potential failure effects (FE) are the resulting malfunctions of the superior SE and the SE assigned via the interfaces.

For the failure analysis of the system FMEA the malfunctions will be deducted and the structures of malfunctions (failure trees, malfunction trees and failure network) drawn up, both based on the well-known functions and structures.

4th step **Effecting of risk assessment**

For the risk assessment the evaluation ranking indexes S, O and D are determined acc. tables 1 and 2 and the risk priority number will be calculated on this basis.

\[ \text{RPN} = \text{S} \times \text{O} \times \text{D} \]

5th step **Carrying out of optimisation**

Optimisations are required for large RPN or large evaluation ranking indexes S, O and D. Optimisations take place according to the following priorities:

1. concept modification in order to exclude the failure cause, or to reduce the severity, respectively,
2. increase of the concept reliability in order to minimise the occurrence of the failure cause,
3. more effective detection of the failure causes (additional testing to be avoided, if possible).

For minimisation of the risks the additional actions are described and for each item a responsible has to be appointed for the conversion to a due date.

In case of far-reaching concept modifications all 5 steps of the FMEA will be run through again for the concerned sections.

If the reliability is increased by preventive measures or by more effective detection the steps 4 and 5 will be repeated.

An entry into the R/T column shows open and decided items of the system FMEA.
<table>
<thead>
<tr>
<th>Potential failure effects</th>
<th>S</th>
<th>Potential failure</th>
<th>Potential failure causes</th>
<th>Preventive measures</th>
<th>O</th>
<th>Detecting measures</th>
<th>D</th>
<th>RPN</th>
<th>R/T</th>
</tr>
</thead>
</table>

S = Severity ranking index  
O = Occurrence ranking index  
D = Detection ranking index  
Risk priority no. RPN = S * O * D
### Evaluation Ranking Indices for Severity S

<table>
<thead>
<tr>
<th>Evaluation ranking Index for the Severity S</th>
<th>Evaluation ranking Index for the Occurrence likelihood O</th>
<th>attributed failure quota in ppm</th>
<th>Evaluation ranking Index for the Occurrence likelihood O</th>
<th>Certainty of detection method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very large</strong></td>
<td>Very large</td>
<td></td>
<td>Very low</td>
<td>90 %</td>
</tr>
<tr>
<td>10 Safety risk, non-compliance with statutory provisions, Conked-out vehicle.</td>
<td>10 Very frequent occurrence of failure cause, 9 unusable, unsuitable design conception.</td>
<td>500.000</td>
<td>10 Detection of occurred failure causes is improbable. Reliability of design has not been or can not be proven. Detection methods are uncertain.</td>
<td>9 %</td>
</tr>
<tr>
<td>Large</td>
<td>Large</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Operability of vehicle considerably impaired. Immediate inspection at garage is urgently required. Restricted functioning of important subsystems.</td>
<td>8 Failure reason occurs again and again, 7 problematic construction, not matured.</td>
<td>50.000</td>
<td>8 Detection of occurred failure causes is less probable. Reliability of design can probably not be proven. Detection methods are uncertain.</td>
<td>97 %</td>
</tr>
<tr>
<td><strong>Moderate</strong></td>
<td>Moderate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Operability of vehicle impaired.</td>
<td>6 Occasionally occurring failure cause, 5 suitable construction advanced in degree 4 of maturity.</td>
<td>5.000</td>
<td>6 Detection of occurred failure causes is probable. Reliability of design could perhaps be proven. Detection methods are relatively certain.</td>
<td>99,7 %</td>
</tr>
<tr>
<td>5 Immediate inspection at garage is not urgently required. Restricted functioning of important comfort and convenience systems.</td>
<td>5 Occurrence likelihood of failure causes is low. Proven design.</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Minor restriction of operability of the vehicle. Clearing at next scheduled inspection in garage. Minor restrictions of comfort and conveniences systems.</td>
<td>3 Occurrence of failure cause is improbable.</td>
<td>50</td>
<td>3 Detection of occurred failure causes is very probable, conformed by several detection methods independent of each other.</td>
<td>99,9 %</td>
</tr>
<tr>
<td>Very low</td>
<td>Very low</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Very minor restriction of operability, discernible only by the skilled personnel.</td>
<td>1 Occurrence of failure cause is improbable.</td>
<td>1</td>
<td>1 Occurrence failure cause will certainly be detected.</td>
<td>99,9 %</td>
</tr>
</tbody>
</table>
Table 2: Criteria for Evaluation ranking indices for the Process potential FMEA

<table>
<thead>
<tr>
<th>Evaluation ranking Index for the Severity S</th>
<th>Evaluation ranking Index for the Occurrence likelihood O</th>
<th>attributed failure quota in ppm</th>
<th>Evaluation ranking Index for the Occurrence likelihood O</th>
<th>Certainty of detection method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very large</td>
<td>Very large</td>
<td></td>
<td>Very low</td>
<td>90 %</td>
</tr>
<tr>
<td>10 Safety risk, non-compliance with statutory provisions, Conked-out vehicle.</td>
<td>10 Very frequent occurrence of failure cause, 9 unusable, unsuitable process.</td>
<td>500.000 100.000</td>
<td>10 Detection of occurred failure causes is 9 improbable, the failure causes will or can not be proven.</td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td>Large</td>
<td></td>
<td>Low</td>
<td>98 %</td>
</tr>
<tr>
<td>8 Operability of vehicle considerably impaired. Immediate inspection at garage is urgently required. Restricted functioning of important subsystems.</td>
<td>8 Failure reason occurs again and again. 7 Inaccurate process.</td>
<td>50.000 10.000</td>
<td>8 Detection of occurred failure causes is 7 less probable. Failure cause will probably not be detected, uncertain examinations.</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate</td>
<td></td>
<td>Moderate</td>
<td>99.7 %</td>
</tr>
<tr>
<td>6 Operability of vehicle impaired. 5 Immediate inspection at garage 4 is not urgently required. Restricted functioning of important comfort and convenience systems.</td>
<td>6 Occasionally occurring failure cause, 5 less accurate process.</td>
<td>5.000 1.000 500</td>
<td>6 Detection of occurred failure causes is 5 probable. Examinations are relatively 4 certain.</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td></td>
<td>Large</td>
<td>99.9 %</td>
</tr>
<tr>
<td>3 Minor restriction of operability of the vehicle, Clearing at next scheduled inspection in garage. Minor restrictions of comfort and conveniences systems.</td>
<td>3 Occurrence likelihood of failure causes is 2 low. Accurate process.</td>
<td>100 50</td>
<td>3 Detection of occurred failure causes is 2 very probable, examinations are certain, e.g. by several tests independent from each other.</td>
<td></td>
</tr>
<tr>
<td>Very low</td>
<td>Very low</td>
<td></td>
<td>Very low</td>
<td>99.9 %</td>
</tr>
<tr>
<td>1 Very minor restriction of operability, discernible only by the skilled personnel.</td>
<td>1 Occurrence of failure cause is improbable.</td>
<td>1</td>
<td>1 Occurrence failure cause will certainly be detected.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Certainty of detection method</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 %</td>
</tr>
<tr>
<td>98 %</td>
</tr>
<tr>
<td>99.7 %</td>
</tr>
<tr>
<td>99.9 %</td>
</tr>
<tr>
<td>Potential failure causes with associated failure and failure effects</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>20</td>
</tr>
</tbody>
</table>
11.5 Flow chart