
Safety and Reliability of Embedded Systems

(Sicherheit und Zuverlässigkeit eingebetteter Systeme)

Safety and Reliability Analysis Models: Overview

Content

- ☐ Classification
- ☐ Hazard and Operability Study (HAZOP)
- ☐ Preliminary Hazard Analysis (PHA)
- ☐ Event Tree Analysis
- ☐ Failure Modes Effects and Criticality Analysis (FMECA)
(DIN 25448, IEC 812)
- ☐ Reliability Block Diagrams (IEC 61078)
- ☐ Markov Analysis (IEC 61165)
- ☐ Fault Tree Analysis (DIN 25424, IEC 61025)

Classification of Safety / Reliability Analysis Techniques

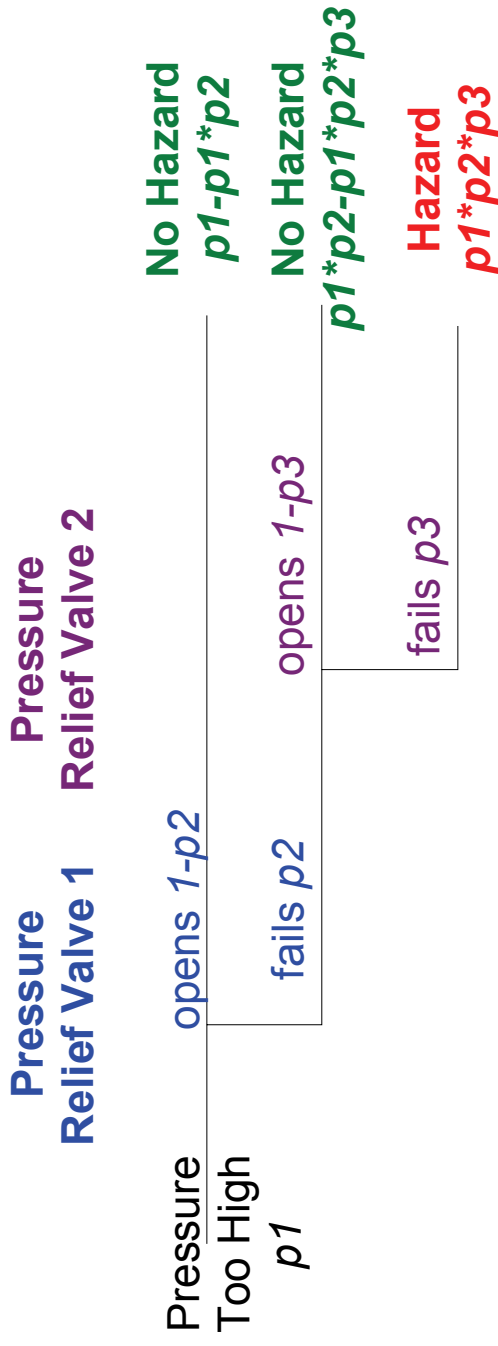
- ☐ Focused Property
 - Safety, Reliability, Availability...
- ☐ Application Area
- ☐ Scope
 - Product / Process, HW / SW, System / Component
- ☐ Process Phase
- ☐ Search Direction
 - Inductive / Deductive
- ☐ Degree of Formality
- ☐ Representation
 - Textual, Graphical, Tabular
- ☐ Model based: Combinatorial vs. State-Based

HAZOP / PHA

- Hazard and Operability Study (HAZOP)
 - From chemical industry
 - Find potential hazards at early process stage
 - Check every "flow" in preliminary design scheme for deviations
 - Manual search using guide-words (more, less, no, reverse...)
- Preliminary Hazard Analysis (PHA)
 - During requirements analysis or early design phase
 - Coarse identification, classification and counter-measures for potential hazards
 - Table representations

Event Tree Analysis

- ☐ Forward-searching technique with graphical representation
- ☐ Search consequences to given hazard, depending on conditions



FMECA

- The Failure Mode, Effects and Criticality Analysis (FMECA) is a preventive method for the identification of problems, their risks and effects
- FMECA has the following goals
 - Detection of hazards and problems
 - Identification of potential risk
 - Quantification of risks
 - Determination of corrective measures
- FMECA can be performed as **component FMECA** (e.g. for a subsystem), as **system FMECA** (a complete system) or as **process FMECA** (e.g. for a development process)

FMECA

- FMECA is done in the following steps
 - Fault analysis: Collection of possible faults including available information about the type, causes and consequences
 - Risk evaluation with the aid of the risk priority number

