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C to D	Allows for designs with severity 10 failure modes as long as occurrence and detection are relatively low. Updated for changes to GS-0004 concerning Key and Safety characteristics and how they are determined. Softens the language of required actions when RPN > 100 in accordance with AIAG's 4 <sup>th</sup> Edition of FMEA standard.

Sauer-Danfoss Global Standard

**GS 0002**

Potential  
Failure Mode and Effect Analysis  
in Design  
(Design FMEA)

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## Scope

This standard introduces the topic potential Failure Mode and Effect Analysis (FMEA) and gives a general guidance in the application of the technique.

An FMEA can be described as a systemized group of activities intended to:

- 1) recognize and evaluate the potential failure of a product or a process and its effects,
- 2) identify actions which could eliminate or reduce the chance of the potential failure occurring, and
- 3) document the process. It is complementary to the design process of defining positively what a design must do to satisfy the customer.

This standard presents the design FMEA which normally follows a system FMEA and itself is followed by a process FMEA. System and process FMEA each have their own standards (GS-0005 and GS-0006). The interaction between the three is illustrated in the figure on page 6.

## Introduction

A design FMEA is an analytical technique utilized primarily by a Design Responsible Engineer and his / her team as a means to assure that, to the extent possible, potential failure modes and their associated causes/mechanisms have been considered and addressed. End items, along with every related system, subassembly and component, should be evaluated. In its most rigorous form, an FMEA is a summary of an engineer's and the team's thoughts (including an analysis of items that could go wrong based on experience and past concerns) as a component, subsystem or system is designed. This systematic approach parallels, formalizes and documents the mental disciplines that an engineer normally goes through in any process.

The design FMEA supports the design process in reducing the risk of failures by:

- Aiding in the objective evaluation of design requirements and design alternatives.
- Aiding in the initial design for manufacturing and assembly requirements.
- Increasing the probability that potential failure modes and their effects on systems and component operation have been considered in the design/development process.
- Providing additional information to aid in the planning of thorough and efficient design test and development programs.
- Developing a list of potential failure modes ranked according to their effects on the "customer", thus establishing a priority system for design improvements as well as development and validation testing / analysis.
- Providing an open issue format for recommending and tracking risk-reducing actions.
- Providing future reference to aid in analyzing field concerns, evaluating design changes and developing advanced designs.

## FMEA Implementation

Because of a company's commitment to continually improve its products whenever possible, the need for using the FMEA as a disciplined technique to identify and help to eliminate potential concern is as important as ever. Case studies of major complaints have shown that a fully implemented FMEA program could have prevented many complaints.

Although responsibility for the "preparation" of the FMEA must, of necessity, be assigned to an individual, FMEA input should be a team effort. A team of knowledgeable individuals should be assembled; e.g., engineers with expertise in Design, Manufacturing, Assembly, Service, Quality and Reliability.

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**Design FMEA**

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One of the most important factors for the successful implementation of an FMEA program is timeliness. It is meant to be a “before-the-event” action, not an “after-the-fact” exercise.

To achieve the greatest value, the FMEA must be done before a design or process failure mode has been unknowingly designed into the product.

**Up front time spent in doing a comprehensive FMEA well, when product or process changes can be most easily and inexpensively implemented, will alleviate late change crisis.**

**An FMEA can reduce or eliminate the chance of implementing a corrective change which could create an even larger concern.**

**Properly applied, it is an interactive process which is never ending.**

There are three basic cases for which FMEAs are generated, each with a different scope or focus.

- Case 1: New designs, new technology, or new process. The scope of the FMEA is the complete design, technology or process.
- Case 2: Modifications to existing design or process (hopefully there is an FMEA for the existing design or process). The scope of the FMEA should focus on the modification to design or process, possible interactions due to the modification, and field history.
- Case 3: Use of existing design in a new environment, location or application. The scope of the FMEA is the impact of the new environment or location on the existing design.

The need for taking effective preventive/corrective actions, with appropriate follow-up on those actions cannot be overemphasized.

Actions should be communicated to all affected activities. A thoroughly thought-out and well-developed FMEA will be of limited value without positive and effective preventive/corrective actions.

The responsible engineer is in charge of ensuring that all recommended actions have been implemented and adequately addressed. The FMEA is a living document and should always reflect the latest relevant actions including those occurring after the start of production.

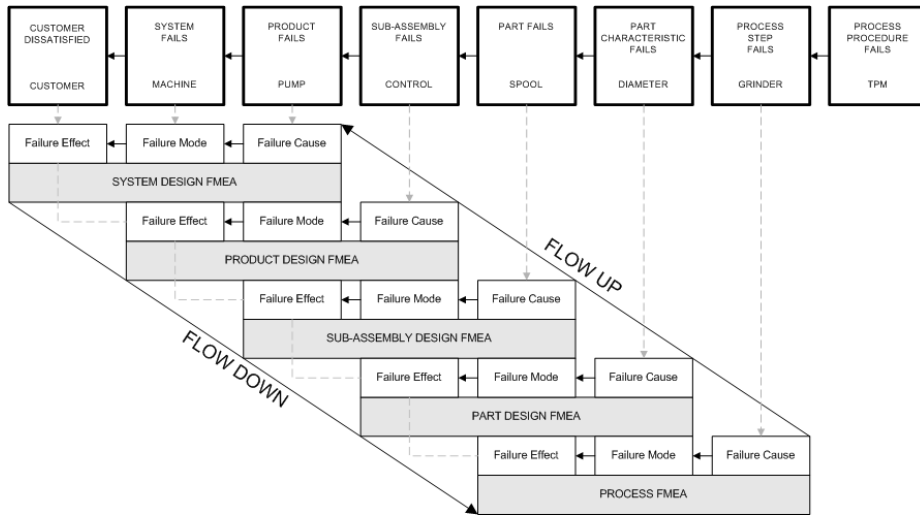
The responsible engineer has several means of assuring that recommended actions are implemented.

They should include, but are not limited to the following,

- a. Reviewing designs, processes and drawings to ensure that recommended actions have been implemented.
- b. Confirming the incorporation of changes to design-, assembly- or manufacturing documentation.
- c. Reviewing design and process FMEAs, special FMEA applications and control plans.

