Control and noise factors

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Red border: emphasized slides

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The engineered system

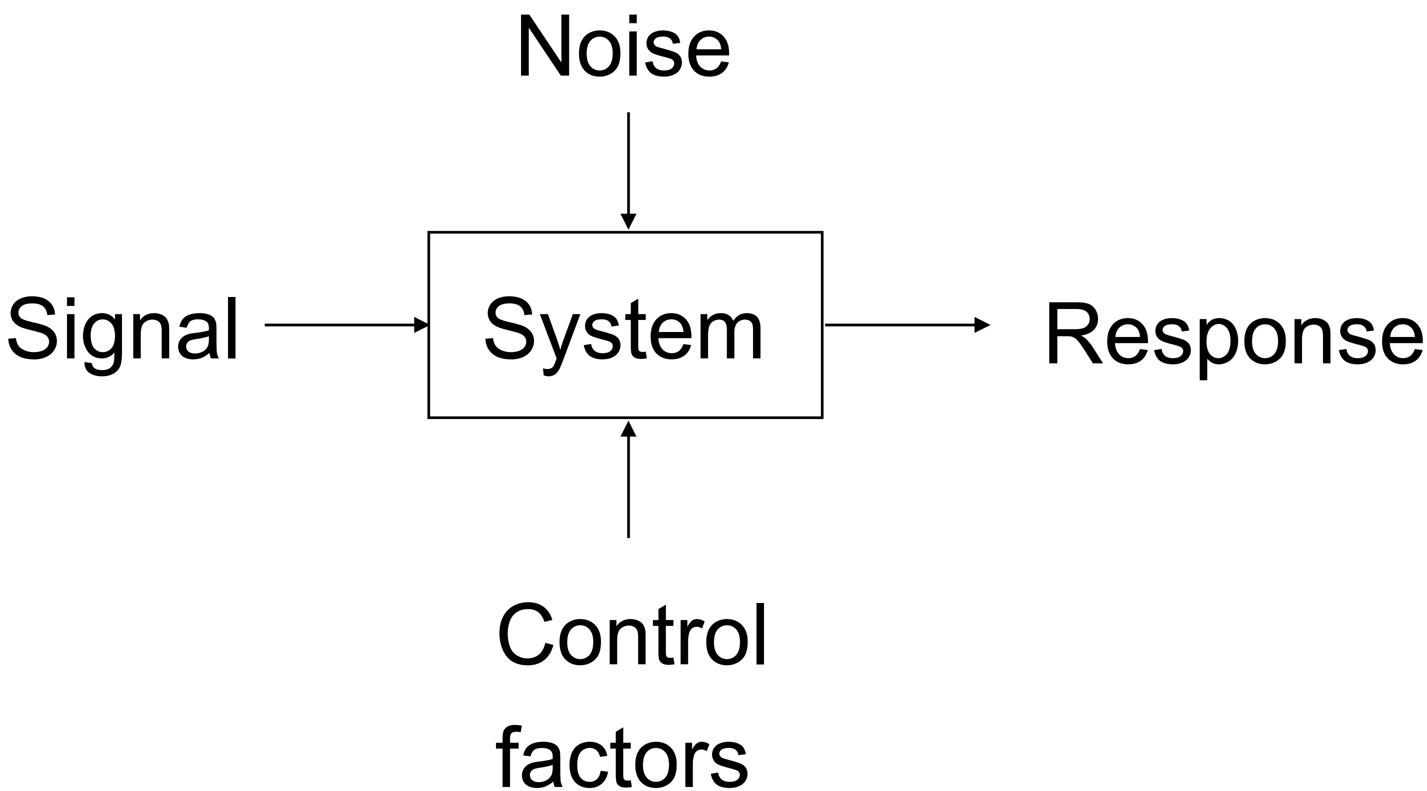


Fig. 2

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

