# Context of Robust Design

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Fig. 1

# Case study

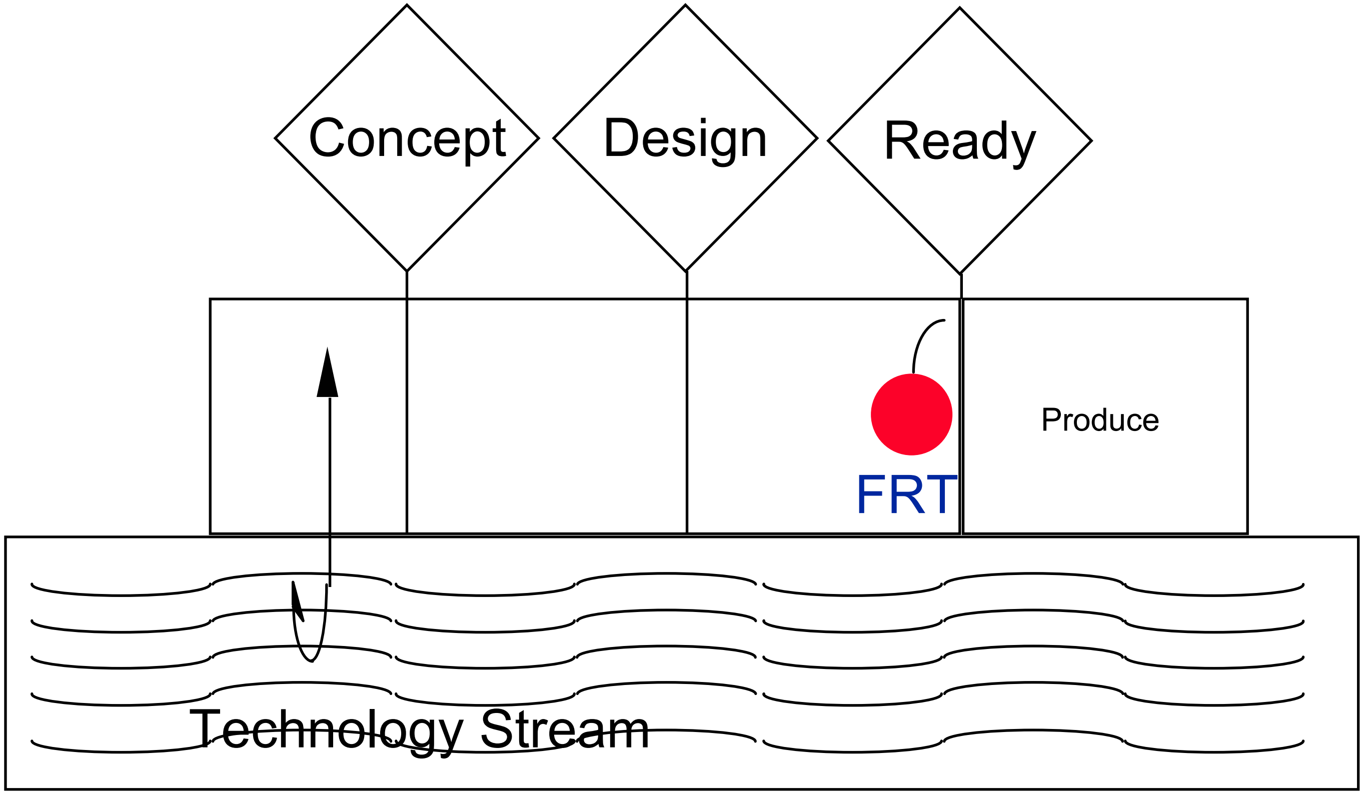
An automatic document handler (ADH) was developed at the SS level. When integrated into the total system there were many new problems. The TQM Problem Solving Process was used, and many problems were solved. However, at the Field Readiness Test (FRT) before entering production the reliability was 15X worse than acceptable.

# Case study questions

- What should they do next?
- What should be done in the future to avoid the same dysfunctional path?
- What is the fundamental problem?

Fig. 3

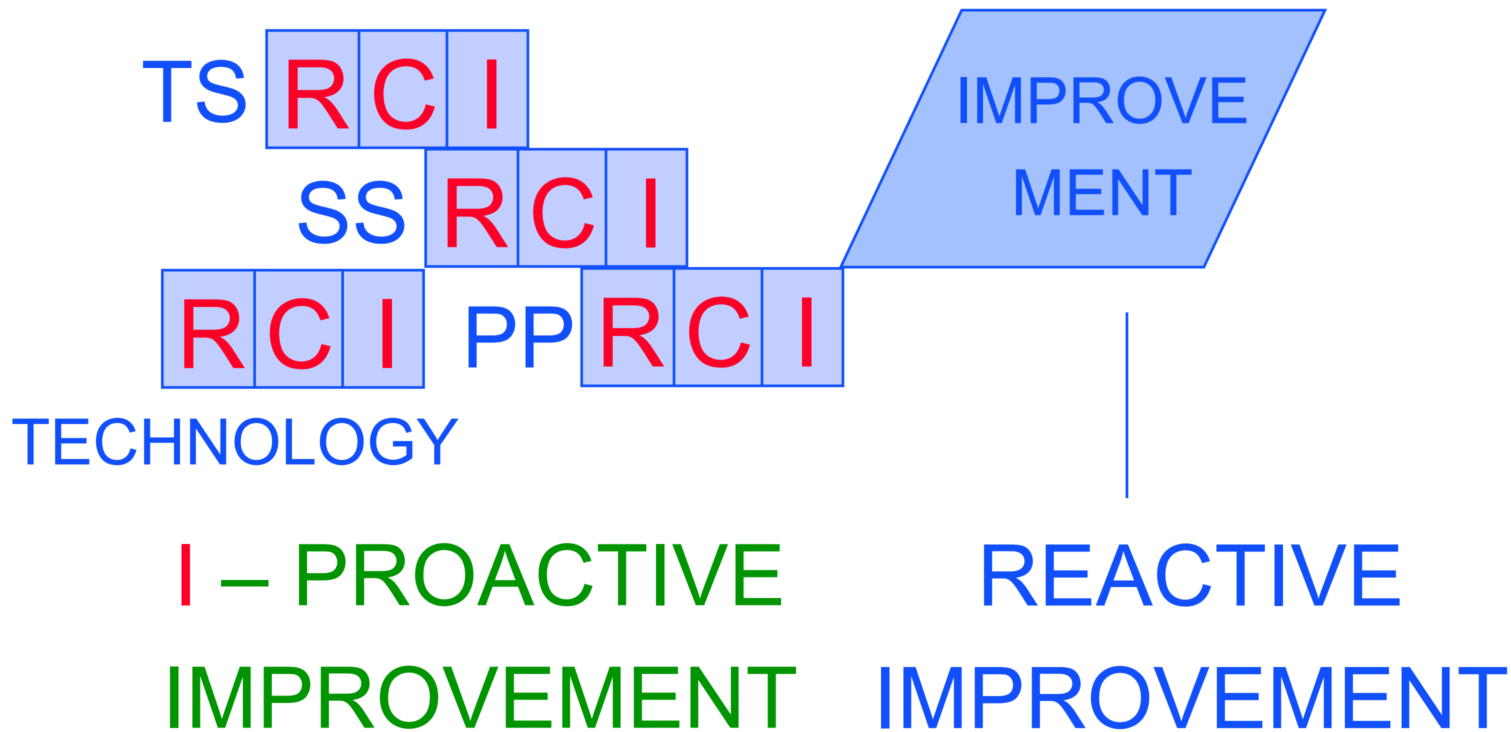
# Bomb alert!




Too much dependence on reactive improvement

Fig. 4

# Improvement to avoid bombs




R: requirements C: concept TS: total system SS: subsystem PP: piece parts

Fig. 5

# Proactive improvement


Fig. 6

# What is wrong here?

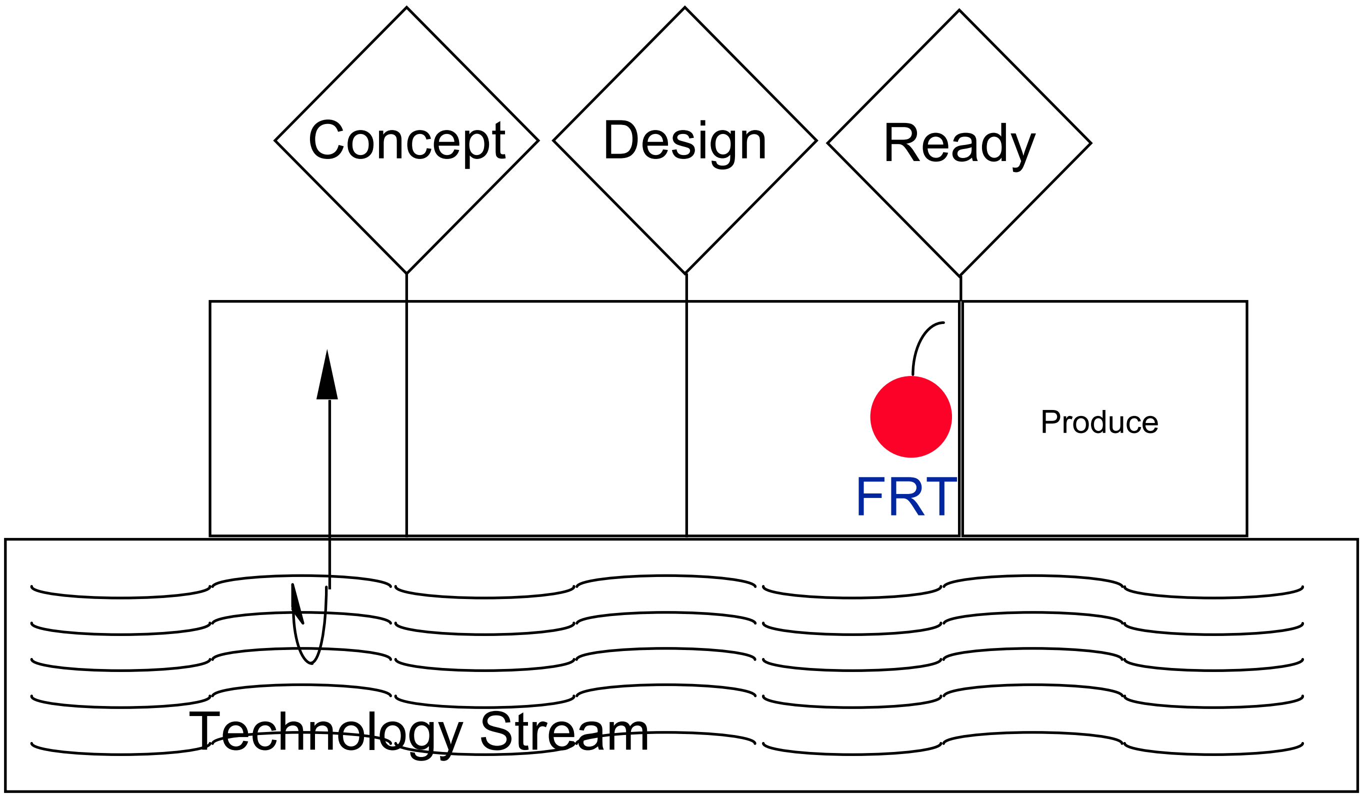



Fig. 7

# Rework – how much is enough?

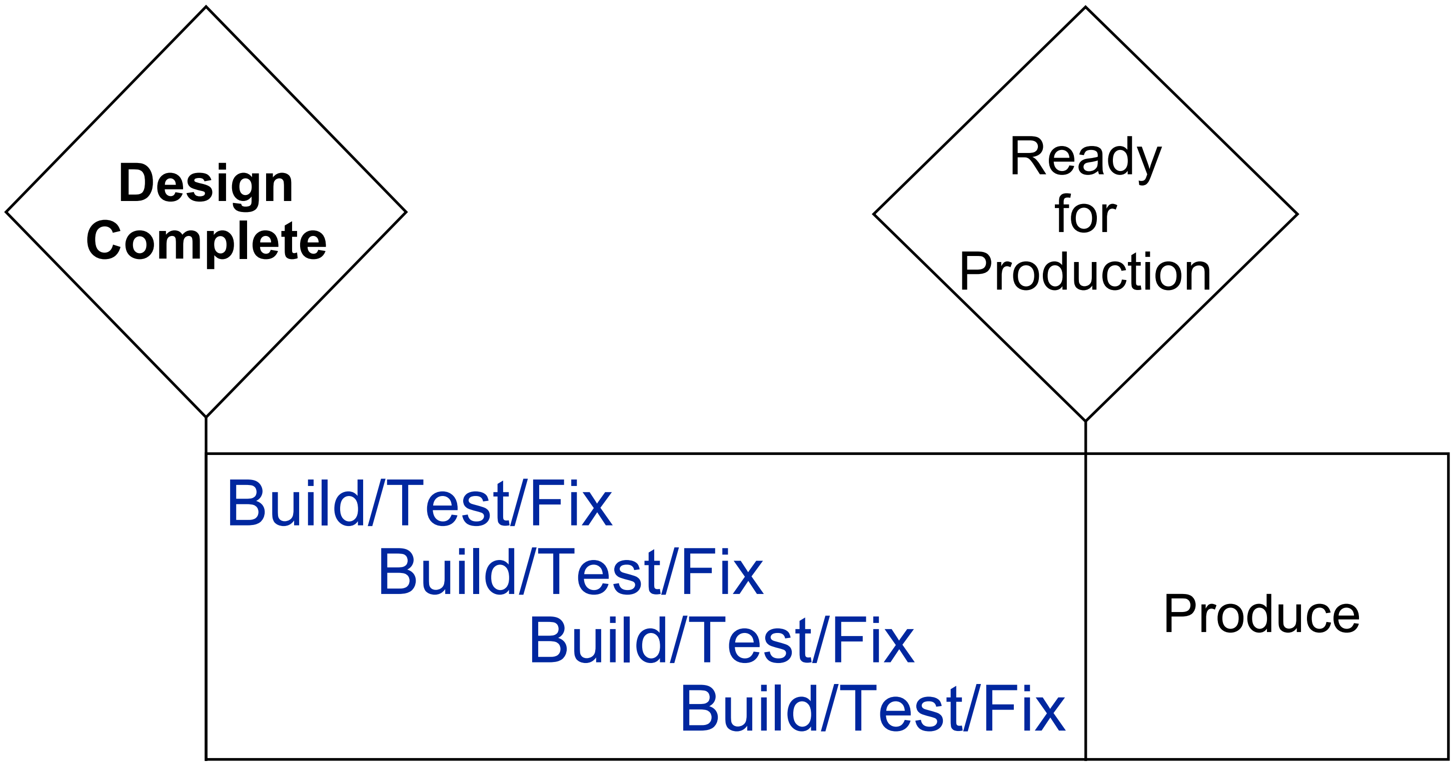



Fig. 8

# Build/test/fix – why?

- Reactive problem solving
  - Too little – limited scope of solutions
  - Too late
- Design contains many unsolved problems
- Biggest problem is lack of robustness
  - System works well in favorable conditions
  - But is sensitive to noises – unfavorable conditions that inevitably occur