The figure beneath illustrates the difference and the connection of System FMEA, Design FMEA and Process FMEA.

Design FMEA



The preferred application method during the Integrated Product Development and Launch Processes (PDLP) is flow-down, where the customer requirements cascade down from one FMEA level to the next. FMEA is used during the early concept phase, as well as the detailed phase, to assess the risk of not delivering a product to the customer with the intended functions. It is also a useful means to document the decision-making process, to identify potential key characteristics (see GS-0004), and to identify elements of **an analysis and** a test plan. The flow-up method is commonly used with the Engineering Change process. It is used to evaluate changes to existing or new applications for existing systems, products, options, parts or processes, as well as a structured problem-solving tool. For Engineering Changes the local Engineering Manager may decide whether a System FMEA is needed or if the Severity can be determined by the DFMEA team.

The Severity rating should reflect the severity of the highest known FMEA level Failure Effect (i.e. the Failure effect in the Process FMEA should be the same words as the Failure Effect of the System FMEA).

### Customer Defined

The definition of “CUSTOMER” for a Design FMEA is not only the “END USER”, but also the design responsible engineers /teams of the product or higher level assemblies, and/or the manufacturing process responsible engineers in activities such as Manufacturing, Assembly, and Service.

The identification of an end customer presents a challenge for products without a single, designated using system. The potential types of typical applications must be identified and a System FMEA should be performed for each one having different failure modes and failure effect severities.

When fully implemented, the FMEA discipline requires a Design FMEA for all new parts, changed parts, and carryover parts in new applications or environments. An engineer from the responsible design activity initiates it, which for a proprietary design may be the supplier.

Design FMEA

### Team effort

During the initial Design FMEA process, the responsible engineer is expected to directly and actively involve representatives from all affected areas. These areas should include, but are not limited to, assembly, manufacturing, materials, quality, service and suppliers, as well as the design area responsible for the next assembly. The FMEA should be a catalyst to simulate the interchange of ideas between the functions affected and thus promote a team approach. In addition, for any (internal/external) supplier designed items, the responsible design engineer should be consulted.

The FMEA should be performed by a cross-functional and multi-disciplined team consisting of four to seven individuals as identified in the following table. The team membership will vary depending on the level of the FMEA, the type of product or system being analyzed, and the technical areas involved. Assembly and machining engineers should be considered for team membership when the product or part requires new manufacturing processes.

Role	FMEA LEVEL			
	System Design (Vehicle) FMEA	Product Design FMEA	Sub-Assembly Design FMEA	Part Design FMEA
Facilitator	X	X	X	X
Responsible Project Engineer	X	X	X	X
Technical Experts (1 minimum required):	X	X	X	X
Independent Design Engineer	Optional	X	X	X
Applications Engineer	X	X	Optional	Optional
Assembly Engineer	Optional	Optional	Optional	Optional
Machining Engineer	Optional	Optional	Optional	Optional

Under no circumstances should the FMEA, either partially or totally, be done by a single individual or as a separate smaller team with the expectation that the Team will subsequently review the FMEA for discrepancies. This review rarely occurs at a sufficient level of scrutiny, and it eliminates an opportunity for the Team to use its potential synergy to identify new issues or to reach a better decision than they could individually.

Facilitator expertise has significant impact on FMEA integrity.

Highly skilled facilitators should be involved in FMEAs of System, critical and complex assemblies or components. Facilitators in training should lead less critical or complex assembly or component FMEAs.

## Design FMEA and its Process counterpart

The Design FMEA is a living document and should be initiated before or at design concept finalization, be continually updated as changes occur or additional information is obtained throughout the phases of product development, and be fundamentally completed before the production drawings are released for tooling.

Considering that manufacturing /assembly needs have been incorporated, the Design FMEA addresses the design intent and assumes the design will be manufactured and assembled to this intent. Potential failure modes and/or causes or mechanisms which can occur during the manufacturing or assembly process might be identified in the Design FMEA, but their identification, effect and control are covered by the Process FMEA.

The Design FMEA does not rely on process controls to overcome potential weaknesses in the design, but it does take technical/physical limits of a manufacturing and assembly process into consideration, e.g.:

- Necessary mould drafts.
- Limited surface finish.
- Assembling space and access for tooling.
- Limited harden-ability of steels.
- Tolerances, process capability, process performance.

The design FMEA can also take into consideration the technical/physical limits of product maintenance (service) and recycling, for example:

- Tool access
- Diagnostic capability
- Material classification symbols (for recycling)

## Development of a Design FMEA

The process must be prevention oriented. The emphasis must be on preventive (analytical) design controls rather than detective (test) design controls. There is no requirement for both preventative and detection controls if proper RPN's (Risk Priority Numbers) can be achieved. An FMEA should be done in advance of planned changes in order to identify potential risks.

The Design responsible engineer has at his or her disposal a number of documents that will be useful in preparing the Design potential FMEA. The process begins by developing a listing of what the design is expected to do, and what it is expected not to do, i.e. the design intent. Customer wants and needs, as may be determined from sources as Quality Function Deployment (QFD), Product Requirements Documents, known product requirements and/or manufacturing and assembly requirements should be incorporated. The better the definition of the desired characteristics, the easier it is to identify potential failure modes for corrective action.

A Design FMEA should begin with a block diagram for the system, subsystem, and/or component being analyzed. An example block diagram is shown in Appendix B. The block diagram can also indicate the flow of information, energy, force, fluid, etc.

The object is to understand the deliverables (input) to the block, the process (function) performed in the block, and the deliverables (output) from the block.

The diagram illustrates the primary relationship between the items covered in the analysis and establishes a logical order to the analysis. Copies of the diagram used in the FMEA preparation should accompany the FMEA.

As preliminary work and as a means to understand the product functions and the possible failure modes a Boundary diagram and a P-diagram may be established as in Appendix C and D.

In order to facilitate documentation of the analysis of the potential failures and their consequences, a form has been designed and is shown in Appendix E.

