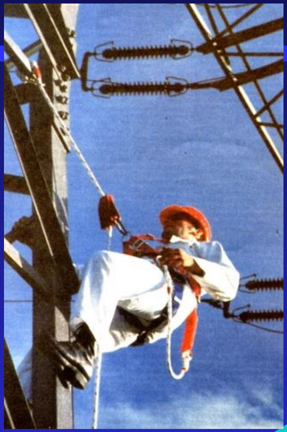
# Human Reliability

*Marek Matyjewski*

# Risk in the M-T-E system



Man

Technology ⟷ Environment


$$\begin{pmatrix} \textit{risk} \\ \textit{measure} \end{pmatrix} = \begin{pmatrix} \textit{unreliability} \\ \textit{measure} \end{pmatrix} \cdot \begin{pmatrix} \textit{hazard} \\ \textit{measure} \end{pmatrix}$$

# Human nature

**It is in the nature of man to err - Cicero**

**Human error is here to stay**

# Human errors

Three out of four aircraft accidents result from inadequate performance of the human component in the aircraft man-machine system.

**F. Hawkins – Human Factors in flight, 1993**

60%÷90% of accidents are the result of human error

# Catastrophes

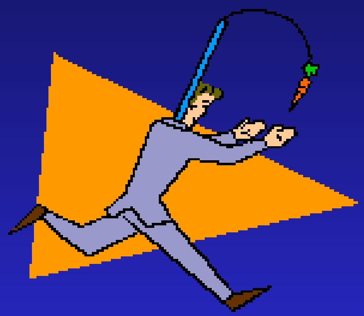
- **Bhopal** (1984, over 2500 fatalities)
- **Chernobyl** (1986)
- North Sea offshore platform **Piper Alpha** destroyed in a fire (1988, 167 fatalities)
- Ferry capsized after leaving the **Zeebrugge** port (1987, 193 fatalities)
- Collision of two aircrafts at **Tenerife** (1977, 583 fatalities)

. . . . . . . . . . . . . . .

**Three-Mile Island** nuclear power plant incident (1979)

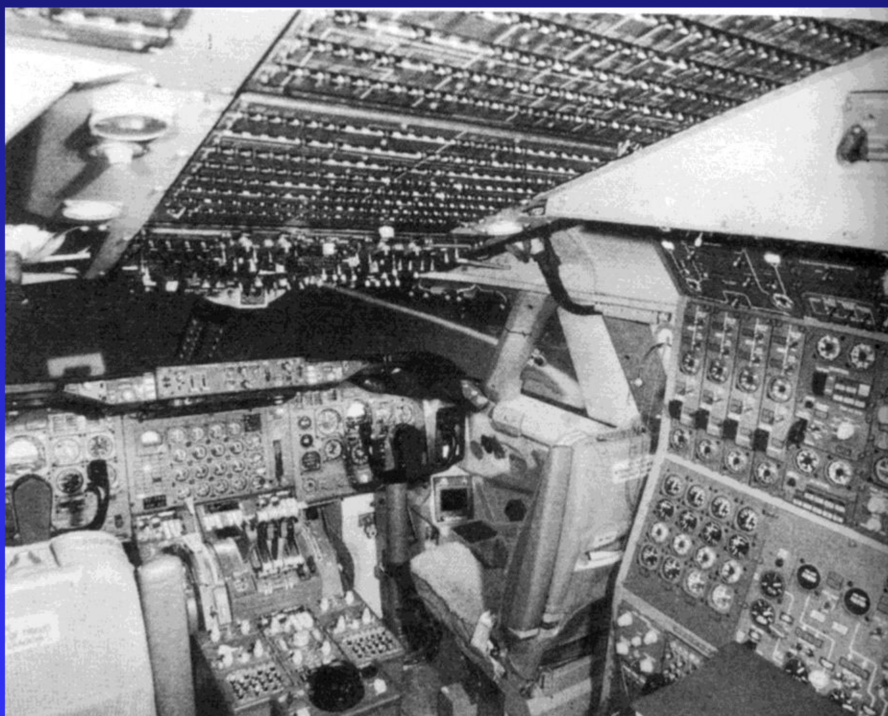
# Bhopal

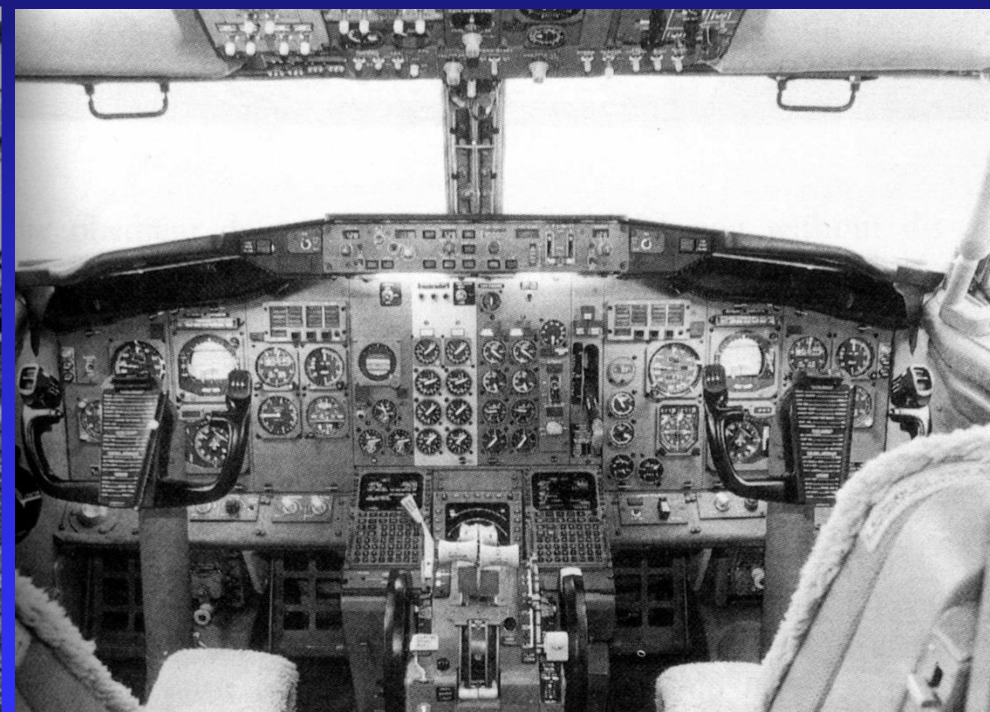
# Factors facilitating occurrence of errors:



- economical
- sociological
- psychological, emotional
- physiological

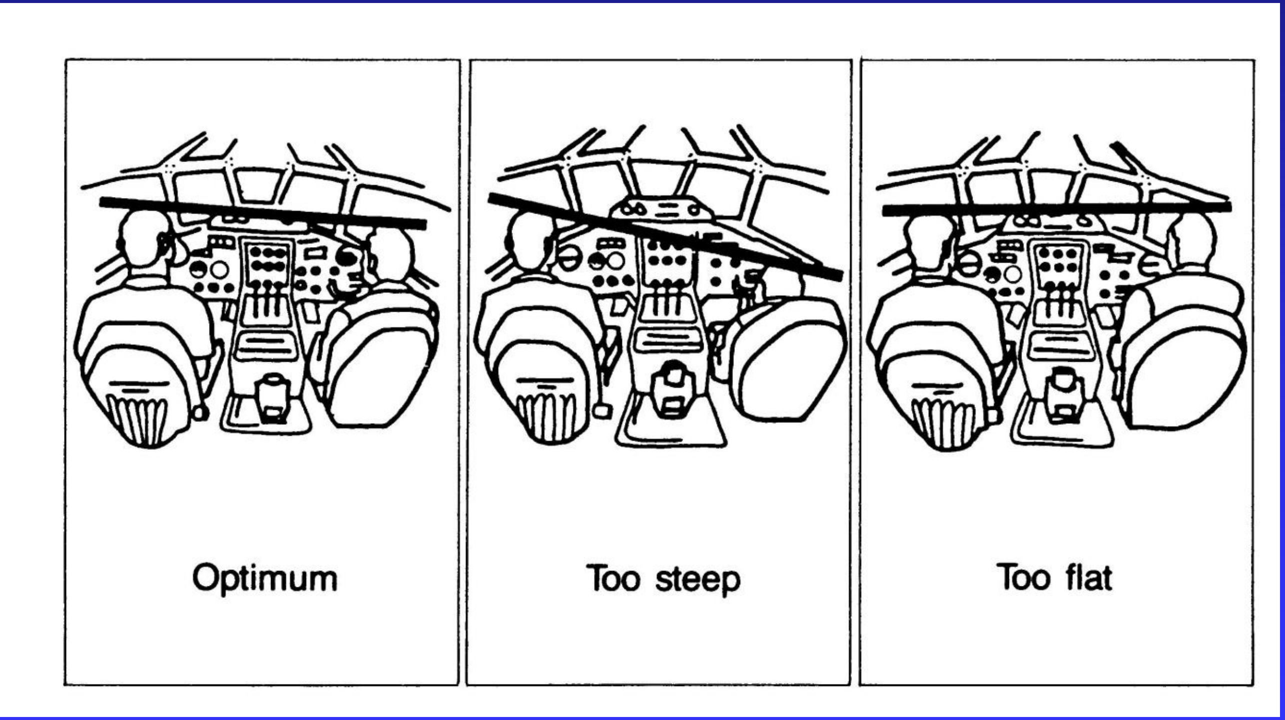
# Boeing 747





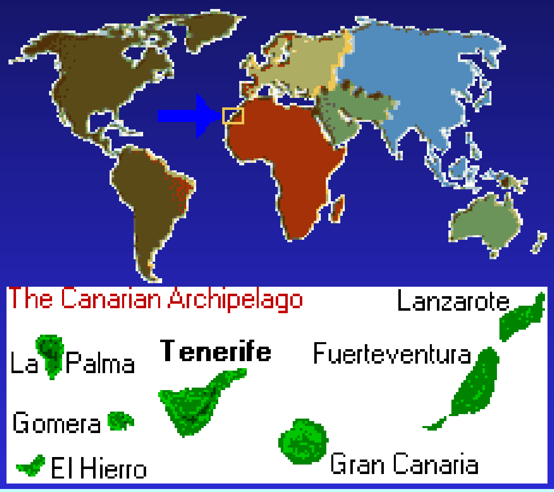
In the 1970s

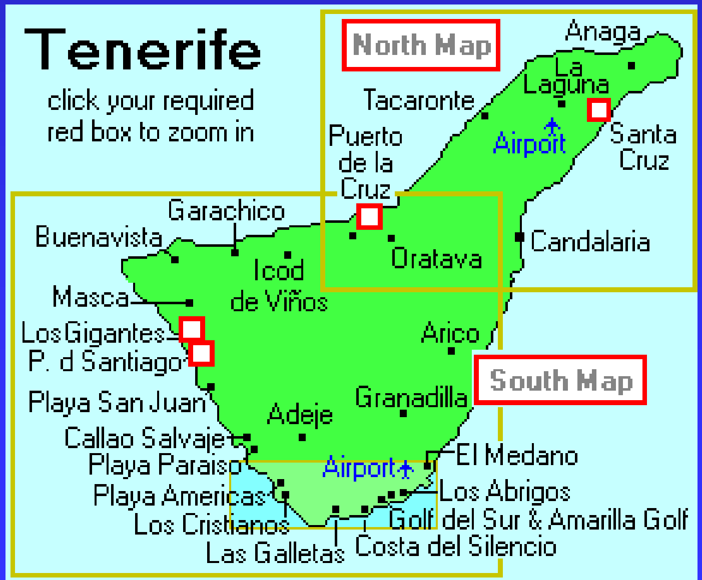
# The trans-cockpit authority gradient

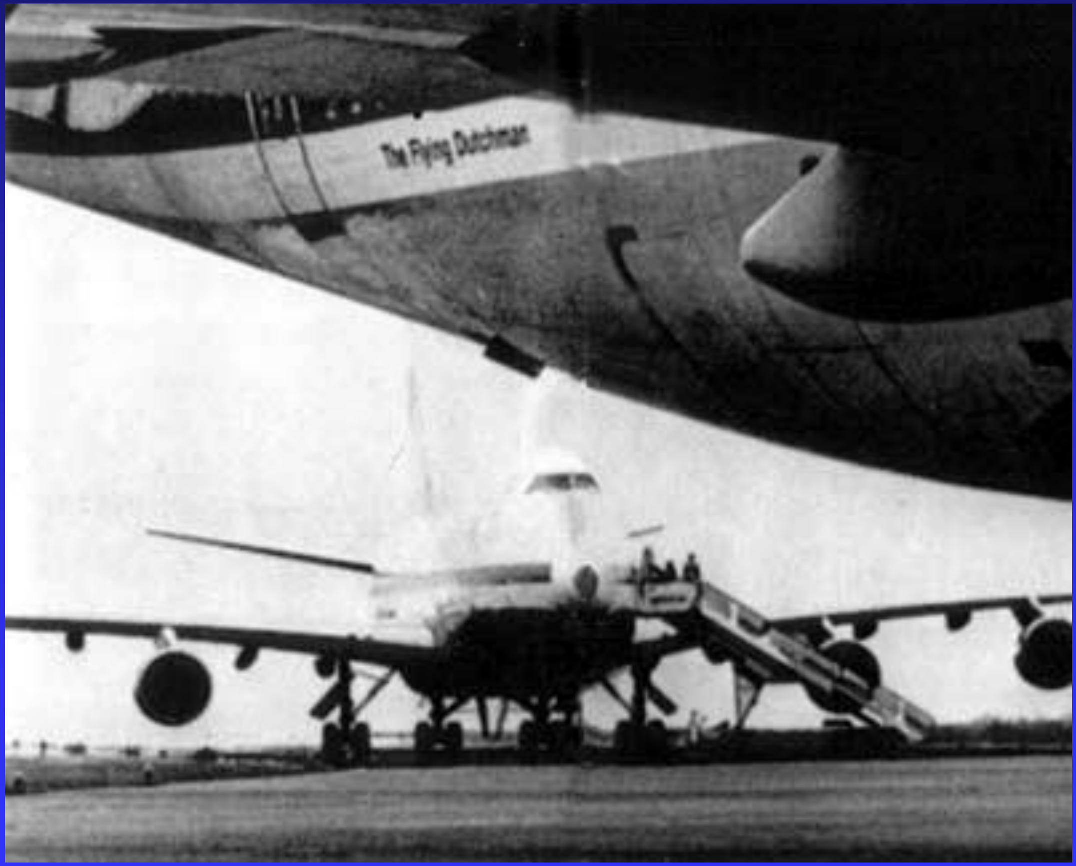


# Tenerife disaster – 1977

Canary Islands

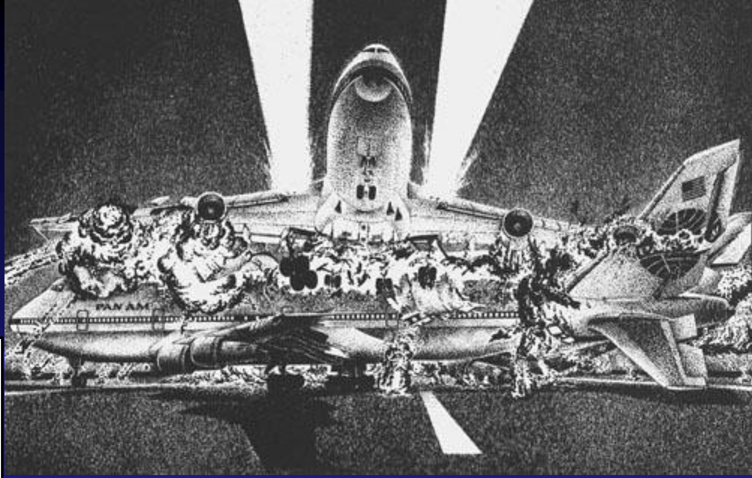


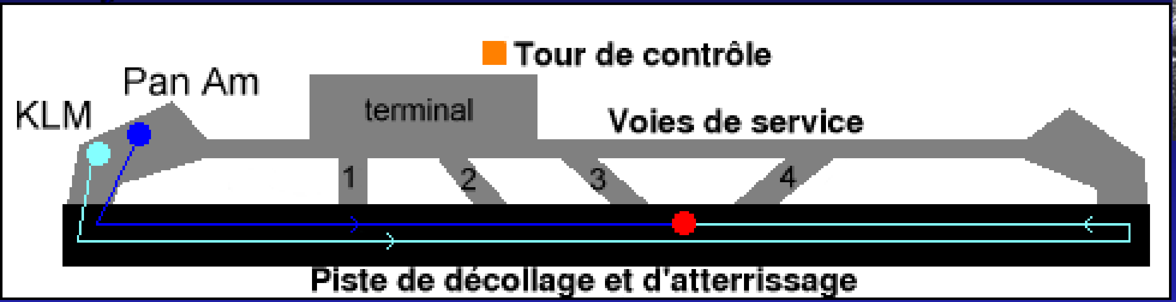



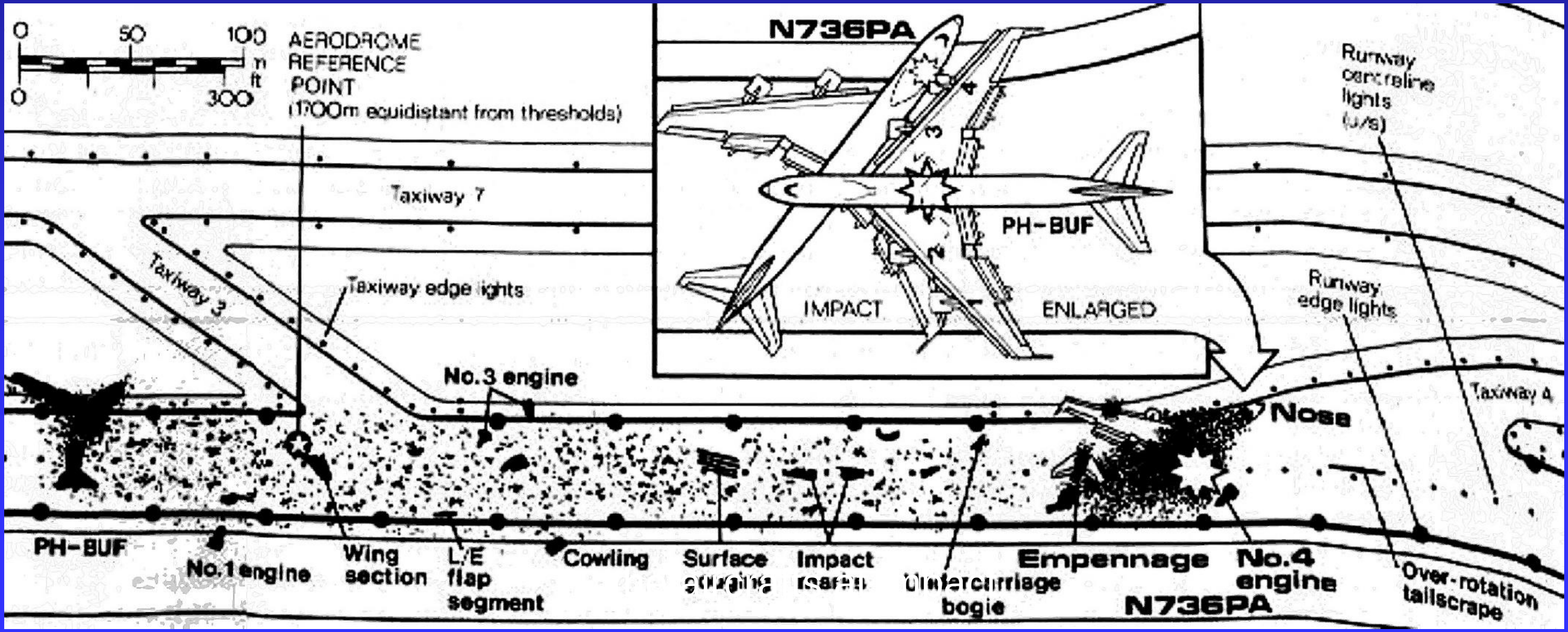




the Boeings 747

# Tenerife disaster





# Victims:

| | |
|---|---|
| **KLM4805:** | **234** passengers and **14** crew members killed<br>Aircraft completely destroyed by fire |
| **PA1736:** | **326** passengers and **9** crew members killed,<br>61 persons were rescued, 9 out of them died in hospital |

# The accident investigation

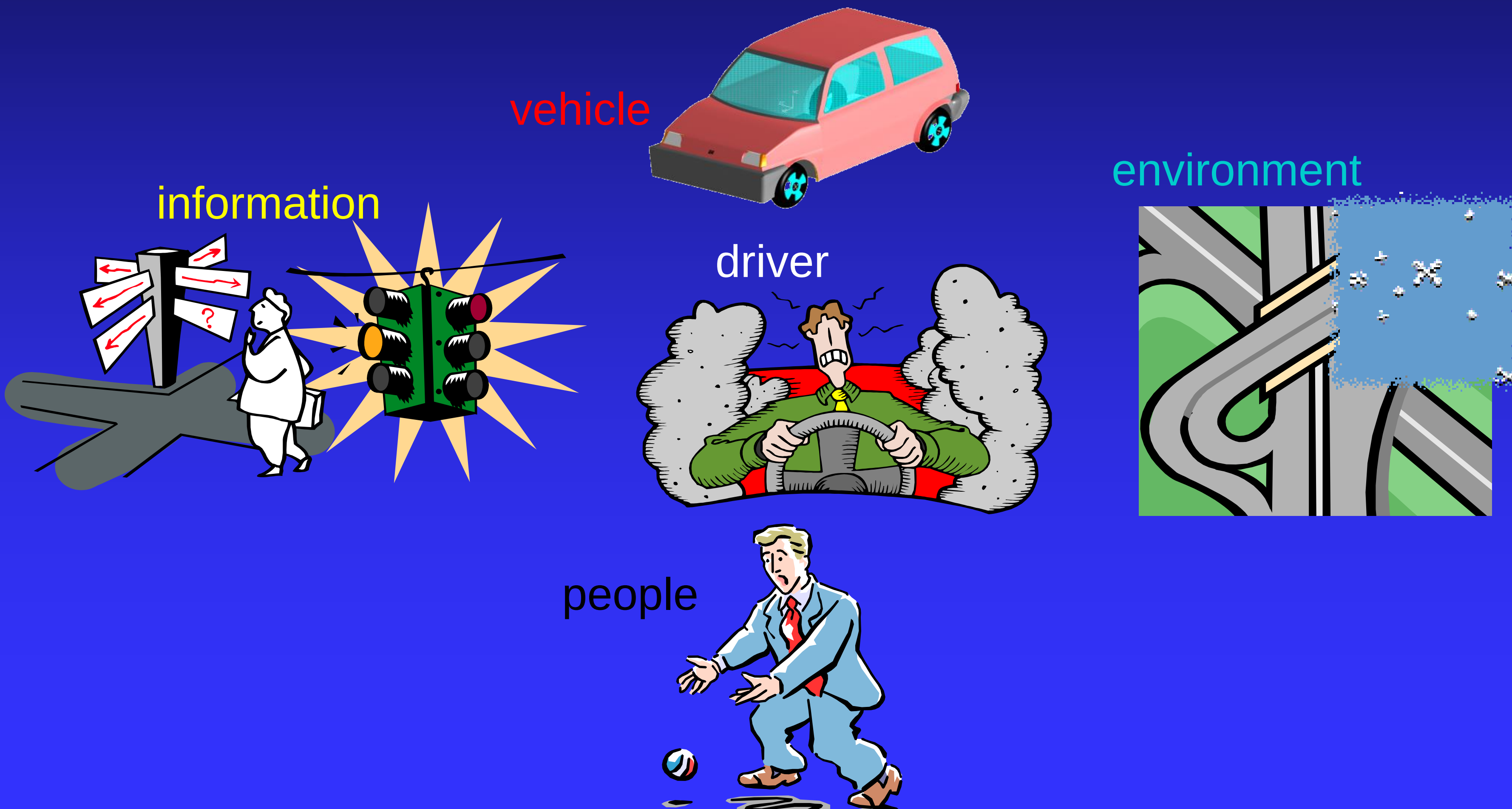
## The investigators questions:

- Why had KLM Captain commenced takeoff without the control tower's clearance to do so?
- Why had PanAm Captain been instructed to vacate the runway at Taxiway 3, one that led back towards the main apron at an angle of 135 degrees from the runway, rather than the far more conveniently placed 45 degree angled Taxiway 4? And unexpected as this instruction was, why had Captain Grubbs disregarded it?
- Why did the KLM crew not grasp the significance of the PanAm aircraft's report that it had not yet cleared the runway, and would report again to the Tower when it did?

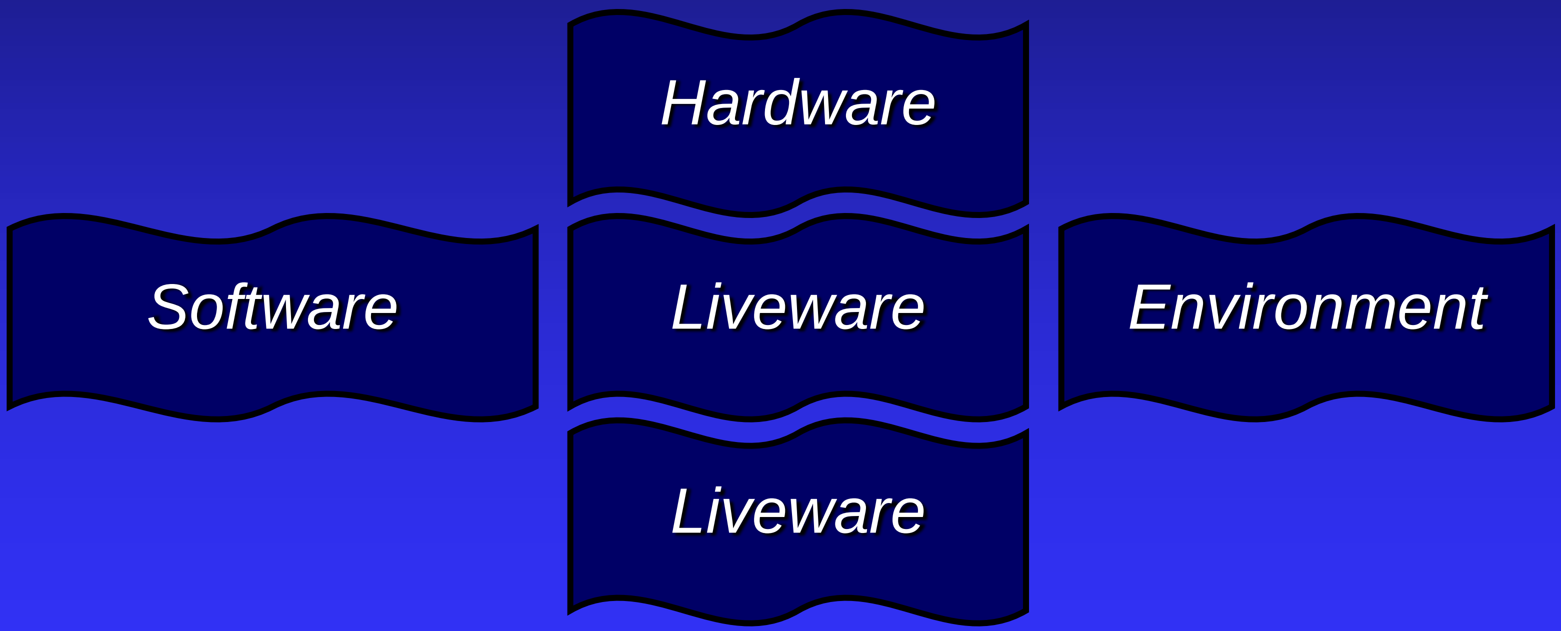
# Human Factors

- Fatigue, stress
- Overload
- Mind set
- Frustration
- Time pressure
- Authority in cockpit
- Passenger satisfaction

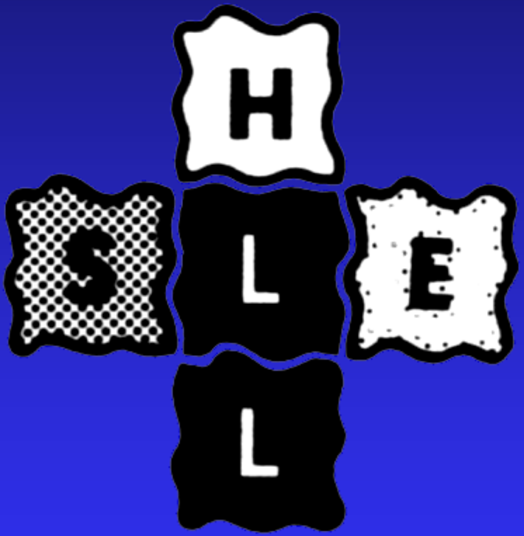
# An example of M-T-E system



# A conceptual model of Human Factors



# The SHEL model




**Human Factors is concerned with the interfaces shown in the model**

# *Liveware* in engineering terms

**Physical size and shape**

In the design of any workplace and most equipment, body measurements and movement play a vital role. These will vary not only between ethnic, age and sex groups, but extensive differences can be expected to occur within any particular group. Fundamental decisions must be taken at an early stage in the design process as to the human dimensions, and consequently the population percentage, which the design is going to satisfy. Data to make such decisions are available from anthropometry and biomechanics.

**Fuel requirements**

In order to function properly, man needs fuelling with food, water and oxygen. Deficiencies in this fuel supply can affect his performance and well-being. This type of information is available from physiology and biology.