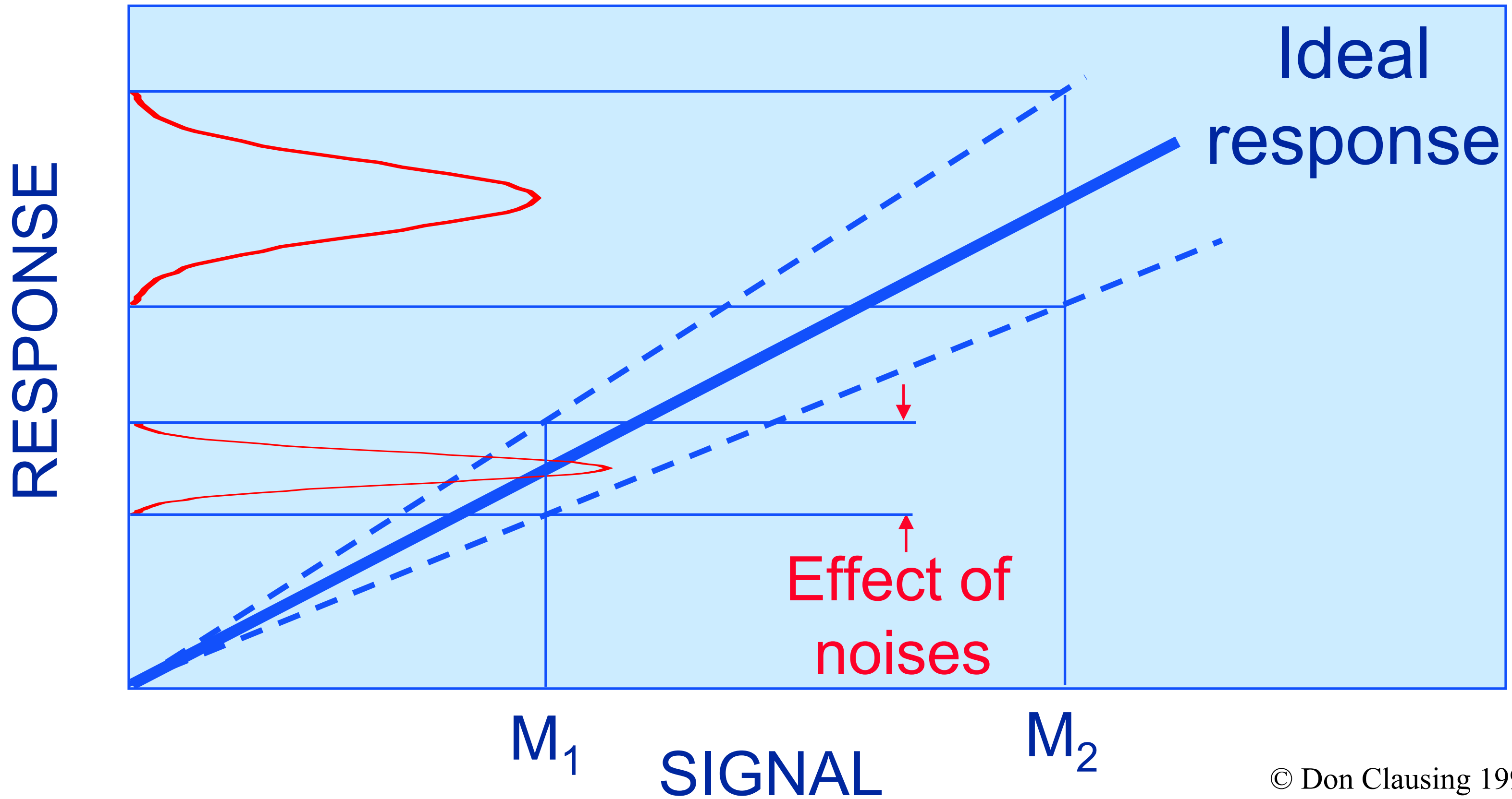


Fig. 4

Response depends on:

- Value of signal factor
- Values of control factors
  - Engineers can select values
  - Examples: dimensions, electrical characteristics
- Values of noise factors
  - Engineers cannot select values
  - Examples: temperature, part variations

