Reliability: The Other Dimension of Quality

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Objectives

- Relationship between **Quality** and **Reliability**.
- Importance of **recognizing, controlling,** and **decreasing** variability to improve reliability of products and processes.
- Role of good **engineering** and **statistical** practices in reliability improvement.
- Make some **predictions** for the future of statistics in engineering reliability.

Industrial Environment (Manufacturing & Services)

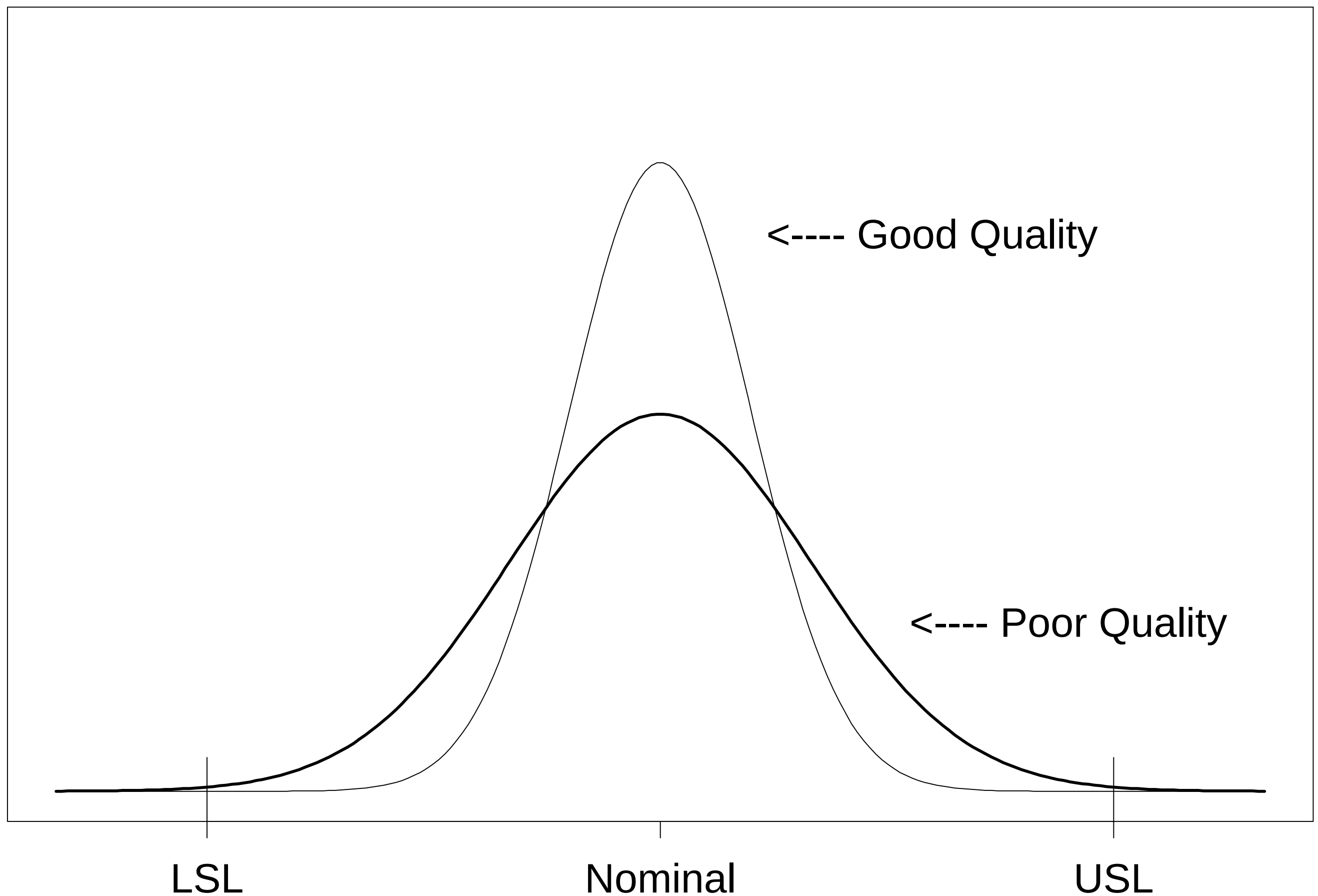
Today's industry faces:

- **Intense** global competition.
- Complex, global, and heterogeneous markets.
- Pressure for **shorter** product-cycle times.
- **Stringent** cost constraints and changing manufacturing strategies (outsourcing manufacturing, services, etc.)
- **Higher** customer expectations for **quality** and **reliability**.