# *Liveware* in engineering terms

Man has been provided with a vast system for collecting information from the world about him. He has means for sensing light, sound, smell, taste, movement, touch, heat and cold. Some senses involve more directional information; some are more sensitive than others. And all are subject to degradation. Physiology and biology are the main sources of knowledge here.

Once information is sensed and processed, messages are sent to the muscles and a feedback system helps to control their actions. We need to know the kind of forces which can be applied and the acceptable direction of movement of controls. Speech characteristics are vital components in the design of efficient voice communication procedures. Here we look to biomechanics and physiology for support.

**Input signals** → **Information processing** → **Output signals**

While the sensing apparatus is vast, the information processing capabilities of man have severe limitations. Poor instrument and warning system design has frequently resulted from a failure properly to take into account the capabilities and limitations of the human information processing system. Many human errors find their origin in this area of information processing. The source of background knowledge here is the discipline of psychology.

# *Liveware* in engineering terms

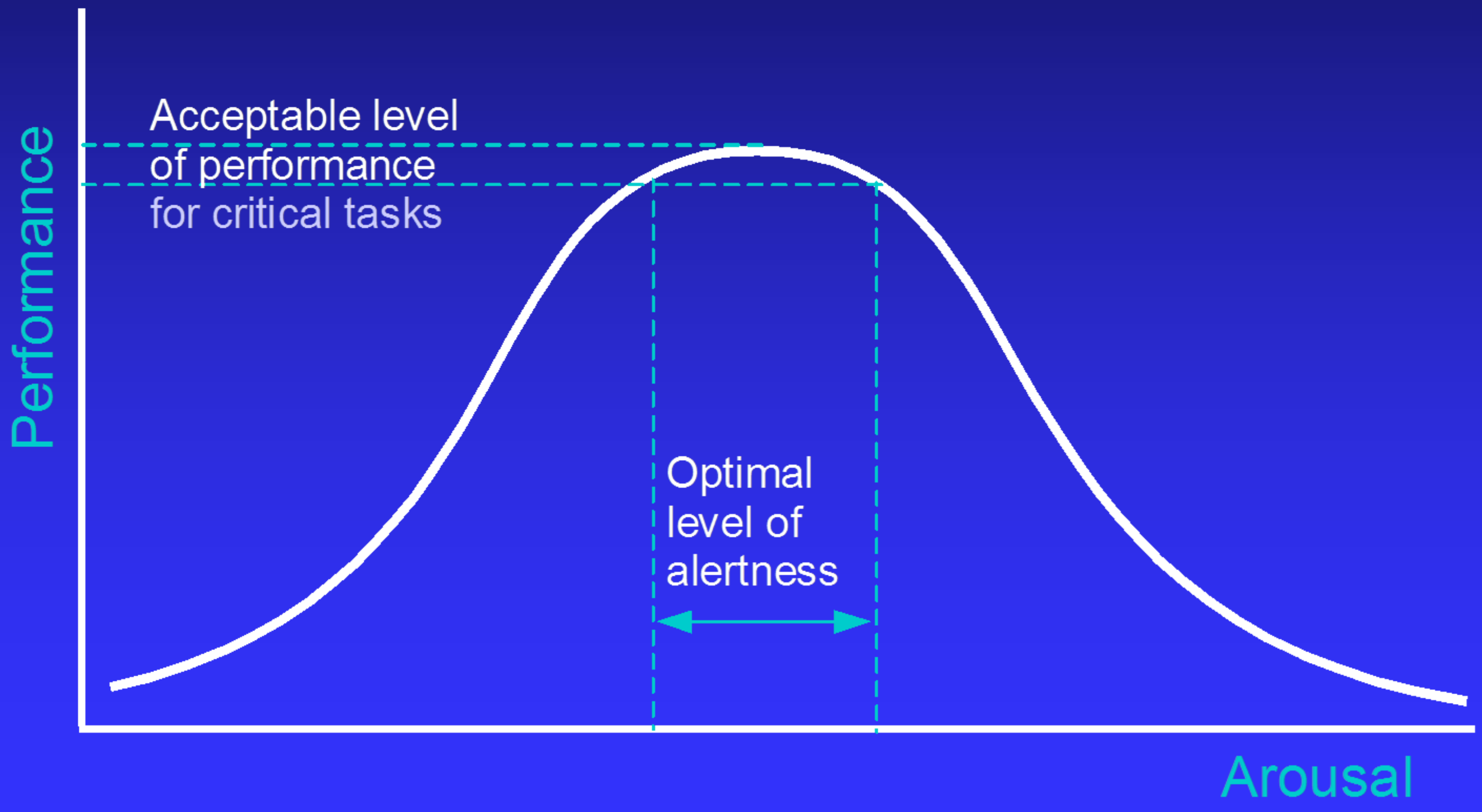
## Environmental tolerances

People, like equipment, are constructed to function effectively only within a rather narrow range of environmental conditions. Temperature, pressure, humidity, noise, time-of-day, light and darkness, can all be reflected in performance and sometimes also well-being. In less tolerant individuals, performance can also be affected by heights (acrophobia), enclosed spaces (claustrophobia). Physiology and biology all provide relevant information on these environmental effects.

## State of a man

A man at work is in a **physical**, **physiological** and **emotional state**.
A boring or a stressful working environment can also be expected to influence performance. Psychology.

# A hypothetical relationship between arousal and performance (1908)



# Piper Alpha


Fire of oil platform
in the North Sea
(1988, 167 employees killed)

# Human Error

The measure of **human reliability** is the probability that a task is **performed correctly** in **specified time**.

## Human Error

*Human error* – any member of a set of human actions or activities that exceeds some limit of acceptability, i.e. an out of tolerance action [or failure to act] where the limits of performance are defined by the system

**Swain, 1989**

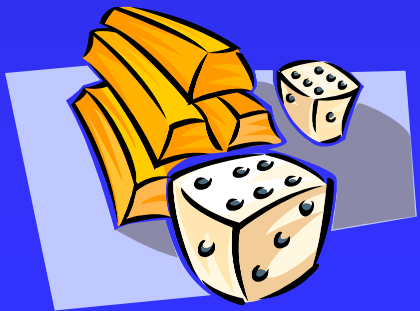
# Human Error Probability (HEP)

**Quantification of human error probability**

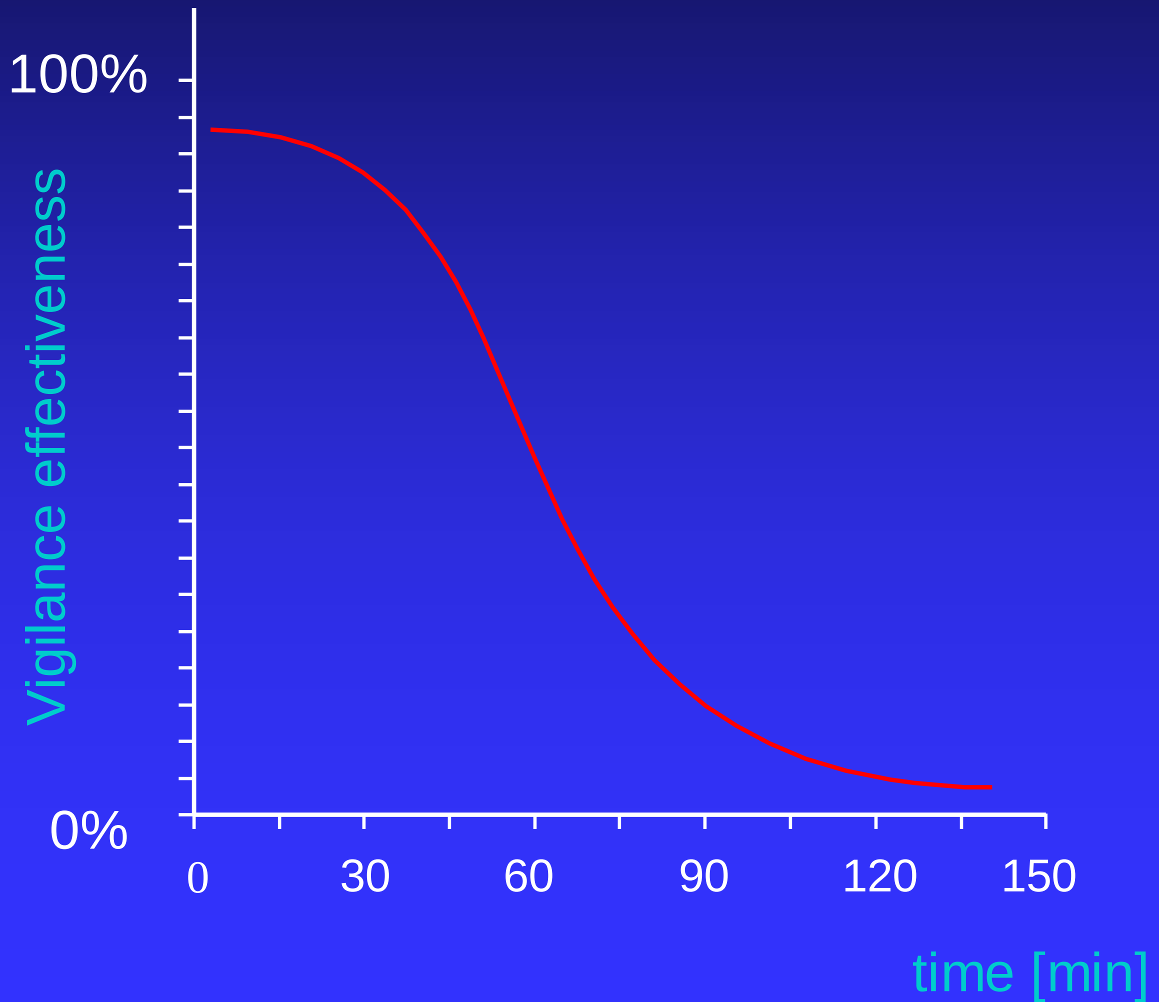
$$Q(A) = \frac{\text{Number of errors occurred}}{\text{Number of opportunities for error}} = HEP$$

# Three basic tenets with respect to human error :

- the origins of errors can be fundamentally different,
- anyone (even very well trained) can and will make errors,
- the consequences of similar errors can also be quite different.



# The effect of performance decline



# Error probability estimation based on statistical data

statistical data is available for $\Delta\tau$ years

**The probability $Q(1)$ of an event $A$ occurrence in one year per one employee**

$$Q(1) = \frac{W(\Delta\tau)}{N \cdot \Delta\tau} \qquad [1/\text{year}]$$

**$W(\Delta\tau)$ – the total number of events $A$, that occurred in $\Delta\tau$ years,**

**$\Delta\tau$ – the number of years of data collection**

**$N$ – the number of concerned workers**

# Events not resulting in injury

$$W(\Delta\tau) = \frac{W_j(\Delta\tau)}{f_j}$$

$$Q(1) = \frac{W(\Delta\tau)}{N \cdot \Delta\tau}$$

$W_j(\Delta\tau)$ – **the number of accidents that caused loss not less then** $c_j$ **,** $j = 1 \div 5$

$f_j$, – **accident factor,**
**the probability that occurrence of the event** ***A*** **causes a loss in category at least** $c_j$

# Changing the time unites

$$Q(1) = \frac{W(\Delta\tau)}{N \cdot \Delta\tau} \quad \text{[1/year]}$$

↓

$$Q = \frac{Q(1)}{d \cdot m} \quad \text{[1/single realisation of an action]}$$

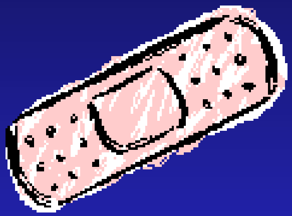
***Q*** – **the probability of the event *A* occurrence during a single execution of the specified action,**

***m*** – **the number of repetitions of the action in one day of work carried out by the worker,**

***d*** – **the average number of work days in a year.**

# Example  Injuries sustained in team games

**Fireman at Warsaw fire-brigade**



PUE – trip over, fall, contact with other players

In **4** years **42** injures were recorded

$$W(\Delta\tau) = \frac{W_2(\Delta\tau)}{f_2} = \frac{42}{0,263} \approx 160 \qquad Q(1) = \frac{W(\Delta\tau)}{N \cdot \Delta\tau} = \frac{160}{825 \cdot 4} \approx 0,048 \quad \text{[1/year]}$$

Probability of **PUE** occurrence

$$Q = \frac{Q(1)}{d} = \frac{0,048}{121} = 0,00040 = 4,0 \cdot 10^{-4} \quad \text{[1/single training]}$$

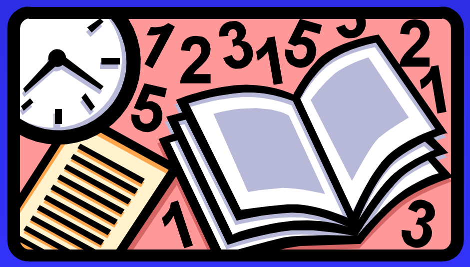
Probability of **injury**

$$Q_{urazu} = Q \cdot f_2 = 4,0 \cdot 10^{-4} \cdot 0,263 = 1,05 \cdot 10^{-5} \quad \text{[1/single training]}$$

$$Q_{urazu}(1) = Q_{urazu} \cdot d = 1,05 \cdot 10^{-5} \cdot 121 = 0,013 \quad \text{[1/year]}$$

# Human error classification

perception errors → cognitive errors → manual errors



# The most important factor in error occurrence:

**group 1** manual errors – execution of tasks

perception errors – observation & identification of signals

**group 2** cognitive errors

(diagnostic errors and errors in decision taking)

caused by information processing and combining it with knowledge, familiar rules and practiced actions

# HEP classification

from THERP method

## Errors of Omission

Omits entire task
Omits a step in a task

## Errors of Commission

Selection error:
Error of sequence
Time error
Qualitative error

- Selects wrong control (switch, display), reads from wrong device,
- Mispositions control (includes reversal errors, improperly made connections, etc.)
- Issues wrong command or information (via voice or writing)

# Cognitive behaviour classification [Rasmussen 79]:

**Skill-based level**

A skill-based behaviour represents a type of behaviour that requires very little or no conscious control to perform or execute an action once an intention is formed. Performance is smooth, automated, and consists of highly integrated patterns of behaviour in most skill-based control (Rasmussen, 1990).