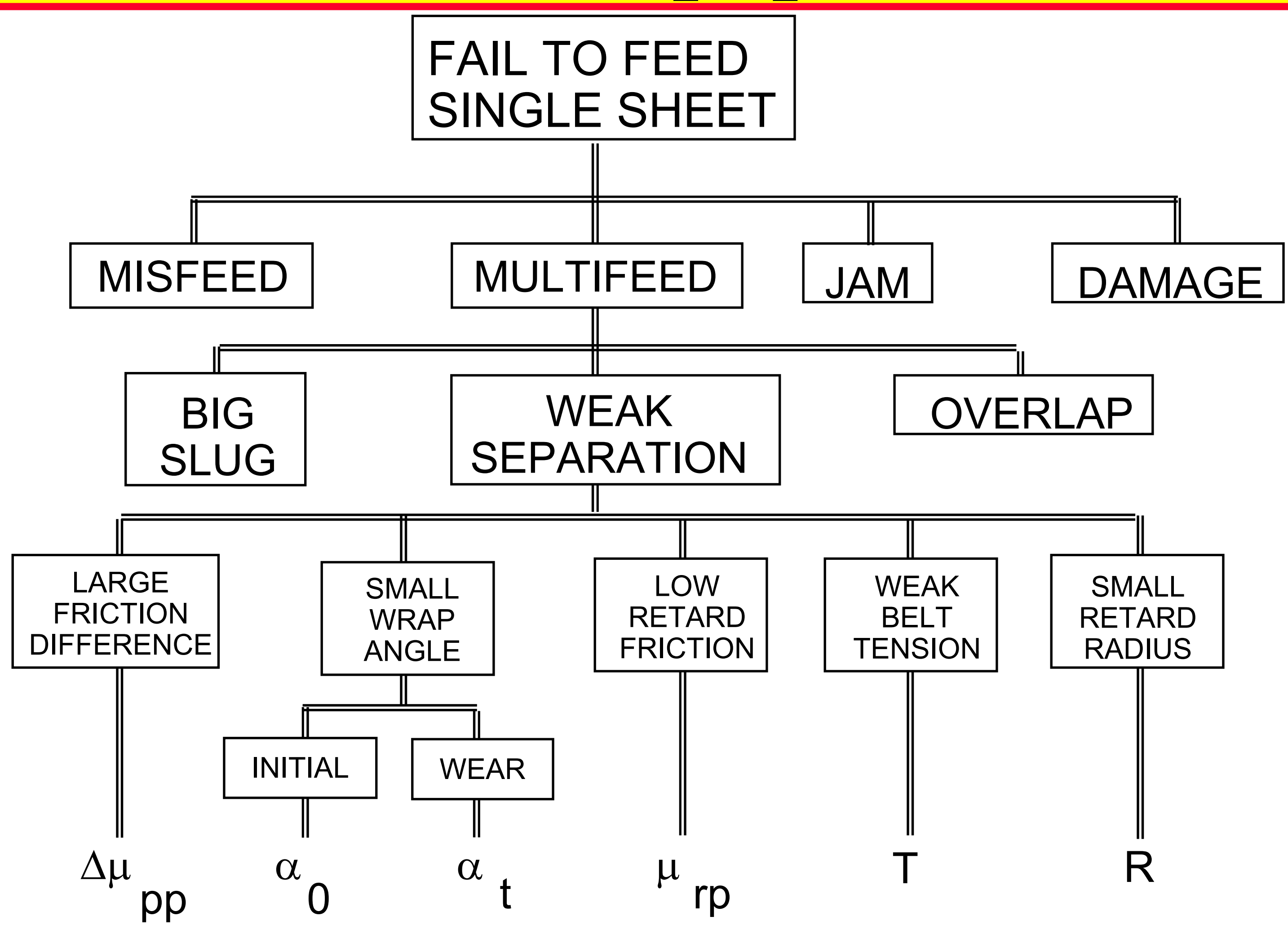
Fig. 5

Critical control parameters

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

Note: IPDT is Integrated Product Development Team

Fault tree for paper feeder



Identification of critical parameters – both control and noise

Fig. 7

Critical parameters at base of tree

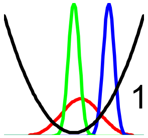
- Both control and noise parameters
- Example of control factors:
  - Roll radius
  - Belt tension
- Example of noise factor: paper-to-paper friction, $\mu_{p\text{-}p}$

Noises

- Affect performance – adversely
- IPDT cannot control – examples:
  - Ambient temperature
  - Power-company voltage
  - Customer-supplied consumables
- IPDT must apply large magnitudes of noise early in the development schedule

Role of control factors

- Values of control factors determine response
- Many combinations of control-factors values will give same value for response
- One of these combinations will give the least sensitivity to undesirable variations (noises)
- Improvement is achieved by searching through the combinations of control-factors values to find the one that gives best performance



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

Three kinds of product noise

- Environment; e.g., ambient temperature
- Manufacturing – no two units of production are exactly alike
- Deterioration – causes further variations in the components of the system

Searching for robustness

1. Select one combination of control-factors values
2. Test performance when a set of noise values are applied: $y_1, y_2 \ldots y_n$ are performance values for n combinations of noise
3. Change values of control factors; repeat 2.
4. Search through control-factor space, testing each point with same set of noises

Introduction of noises

- Natural noises are often small in laboratory environment; therefore slow to learn effect
- Therefore we consciously introduce large magnitufes of noises to obtain quick evaluation of effect of noises
- Example: (1) high temperature, high humidity, (2) low temperature, low humidity
- Measure y_1 and y_2