$RPZ = \text{occurrence probability} * \text{severity of consequences} * \text{probability of non-detection}$

- If for the three influencing factors a value between 1 and 10 is used (1= no risk, minor occurrence; 10 = high risk, high occurrence), the RPZ is a value between 1 and 1000
- The risk priority number generates a ranking for the causes of faults
- Causes of faults with a high risk priority number are to be handled with priority

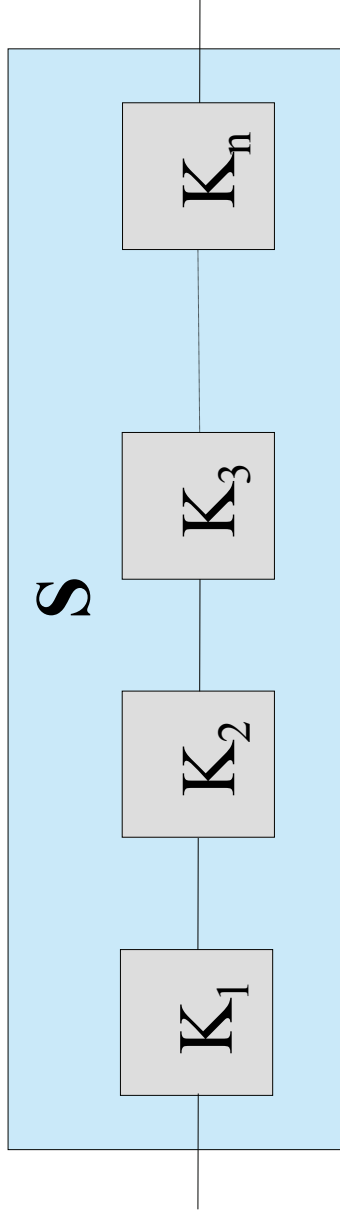
Reliability Block Diagrams

- ☐ Interconnection of all components of a system which are involved in performing the required function; represented as a flow chart
- ☐ RBDs distinguish only two states (intact/failed)
- ☐ Reliability function $R(t)$
 - $F(t)$ gives the probability that at time t at least one failure has occurred; thus $R(t) = 1 - F(t)$ is the probability that at time t no failure has occurred yet

Reliability Block Diagrams

Serial Connection

- n serial connected components K_i . The system S fails if one of the components fails



$$R_S(t) = R_{K_1}(t) R_{K_2}(t) R_{K_3}(t) \dots R_{K_n}(t) = \prod_{i=1}^n R_{K_i}(t)$$

- Example:

Two components with $R_1 = R_2 = 0,8$: $R_S = 0,64$

Reliability Block Diagrams

Parallel Connection

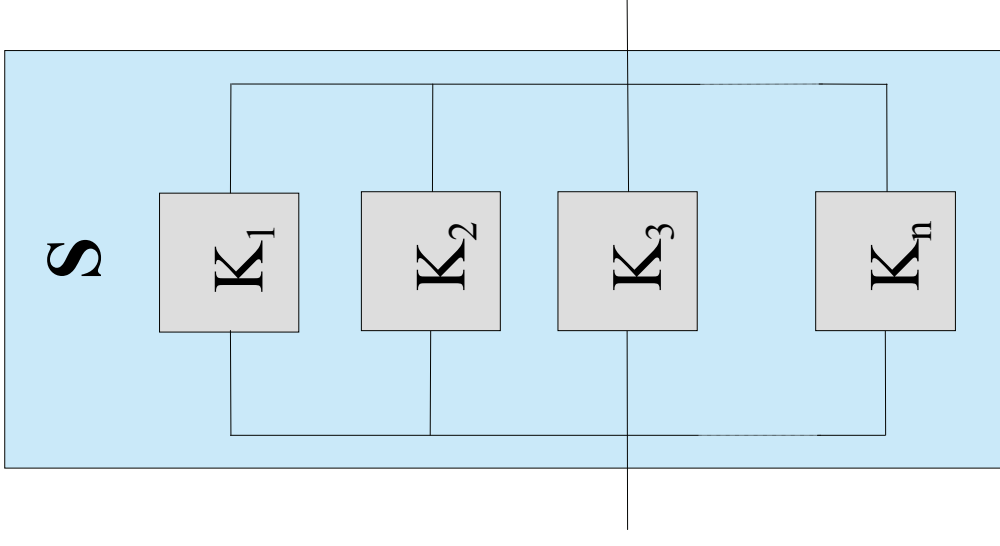
- n parallel connected components K_i . The system S fails if all components fail

$$F_S(t) = F_{K_1}(t) F_{K_2}(t) F_{K_3}(t) \dots F_{K_n}(t) = \prod_{i=1}^n F_{K_i}(t)$$

$$R_S(t) = 1 - F_S(t) = 1 - \prod_{i=1}^n F_{K_i}(t) = 1 - \prod_{i=1}^n (1 - R_{K_i}(t))$$