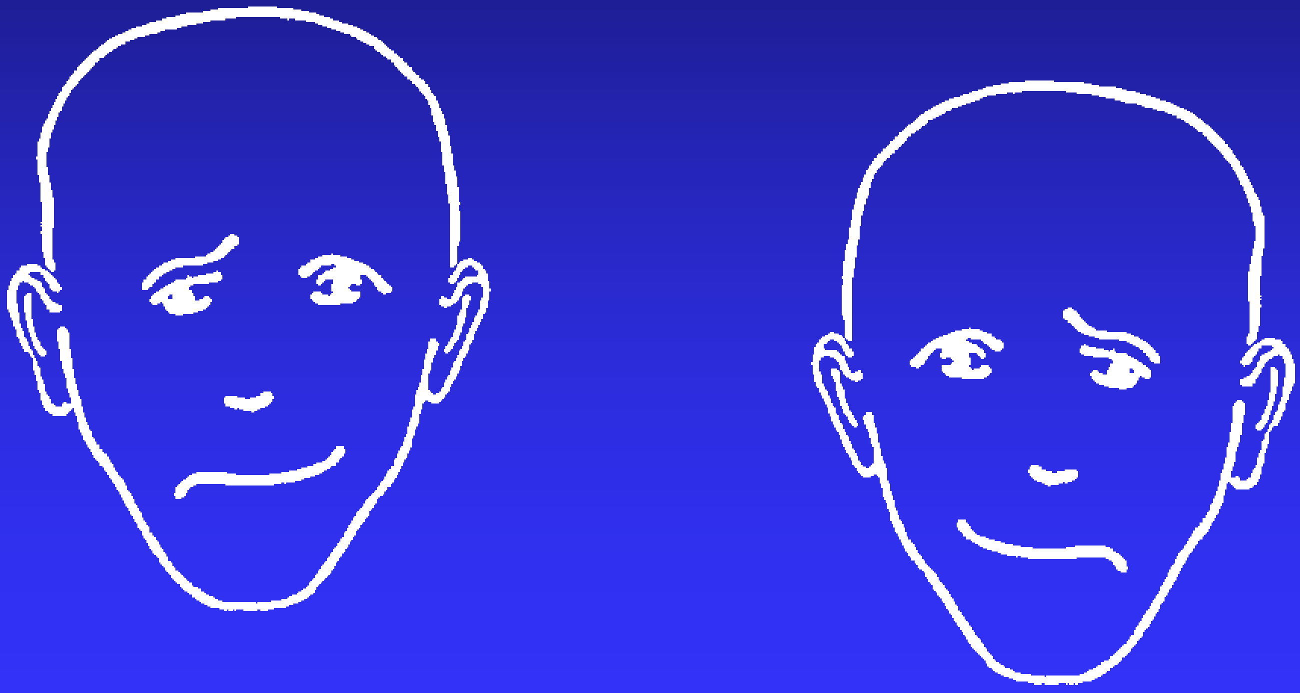
**Rule-based level**

A rule-based behaviour is characterised by the use of rules and procedures to select a course of action in a familiar work situation (Rasmussen, 1990). Operators are not required to know the underlying principles of a system, to perform a rule-based control.

**Knowledge-based level**

A knowledge-based behaviour represents a more advanced level of reasoning. This type of control must be employed when the situation is novel and unexpected. Operators are required to know the fundamental principles and laws by which the system is governed.

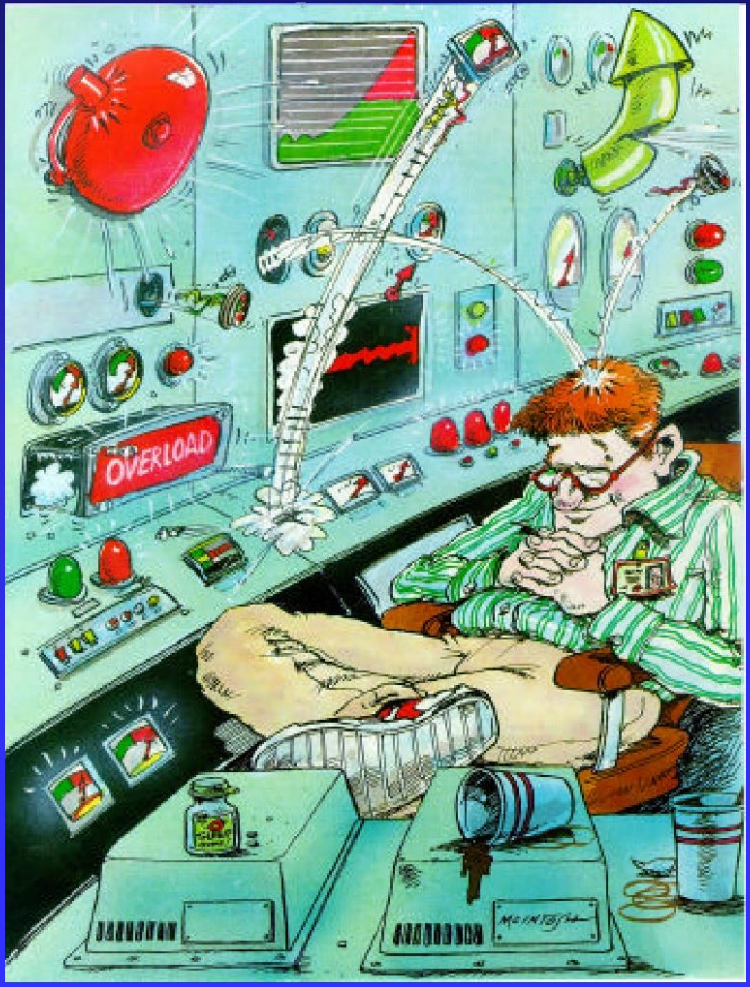
# Which face is happier?



# Factors influencing the human reliability

- performance shaping factors

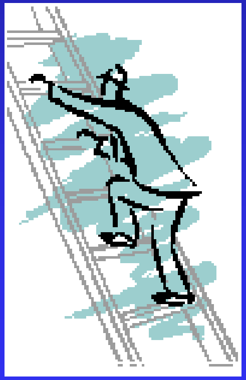
- visual illusions
- quality of instructions & documentation
- motivation
- time



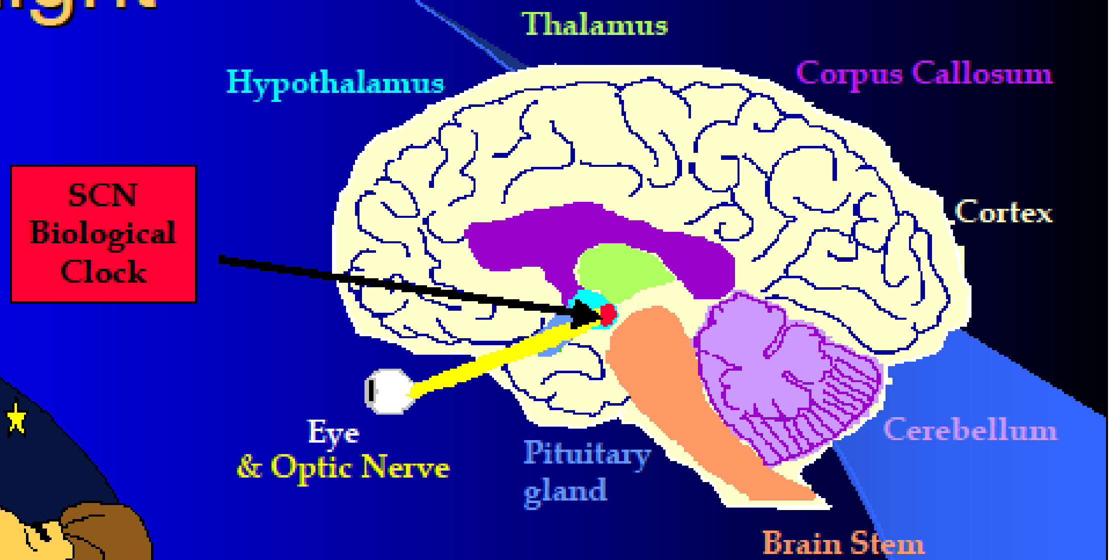
# PSF
# Performance Shaping Factors

**(Influence factors)**

| External | Internal |
|---|---|
| organizational features | competence |
| technical features | physiological and psychological factors |