Effect of noises, 1 & 2

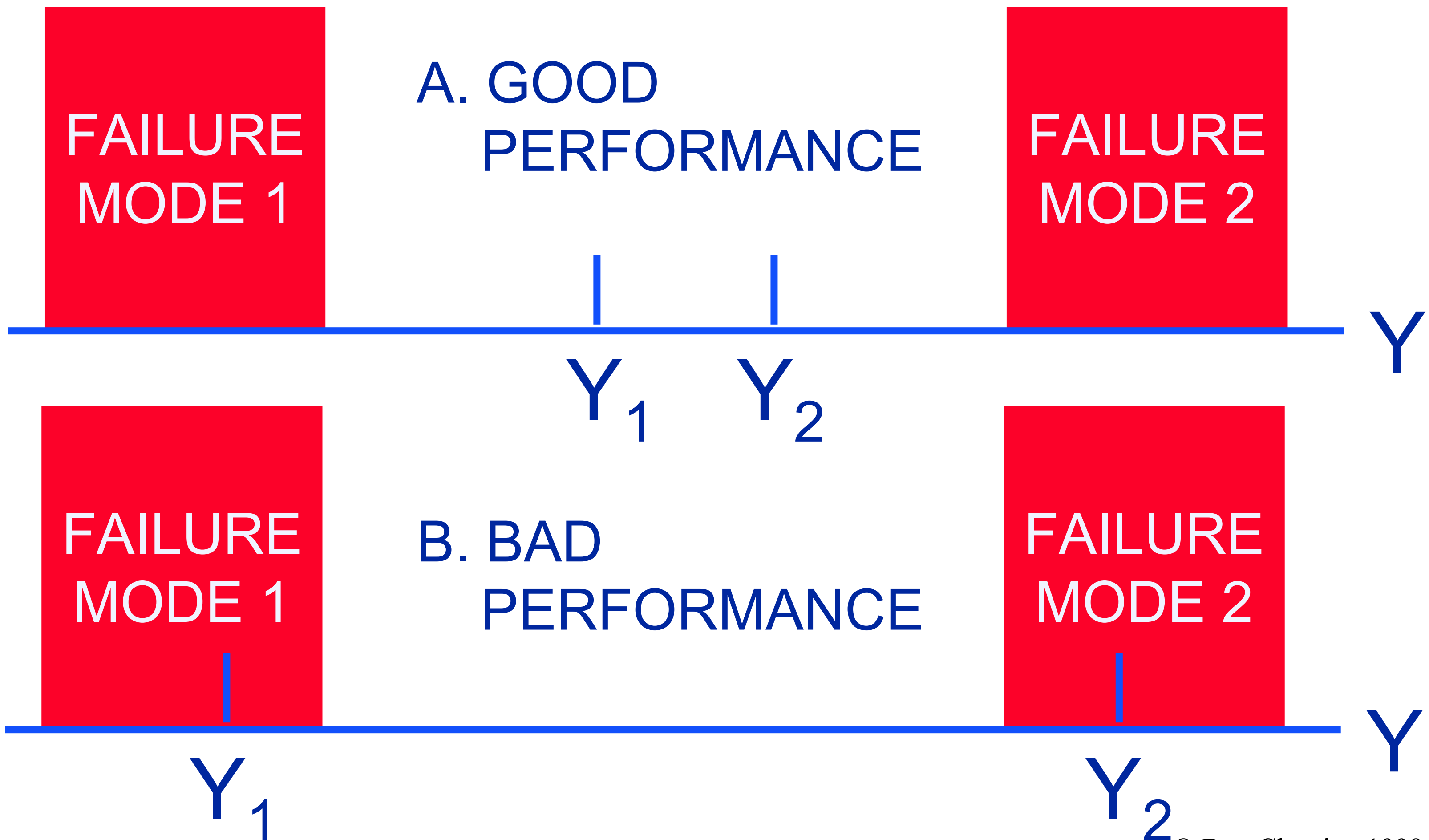


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Fig. 15

Understanding performance

- Case A: Is good performance due to:
  - Good system?
  - Small magnitude of noises?
- Winning approach:
  - Apply large magnitudes of noises 1 & 2 to create Case B
  - Then improve values of control factors; B → A
  - Increase noises; repeat improvement, B → A

Path to success

	CONTROL FACTOR SET	NOISE 1	Y_1	NOISE 2	Y_2	Y_2-Y_1
1	C F SET 1	MODERATE	5	MODERATE	25	20
2	C F SET 2	MODERATE	14	MODERATE	16	2
3	C F SET 2	STRONG	8	STRONG	22	14
4	C F SET 3	STRONG	14	STRONG	16	2

IMPROVEMENT PATH: CF1 → CF2 → CF3

Noises and failure modes

- Apply one noise, N_i , for each failure mode
- Example: combination of resistances, capacitances, transistor characteristics, and temperature have strong effect on performance
  – Adjust values, N_1, to cause low voltage out, Y_1
  – Adjust values, N_2, to cause high voltage out, Y_2
- Then optimize control factors; minimize Y_2-Y_1