Fig. 9

# Proactive problem solving

- Must shift from emphasis on build/test/fix
- Must address effects of noises
  - Erratic performance
  - Leads to delusionary problem solving; chases problem from one failure mode to another

Fig. 10

# Noises

- Affect performance – adversely
- IPDT cannot control – examples:
  - Ambient temperature
  - Power-company voltage
  - Customer-supplied consumables
- Noises lead to erratic performance

IPDT: Integrated product development team

Fig. 11

# Failure modes

- Noises lead to failure modes (FM)
- One set of noise values leads to $FM_1$
- Opposite set of noise values leads to $FM_2$
- Simple problem solving chases the problem from $FM_1$ to $FM_2$ and back again, but does not avoid both FMs with the same set of design values – endless cycles of build/test/fix (B/T/F)

Fig. 12

# Performance; favorable conditions

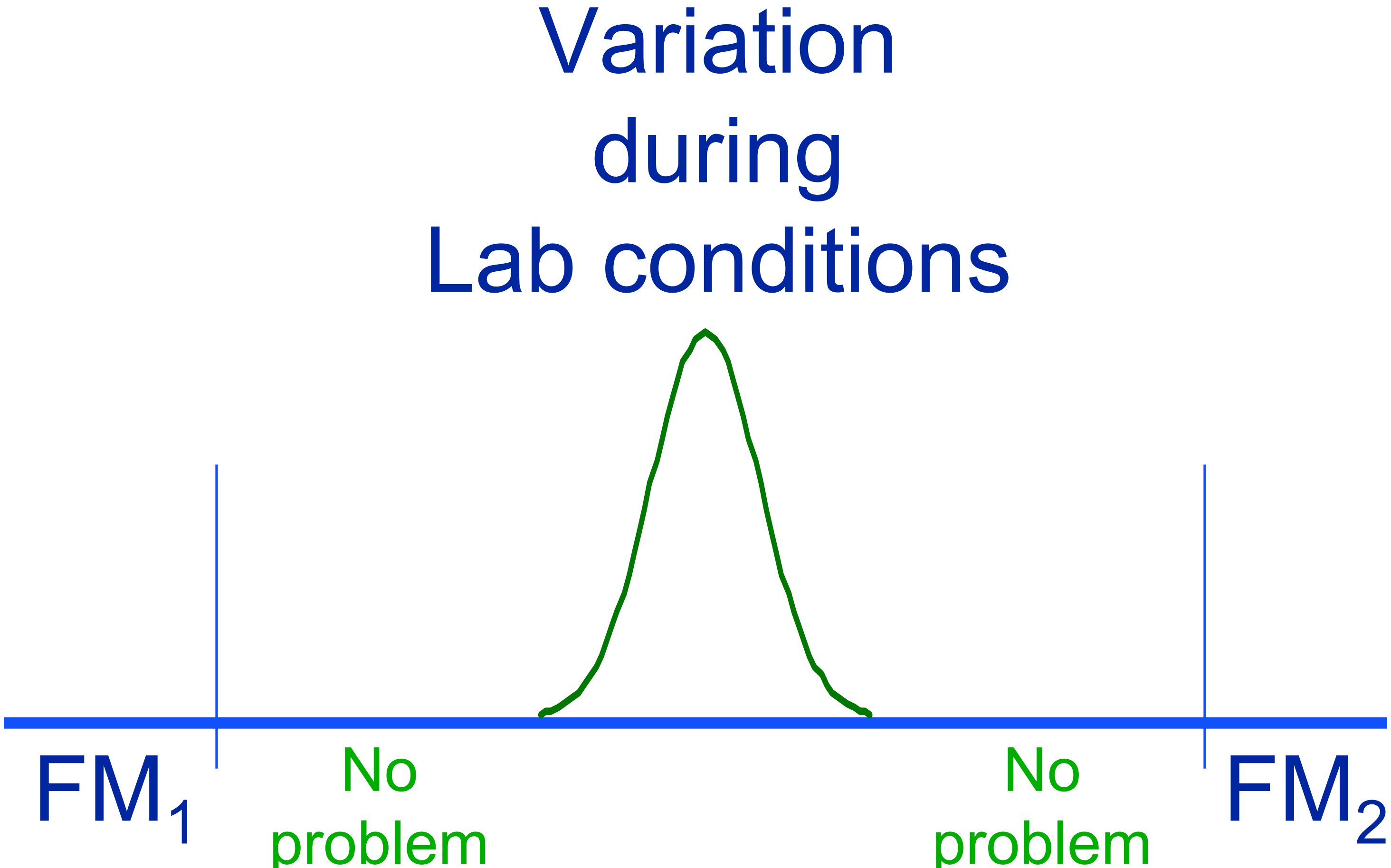



Fig. 13

# Simple problem solving

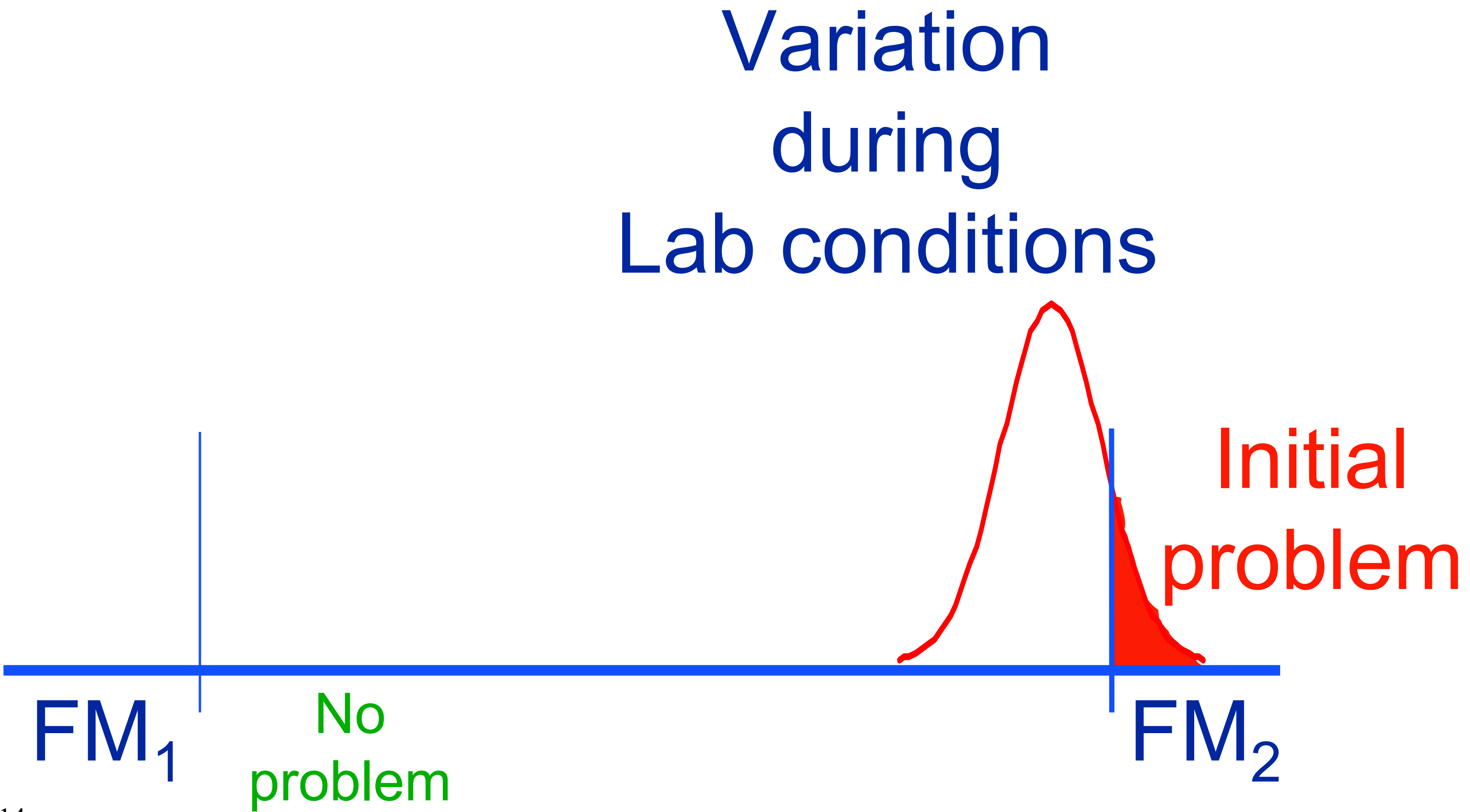



Fig. 14

# Simple problem solving

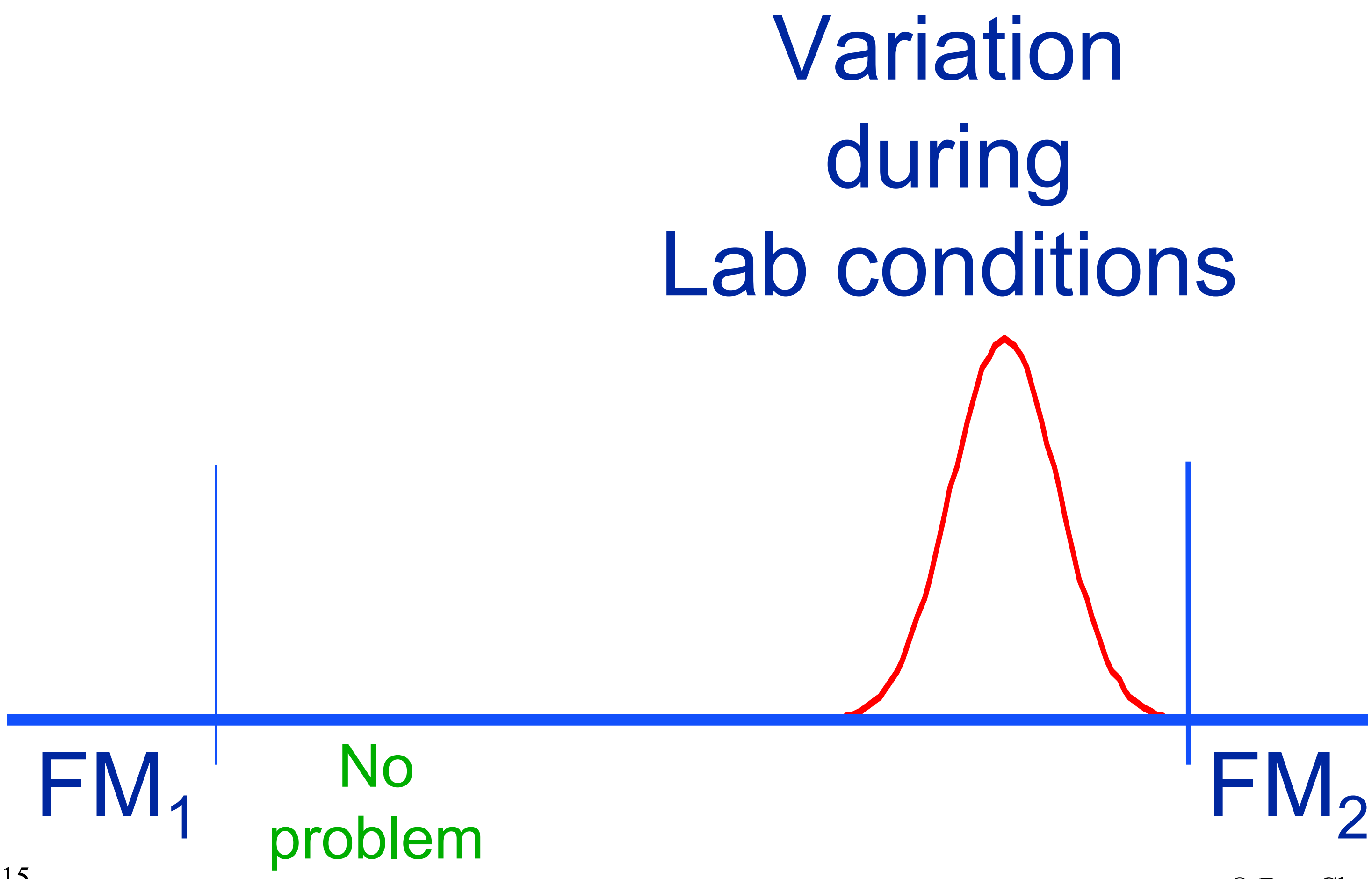