A template for this form is available on Navigator under Quality ▶ Templates.

The template will use English headings. The DFMEA document may be done in the local language. The responsible design team may be requested to translate into English based on customer or other plant site needs.

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Application of the form is described below; points are numbered according to the numbers on the form shown in Appendix E.

All problems are not equally important. It is important during a flow-down FMEA to identify the areas of highest risk using customer statements or the Severity Occurrence Number - SON and to prioritize efforts, including additional analysis, testing, and a next level FMEA. The Risk Priority Number (RPN) is commonly used during a flow-up FMEA for existing products to identify areas of highest risk. SON is typically used for new products and parts since detection is often rated as a 10 due to missing, incomplete or non-applicable analysis and testing, whereas RPN is typically used for existing products since some detection is usually complete and applicable.

When entering information in the FMEA form try to limit the amount of words, but still **and that is very important** make sure you are adequately specific, so that persons not in the initial FMEA team can still understand the meaning.

The FMEA is said to be a living document, but it will often be kept alive by persons not involved in the first issue.

## Content of the form

**1. FMEA number**

Enter the FMEA document number, which may be used for tracking.

**2. System, subsystem or component name and number**

Indicate the appropriate level of analysis and enter the name and number of system, subsystem, or component being analyzed.

The FMEA team members must decide on what constitutes a system, subsystem or component for their specific activities.

The actual boundaries that divide a system, subsystem and component are arbitrary and must be set by the FMEA team.

Some descriptions are provided below and an example can be seen on the figure on page 6.

***System FMEA scope***

A system can be considered to be made up of various subsystems. These subsystems often have been designed by different teams. Some typical system FMEA's might, for a car, cover the following systems: Chassis system, power train system, interior system etc. Thus the focus of the system FMEA is to ensure that all interfaces and interactions are covered among the various subsystems that make up the system, as well as interfaces to other vehicle systems and to the customer.

***Subsystem FMEA scope***

A subsystem FMEA is generally a sub-set of a larger system.

For example on a car the front suspension subsystem is a sub-set of the chassis system. Thus the focus of the subsystem FMEA is to ensure that all interfaces and interactions are covered among the various components that make up the subsystem.

***Component FMEA scope***

A component FMEA is generally an FMEA focused on the sub-set of a subsystem. For example a strut is a component of the front suspension (which is a subsystem of the chassis system).

The component will normally consist of several parts, which each has a number of lines in the FMEA form.

**3. Design responsibility**

Enter OEM, department and division as appropriate. Also include the supplier name if known.

**4. Prepared by**

Enter the name, telephone number, company of engineer responsible for preparing the FMEA.

**5. Key date**

Enter initial FMEA due date, which should not exceed the scheduled production design release date.

Design FMEA

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**6. FMEA date**

Enter the date the original FMEA was compiled, and the latest revision date.

**7. Core team**

List the names of the responsible individuals and departments which have the authority to identify and/or perform tasks. (It is recommended that all team members' names, departments, telephone numbers, addresses, etc. be included on a distribution list.)

**8. Item**

Enter the name and number of the item being analyzed.

**9. Function**

Enter, as concisely as possible the function of the item being analyzed to meet the design intent. Include information regarding the environment in which this system operates (e.g. define temperature, pressure, humidity ranges). If the item has more than one function with different potential modes of failure, list all the functions separately. Brainstorming on the basis of function diagram, boundary diagram, part prints or actual hardware, can be useful.

**10. Potential Failure Mode**

Potential failure mode is defined as the manner in which a component, subsystem, or system could potentially fail to meet the design intent. The potential failure mode may also be the cause of a potential failure mode in a higher level subsystem, or system, or be the effect of a failure mode in a lower level component.

See the interaction figure on page 6.

List each potential failure mode for the particular item and item function. The assumption is made that the failure could occur, but may not necessarily occur. A recommended starting point is a review of past things-gone-wrong, concerns reports, and group "brainstorming", as well as the P-diagram (appendix D).

Potential failure modes that could only occur under certain operating conditions (i.e. hot, cold, dry, dusty, etc.) and under certain usage conditions (i.e. above average mileage, rough terrain, not specified use, etc.) should be considered.

There are two approaches to identifying failure modes, functional (sometimes in NOR referred to as technical) and hardware (sometimes in NOR referred to as physical).

The functional approach shall be used at the system and product levels of the FMEA.

The hardware approach is preferred at the part level.

Either approach is allowed at the sub-assembly level.

Functional failure modes can be described in terms of the "Anti-Function" which could be as mentioned beneath:

- Over achieve function
- Under achieve function
- Non function
- Intermittent function
- Degrading function

For example, the function of a bulb may be "provide light at  $5 \pm 0.2$  candela for 50 hours." The failure modes for a light bulb might then include: no light; dim light; erratic blinking light; gradual dimming of light; and light too bright.

Design FMEA

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Hardware failure modes should be defined in the physical manner which the part may fail to meet or deliver the intended function.

Typical hardware failure modes could be, but are not limited to:

Cracked	Sticking
Deformed	Short circuited (electrical)
Loosened	Oxidized
Leaking	Fractured
Drift	No support (structural)
No signal	Intermittent signal
Inadequate signal	Inadequate support (structural)
Harsh engagement	Does not transmit torque
Disengages too fast	Slips (does not hold full torque)
EMC / RFI	

Note: Potential failure modes should be described in "physical" or technical terms, not as a symptom noticeable by the customer, as this will be covered as effect of failure.

If you have a hard time thinking of a failure mode - just use "no function" or "anti function". And then try to be more specific by identifying as many causes as possible. List all failure modes before proceeding to the identification of failure effects.

**11. Failure number**

For easy identification and recognition of failure modes, causes and verification, each row / line should be identified by its own current number.

**12. Potential effects of failure**

Potential Effects of Failure are defined as the effects of the failure mode on the function as perceived by the customer.

Describe the effects of failure in terms of what the customer might notice or experience, remembering that the customer may be an internal customer as well as the ultimate end user.

State clearly if the function could impact safety or non-compliance to regulations. The effects should always be stated in terms of the specific system, subsystem or component being analyzed.