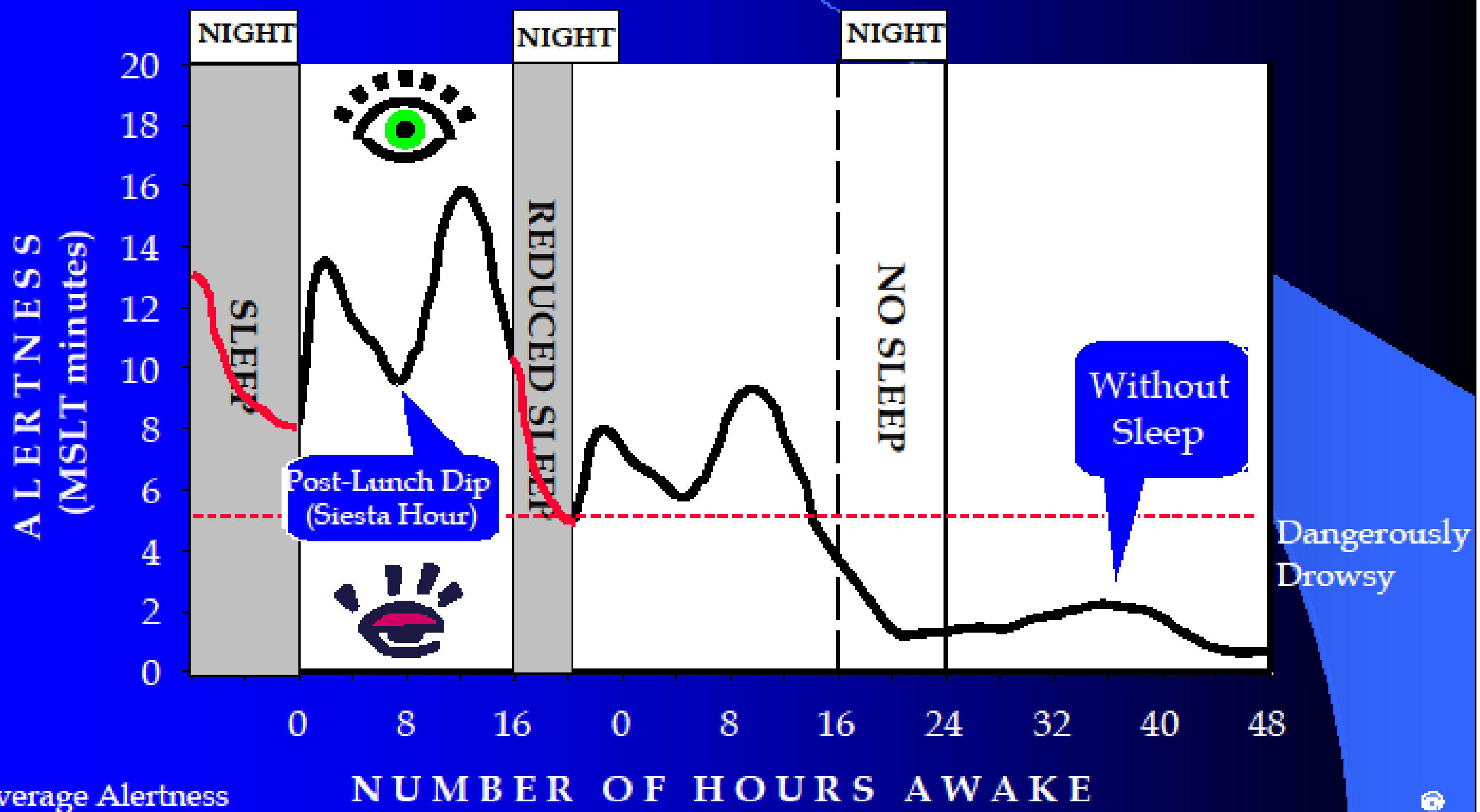


# Humans were designed to SLEEP at night



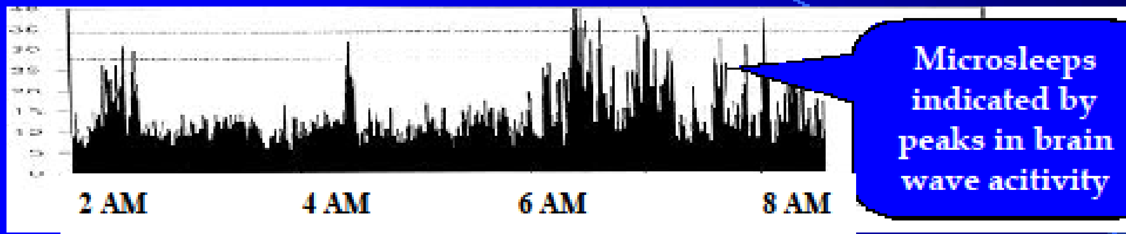

Sleep and alertness cycle is controlled by a biological clock in the brain

# Daily Circadian Rhythm of Alertness

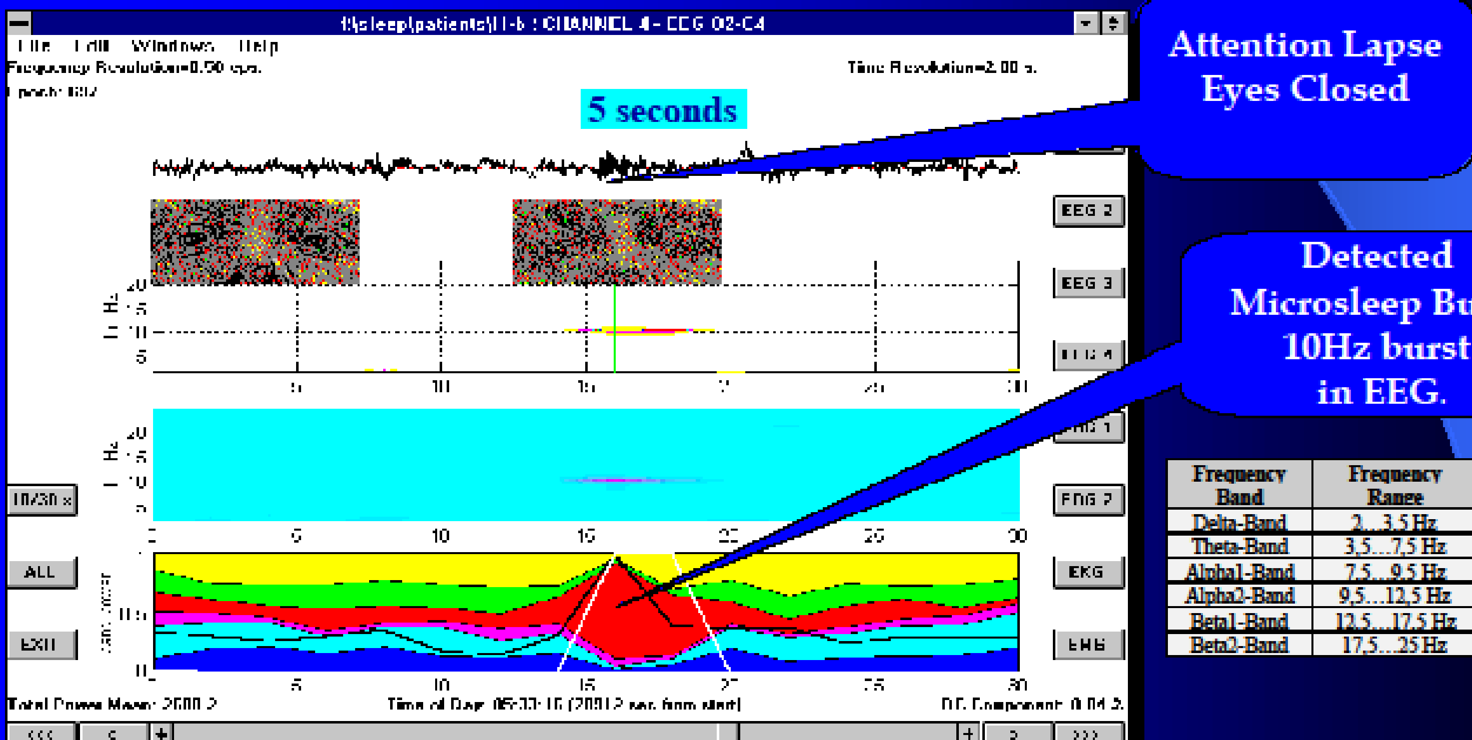



Average Alertness Curve from 9 Published Research Studies

# Microsleeps with Total Lapses in Attention while Driving or Monitoring Colo

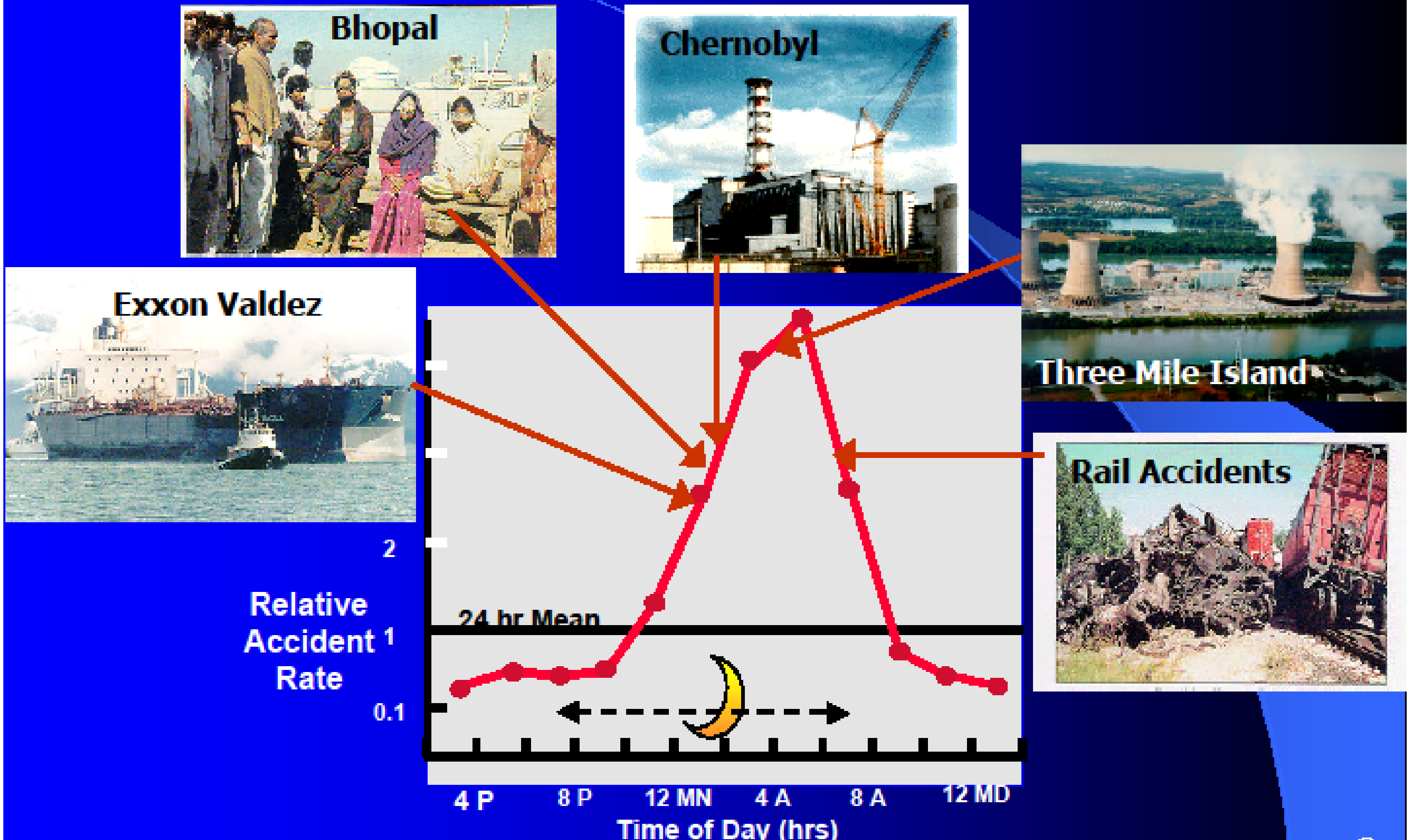



99.9999



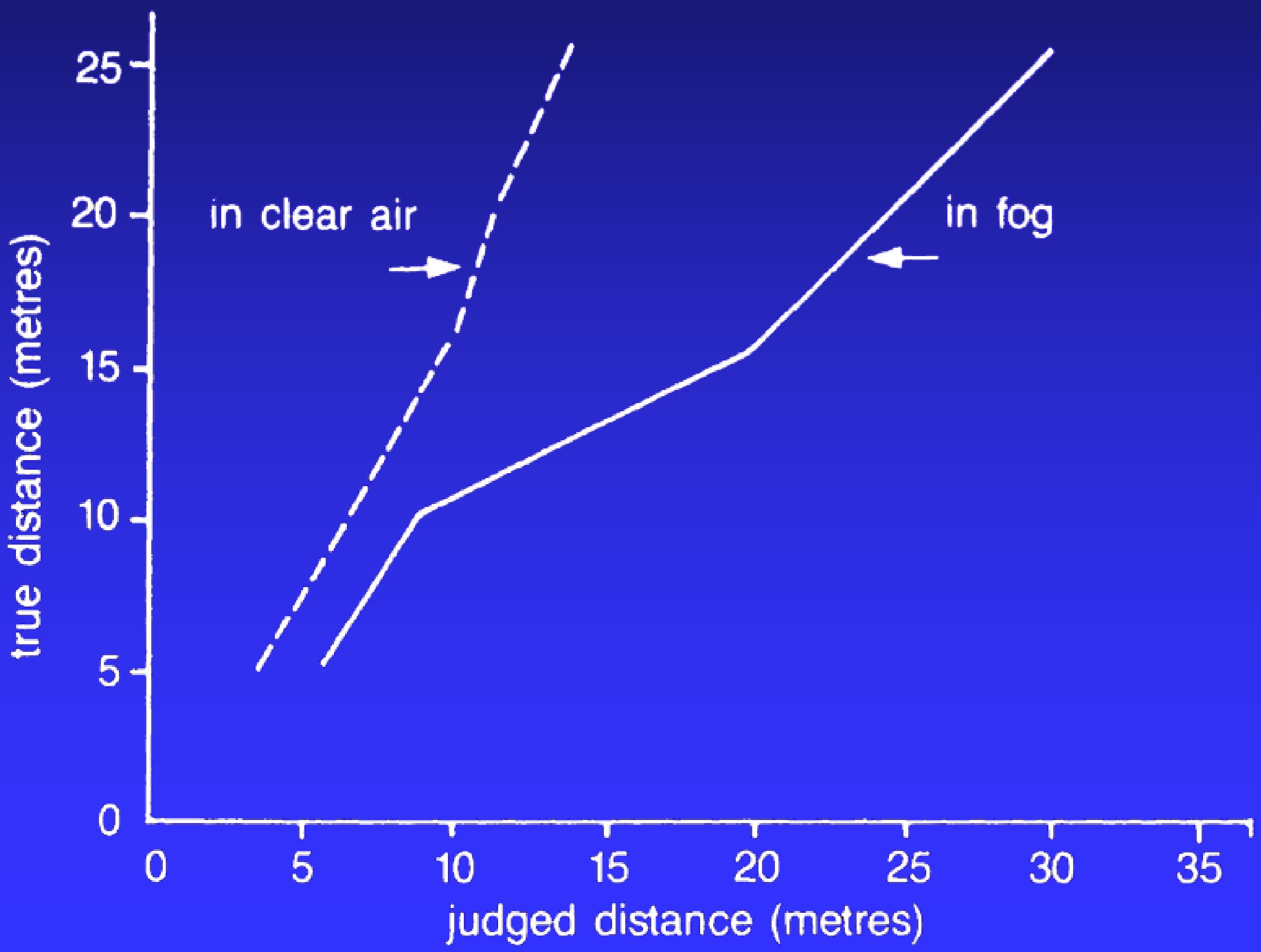

| Frequency Band | Frequency Range | Color |
|---|---|---|
| Delta-Band | 2...3,5 Hz | Blue |
| Theta-Band | 3,5...7,5 Hz | Cyan |
| Alpha1-Band | 7,5...9,5 Hz | Magenta |
| Alpha2-Band | 9,5...12,5 Hz | Red |
| Beta1-Band | 12,5...17,5 Hz | Green |
| Beta2-Band | 17,5...25 Hz | Yellow |

# 24/7 Business Costs: Night Time Accidents



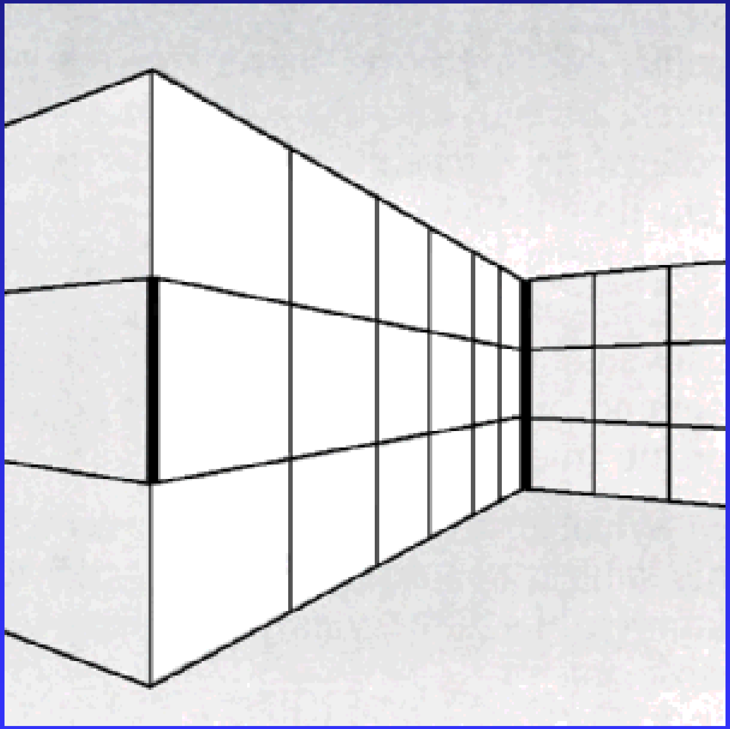
# Influence of fog on distance estimation

[Ross 1975]