What is Good Quality?

- **Current View:** Quality is customer satisfaction.
- Good quality implies delivering products/services/processes within specifications, on time, at the lowest possible cost.
- If product specification include customer requirements, the **quality level** can be measured by the fraction of units/services delivered that meet the customer requirements.
- **High quality levels** are necessary for good quality. But it is also necessary that the quality characteristic is close to the nominal or target value.

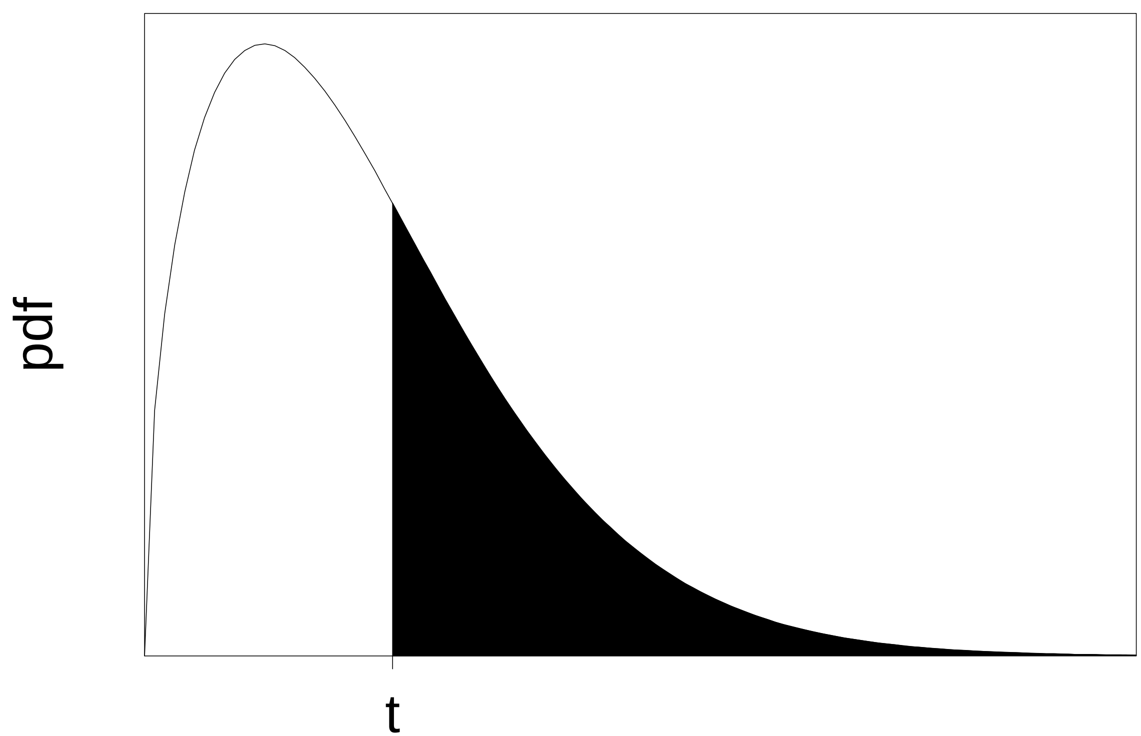
Good and Bad Quality



Statistical Definition of Reliability

Reliability is the probability that a system, vehicle, machine, device, and so on, will perform its intended function under **encountered** operating conditions, for a specified period of time

$$R(t) = \Pr(T > t)$$



Reliability Scope

- In general, reliability relates to the proper functioning of equipment, systems, and processes.
- The reliability function $R(t) = \Pr(T > t)$ depends on many factors including: **environmental** factors, **human** factors, software, and hardware.
- Reliability is closely related to risk and safety factors where failure can have catastrophic consequences.
- An important aspect is the **economical** consequences of poor reliability.
- See also Lawless (2000).

Reliability as a Quality Concept

- Condra (1993): **"Reliability is quality over time."** Thus good quality is necessary but not sufficient for good reliability.
- Condra (2001): **"A reliable product is one that does what the user wants it to do, when the user wants it to do so."**
- Reliability has to do with the number of units that still meet specifications after a given period of time (weeks, years, miles, cycles, etc).
- To assess, predict, and build in reliability, reliability scientists use: engineering, historic knowledge, experimentation, statistical models, data analysis, simulation, optimization, etc.