Remember that the hierarchical relationship exists between the component, subsystem, and system levels.

For example, a part could fracture, which may cause the assembly to vibrate, resulting in an intermittent system operation. The intermittent system operation could cause performance to degrade, and ultimately lead to customer dissatisfaction. The intent is to forecast the failure effects to the Team's level of knowledge.

Typical failure effects could be, but are not limited to:

Noise	Rough
Erratic operation	Inoperative
Poor appearance	Unpleasant handling
Unstable	Operation impaired
Intermittent operation	Leaks
Thermal event	Regulatory non-compliance

Design FMEA

13. Severity (S)

Severity is an assessment of the seriousness of the effect (listed in the previous column) of the potential failure mode to the next component, subsystem, system, or customer if it occurs. Severity applies to the effect only. A reduction in Severity Ranking index can be effected through a design change that makes the failure mode disappear.

Severity should be estimated on a “1” to “10” scale.

Assign all severities before proceeding to the identification of potential causes.

**Suggested evaluation criteria:**

High severity rankings can sometimes be reduced by making design revisions that compensate or reduce the resultant severity of failure. For example, "run flat tires" can reduce the severity of sudden tire blow-out, and "seat belts" can reduce the severity of a vehicle crash.

The different **divisions** such as Propel, Work Functions, **Controls**, and **Open Circuit** might have extra guidelines, which give a more specific explanation of the criteria of the rankings. Examples could be used as illustrations.

The guidelines cannot be **contradictory** to the table below.

Effect	Criteria: Severity of Effect	Ranking
Hazardous without warning	Very high severity ranking when a potential failure mode affects safe operation and/or involves non-compliance with government regulation without warning. Requires abnormal operator / user response. Requires emergency actions.	10
Hazardous with warning	Very high severity ranking when a potential failure mode affects safe operation and/or involves non-compliance with government regulation with warning. Such as audible or visual alarms.	9
Very High	Item inoperable, with loss of primary functions. Noticeable to all operators / users.	8
High	Item operable, but reduced level of performance. Customer dissatisfied.	7
Moderate	Item operable, but at reduced level of performance or life for a primary function or loss of a non-primary function. Noticeable by skilled operators / users. Normal responses required from operator. Customer experiences discomfort.	6
Low	Item operable, but works at reduced level of performance. Customer experiences some dissatisfaction.	5
Very Low	Product works at reduced level of performance for a non-primary function. Noticeable to a skilled operator / user. Defects noticed by most customers (> 75 %).	4
Minor	Fit & Finish items do not conform. Product works at reduced level of performance or life for a non-primary function. Defect noticeable by average customer. (50%).	3
Very Minor	Defect noticeable by discriminating customer. (<25%) No response required from operator / user.	2
None	No effect	1

You could also look at it this way:

If the effect of the failure mode generally will result in a complaint from the customer, your ranking should be in the area from 5 - 10.

If it won't result in a complaint, you are in the area 1 - 4.

Design FMEA

You may consider drawing lesser attention to severities from 1 - 2, meaning that when you have established this low ranking, you cancel further work in this line, at least for the time being.

If the effect of a failure mode is rated 9 or 10, special effort should be made to identify as many potential root causes as possible.

If we have a severity ranking of 8 - 10 and low rankings (1 - 2) for occurrence and detection, you still should consider whether the failure mode or the failure cause could appear during manufacturing, and if so pass it on to process FMEA by writing process FMEA in the recommended actions column.

A severity rating of 9 or 10 will normally call for a design change that makes the failure mode disappear. If a design change seems impossible (the failure mode is an integral part of the design), special initiatives must be taken.

According to GS-0004, a severity rating of 9 or 10 for a function and its corresponding failure mode requires that the contributing characteristic(s) be labeled as a 'safety characteristic(s)'.

**Special initiatives for the severity rating of 9 or 10:**

The preferred way to address a nine or ten-point severity rating is to change the design. If no immediate design changes are possible, the design FMEA team must ensure that these ratings are specially discussed and approved during the design review process.

One solution could be a total redesign of the product.

Another solution could be a remedial provision at the system level (e.g. redundancy or failsafe). This remedial measure must be strongly pointed out in the technical information papers accompanying the product, as a warning. Documentation e.g. in a Product Specification needs to ensure that Severity Rankings of 9 and 10 flow up into future S-FMEAs.

In some cases it might be necessary to put a warning label on the product or maybe on the equipment where the product is utilized.

Finally, if a rating of 9 or 10 in severity cannot be eliminated or reduced, it must be accompanied by relatively low rankings of Occurrence and Detection (described in later sections), resulting in an acceptable RPN (also described in a later section). These failure modes must also be noted and passed along to the process FMEA to ensure that the production process is sufficiently safeguarded.

D.H. Stamatis in his book "Failure Mode Effect Analysis" page 35, points to a set of rules:

Assessment rating			Failure situation	Action taken
S	O	D		
1	1	1	Ideal situation (goal)	No action (N/A)
1	1	10	Assured mastery	N/A
10	1	1	Failure does not reach user	N/A
10	1	10	Failure reaches user	Yes
1	10	1	Frequent fails, detectable, costly	Yes
1	10	10	Frequent fails, reaches the user	Yes
10	10	1	Frequent fails with major impact	Yes
10	10	10	Trouble!	Yes, Yes, Yes, Yes

Design FMEA

**14. Potential Causes/Mechanisms of Failure**

Potential cause of failure is defined as an indication of a design weakness, the consequence of which is the failure mode.

List, to the extent possible, every conceivable failure cause and/or failure mechanism for each failure mode. The cause/mechanism should be listed as concisely and completely as possible so that remedial efforts can be aimed at pertinent causes.

Typical failure causes may include, but are not limited to:

- Incorrect material specified
- Inadequate design life assumption
- Over-stressing
- Insufficient lubrication capability
- Inadequate maintenance instructions
- Improper maintenance instructions
- Poor environment protection
- Incorrect algorithm
- Improper tolerance specified
- Improper friction material specified
- Improper surface finish specification

Typical failure mechanisms may include, but are not limited to:

- |                      |                    |
|----------------------|--------------------|
| Yield                | Creep              |
| Fatigue              | Wear               |
| Material instability | Corrosion          |
| Electro migration    | Chemical oxidation |

**15. Occurrence (O)**

Occurrence is the likelihood that a specific cause/mechanism (listed in the previous column) will occur during the design life.