Fig. 15

# Simple problem solving

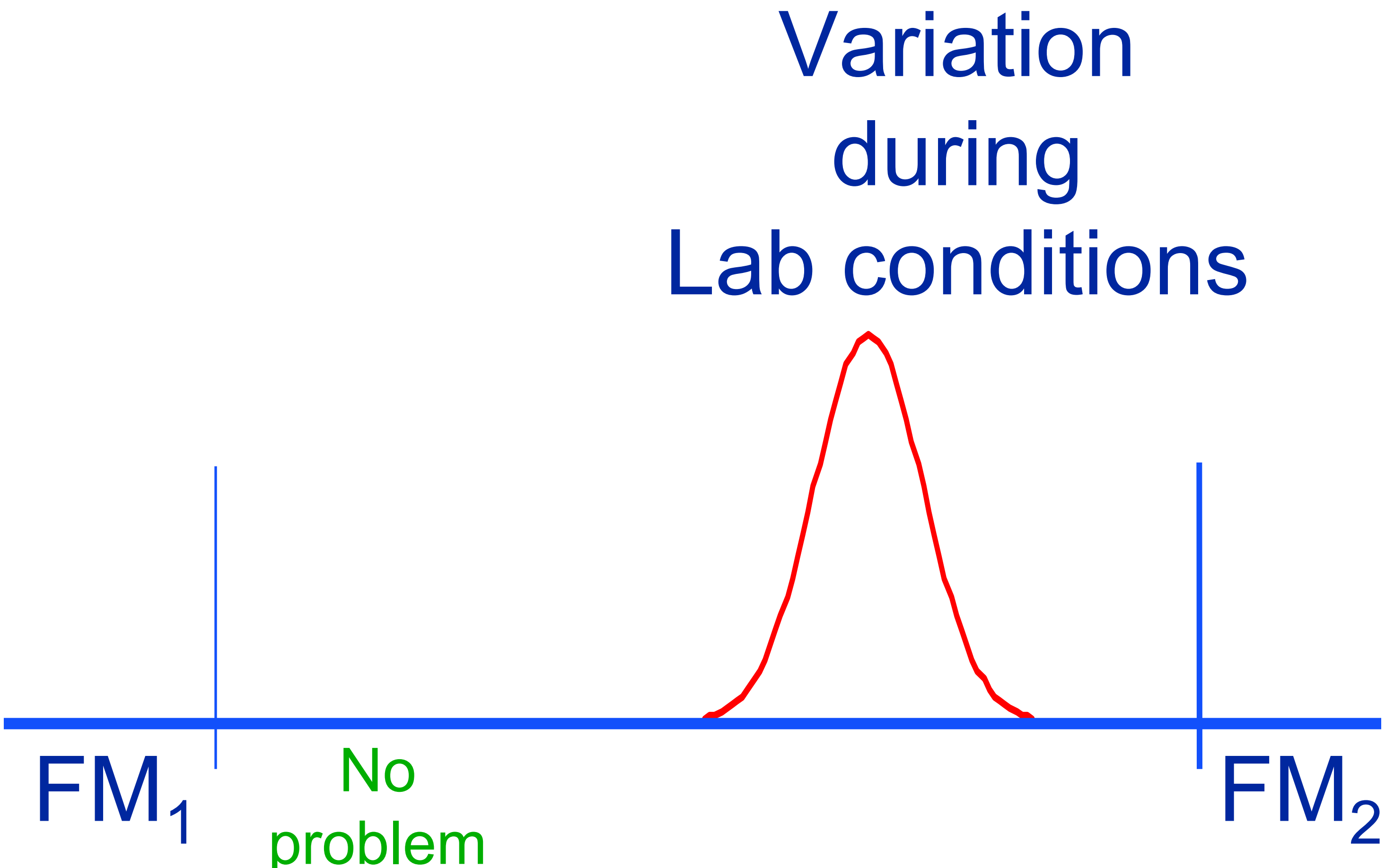



Fig. 16

# Simple problem solved

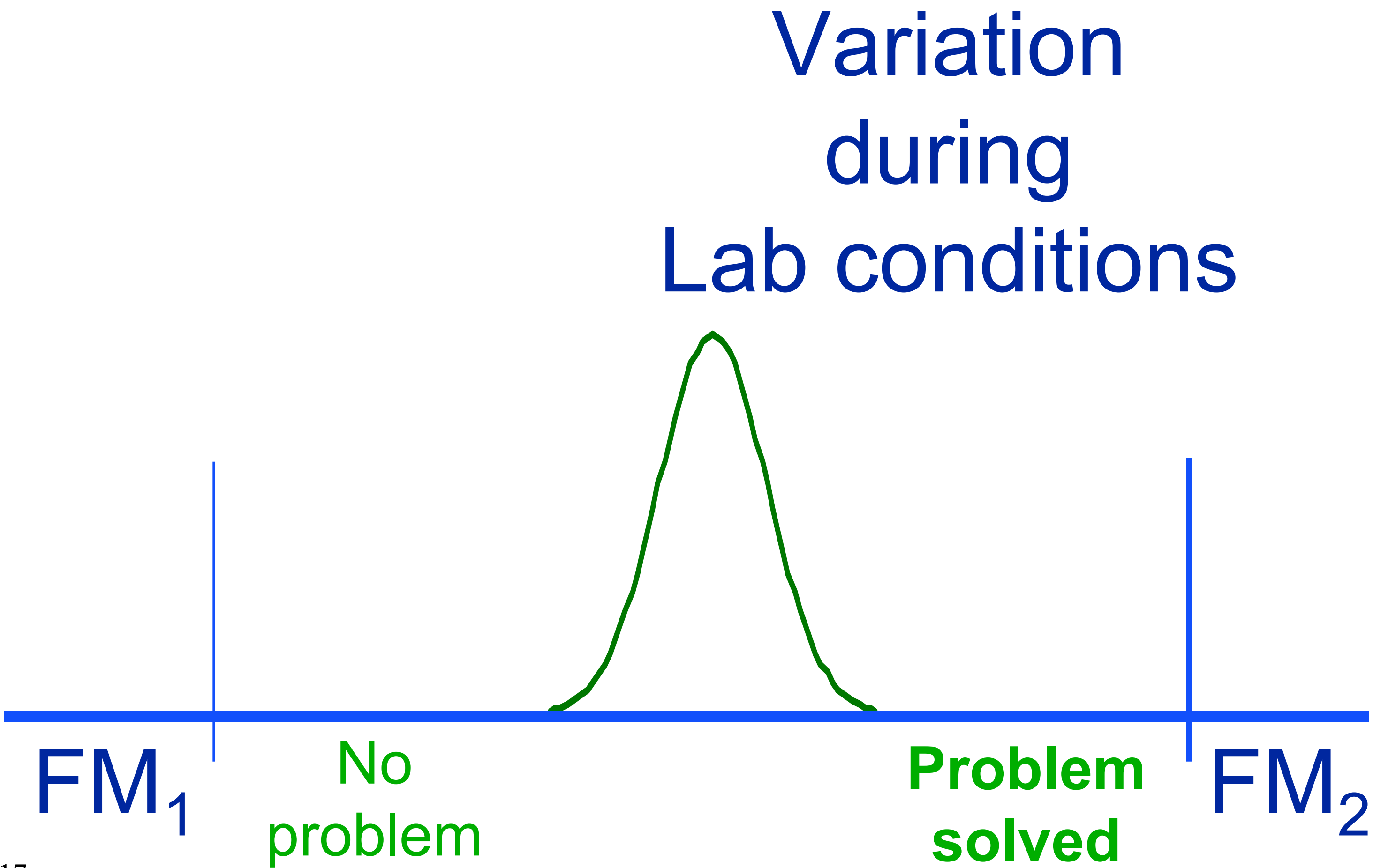



Fig. 17

# Much more difficult problem

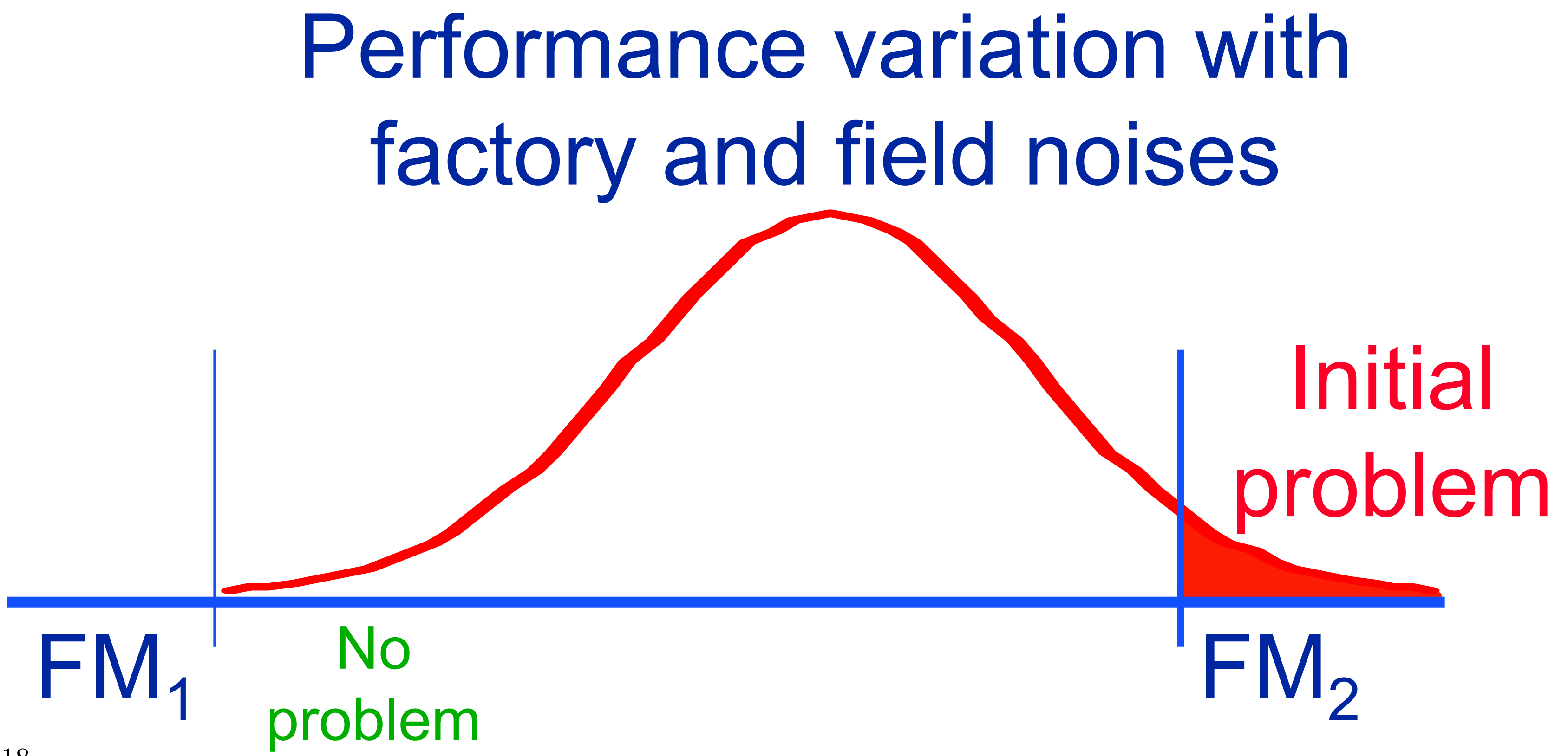



Fig. 18

# Simple solution

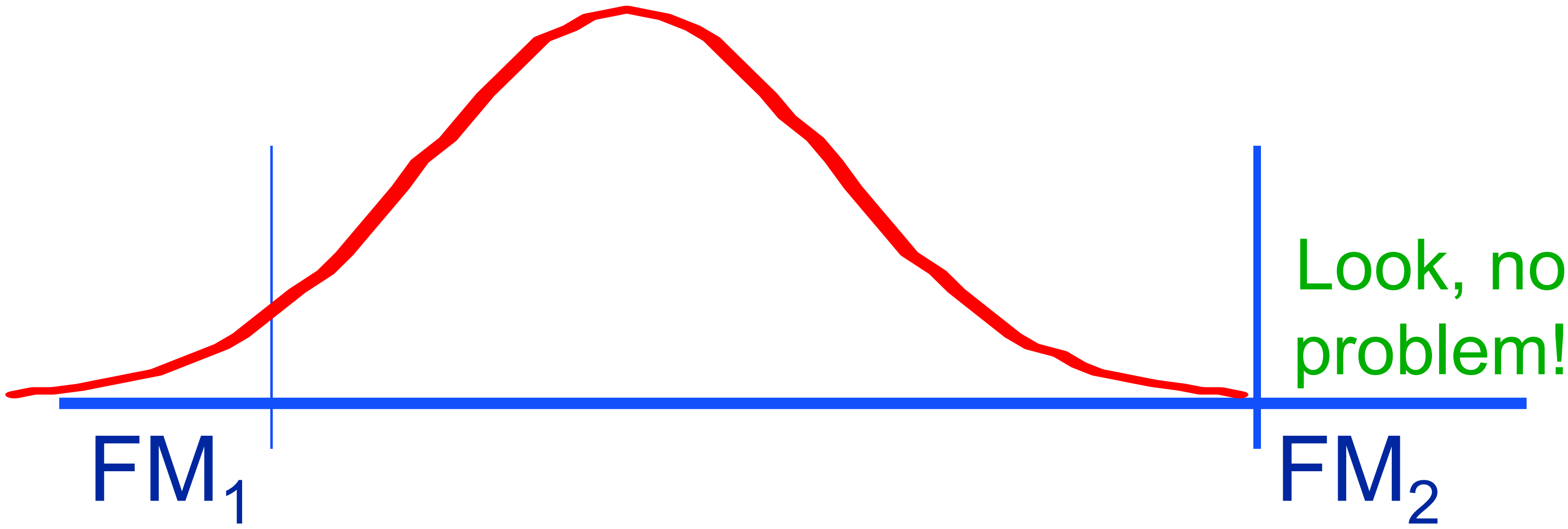



Fig. 19

# Oops!

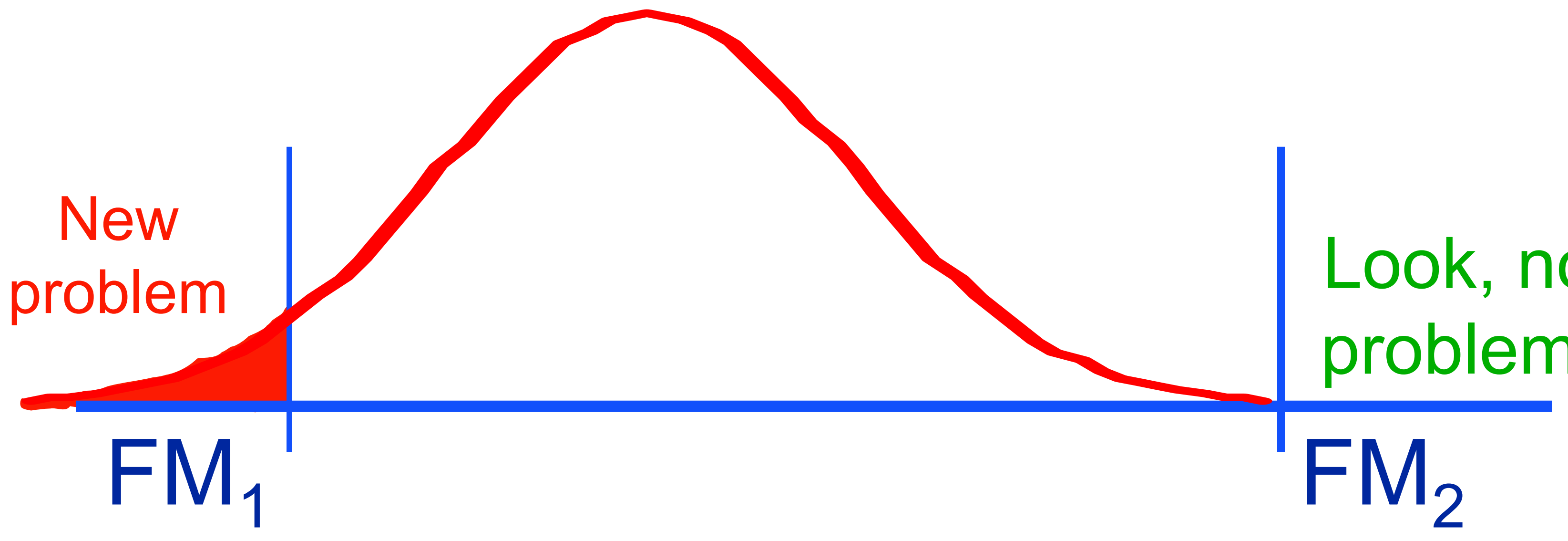



Fig. 20

# Build/test/fix

B/T/F chases problems from $FM_2$ to $FM_1$ – and back again

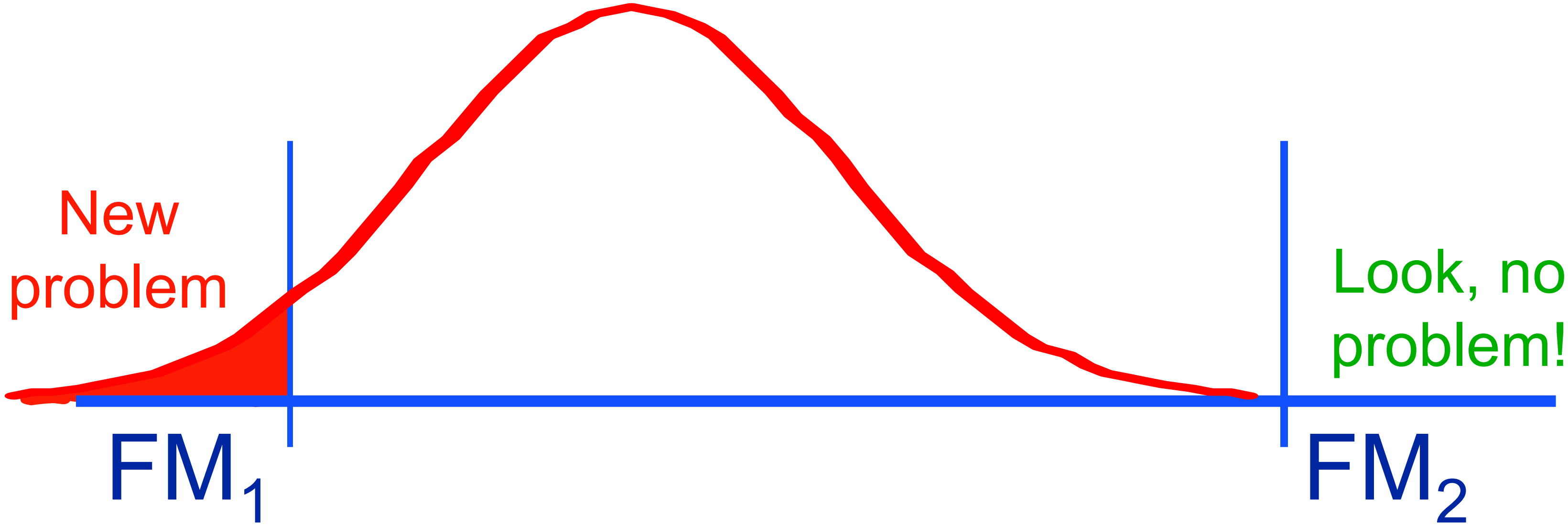



Fig. 21

# Build/test/fix

B/T/F chases problems from $FM_2$ to $FM_1$ – and back again

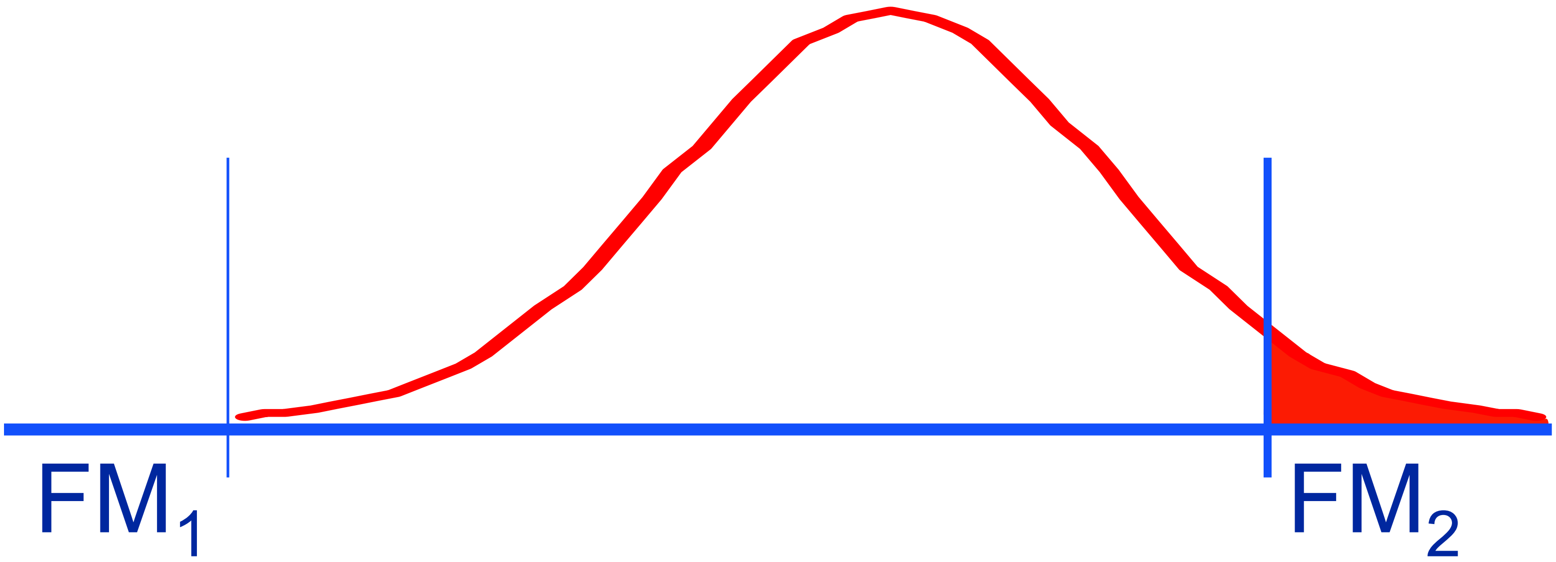



Fig. 22

# Build/test/fix

B/T/F chases problems from $FM_2$ to $FM_1$ – and back again

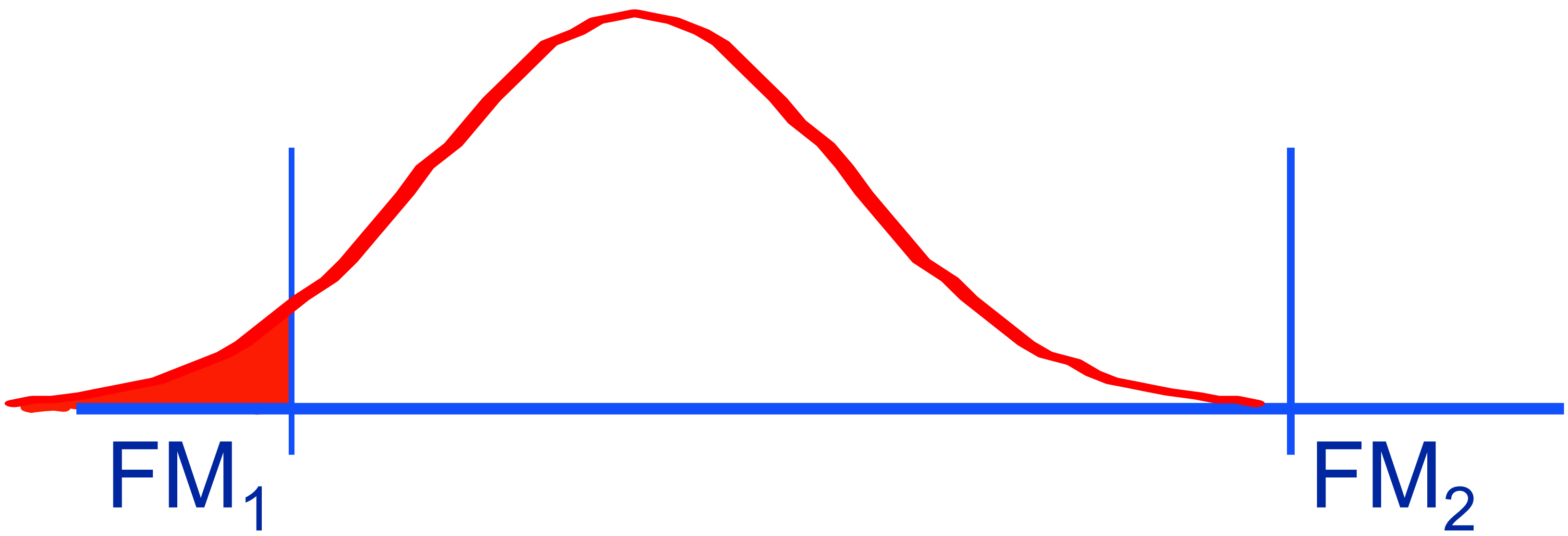



Fig. 23

# Build/test/fix

B/T/F chases problems from $FM_2$ to $FM_1$ – and back again

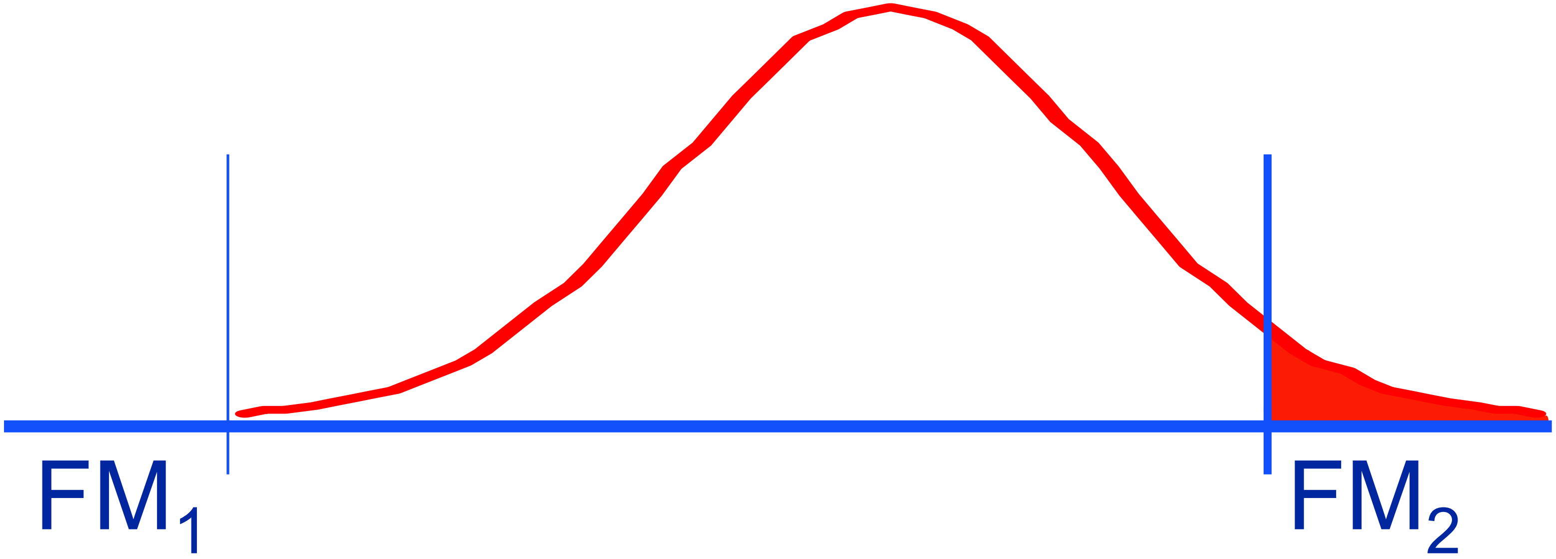



Fig. 24

# Build/test/fix

B/T/F chases problems from $FM_2$ to $FM_1$ – and back again

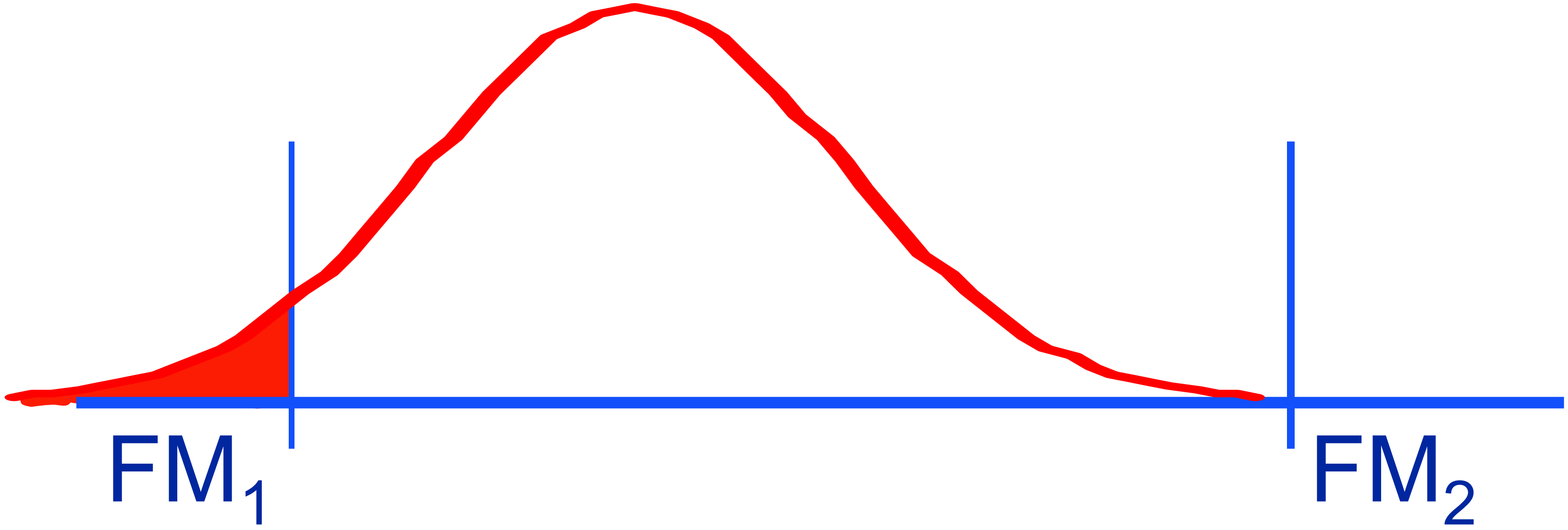



Fig. 25