Fundamental noise situation

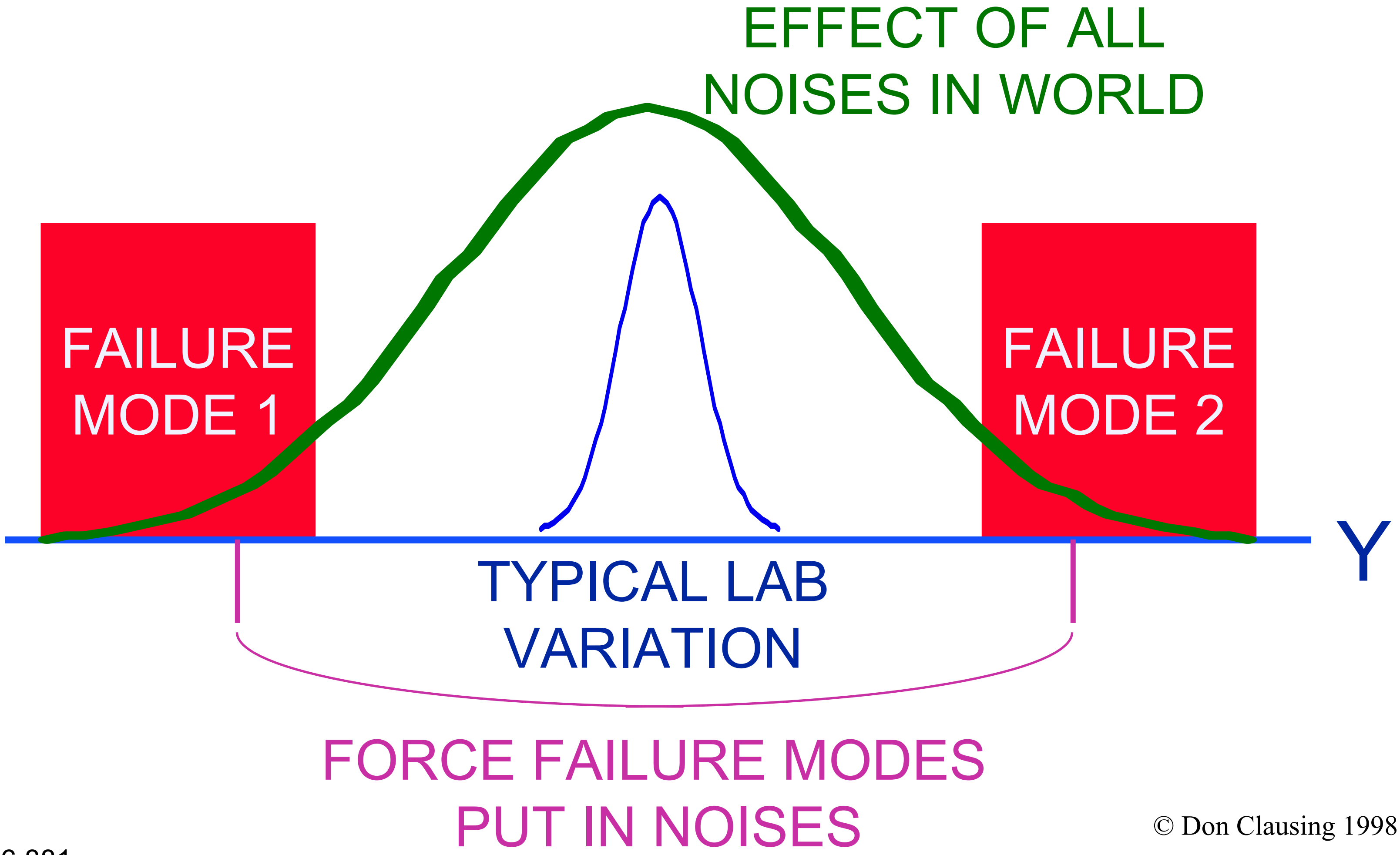


Fig. 19

Robustness improvement

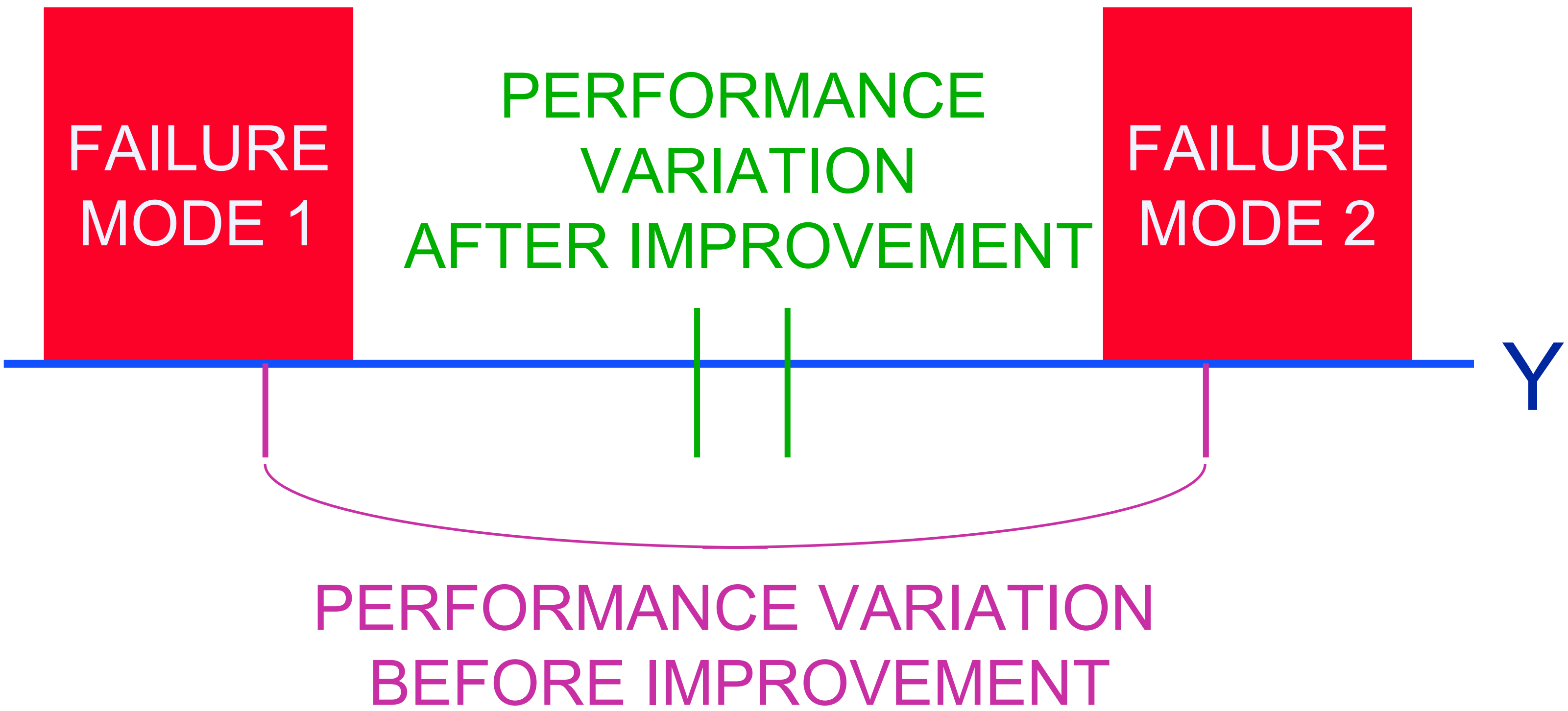


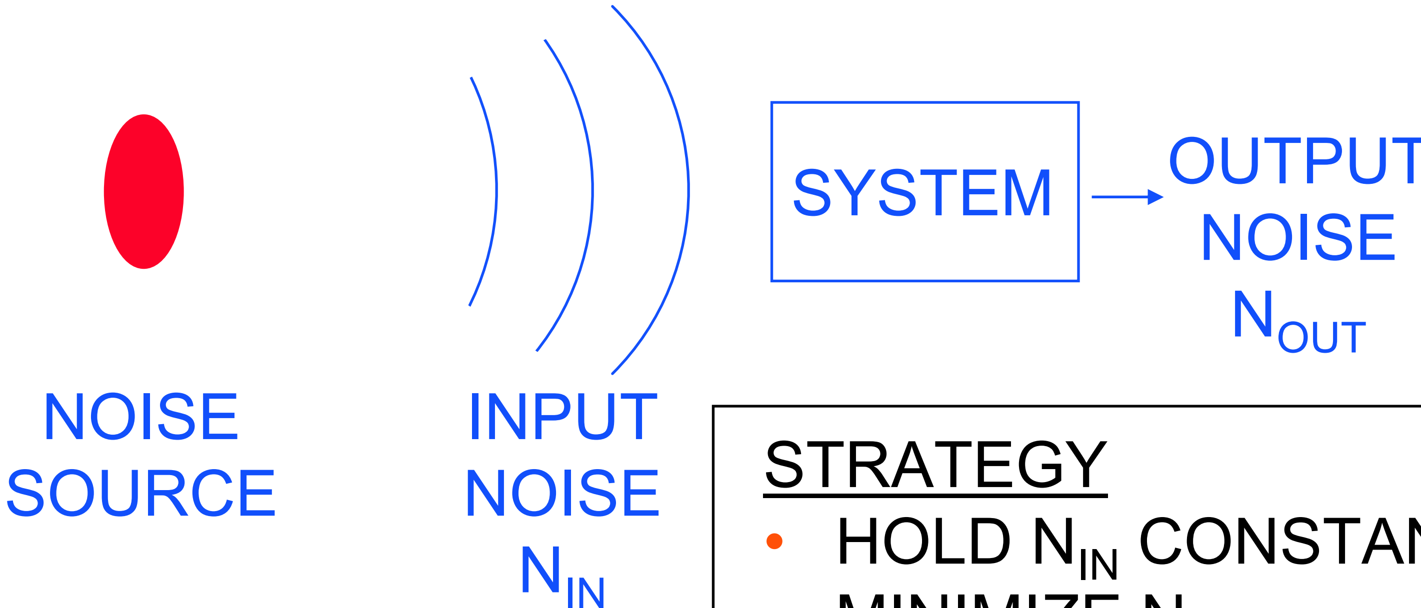
Fig. 20

Important noise strategy

- Not all sources of noise need to be used
- Identify key noise functional parameter; e.g.
  - Interface friction in paper stack, μp-p
  - 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. 21