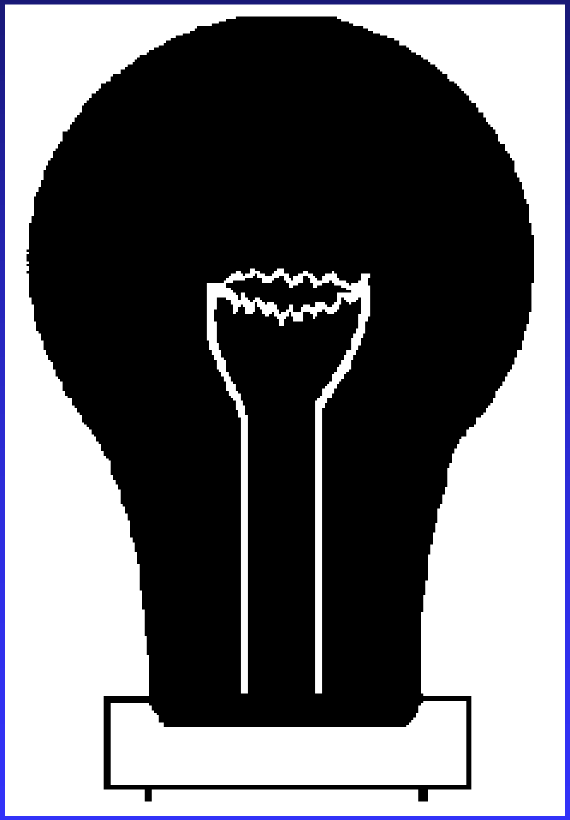


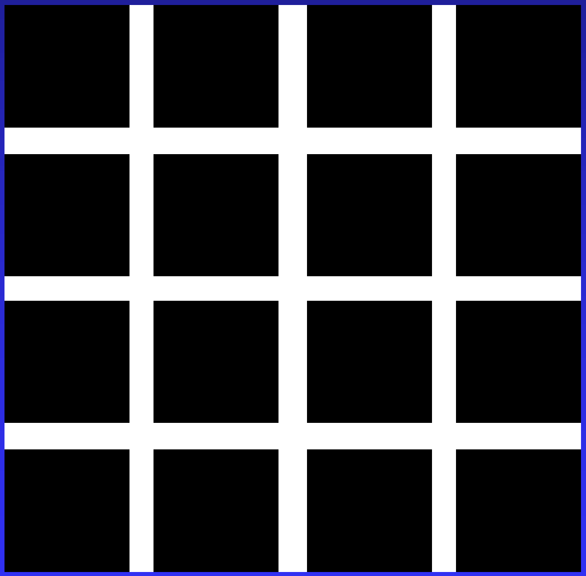
# http://erikjohanssonphoto.com

# Visual illusions



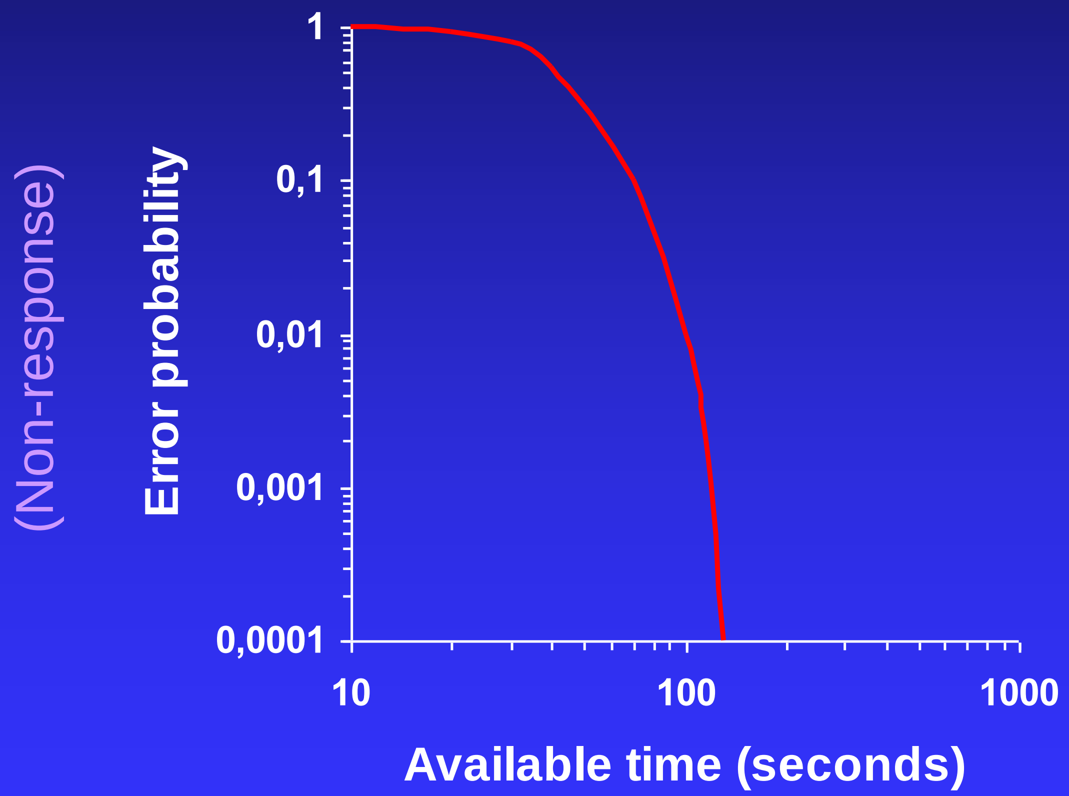
# Visual illusions





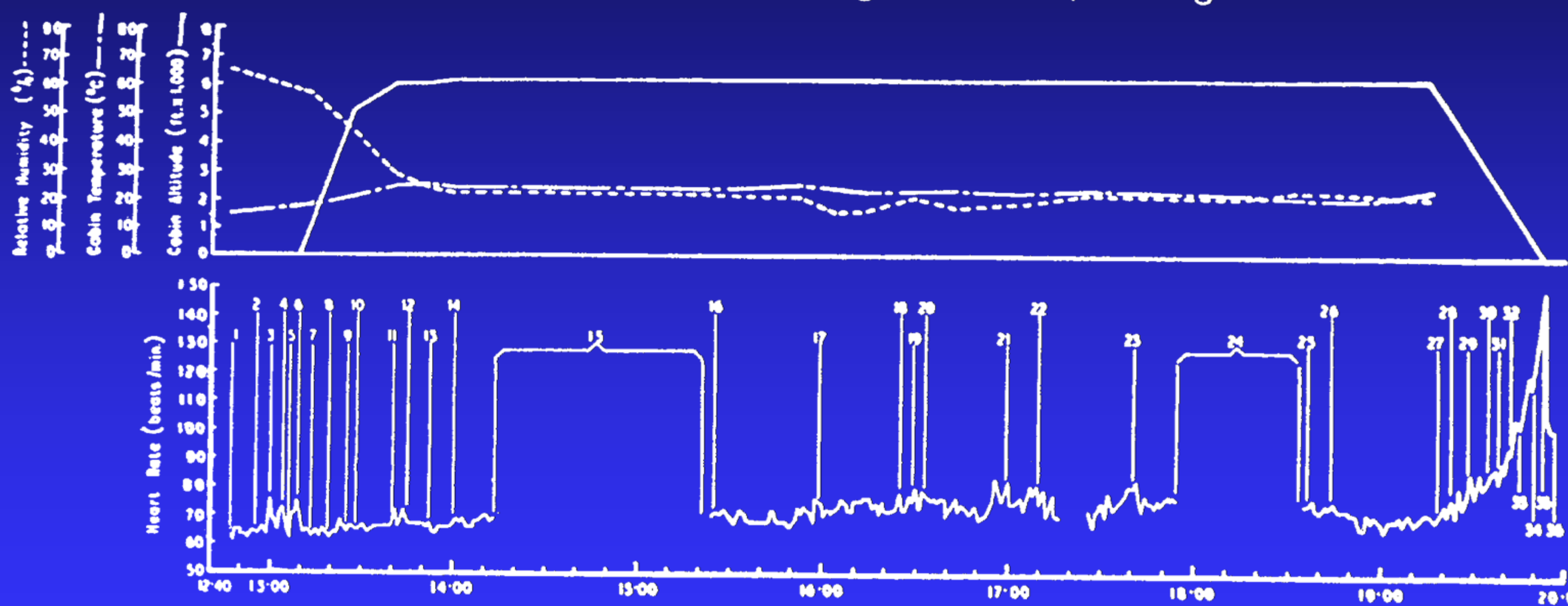
# Perception depends on context

# TRC
# Time Reliability Correlation




# Stress

Heart rate of North Atlantic Captain taking off London, landing New York




1 Doors closed
2 Start engines
3 Taxi
4 Holding point
5 Lining up
6 Take-off
7 7000 feet
8 Auto pilot in
9 26,000 feet
10 Refreshments
11 PA to passengers
12 PA to passengers
13 Shannon
14 35,000 feet
15 Captain taking meal in passenger cabin
16 Captain passing position report
17 Visitors to flight deck
18 Selcall
19 Captain on R/T
20 Tea and sandwich
21 First officer passes position report for 50W
22 SCAD boundary
23 On HL 562
24 Captain talking to passengers
25 Tea and sandwich
26 Presque Isle
27 35,000 feet
28 PA to passengers
29 26,000 feet
30 Start descent
31 Auto pilot out
32 10,000 feet
33 6,000 feet
34 On finals
35 Land
36 Engines off

# Classification of Human Reliability Models

- decomposition methods (THERP),
- expert estimation methods (APJ, PC),
- Time dependent methods (HCR).

**Sources of data for estimating error probabilities:**

- expert methods,
- statistical methods,
- data base methods.

# THERP method

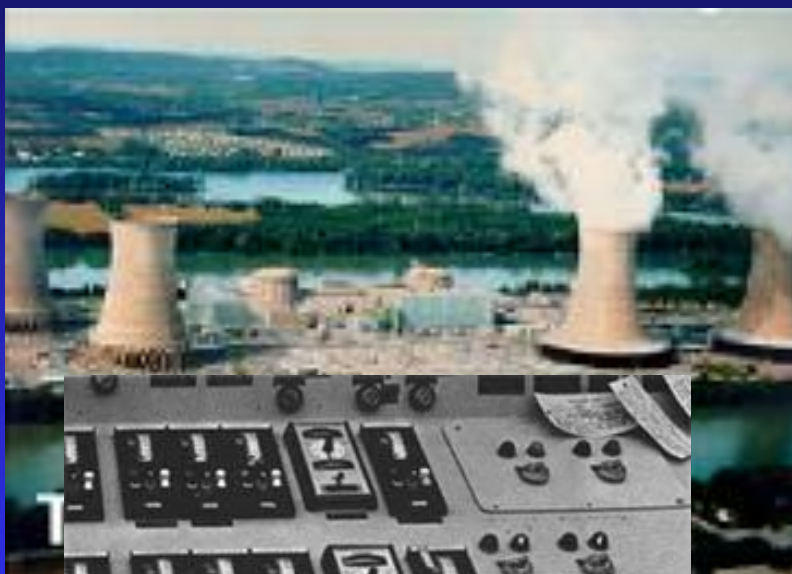
(Technique for Human Error Rate Prediction)

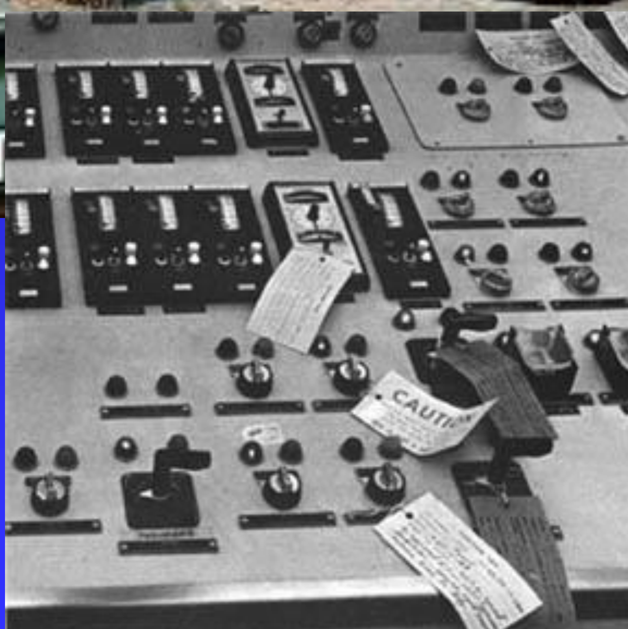
- Data base containing HEPs
  (Human Error Probabilities)
- Performance Shaping Factors
- Event tree method
- Handling of dependencies between errors
- Handling of error correction (recovery)

# Classification of steps for human reliability analysis

| Step | Level of analysis: error identification | Level of analysis: error quantification |
|---|---|---|
| 1) plant visit | X | |
| 2) review information from fault tree analyst | X | |
| 3) talk-through | X | |
| 4) task analysis | X | X |
| 5) develop HRA event trees | | X |
| 6) assign human error probabilities (HEPs) | | X |
| 7) estimate the relative effects of performance shaping factors (PSFs) | | X |
| 8) assess dependence | | X |
| 9) determine success and failure probabilities | | X |
| 10) determine the effects of recovery factors | | X |
| 11) perform a sensitivity analysis, if warranted | | |
| 12) supply information to the fault tree analyst | | |

# Three-Mile Island (1979)





# Operator Action Tree

**Explanation of symbols**

**A** – capital letter probability of an error,
**a** – minuscule (lowercase) letter probability of a success,

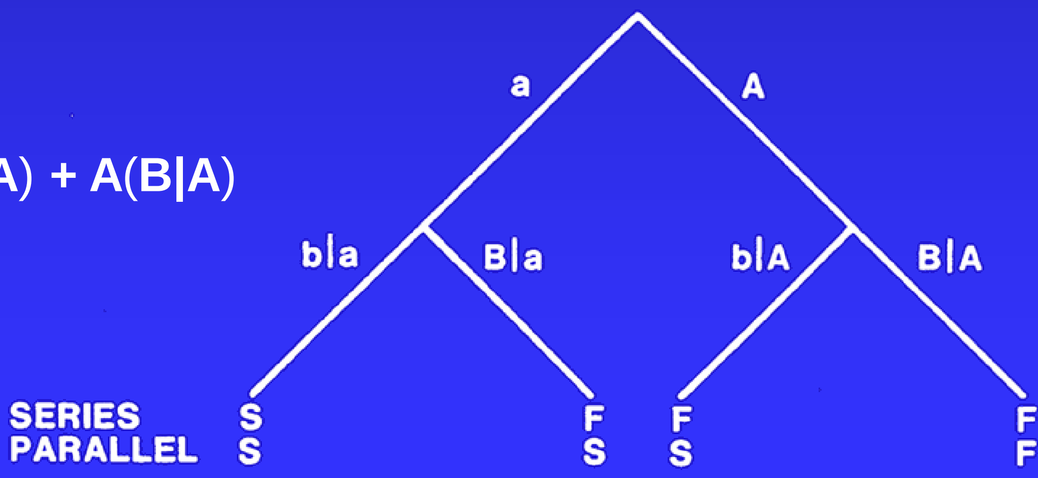
$$A + a = 1$$

**b|A** – probability for **b** on condition that error **A** has occurred,
**b|a** – probability for **b** on condition that success **a** has occurred.

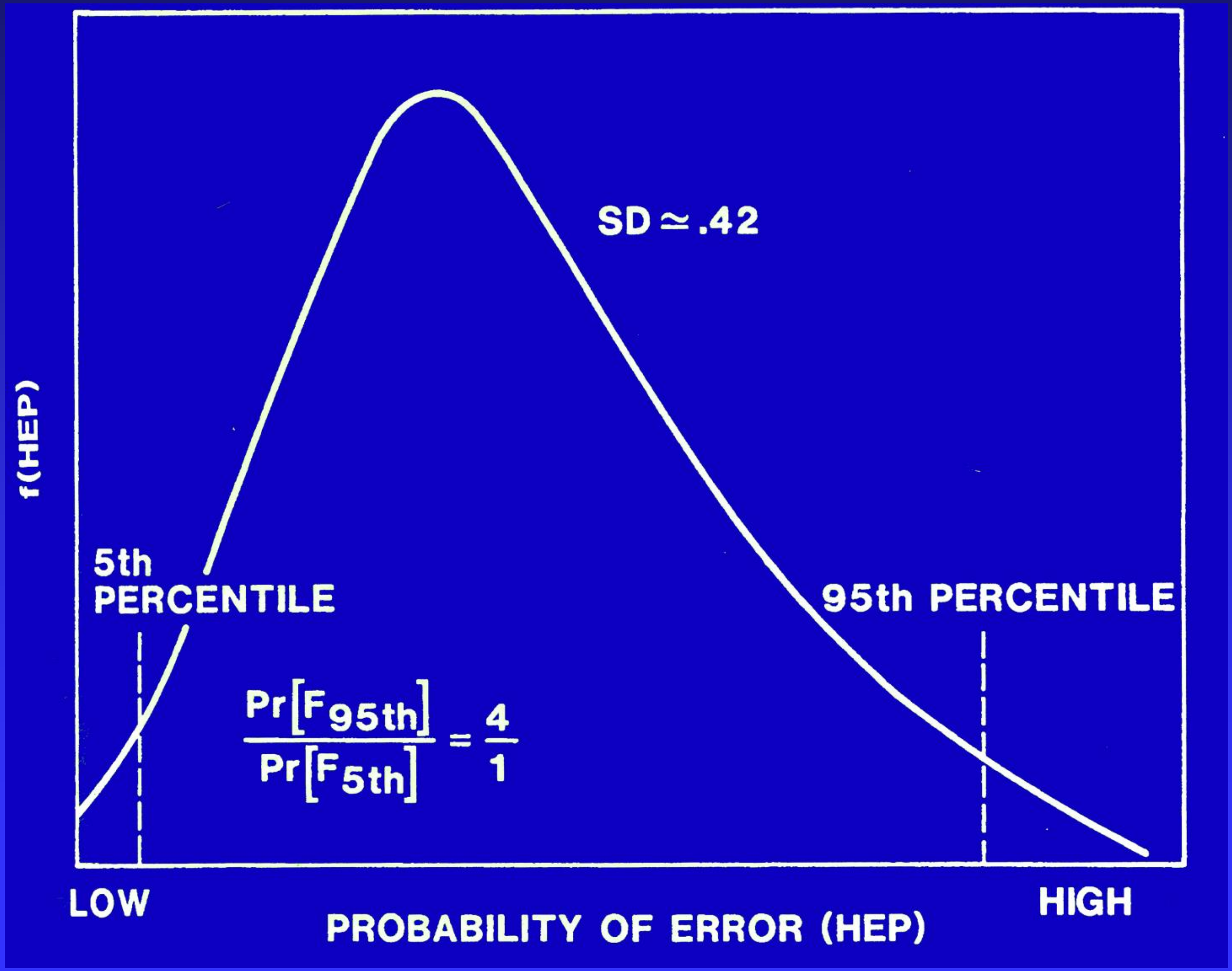
P(S) = **a(b|a)**

P(F) = **1 - a(b|a) = a(B|a) + A(b|A) + A(B|A)**

**Event tree**



# Log-normal distribution



# Error Factor

uncertainty bands

HEP is 0,003 (0,001 to 0,01)