# Build/test/fix

B/T/F chases problems from $FM_2$ to $FM_1$ – and back again

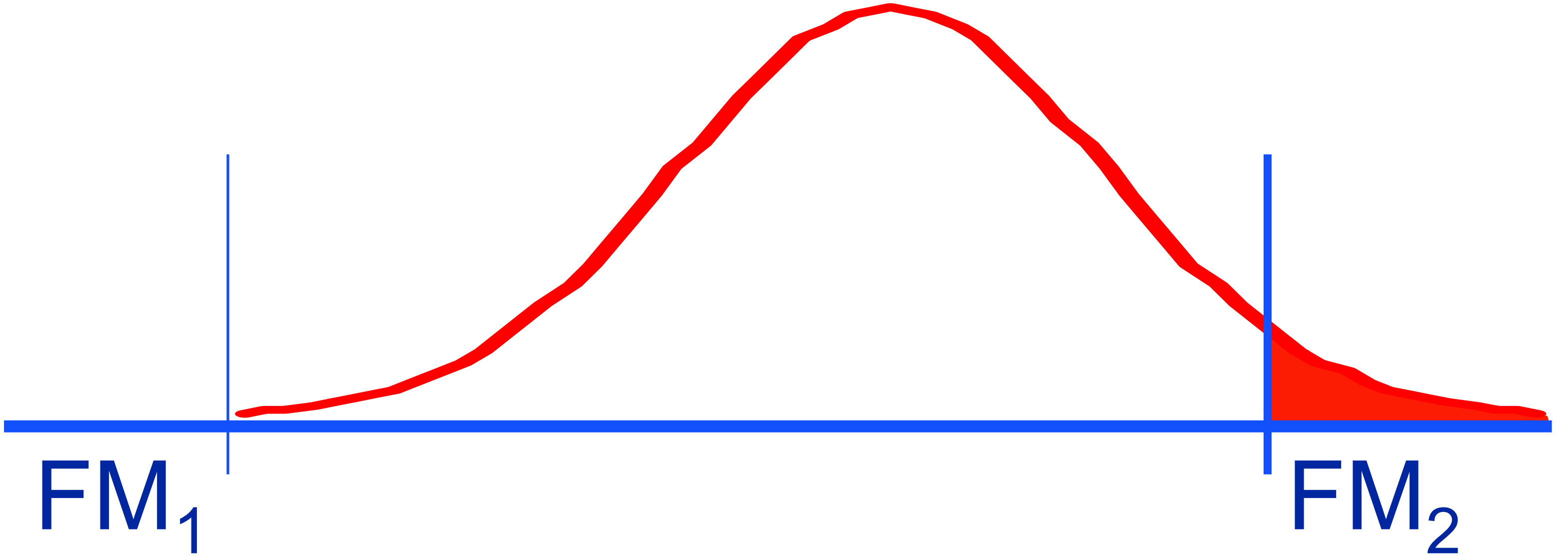



Fig. 26

# Build/test/fix

## B/T/F chases problems from $FM_2$ to $FM_1$ – and back again

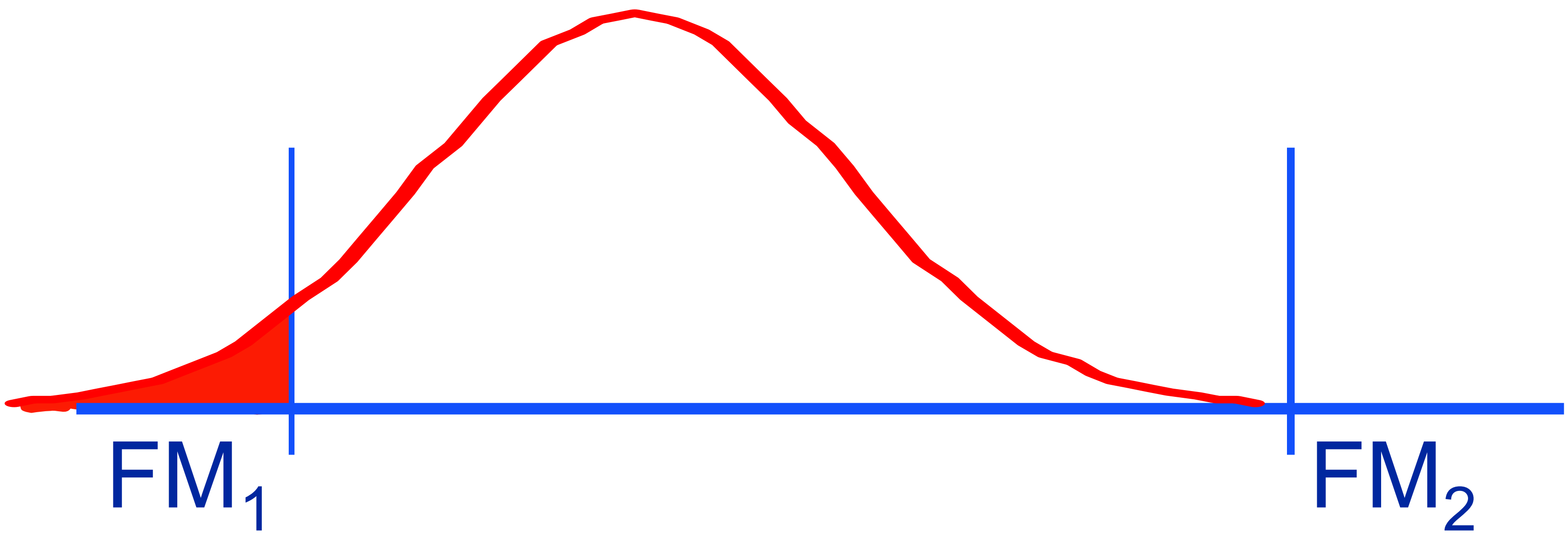



Fig. 27

# Build/test/fix

B/T/F chases problems from $FM_2$ to $FM_1$ – and back again

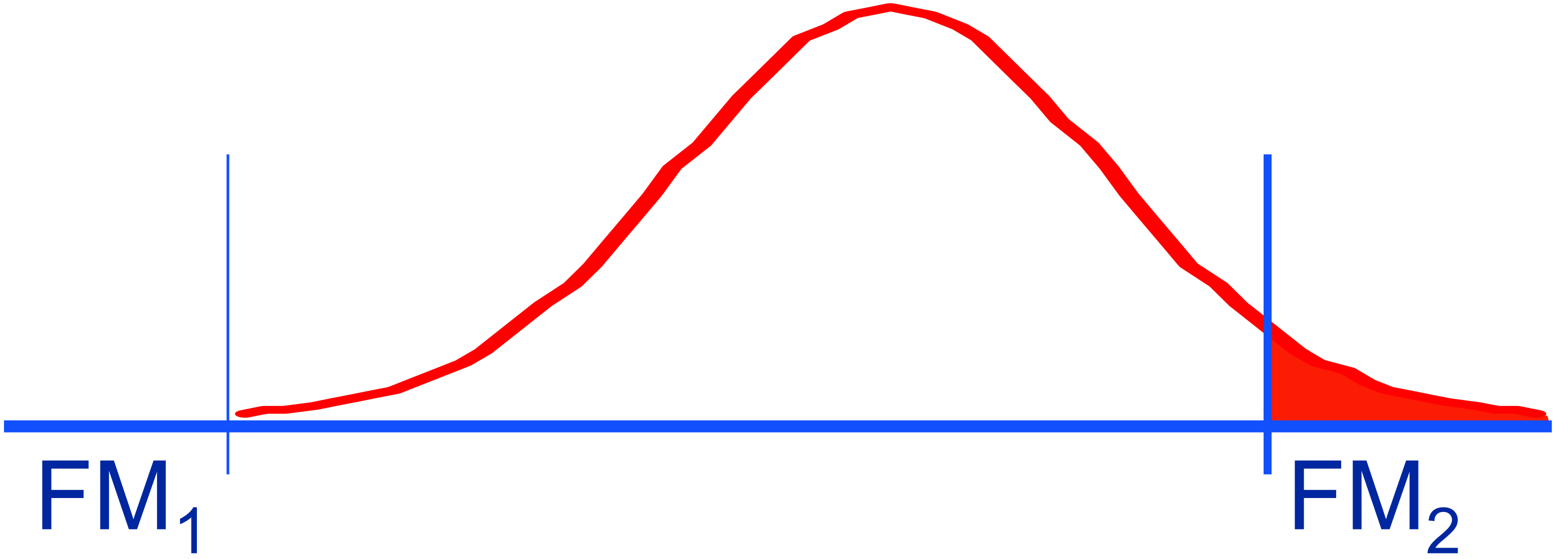



Fig. 28

# Robustness solves problem

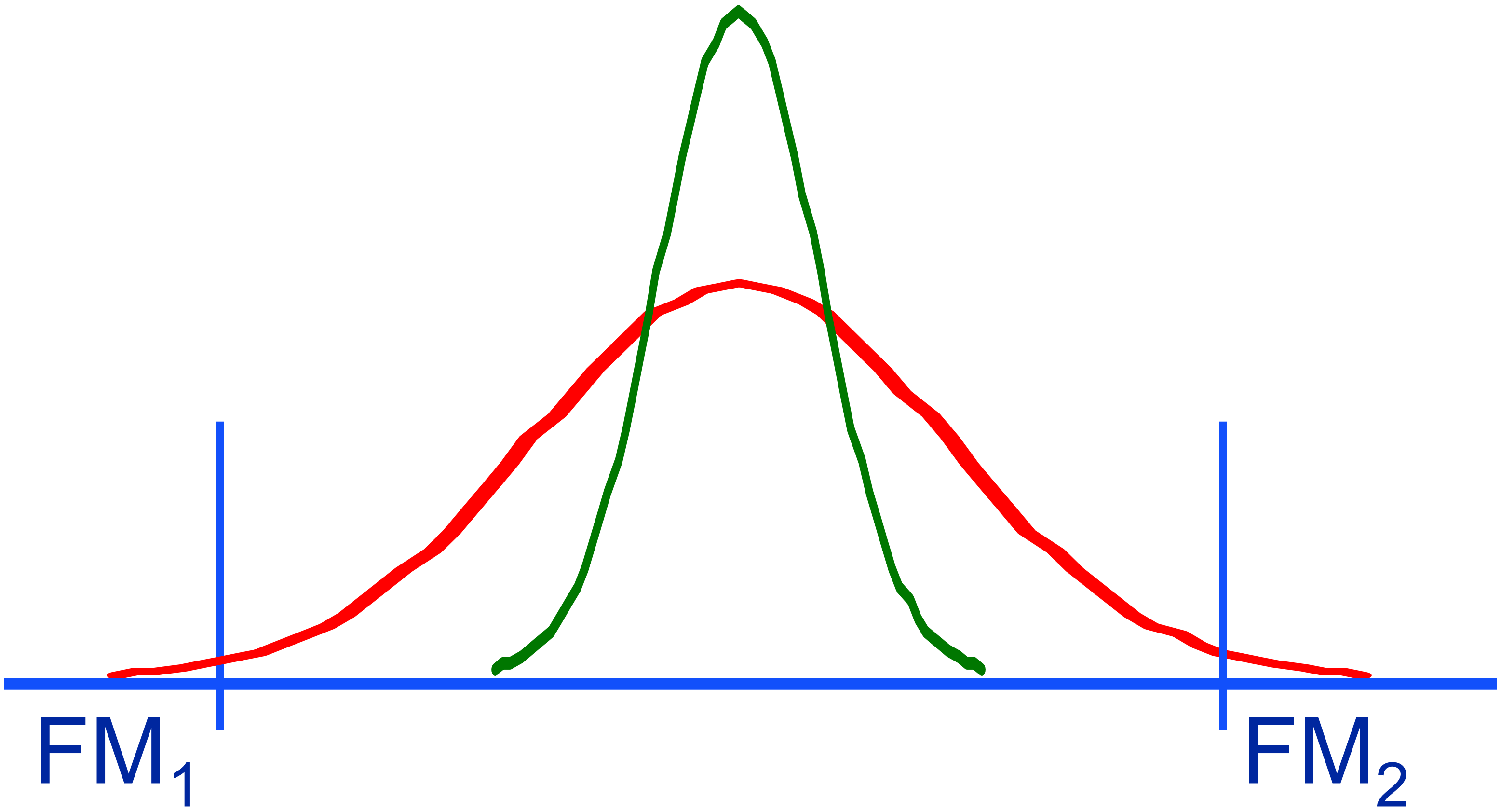



Fig. 29

# Robustness makes money

- Robustness reduces performance variations
- Avoids failure modes
- Achieves customer satisfaction
- Also shortens development time – reduces build/test/fix

Fig. 30

# Noises cause performance variations

- Noises are input variations that we cannot control
- They cause performance variations
  - Which cause failure modes
  - Lose customer satisfaction
- Example: temperature – affects performance of cars, chips, and many other products

Fig. 31

# Three kinds of noises in products

- Environment – ambient temperature
- Manufacturing – no two units of production are exactly alike; machine-to-machine variation