Preventing or controlling one or more of the causes/mechanisms of the failure mode through a design change or design process change is the only way a reduction in the occurrence ranking can be effected. Design process change could be through Design Review, Design Guide or Design Checklist. Controlling could be through extended calculations and tests, **or special work to improve the Engineering organisation's fundamental knowledge of the cause of failure.**

Estimate the likelihood of occurrence of potential failure cause/ mechanism on a "1" to "10" scale. In determining this estimate questions such as the following should be considered:

- What is the service history/field experience with similar components or subsystems?
- Is component carryover or similar to a previous level component or subsystem?
- How significant are changes from a previous level component or subsystem?
- Is component radically different from a previous level component or subsystem?
- Is the component completely new?
- Has the component application changed?
- What are the environmental changes?
- Has an engineering analysis been used to estimate the expected comparable occurrence rate for the application?
- Have preventive controls been put in place?

A consistent occurrence ranking system, as seen in the table next page, should be used to ensure continuity.

Design FMEA

**Occurrence (O) Suggested Evaluation Criteria**

The column “Possible failure rates” fits for a process FMEA, but is difficult to use in the context of engineering causes of failure modes.

Instead use the area of “Occurrence likelihood” and among the four columns find the one that best fits with the appropriate situation.

Hereafter you have maximum three figures to choose from, which you must do to the best of your ability.

Probability of Failure	Possible Failure Rates	Rating	Criteria: Occurrence Likelihood			
			Calculation and Analysis	Design Margin Design Experience	Lab and Field Test Results	Deviation
Very High, Failure is almost inevitable	≥1 in 2	10	Not possible	Unknown	Similar designs in similar applications frequently show problems	Typically not approved
	1 in 3	9				
High, Repeated failures	1 in 8	8	Possible, with low correlation to test results	Small, not well established or understood	Similar designs in similar applications sometimes have problems	
	1 in 20	7				
Moderate, Occasional failures	1 in 80	6	Possible, with generally acceptable correlation to test results	Small, somewhat established and understood	Some problems detected in first round of testing, but easy to overcome with help of analysis	Typically approved for small differences, <33% of tolerance range
	1 in 400	5				
	1 in 2000	4				
Low, Relatively few failures	1 in 15000	3	Possible, with high level of correlation to test results	Large, somewhat established and understood	Proven design which typically passes first round of testing, similar designs in similar applications do not have problems	Typically approved for larger differences, up to 100% of tolerance range
	1 in 150.000	2				
Remote	1 in 1.500.000	1	Common, with high level of correlation to test results	Large, well established and understood		

**Design Margin** could also be interpreted as **Design Experience** which makes it clear that the experience of the design team is the main influence for the occurrence.

The column **Lab and Field Test Results** means, that whatever testing we have done at the time we do the DFMEA, they will add to our knowledge and therefore influence the risk that we design a failure mode into the product.

In such cases we may give the same ranking to Occurrence and Detection.

**16. Severity Occurrence Number (SON)**

The severity rating can be multiplied with the occurrence rating to form the SON rating. SON can be useful in the early design phases, where detection is not yet specified.

**In this way** the SON value is **an early indicator of the relative levels of risk in a design.**

If a function and its corresponding failure mode obtains **a severity value of 5 or greater and an occurrence value of 4 or greater, GS-0004 requires that that the characteristic(s) affecting that function be labeled as a 'key characteristic(s)'**. This should **then** be stated on the drawing or on similar relevant documents **through the designation of a pentagon with a 'K' inside it. It is possible to reduce the amount of "K" through further analysis utilizing the "loss function" as described in GS-0004.**

A function and its failure mode can, however, be formed of several connected dimensions on a drawing or drawings. In such cases it must be very carefully considered which of the dimensions shall have the symbol K.

**17. Classification**

This column can be used to the choice of the team. It may be used to classify any special product characteristics (e.g., key **or safety**) for components, subsystems, or systems that may require additional process controls. The classification can originate from customer demands or from the S and O values as described in GS-0004.

Any item deemed to require special process controls should be identified on the Design FMEA form with the appropriate character or symbol in the Classification column and should be addressed in the recommended actions column.

Each item identified as above in the Design FMEA should have the special process controls identified in the Process FMEA.

It might also be used as an explanation of a high score for a failure mode that will never reach a customer and thus should have a low score. But being a failure mode that is discovered late in the production process and therefore is expensive to correct means it is given a high score. That could be marked with an E for economy in the classification column.

**18. Current Design Verification**

List the prevention, detection, design validation/verification (DV), or other activities that have been completed and that will assure the design adequacy for the failure mode and/or cause/mechanism under consideration.

Current verifications (e.g. road testing, design reviews, fail-safe (pressure relief valve), mathematical studies, rig or lab testing, feasibility reviews, prototype test, field testing) are those that have been or are being used with the same or similar designs.

The team should always be focused on improving design verifications; for example, creating new system tests in the lab, or creating new system modeling algorithms, etc.

There are three types of Design Verifications/Features to consider; those that:

- (1) prevent the cause/mechanism or failure mode/effect from occurring, or reduce their rate of occurrence,
- (2) detect the cause/mechanism and lead to corrective actions,
- (3) detect the failure mode.

The preferred approach is to first use type (1) verifications if possible; second, use the type (2) verifications; and third, use the type (3) verifications.

Design FMEA

The initial occurrence rankings will be affected by the type (1) verifications provided they are integrated as part of the design intent.

The initial detection rankings will be based upon the type (2) or type (3) current verifications, provided the prototypes and models used are representative of design intent.

You can distinguish between preventive and detective controls by using either the prevention or detection part of the design verification column.

Once the design verifications have been identified and ranked, review all verifications to determine if any of the preceding occurrence ratings need to be revised.