- Example:

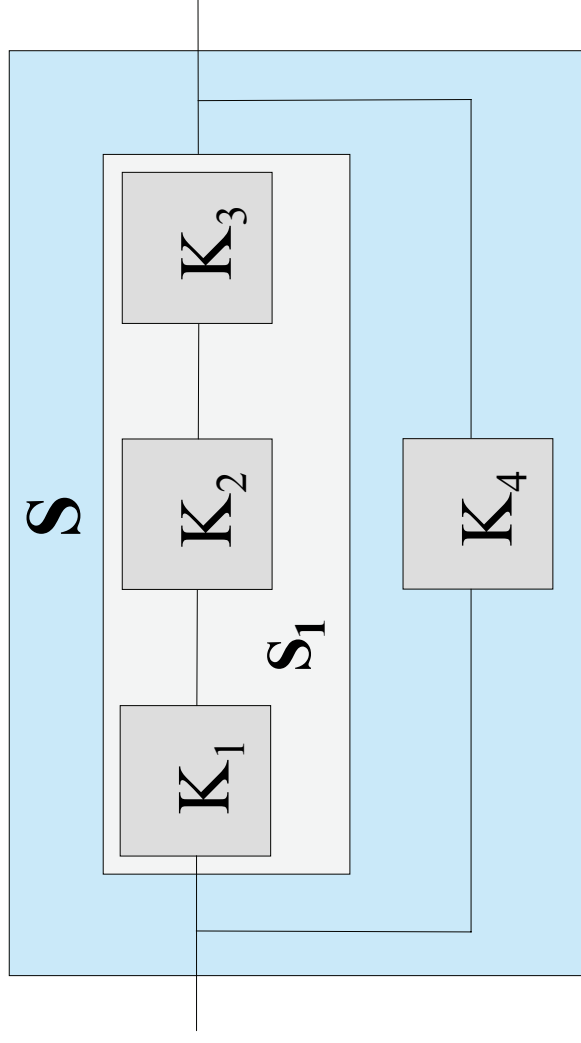
Two components with $R_1 = R_2 = 0,8$: $R_S = 0,96$



Reliability Block Diagrams

Combined Serial/Parallel Connection

- Combinations of serial and parallel connections can be solved hierarchically



Reliability Block Diagrams

□ Example:

System S is a parallel connection of the subsystem S_1 with component K_4

The reliability of the subsystem S_1 is:

$$R_{S_1}(t) = R_{K_1}(t) R_{K_2}(t) R_{K_3}(t)$$

The reliability of the system S is:

$$\begin{aligned} R_S(t) &= 1 - [(1 - R_{K_4}(t)) (1 - R_{S_1}(t))] \\ &= 1 - [(1 - R_{K_4}(t)) (1 - R_{K_1}(t) R_{K_2}(t) R_{K_3}(t))] \end{aligned}$$

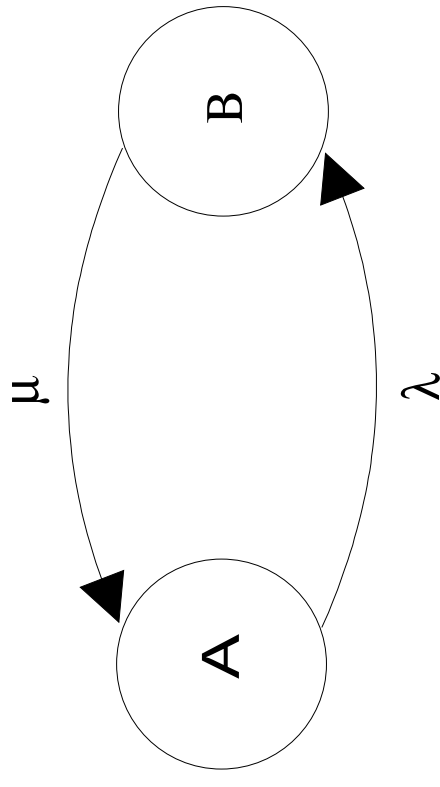
All components have the reliability $R = 0,8$: $R_S = 0,9024$