- Deterioration – causes further variations in the components of the system

Fig. 32

# Manufacturing noise in products

- Unit-to-unit variations
- Caused by noises in factory; e.g.,
  - Temperature and humidity variations
  - Cleanliness variations
  - Material variations
  - Machine-tool and cutting-tool variations
- Factory can be made more robust; reduces one type of noise in product

Fig. 33

# Role of noises

- Traditional approach
  - Make product look good early
  - Keep noises small
  - Reactive problem solving does not explicitly address noises
- Proactive problem solving
  - Introduce realistic noises early
  - Minimize effect of noises – robustness

Fig. 34

# Introduction of noises during development

- Product
  - Noises are often small in lab
  - Therefore must consciously introduce noises
- Factory
  - Noises naturally present during production trials
  - Operate in natural manner
    Don’t take special care

Fig. 35

# Introduce product noises early

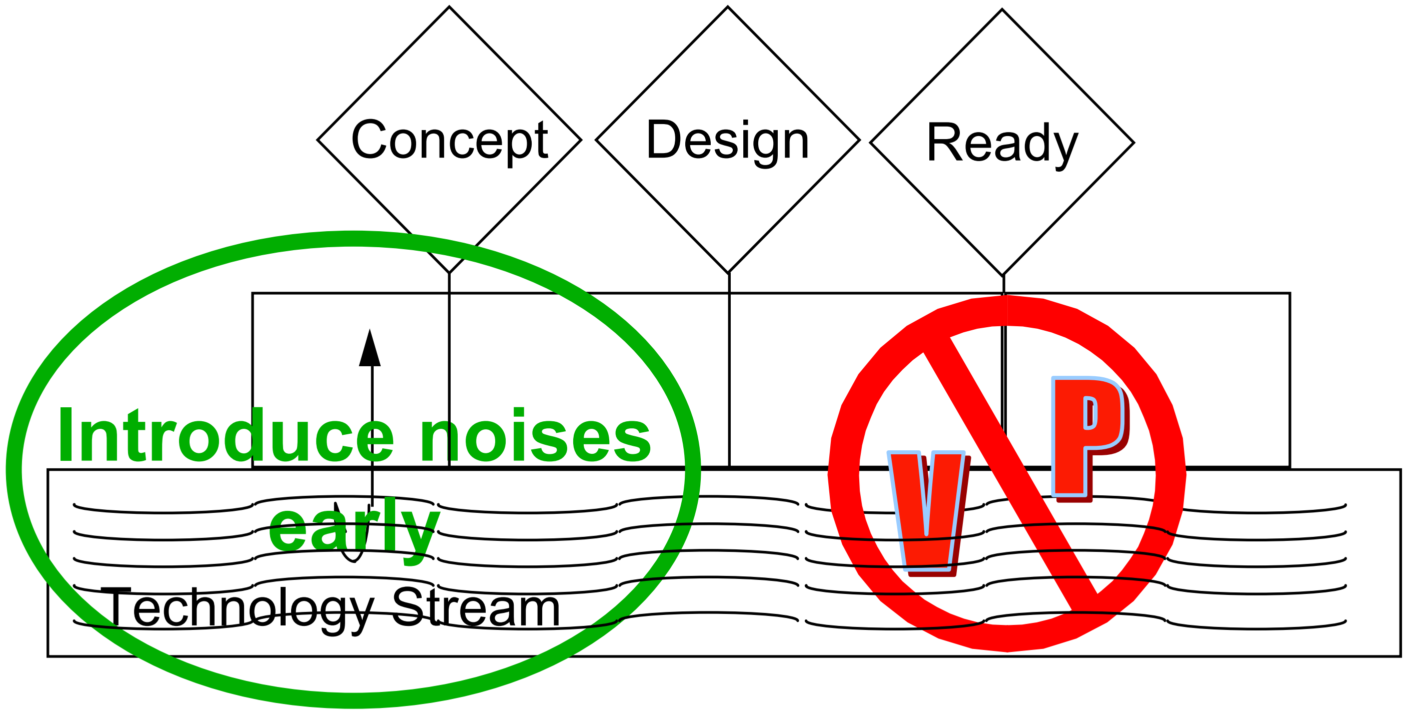