**19. Detection (D)**

Detection is an assessment of the ability of the proposed type (2) current design verifications, listed in column 18, to detect a potential cause/mechanism (design weakness), or ability of the proposed type (3) current design controls to detect the subsequent failure mode, before the component, subsystem, or system is released for production. In order to achieve a lower ranking, generally the planned design verifications (e.g., preventative, validation, and/or verification activities) have to be improved.

In the early stage of a project the detection discussion will result in parts of the Analysis Plan (=Prevention) and the Test Plan (=Detection) per PDL.P.

**Detection, Suggested Evaluation Criteria:**

Detection	Likelihood of Detection by Design Verification	Ranking
Absolute uncertainty	Design Verification will not and/or cannot detect a potential cause/mechanism and subsequent failure mode; or there is no Design verification.	10
Very remote	Very remote chance the Design Verification will detect a potential cause/mechanism and subsequent failure mode.	9
Remote	Remote chance the Design verification will detect a potential cause/mechanism and subsequent failure mode.	8
Very Low	Very low chance the Design verification will detect a potential cause/mechanism and subsequent failure mode.	7
Low	Low chance the Design verification will detect a potential cause/mechanism and subsequent failure mode.	6
Moderate	Moderate chance the Design verification will detect a potential cause/mechanism and subsequent failure mode.	5
Moderately high	Moderately high chance the Design verification will detect a potential cause/mechanism and subsequent failure mode.	4
High	High chance the Design verification will detect a potential cause/mechanism and subsequent failure mode.	3
Very high	Very high chance the Design verification will detect a potential cause/mechanism and subsequent failure mode.	2
Almost certain	Design verification will almost certainly detect a potential cause/mechanism and subsequent failure mode.	1

Remember - the Detection ranking can also influence the Occurrence rating. See section 21 for explanation.

Design FMEA

**20. Risk Priority Number (RPN)**

The Risk Priority Number is the multiplication of the Severity (S), Occurrence (O), and Detection (D) ranking

$$RPN = (S) \times (O) \times (D)$$

The Risk Priority Number is a measure of design risk. This value **may** be used to **roughly** rank order the concerns in the design (e.g., in Pareto fashion). The RPN will be between “1” and “1000”. **In employing the DFMEA as a continuous improvement tool, for higher RPNs, the team **should** undertake efforts to reduce this calculated risk through corrective action(s). In general practice, regardless of the result of the RPN, special attention should be given when Severity is high - meaning 9 or 10.**

**21. Recommended Action(s)**

When failure modes have been rank ordered by RPN, corrective action should be first directed at the highest ranked concerns and critical items. This means ranking

- A: Severity 9 or 10
- B: High Severity **and** Occurrence rating (“K”, see GS-0004)
- C: RPN above 100

The intent of any recommended action is to reduce any one or all of the occurrence, severity, and /or detection rankings. **In general practice when the severity is a 9 or 10, special attention must be given to ensure that the risk is addressed through existing design controls for preventive / corrective action(s) regardless of the RPN. In all cases where the effect of an identified potential failure mode could be a hazard to the end user, preventive corrective actions should be considered to avoid the failure mode by eliminating, mitigating, or controlling the cause(s). In a situation where the team has been unable to reduce an RPN below 100 on a severity 9 or 10 failure mode, approval must be specifically granted in the design review process.**

An increase in design validation/verification actions will result in a reduction in the detection ranking. A reduction in the occurrence ranking can be effected only by removing or controlling one or more of the causes/mechanisms of the failure mode through a design revision **or improved fundamental knowledge.**

In some cases a reduction in the Detection rating can also improve the Occurrence rating as new knowledge from calculations or testing can give the designer a more firm ground for his / her considerations.

Only a design revision can bring about a reduction in the severity ranking. Actions such as the following should be considered, but are not limited to:

- Design of experiments (particularly when multiple or interactive causes are present).
- Revised Test Plan.
- Revised Design, geometry and/or tolerances.
- Revised Material Specification.

The primary objective of recommended actions is to reduce risks and increase customer satisfaction by improving the design.

If no actions are recommended for a specific cause, this could be indicated by entering a “NONE” in the column.

On page 35 in his book, Stamatis points at a number of corrective actions and their influence on S, O and D.

Design FMEA

Corrective actions	S	O	D
Redesign the product	Y	Y	Y
Improve current control	N	N	Y
Change material parts	Y	N	Y
Change the application	Y	Y	Y
Change the field environment	Y	Y	Y
Improve reliability program	Y	N	Y
Improve employee training	N	N	Y
Implement FMEA program	Y	Y	Y
Implement SPC program	N	N	N
Improve quality plan	N	N	N

(Y= Yes, N= No)

This column could also be used for the remark "Process FMEA" which means that a Failure Mode has been identified which originates from the product design but which can also appear in the production process.

**22. Responsibility (for the recommended action)**

Enter the organization and individual responsible for recommended action and the target completion date.

**23. Actions Taken**

After an action has been implemented, enter a brief description of the actual action and effective date.

**24. Resulting RPN**

After the corrective action has been identified, estimate and record the resulting Severity, Occurrence, and Detection rankings. Calculate and record the resulting RPN. If no actions are taken, leave the "Resulting RPN" and related ranking columns blank.

All resulting RPN(s) should be reviewed and if further action is considered necessary, repeat steps 20 through 23.

If it is considered appropriate, the rankings can be estimated before the corrective action has been implemented and the resulting RPN calculated.

The purpose is to estimate if the recommended action will give a satisfactory low score.

**Follow-Up**

The design responsible engineer is responsible for assuring that all actions recommended have been implemented or adequately addressed.

The FMEA is a living document and should always reflect the latest design level, as well as the latest relevant actions, including those occurring after start of production.

The design responsible engineer has several means of assuring that concerns are identified and recommended actions are implemented. They include, but are not limited to:

- Assuring design requirements are achieved.
- Review of engineering drawings and specifications.
- Confirmation of incorporation to assembly/manufacturing documentation.
- Review of Process FMEAs and Control Plans.