Noise strategy



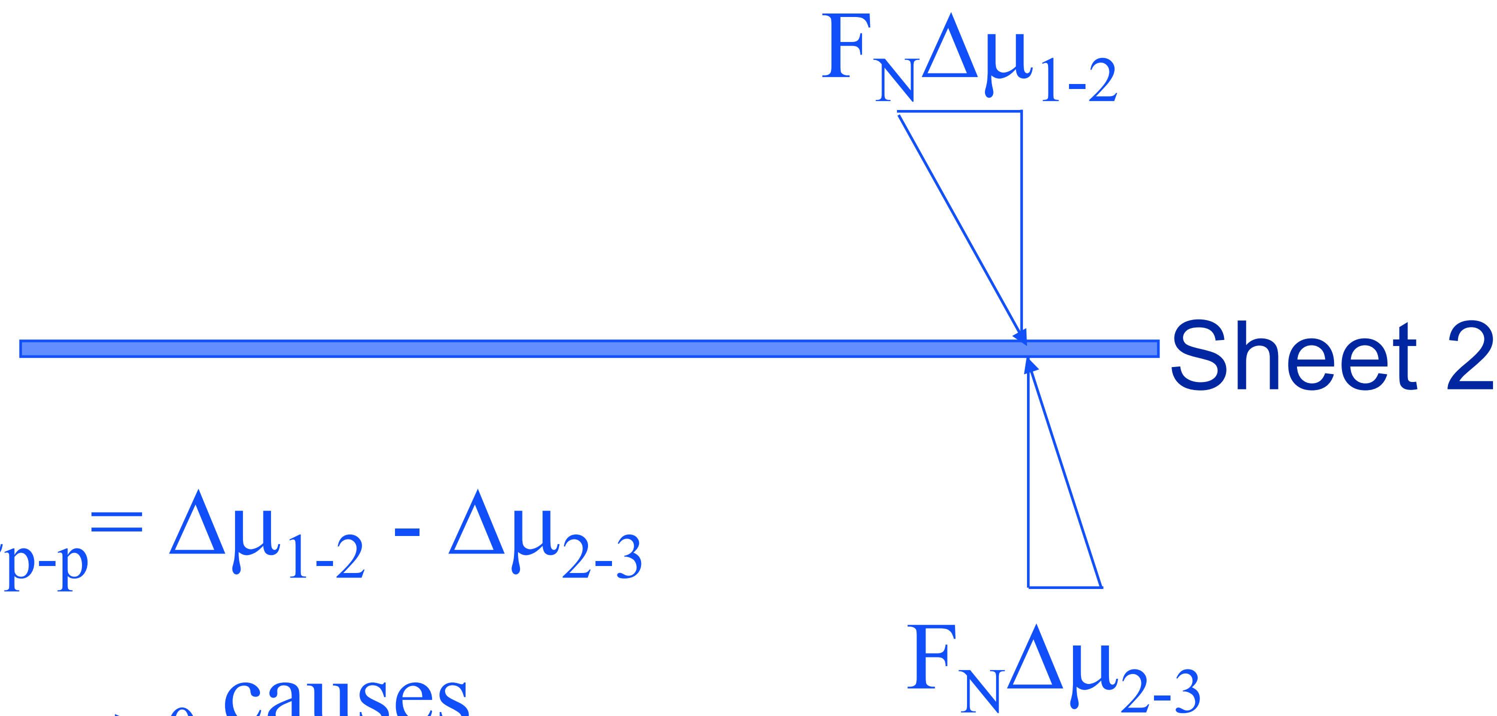
STRATEGY
- HOLD N_{IN} CONSTANT
- MINIMIZE N_{OUT}

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

Example of noise strategy

- Paper feeder failiure modes:
- Sheet 1 arrives too soon: paper jam
- Sheet 1 arrives too late: misfeed
- Sheet 2 arrives too soon: multifeed
  - Caused by large change in paper friction, $\Delta\mu_{p\text{-}p}$
  - Strategy for implementation during improvement?

Introduce large $\Delta\mu_{p\text{-}p}$



$\Delta\mu_{p\text{-}p} = \Delta\mu_{1\text{-}2} - \Delta\mu_{2\text{-}3}$

$\Delta\mu_{p\text{-}p > 0}$ causes sheet 2 to move

Noises for multifeeds

- Make $\Delta\mu_{p\text{-}p}$ large, ≈0.1
- Will cause many multifeeds; enable quick improvement
- Ignore
  - Paper brands
  - Customer usage, etc.
- Concentrate on creating paper stack with large $\Delta\mu_{p\text{-}p}$