- Drive the performance away from ideal
- Do it early. Don't wait for the factory or customers to introduce noises
- IPDT needs to develop the skill of introducing these noises
- Management needs to design this into the PD process and check that it is done to an appropriate degree

Fig. 36

# Cultural change

- Early introduction of noises goes against engineers' culture of making product look good
- Two most important elements for success:
  - Early introduction of noises
  - Recognition that performance variation must be reduced – while noise values are large

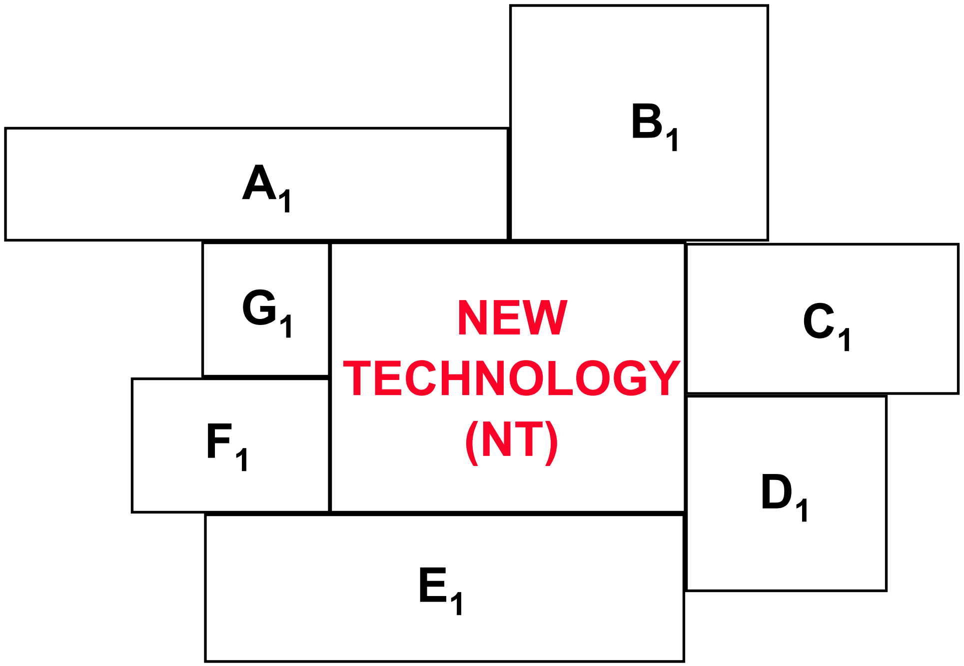
# Problem prevention




Reduce Variations – then no Problems

Fig. 38

# Integration of new technologies




A - G present new noises to NT – cause "integration problems."
Robustness enables smooth integration; minimizes build/test/fix.

Fig. 39

# Robust design

- Achieves robustness; i.e., minimizes effects of noises
- Proactive problem solving – robustness before integration
- Optimize values of critical design (control) parameters to minimize effects of noise parameters