Design FMEA

**References:** Potential Failure mode and Effects Analysis (FMEA)  
 Reference manual, February 1995 by Chrysler, Ford and General Motors  
 Fourth edition of 2008. (Technical equivalent of SAE J 1739)

D.H. Stamatis "Failure Mode Effect Analysis" Second edition.  
 ASQ Quality Press.

**CHANGE HISTORY**

Date	Old/New Rev.	Description of Change
2004-08-18	A / B	GS-0003 integrated into GS-0002. Same severity ranking to be used in D-, S- and P-FMEA. Exploitation of facilitator expertise. Actions to be taken if severity rating = 9 or 10. Critical and key SON to be specified on drawings. Corrective actions recommended by D.H. Stamatis
2005-07-07	B / C	Severity ranking: Customer complaint added. "The team should agree ..." has been taken away as it can cause confusion (the same goes for Occurrence and Detection) Occurrence Criteria: Design margin/design experience and lab and field test results. Illustrations to Classification. Resulting RPN: Estimating corrective actions.
2009-08-10	C / D	Allows for designs with severity 10 failure modes as long as occurrence and detection are relatively low. Updated for changes to GS-0004 concerning Key and Safety characteristics and how they are determined. Softens the language of required actions when RPN > 100 in accordance with AIAG's 4 <sup>th</sup> Edition of FMEA standard.

## Appendix A

### FMEA Terms and Definitions

**Boundary Diagram** – A graphical representation of the system, product, sub-system, sub-assembly, or product that shows what is being analyzed (e.g. parts list and/or layout), what its interfaces are (e.g. other parts, sub-systems, products), and what its inputs and outputs are. See Appendix C for an example.

**Brainstorming** – A method of shared idea-generation or problem solving in which all team members spontaneously contribute ideas.

**Characteristic** – A measurable parameter or dimension of a product distinguished by its numerical value and measurable units.

**Customer** – Customers exist at all levels of the FMEA. The end user of a system is called the end customer.

**Design Intent** – What a given system, product, sub-assembly, sub-system, or part is expected to do or not to do.

**Design Margin** - The additional performance capability above the requirements to compensate for uncertainties.

**Detection** – A past-oriented design control strategy that attempts to identify unacceptable output or results after the system, product, sub-assembly, sub-system, or part is produced.

**Facilitator** – A person with no vested interest in the design being analyzed who is knowledgeable about the FMEA process and is able to guide the Core Team.

**Failure Mode** – The manner in which a system, product, sub-system, sub-assembly, or part could potentially fail to meet or deliver the intended function, including complete function failure, partial failure, intermittent failure, failure over time, or over-performance of a function. The failure mode may also be the cause of a potential failure mode in a higher FMEA level.

**Function** – What a system, product, sub-system, sub-assembly, or part is intended to do.

**Functional Block Diagram** – A graphical representation of the functional relationships within a system, product, sub-system, or sub-assembly. Each block represents one element, along with its inputs, outputs, and transfer function. See Appendix B for an example.

**Occurrence Ranking** – A numerical value corresponding to the likelihood of a design error.

**P-Diagram** – A diagram that shows the inputs, control factors, error states, ideal functions, and noise factors for a system, product, sub-assembly, or sub-system. Noise factors are categorized as: piece-to-piece variation; deterioration or degradation over time; other systems; customer usage or duty cycle; and the environment. See Appendix C for an Example.

**Part Level FMEA** – An FMEA that focuses on a sub-set of a product, sub-system, or sub-assembly that is comprised of a single piece of hardware or software. A level of detail where a design is considered not to be further subdivided into separate components. May also be referred to as a component level FMEA.

**Product Level FMEA** – An FMEA that focuses on the product, such as a pump, motor, or valve, that is sold by Sauer-Danfoss for use in a system.

**Recommended Action** – Any action intended to mitigate risk by reducing the severity, occurrence, detection, or all three ratings.

**Risk Priority Number (RPN)** – The multiplied product of the severity, occurrence, and detection ratings.

**Severity Occurrence Number (S.O.N.)** – A measure of design risk that is the multiplied product of the severity and occurrence rankings.

**Severity Ranking** – A numerical value corresponding to the seriousness of the effect of a potential failure mode on the upper levels of the FMEA.

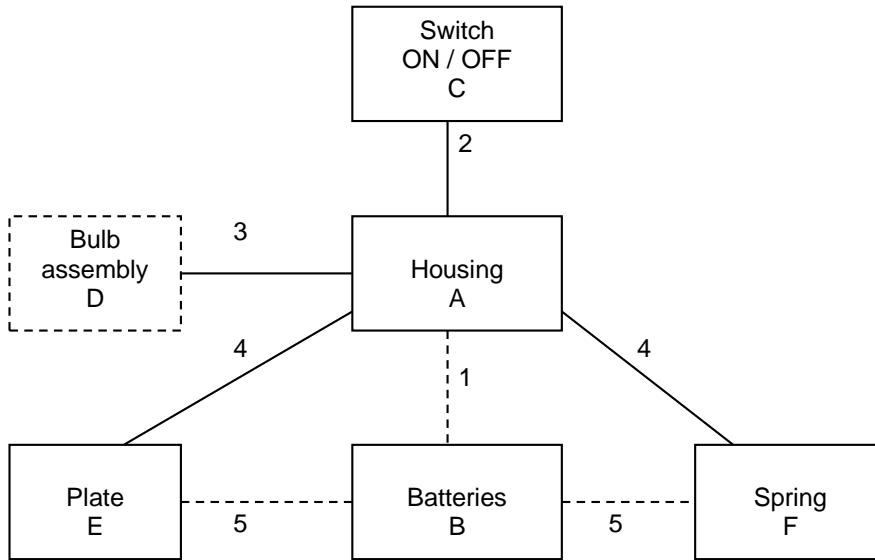
**Sub-Assembly Level FMEA** – An FMEA that focuses on a group of parts from a product that fulfills a specific sub-set of product functions.

**Sub-System Level FMEA** – See Sub-Assembly level FMEA.

**System Level FMEA** – An FMEA that focuses on a combination of connected elements that fulfills a specific set of functions, typically for a vehicle.

Appendix B

Example of a Block Diagram for a Flashlight.