Markov Modeling

□ Markov models are based on a description of the system behavior with state machines

□ Example

- A system with failure rate λ and repair rate μ is to be analyzed with the aid of a Markov model. The Markov model has the states A and B
- A is the state where the system is intact. B is the state where the system failed
- The system changes with the failure rate λ from the intact state into the failed state. With the repair rate μ it changes from the failed state into the intact operation



Markov Modeling

$$\frac{dP_A(t)}{dt} = -\lambda P_A(t) + \mu P_B(t)$$

$$\frac{dP_B(t)}{dt} = \lambda P_A(t) - \mu P_B(t) = -\frac{dP_A(t)}{dt}$$

$$P_A(t) + P_B(t) = 1$$

$$P_A(t) = \frac{\mu}{\mu + \lambda} + \left(c - \frac{\mu}{\mu + \lambda}\right) e^{-(\mu + \lambda)t}$$

$$P_B(t) = 1 - P_A(t) = 1 - \left[\frac{\mu}{\mu + \lambda} + \left(c - \frac{\mu}{\mu + \lambda}\right) e^{-(\mu + \lambda)t}\right]$$

Markov Modeling

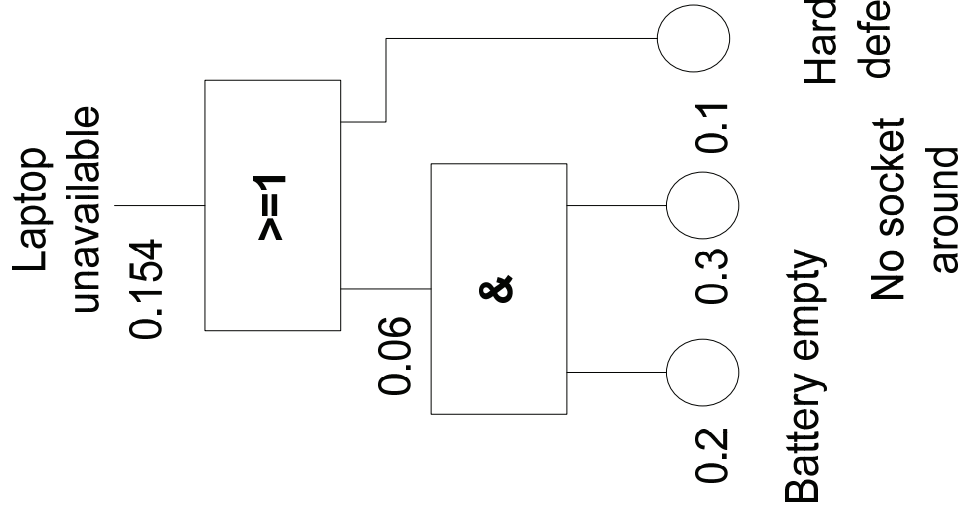
- For t towards infinite one gets the steady state of the system

$$\lim_{t \rightarrow \infty} P_A(t) = \frac{\mu}{\mu + \lambda}$$

$$\lim_{t \rightarrow \infty} P_B(t) = 1 - \frac{\mu}{\mu + \lambda}$$

- If the repair rate is high compared to the failure rate the probability that the system is intact approaches 1
- If the repair rate is low compared to the failure rate the probability that the system is intact approaches zero
- These layover probabilities are independent of the initial layover probabilities

Fault Tree Analysis



- ☐ Analysis method for the qualitative and quantitative evaluation of a *specific* failure of a system
- ☐ Deductive (backward searching)
- ☐ Graphical and intuitive technique
- ☐ Based on Boolean logic and combinatorics
- ☐ Widely accepted, captured in standards / handbooks
- ☐ Has been used and extended since 1961

Model-Based Safety and Reliability Analysis Methods

Literature

- Liggesmeyer 2000, Qualitätssicherung softwareintensiver technischer Systeme, Heidelberg: Spektrum-Verlag 2000
- DIN 25424; DIN 25424-1, Fehlerbaumanalyse Methoden und Bildzeichen, September 1981; DIN 25424-2: Fehlerbaumanalyse Handrechenverfahren zur Auswertung eines Fehlerbaumes, April 1990; Berlin: Beuth Verlag
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- IEC 812, Analysis Techniques for System Reliability - Procedure for Failure Mode and Effect Analysis (FMEA), International Electrotechnical Commission 1985
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- IEC 61078, Analysis techniques for dependability - Reliability block diagram method, International Electrotechnical Commission 1991
- IEC 61165, Application of Markov techniques, International Electrotechnical Commission 1995