# The engineered system

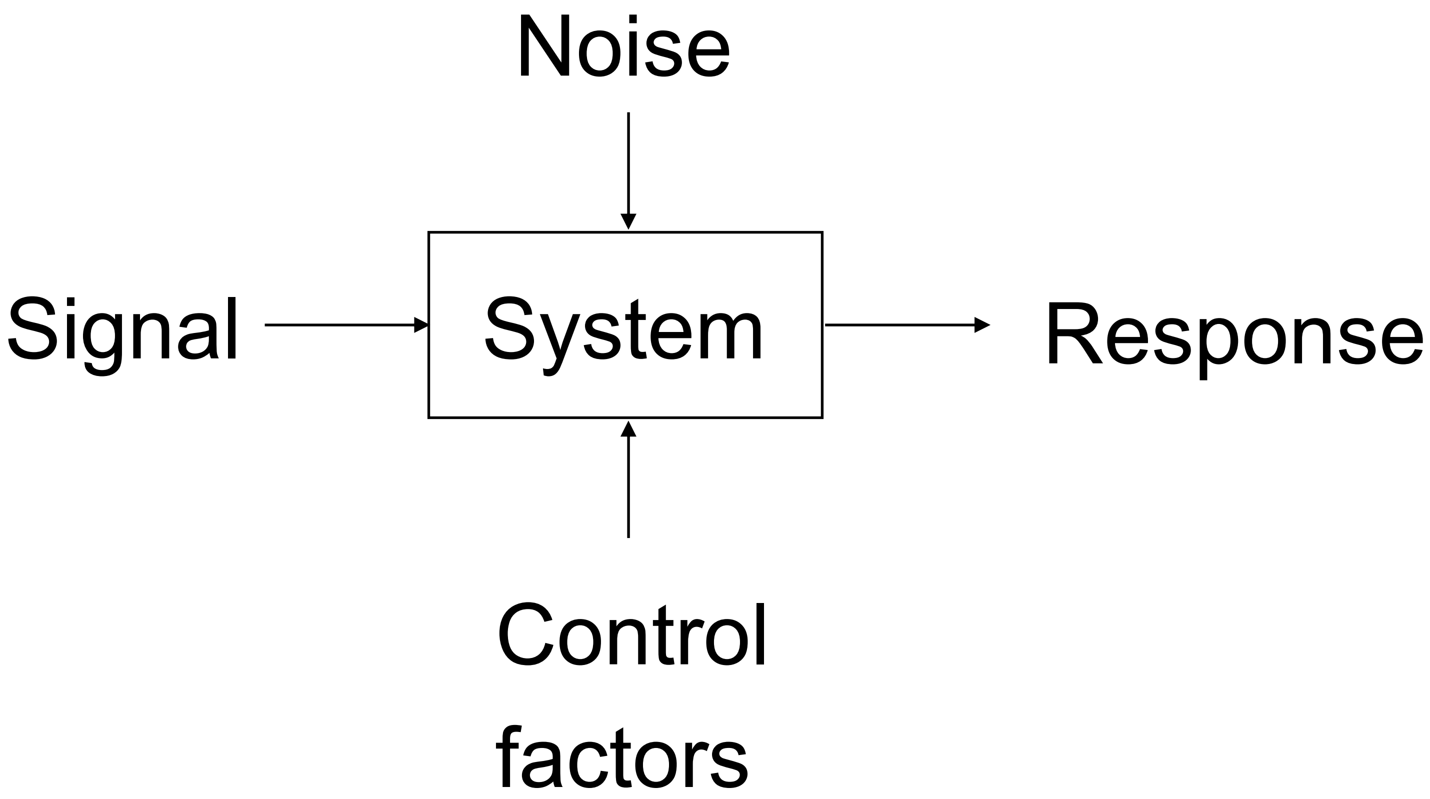



Fig. 41

# Ideal response

- Want Ideal Response to Signal – usually straight-line function
- Actual response is determined by values of control factors and noise factors
- If noise factors are suppressed early, then difficult problems only appear late
- Introduce noises early!

# Actual response

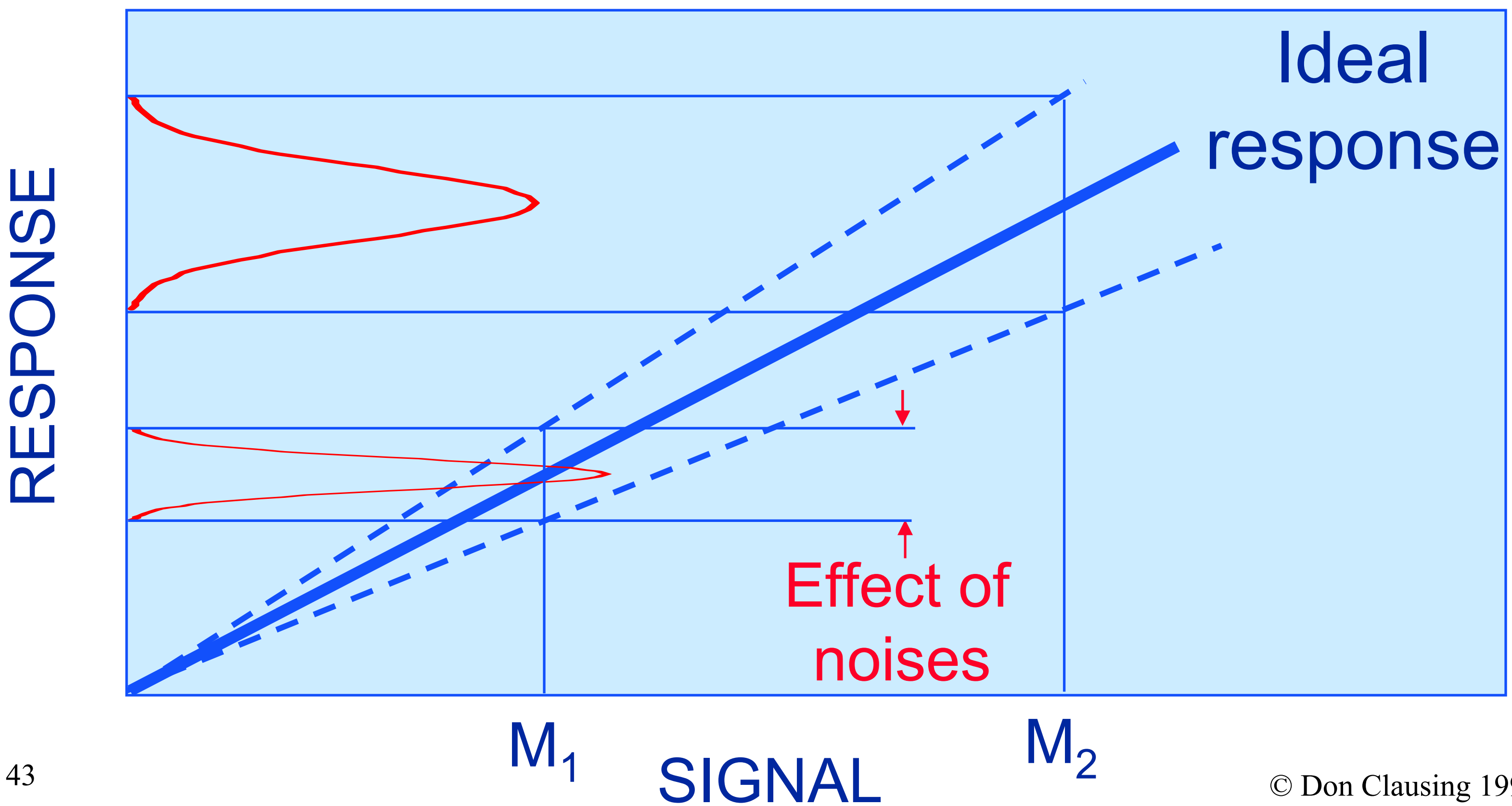



Fig. 43

# Robustness

- Keeps the performance (response) of the system acceptably close to the ideal function
- Minimizes effect of noise factors
- Key to proactive improvement

Fig. 44

# Parameter design

Purpose – to optimize the nominal values of critical system parameters; for example:

- Capacitor is selected to be 100 pF
- Spring is selected to be 55 N/mm

Improves performance so that it is close to ideal – under actual conditions

Fig. 45

# Signal/noise ratio

- Measure of deviation from ideal performance
- Based on ratio of  deviation from straight line divided by slope of straight line
- Many different types – depends on type of performance characteristic
- Larger values of SN ratio represent more robust performance

Fig. 46

# Critical control parameters

- Strongly affect performance of the system
- IPDT can control (select) the value
- Fault trees help IPDT to identify
- Complex systems have hundreds of critical control parameters

Note: IPDT is Integrated Product Development Team

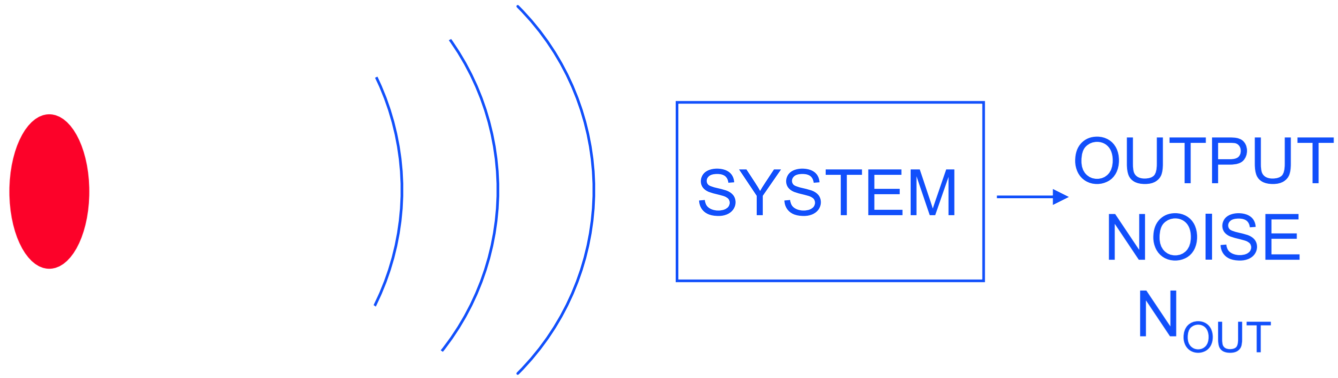
Fig. 47

# Important noise strategy

- Not all sources of noise need to be used
- Identify key noise functional parameter; e.g.
  - Interface friction in paper stack
  - EM radiation in communications
- Specific source is not important
- Magnitude enables quick optimization
  - Specs on noise are not important
  - Worse noise in field is not important

Fig. 48

# Noise strategy




NOISE SOURCE

INPUT NOISE $N_{IN}$

STRATEGY
- HOLD $N_{IN}$ CONSTANT
- MINIMIZE $N_{OUT}$

NOT IMPORTANT
- SPECIFIC SOURCE
- MAGNITUDE OF $N_{IN}$

Fig. 49

# Successful noise strategy

- Enables quick optimization
- Provides best performance inherent in concept
  - Even when future noise sources change
  - Even when future noises are larger
  - Even when spec changes
- Performance is as robust as possible
- Future improvements will require new concept

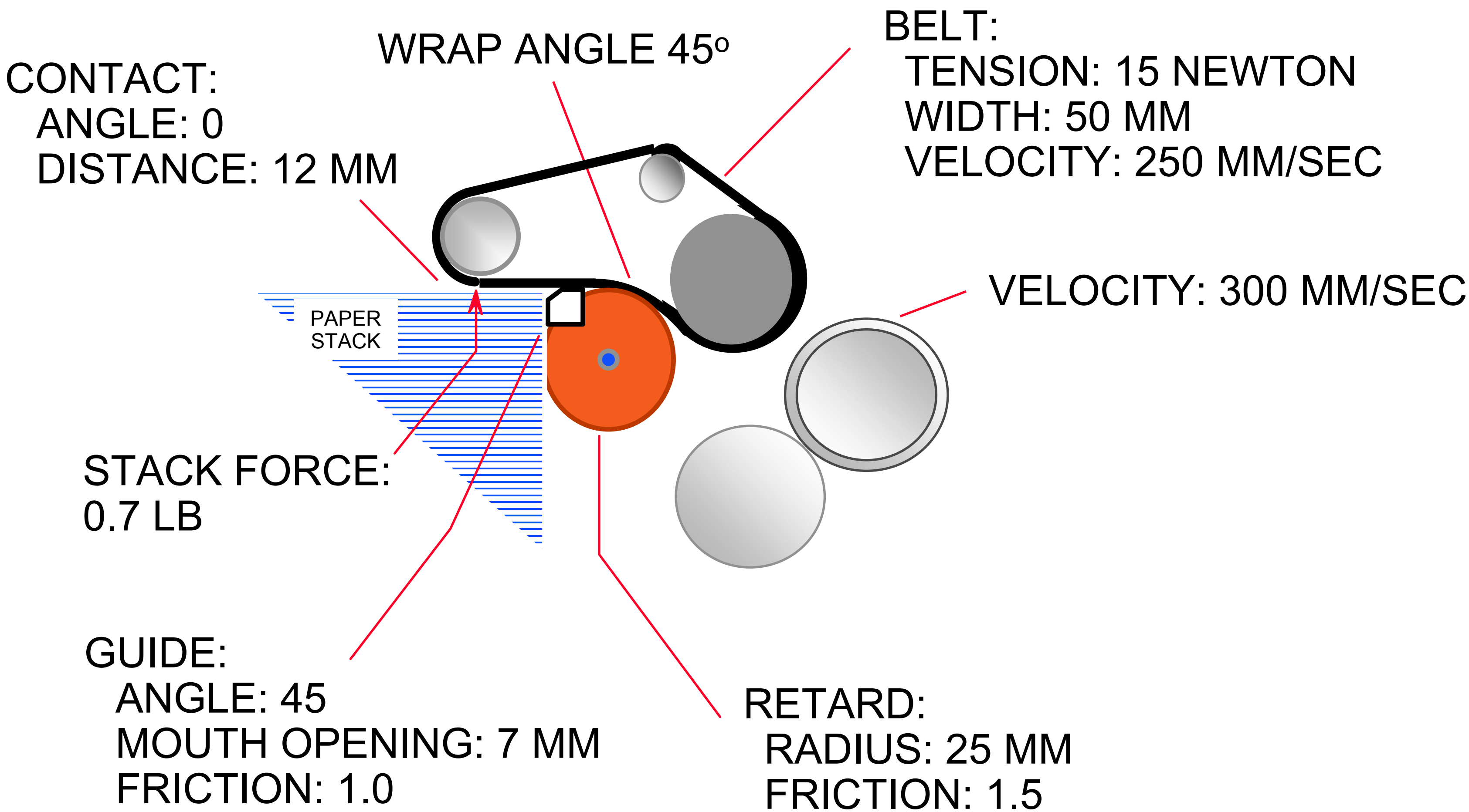
Fig. 50

# Important steps in parameter design

- Define ideal performance
- Select best SN definition
- Identify critical parameters
- Develop sets of noises that will cause performance to deviate from ideal
- Use designed experiments to systematically optimize control parameters

Fig. 51

# Critical parameter drawing for paper feeder




**Optimized values of critical parameters guide the detailed design**

Fig. 52

# Culture change

- Emphasize
  - Ideal function
  - Noise strategy
  - Parameter design
- Do it early! Be proactive!