EF = 3 - ***E****rror* ***F****actor*

so HEP is 0,003 (EF = 3)

$$EF = \sqrt{\frac{Q_u}{Q_l}} = \sqrt{\frac{0{,}01}{0{,}001}} = \sqrt{10} \approx 3,$$

# Example

**A = 0,01** **B|a = 0,001** **EF = 3**

**B|A = 0,05** **EF = 5**

a = 0,99 (0,97 to 0,997)
A = 0,01 (0,003 to 0,03)
b|a = 0,999 (0,997 to 0,9997)
B|a = 0,001 (0,0003 to 0,003)
b|A = 0,95 (0,75 to 0,99)
B|A = 0,05 (0,01 to 0,25)

P(F) = **1 - a(b|a)**

**HEP nominal values**
P(F) = 1 – 0,99(0,999) = 1 – 0,989 = 0,011

**Lower uncertainty band**
P(F) = 1 – 0,997(0,9997) = = 1 – 0,9967 = 0,0033

**Upper uncertainty band**
P(F) = 1 – 0,97(0,997) = 1 – 0,967 = 0,033

**Total HEP is:**

**0,011 (0,0033 to 0,033)**

# Errors of omission

Table 20-7 Estimated probabilities of errors of omission per item of instruction when use of written procedures is specified* (from Table 15-3)

| Item** | Omission of item: | HEP | EF |
|---|---|---|---|
| | When procedures with checkoff provisions are correctly used†: | | |
| (1) | Short list, ≤10 items | .001 | 3 |
| (2) | Long list, >10 items | .003 | 3 |
| | When procedures without checkoff provisions are used, or when checkoff provisions are incorrectly used††: | | |
| (3) | Short list, ≤10 items | .003 | 3 |
| (4) | Long list, >10 items | .01 | 3 |
| (5) | When written procedures are available and should be used but are not used†† | .05‡ | 5 |

*The estimates for each item (or perceptual unit) presume zero dependence among the items (or units) and must be modified by using the dependence model when a nonzero level of dependence is assumed.

**The term "item" for this column is the usual designator for tabled entries and does not refer to an item of instruction in a procedure.

†Correct use of checkoff provisions is assumed for items in which written entries such as numerical values are required of the user.

††Table 20-6 lists the estimated probabilities of incorrect use of checkoff provisions and of nonuse of available written procedures.

‡If the task is judged to be "second nature," use the lower uncertainty bound for .05, i.e., use .01 (EF = 5).

oral instruction items not written down

# Errors in recalling instructions

| Item | Number of oral instruction items | Pr[F] to recall item „N", order of recall not important | | Pr[F] to recall all items, order of recall not important | | Pr[F] to recall all items, order of recall is important | |
|---|---|---|---|---|---|---|---|
| | | (a) | | (b) | | (c) | |
| | | HEP | EF | HEP | EF | HEP | EF |
| Oral instructions are detailed: | | | | | | | |
| (1) | 1 | 0,001 | 3 | 0,001 | 3 | 0,001 | 3 |
| (2) | 2 | 0,003 | 3 | 0,004 | 3 | 0,006 | 3 |
| (3) | 3 | 0,01 | 3 | 0,02 | 5 | 0,03 | 5 |
| (4) | 4 | 0,03 | 5 | 0,04 | 5 | 0,1 | 5 |
| (5) | 5 | 0,1 | 5 | 0,2 | 5 | 0,4 | 5 |
| Oral instructions are general: | | | | | | | |
| (6) | 1 | 0,001 | 3 | 0,001 | 3 | 0,001 | 3 |
| (7) | 2 | 0,006 | 3 | 0,007 | 3 | 0,01 | 3 |
| (8) | 3 | 0,02 | 5 | 0,03 | 5 | 0,06 | 5 |
| (9) | 4 | 0,06 | 5 | 0,09 | 5 | 0,2 | 5 |
| (10) | 5 | 0,2 | 5 | 0,3 | 5 | 0,7 | 5 |

# Errors of Commission

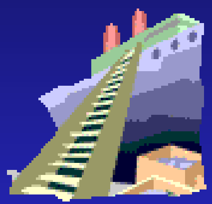
Table 20-10 Estimated HEPs for errors of commission in reading and recording quantitative information from unannunciated displays (from Table 11-3)

| Item | Display or Task | HEP* | EF |
|---|---|---|---|
| (1) | Analog meter | .003 | 3 |
| (2) | Digital readout (≤ 4 digits) | .001 | 3 |
| (3) | Chart recorder | .006 | 3 |
| (4) | Printing recorder with large number of parameters | .05 | 5 |
| (5) | Graphs | .01 | 3 |
| (6) | Values from indicator lamps that are used as quantitative displays | .001 | 3 |
| (7) | Recognize that an instrument being read is jammed, if there are no indicators to alert the user | .1 | 5 |
| | Recording task: Number of digits or letters** to be recorded | | |
| (8) | ≤ 3 | Negligible | - |
| (9) | > 3 | .001 (per symbol) | 3 |
| (10) | Simple arithmetic calculations with or without calculators | .01 | 3 |
| (11) | Detect out-of-range arithmetic calculations | .05 | 5 |

*Multiply HEPs by 10 for reading quantitative values under a high level of stress if the design violates a strong populational stereotype; e.g., a horizontal analog meter in which values increase from right to left.

**In this case, "letters" refer to those that convey no meaning. Groups of letters such as MOV do convey meaning, and the recording HEP is considered to be negligible.

# Modifications of base probabilities

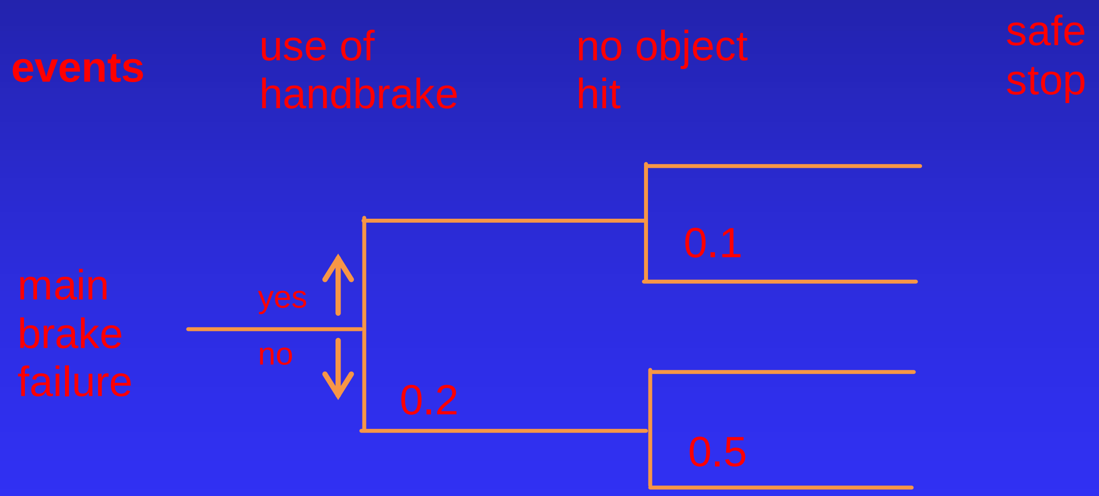


| | Stres level | Experienced operator | Unexperienced Operator |
|---|---|---|---|
| (1) | **Very small** | x2 | x2 |
| | **Optimal** | | |
| (2) | Step by step | x1 | x1 |
| (3) | dynamic | x1 | x2 |
| | **Relatively high** | | |
| (4) | Step by step | x2 | x4 |
| (5) | dynamic | x5 | x10 |
| | **Very high** | | |
| (6) | Step by step | x5 | x10 |
| (7) | dynamic | .25 (EF = 5) | .50 (EF = 5) |

Real HEP values
not modification factors

# Problem

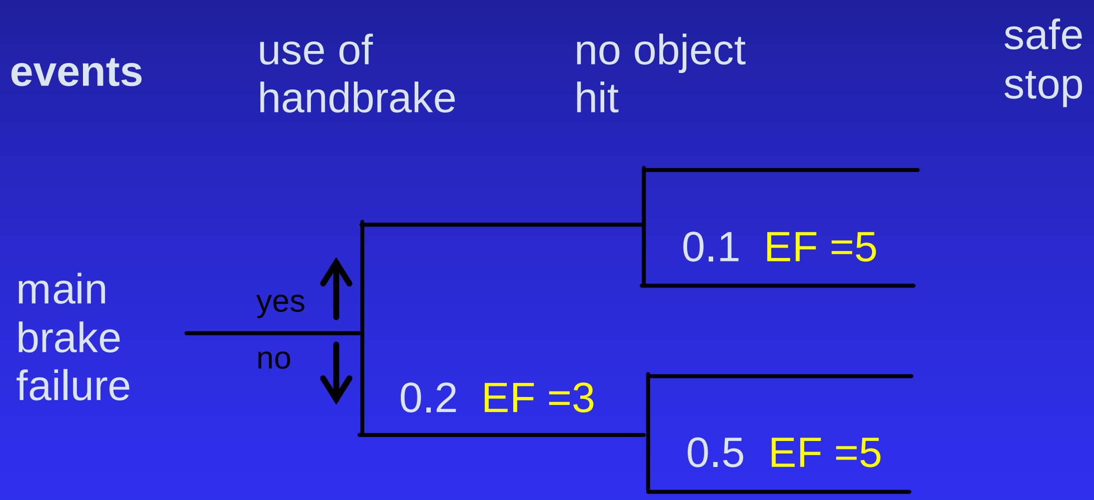
The main (foot-operated) brake on a car has failed while the car is in motion. The driver should bring the vehicle to a safe stop using the handbrake. He can also steer to avoid hitting large objects.




Calculate the probability of success, i.e. safe stop.

# Problem

Calculate the probability of success, i.e. safe stop.




Error Factor (EF) values are also shown in the event tree. Calculate the success probability for the worst case, when the upper failure probabilities $Q_u$ occur.

$$\mathbf{EF} = \sqrt{\frac{Q_u}{Q_l}} \qquad Q = \frac{Q_u}{\mathrm{EF}}$$

# Dependencies between errors

**ZD** – zero dependence

**LD** – low dependence

**MD** – moderate dependence

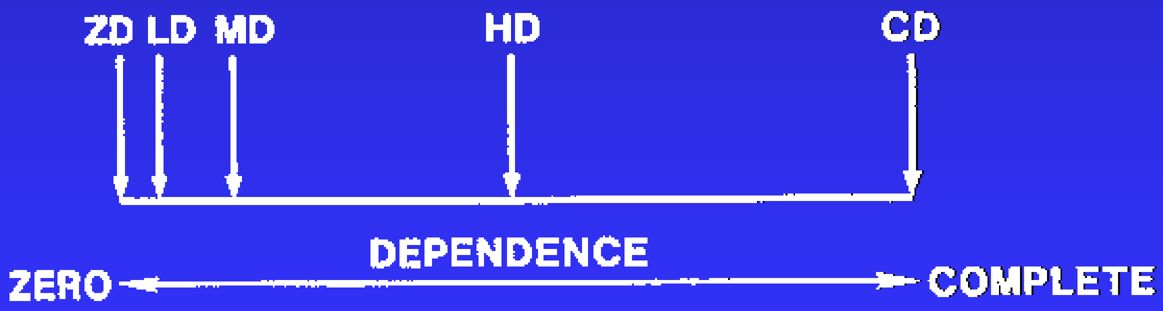
**HD** – high dependence

**CD** – complete dependence

$$P(B|A|\mathbf{HD}) = \frac{1+B}{2}$$

$$P(B|A|\mathbf{MD}) = \frac{1+6\cdot B}{7}$$

$$P(B|A|\mathbf{LD}) = \frac{1+19\cdot B}{20}$$

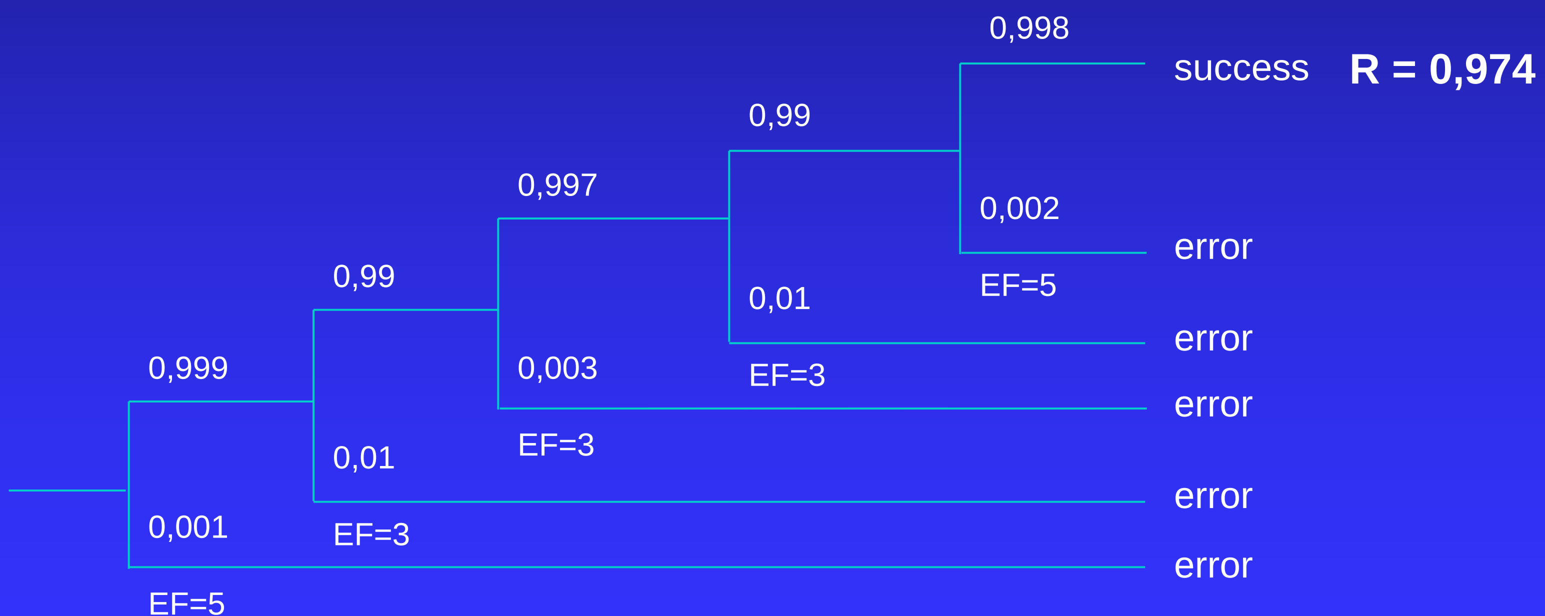



**Example**

$$P(B|A|\mathbf{LD}) = \frac{1+19\cdot(0{,}003)}{20} = 0{,}05285 \approx 0{,}05$$