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

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

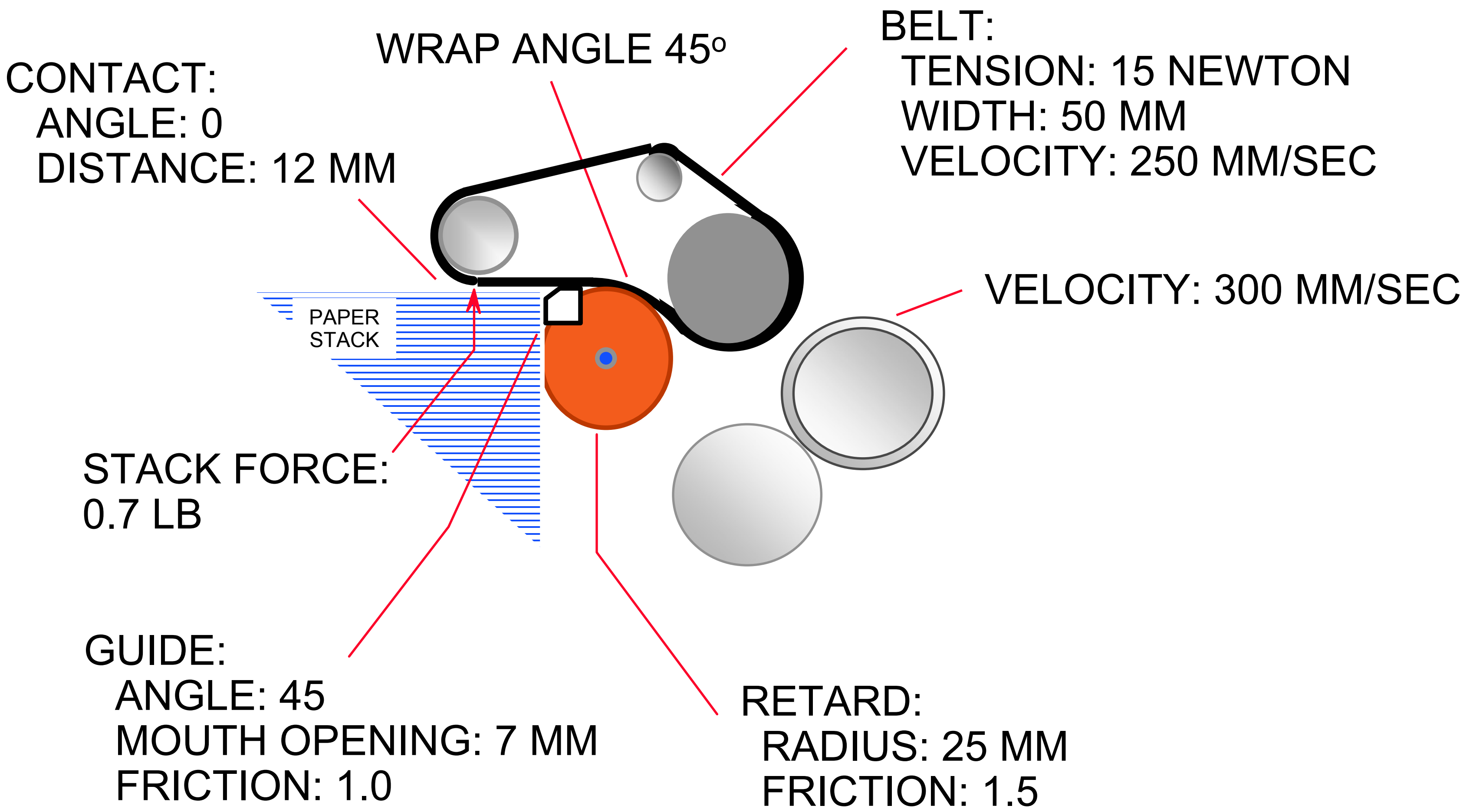
Critical control-factor range

- IPDT judges best nominal value
- Then select larger value and smaller value – feasible but significant changes
- Gives 3 values for each of 13 parameters
- 3^{13}=1,594,323 candidate sets of values
- Must then choose trials to systematically probe 1,594,323 candidates

Optimization

- Use designed experiments to select 27 out of 1,594,323 control-factor options
- Subject each option to same set of noises
- Select option that gives best SN ratio
- Enter selected values for critical control factors into critical parameter drawing; become requirements for detailed design

Critical parameter drawing for paper feeder



Optimized values of critical parameters guide the detailed design

Robustness

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

Signal/noise ratio

- Measure of deviation from ideal performance (noise here is N_{out})
- 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

Manufacturing

- Machine-to-machine variation is one of three types of noise that affects product
- Machine-to-machine variations can be reduced by making production more robust
- N_{out} for production is one type of N_{in} for product

Examples of manufacturing noise

- Temperature variations
- Humidity variations
- Cleanliness variations
- Material variations
- Machine-tool variations
- Cutting-tool variations

Noise strategy for production

- Simply operate in normal manner during optimization of production robustness
- Don't take special care
  Would reduce magnitude of normal noises
- Assure that every trial is done in normal manner – realistic noises are present and the part variation is typical of actual production

Tolerance design

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

Summary; control & noise basics

- Control factors are systematically varied through large ranges seeking best combination
- Noise values are set at large values to enable quick improvement
- Tolerance design selects variation range to be used during production

Clarify these three variations in your mind; you will be well on your way to Master$_{RD}$