# Improvement activities

- Robust design – minimize variation
  - **Parameter design** – optimization of nominal values of critical design parameters
  - **Tolerance design** – economical precision around the nominal values
- **Mistake minimization**
- Three activities requiring very different approaches

Fig. 54

# Tolerance design

- Select economical precision
- Determines typical machine-to-machine variation around optimized nominal value
- Primary task is selection of production process (or quality of purchased component) – determines variation of production
- Then put tolerance on drawing

# Mistake Minimization

- Mistakes are human errors
  - Diode is backwards
  - Cantilevered shaft has excessive deflection
- Mistake minimization approach:
  - Mistake prevention
  - Mistake elimination

Fig. 56

# Summary of improvement activities

- Robust design
  - **Parameter design** – optimization of nominal values of critical design parameters
  - **Tolerance design** – economical precision around the nominal values
- **Mistake minimization**

Fig. 57

# Planning for improvement – schedule

- Accept only robust technologies
- Complete optimization early
  - Critical parameter drawing displays requirements for detailed design
  - Detailed design objective is to make low-cost design that achieves optimized nominal values
- Do tolerance design during detailed design
- Also plan mistake minimization

Fig. 58

# Technology development

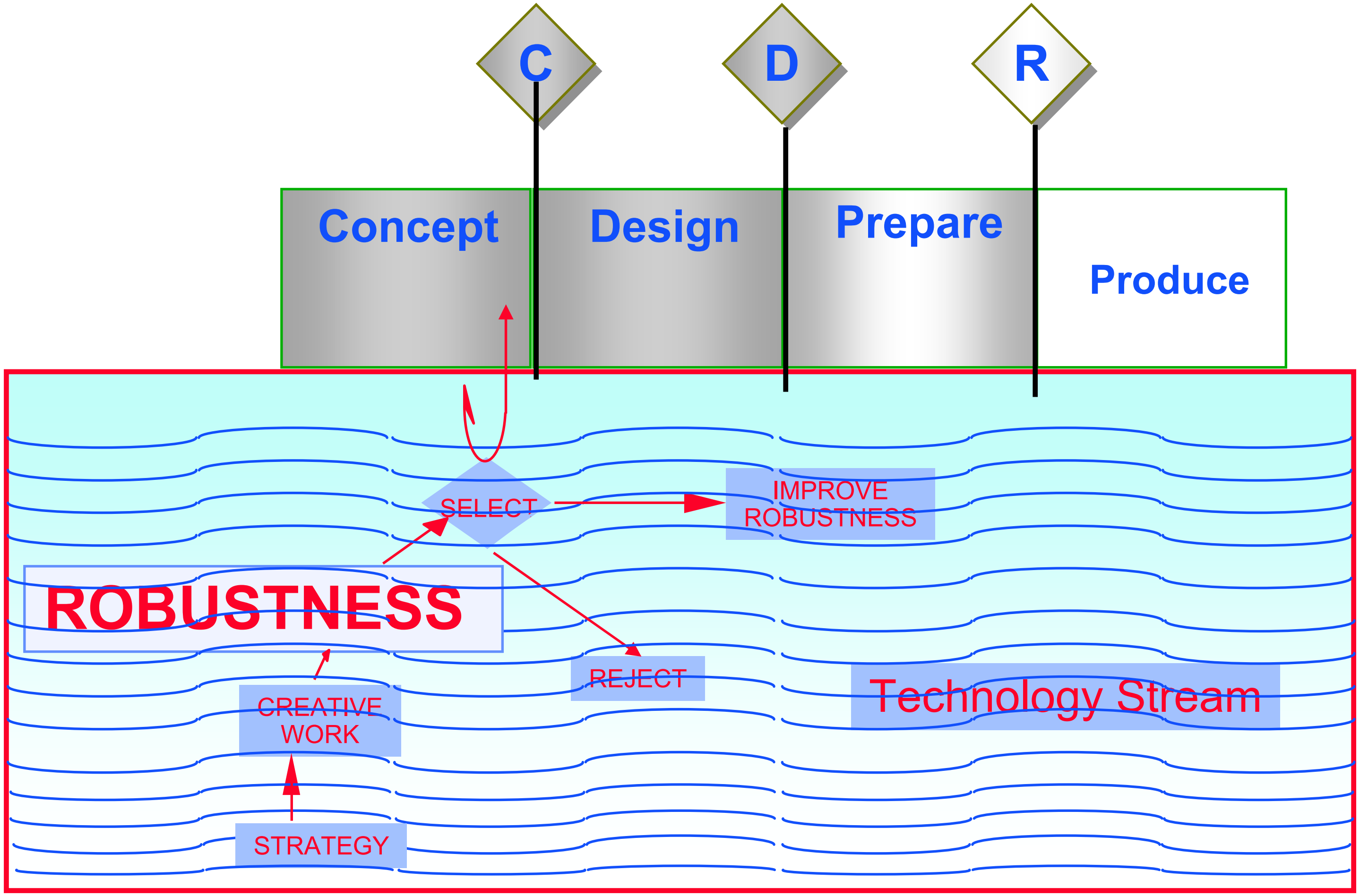
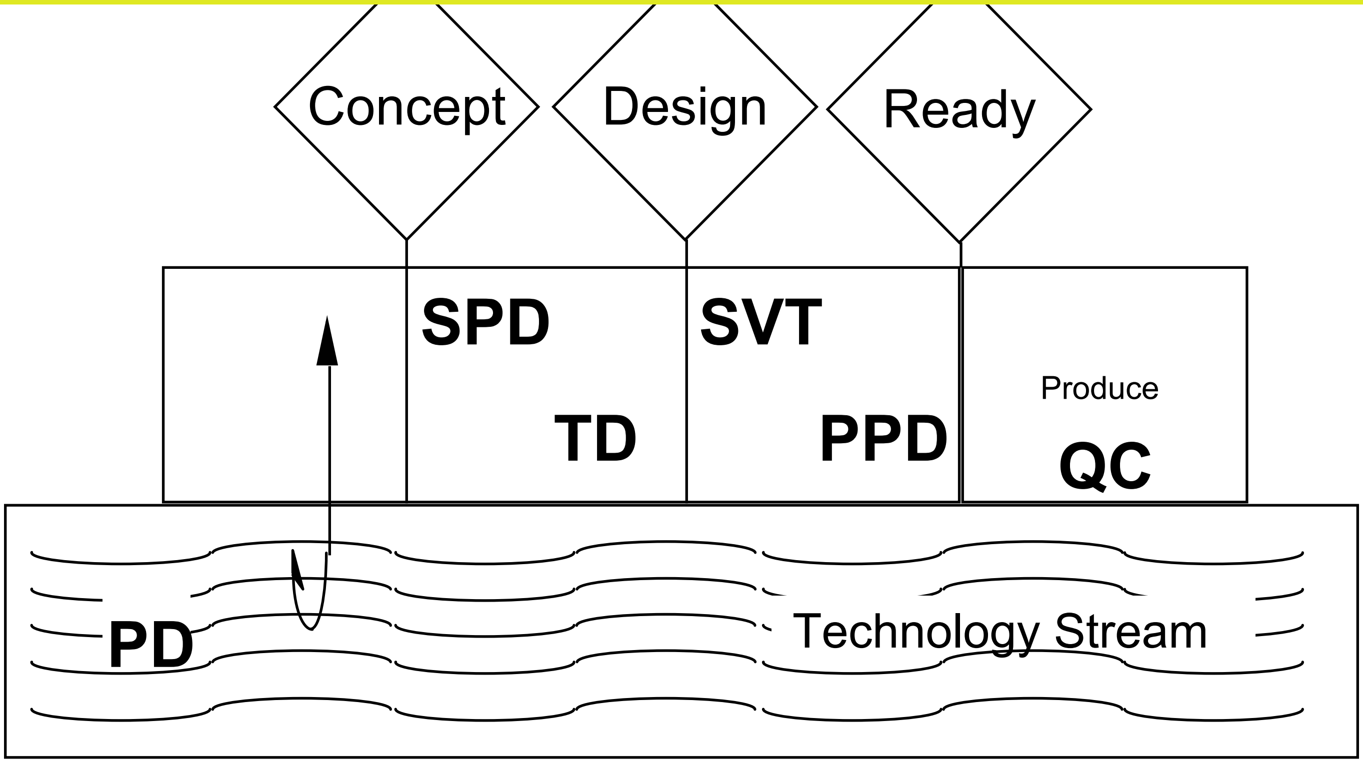



Fig. 59

# Robust design timing



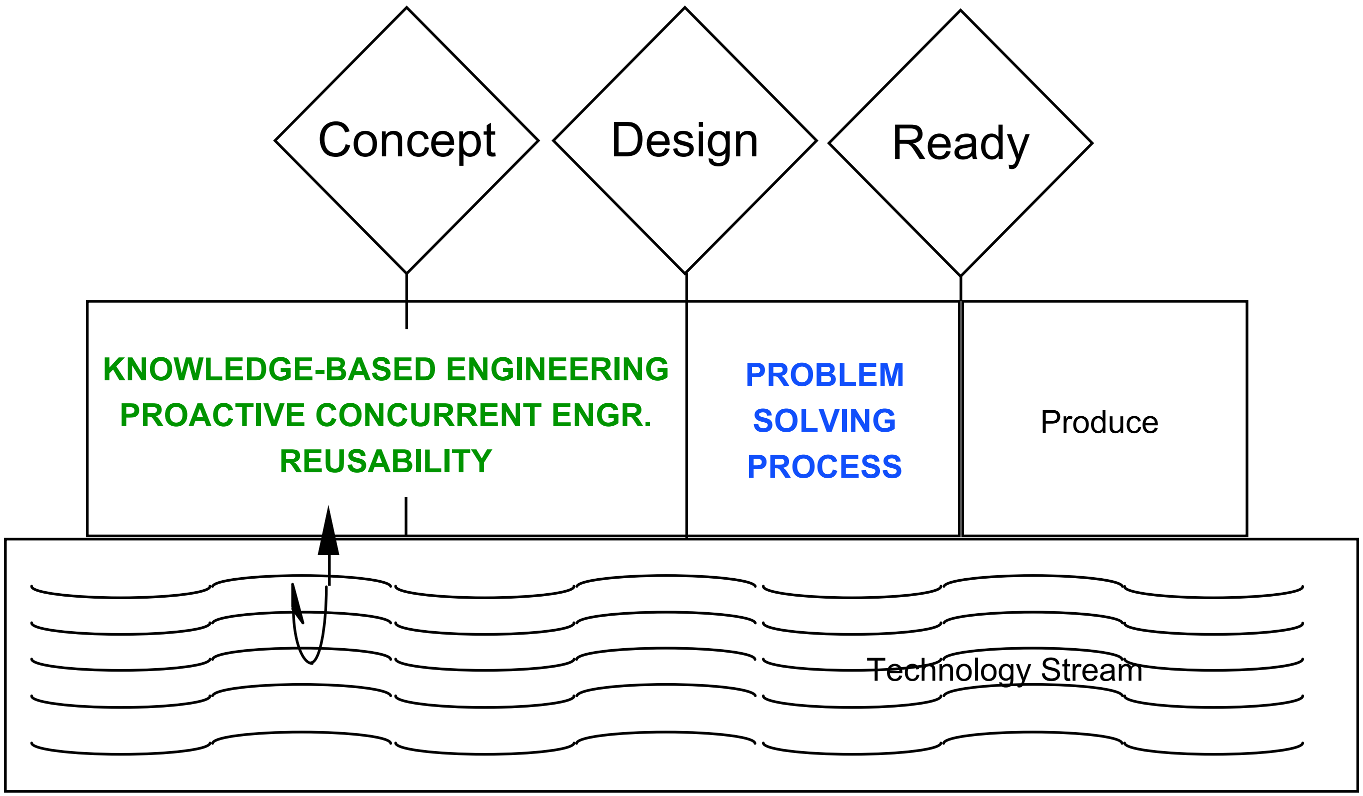

PD – PARAMETER DESIGN, NEW PRODUCT & PROCESS TECHNOLOGIES
SPD – SYSTEM (PRODUCT) PARAMETER DESIGN
TD – TOLERANCE DESIGN
SVT – SYSTEM VERIFICATION TEST
PPD – PROCESS PARAMETER DESIGN
QC – ON LINE QUALITY CONTROL (FACTORY FLOOR)

Fig. 60

# Inspection for robustness

- Have noises been applied?
- Have all failure modes been exercised?
- Has optimization made the failure modes more difficult to excite?
- Has head-on comparison been made with benchmark?
  – Same set of noises applied to both
  – Our system (or subsystem) has better robustness

# Mistake minimization




PROACTIVE REACTIVE

Fig. 62

# Quality and reliability

- Robust design plus mistake minimization is the effective approach to the improvement of quality/reliability - usually also leads to the lowest total cost
- Q & R are not separate subjects – manage robust design and mistake minimization and Q & R are the result

Fig. 63

# Summary

- Early development of **robustness** is key to proactive improvement
  - Early application of noises
  - Optimize robustness – avoid all failure modes
- Supplement with **tolerance design** and **mistake minimization**

Fig. 64

# Benefits of robust design

- Shorter time to market
- Customer satisfaction – performance closer to ideal
- Reduced manufacturing cost
- Flexible integration of systems – responsiveness to the market

Fig. 65

End