# EXAMPLE
# work on a machine tool

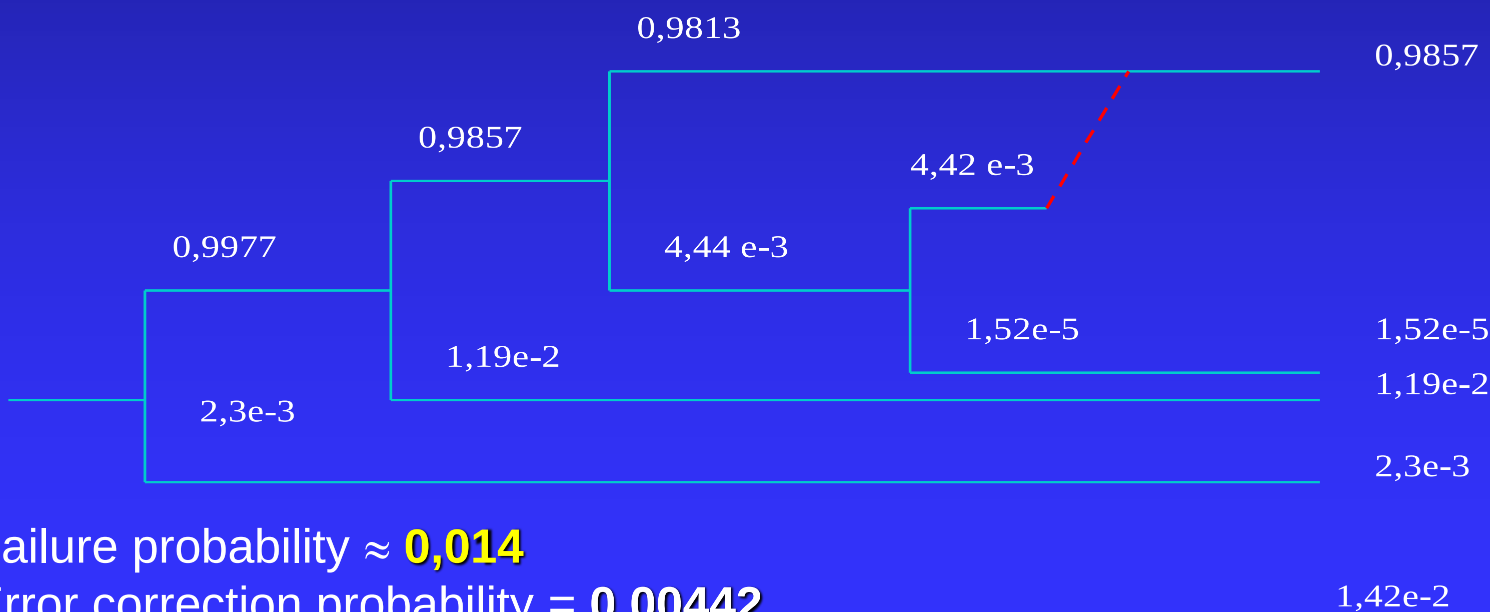
| **Human action** | clamps machined part | determines machining parameters | sets transmission ratio | reads and sets depth of cut | controls the turning process |
|---|---|---|---|---|---|
| **Event number** | 1 | 2 | 3 | 4 | 5 |




Task error probability **Q = 1- 0,974=0,026**

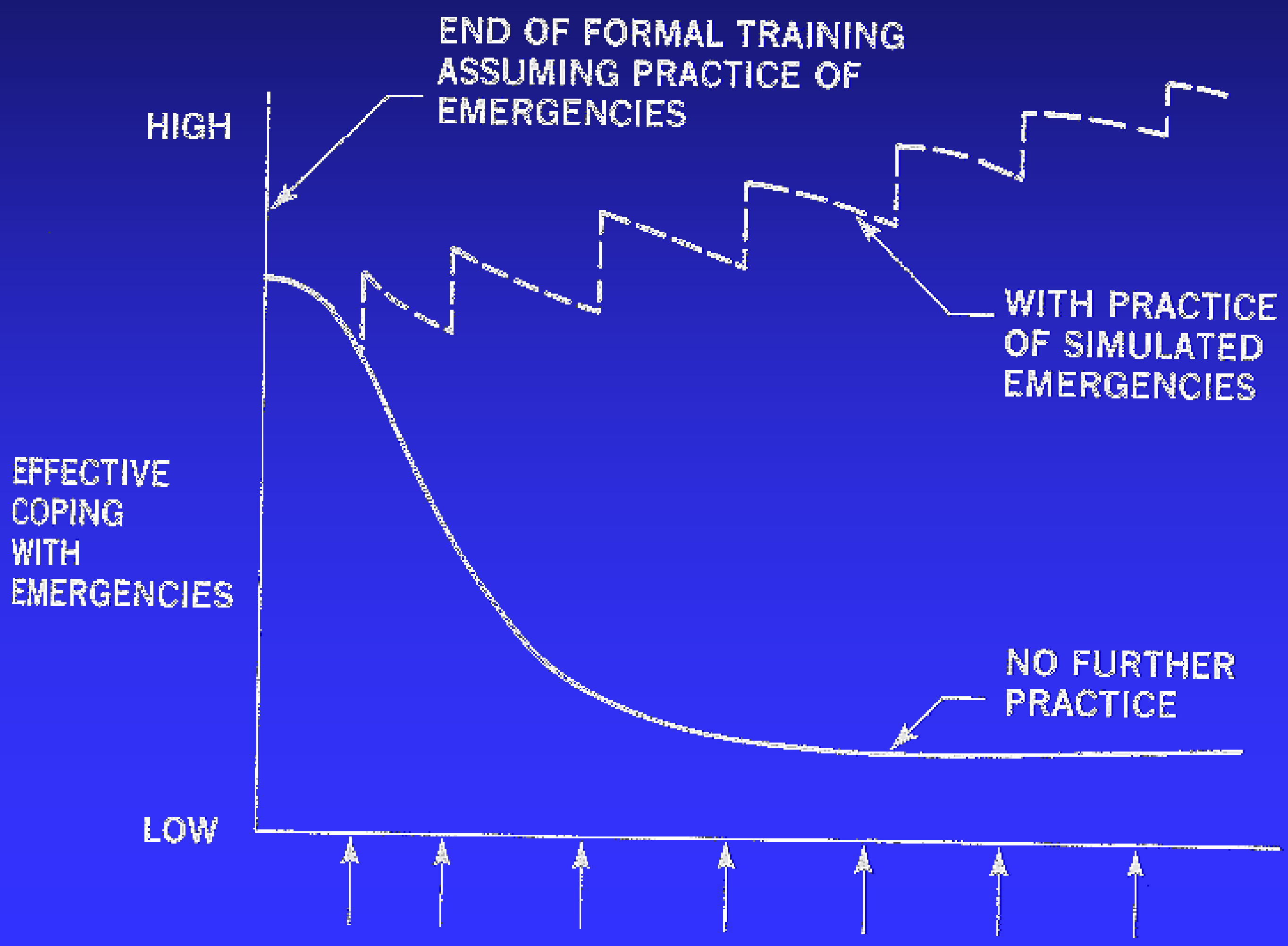
# Error correction

| ACTION | Operator checks plant conditions | Operator diagnoses fault | Operator takes remedial action | Operator re-checks plant condition |
|---|---|---|---|---|
| Event No. | 1 | 2 | 3 | 4 |



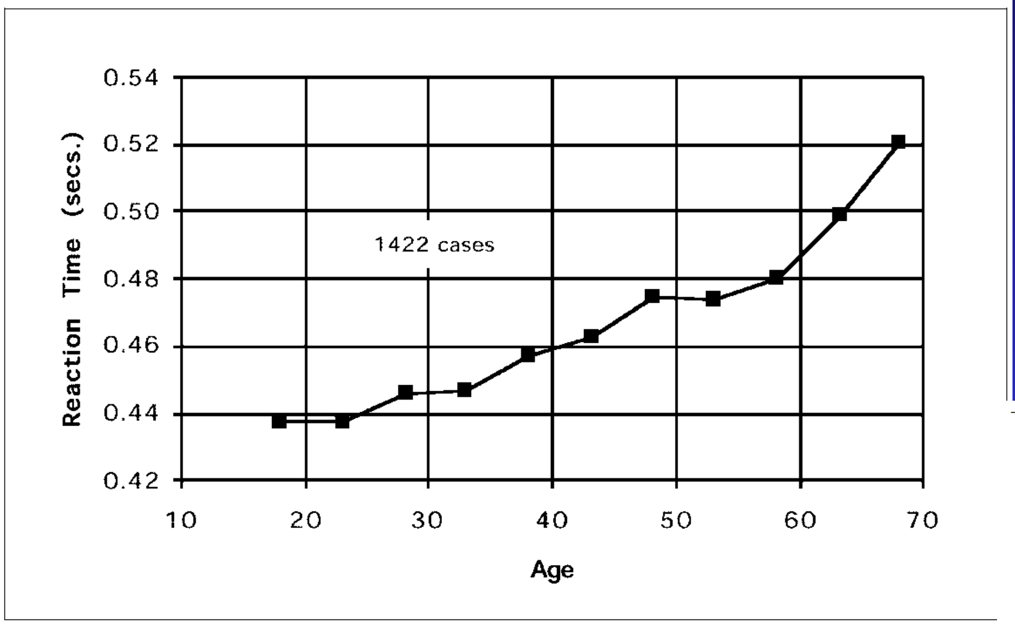

Failure probability ≈ **0,014**
Error correction probability = **0,00442**
Failure probability diminishes by **24%**

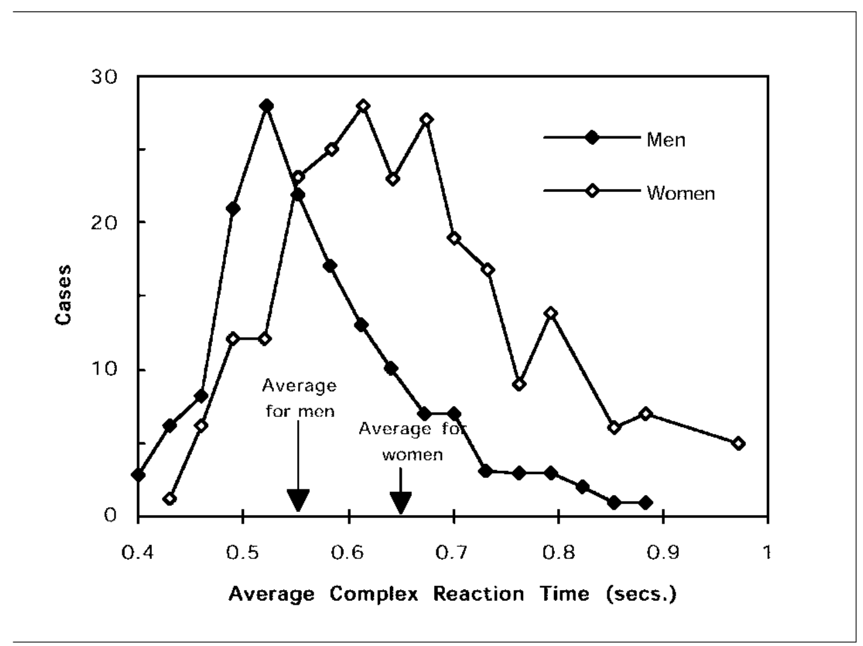
# The influence of training



# Human reaction time

# The reaction time



# The influence of speed on the stopping distance

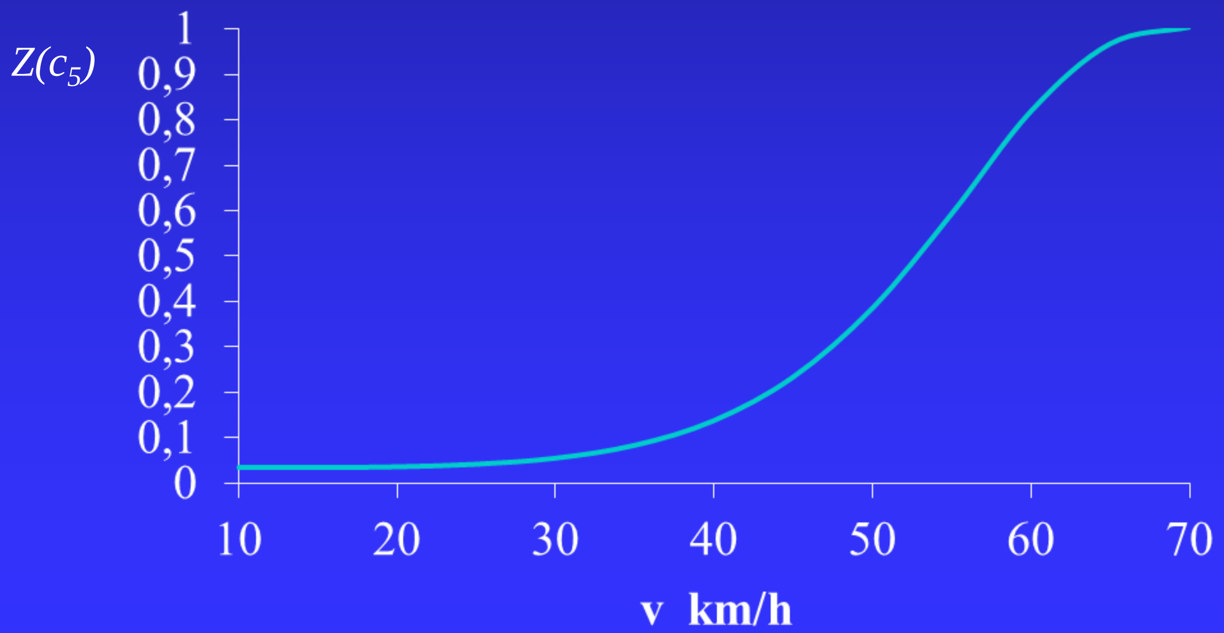

driver reaction time **1s**

car deceleration = **7m/s$^2$**

# The influence of speed on the stopping distance

car 1 in the distance of **10,9** meters decelerates by **19.7 km/h**

car 1 passes the stopping line of car 2 with the speed over **40 km/h**



# HCR Method
# (Human Cognitive Reliability)