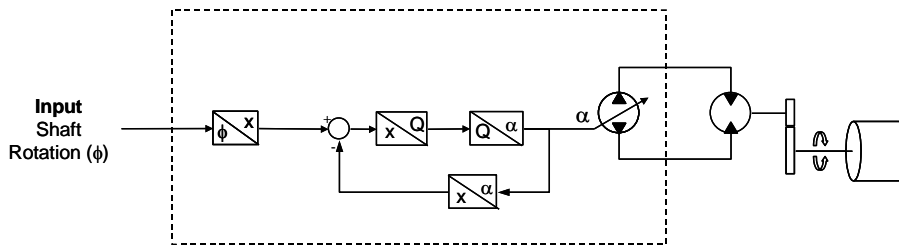
**Components**

- A. Housing
- B. Batteries (2C-cell)
- C. On/Off Switch
- D. Bulb Assembly
- E. Plate
- F. Spring

**Attaching method**

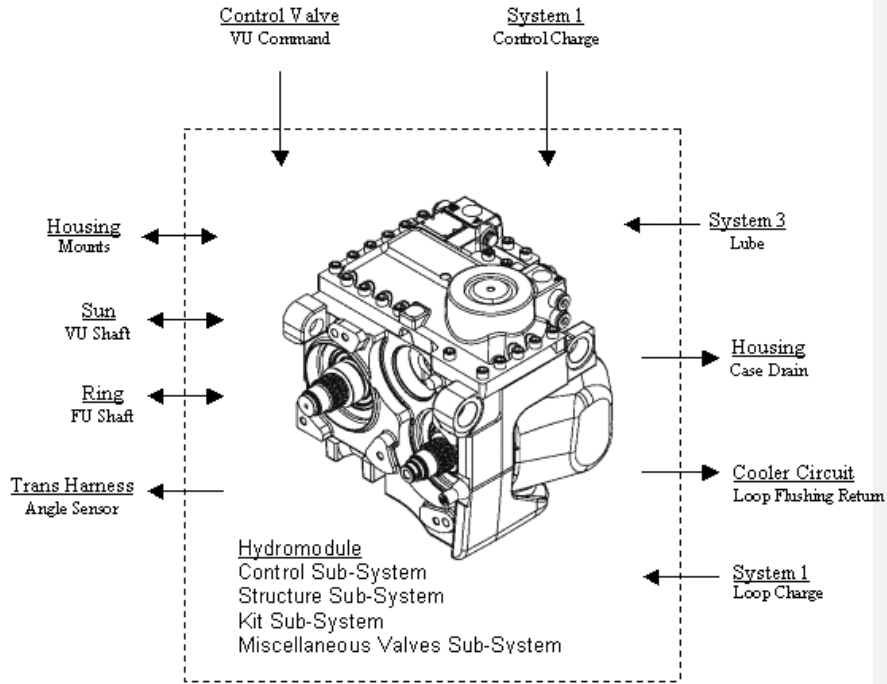
- 1. Slip fit
- 2. Rivets
- 3. Thread
- 4. Snap fit
- 5. Compressive fit

Functional Block Diagram Example – Mechanical Displacement Control



**Appendix C**

**Boundary Diagram Example - Hydromodule**



Appendix D

P-Diagram Example - Hydromodule

**Causes (Noise Factors)**

**1. Piece to Piece Variation**

- a. Kits
- b. Control
- c. Loop flushing
- d. Yoke seal
- e. Assembly process
- f. Torque on fasteners
- g. Sweetpoint location
- h. Yoke running face flatness
- i. Speed sensor

**2. Other Systems**

- a. Control Valve
- b. System 1
- c. System 3
- d. Housing
- e. Cooler Circuit
- f. Trans Harness
- g. Ring
- h. Sun
- i. Housing
- j. Engine

**3. Customer Usage/Duty Cycle**

- a. Overload
- b. Aftermarket changes
- c. Poor service practices
- d. Poor oil quality
- e. Infrequent oil changes
- f. Heavy sustained transport
- g. Extreme duty cycle in high heat
- h. Trash in/blocked oil cooler
- i. Heavy sustained tillage

**4. Deterioration/degradation over time**

- a. Self generated debris
- b. Bearing wear
- c. Yoke seal wear
- d. Cam follower wear
- e. Kit wear
- f. Synch joint wear

**5. Environment**

- a. Contamination
- b. Air
- c. High ambient temperatures
- d. High oil temperatures

**Inputs**

- a. Control charge pressure/flow
- b. Lube pressure/flow
- c. Loop charge pressure/flow
- d. FU shaft torque/speed
- e. Mount load/position
- f. VU control pressure/flow

**HYDROMODULE**

**Ideal Functions**

- a. Supply transmission torque/speed ratio independent of load and proportional to hydraulic signal pressure (transmit power)
- b. Meet noise requirements
- c. Meet efficiency requirements
- d. Provide hydraulic supply/return connections
- e. Support gears
- f. Provide iso mount connections
- g. Trap isolator/mount in event of isolator failure
- h. Route lube oil to gears and bearings
- i. Provide angle sensor interface

**Design Verification**

- a. Hydro Specification
- b. GPM program deliverables
- c. Part and Assy Drawings
- d. HPP-82, HPP-85, HPP-117, HPP-122, HPP-123, HPP-125, HPP-124, HPP-132, HPP-133, HPP-134, HPP-135, HPP-137

**Failure Modes**

- a. Does not Supply transmission torque/speed ratio independent of load and proportional to hydraulic signal pressure (transmit power)
- b. Fails noise requirements
- c. Fails efficiency requirements
- d. Does not provide hydraulic supply/return connections
- e. Does not support gears
- f. Does not provide iso mount connections
- g. Does not trap isolator/mount in event of isolator failure
- h. Does not route lube oil to gears and bearings
- i. Does not provide angle sensor interface

If you do not want to make the full P-diagram, at least list all functions for the product, the sub-assemblies, and for each part of the product.

For each function of the part, list all possible failure modes, bearing in mind the total amount of functions.

This is the least preparation you can do, and it is a **must**.