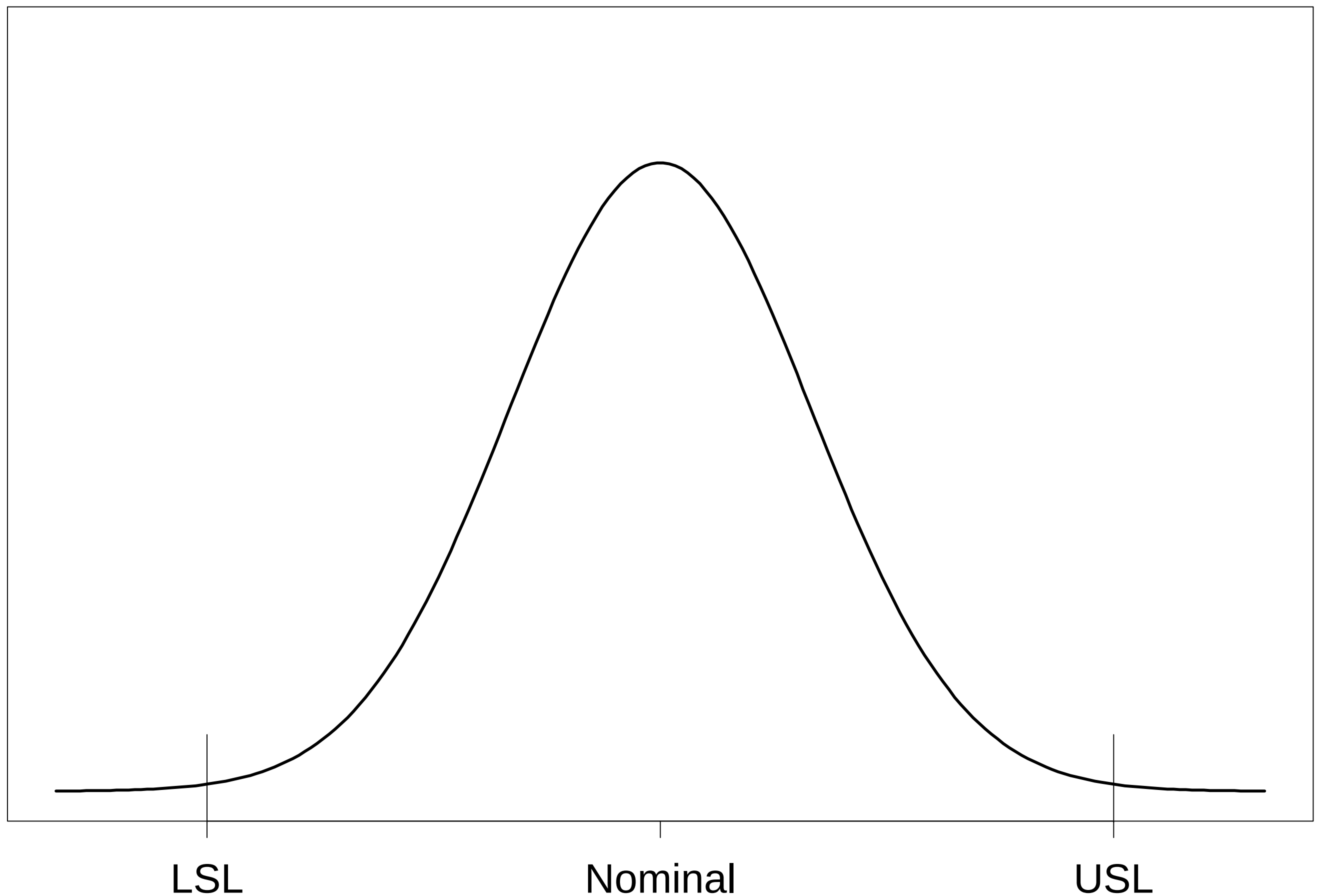
The Reliability Challenge

- **Difficulty:** Reliability assessed **directly** only after a product has been in the field for some time; reliability prediction is difficult.
- Reliability relies heavily on **engineering.** Statistics provides important tools for understanding, improving, and maintaining reliability.
- Much engineering effort is (correctly) focused on **reliability improvement.**
- Most statistical effort has been on methods for **assessing** reliability, which might be the least productive approach. Recently statisticians have begun to have an impact in improving reliability.
- Modern quality practices (i.e., **Six Sigma**) institutionalize interdisciplinary reliability teams.

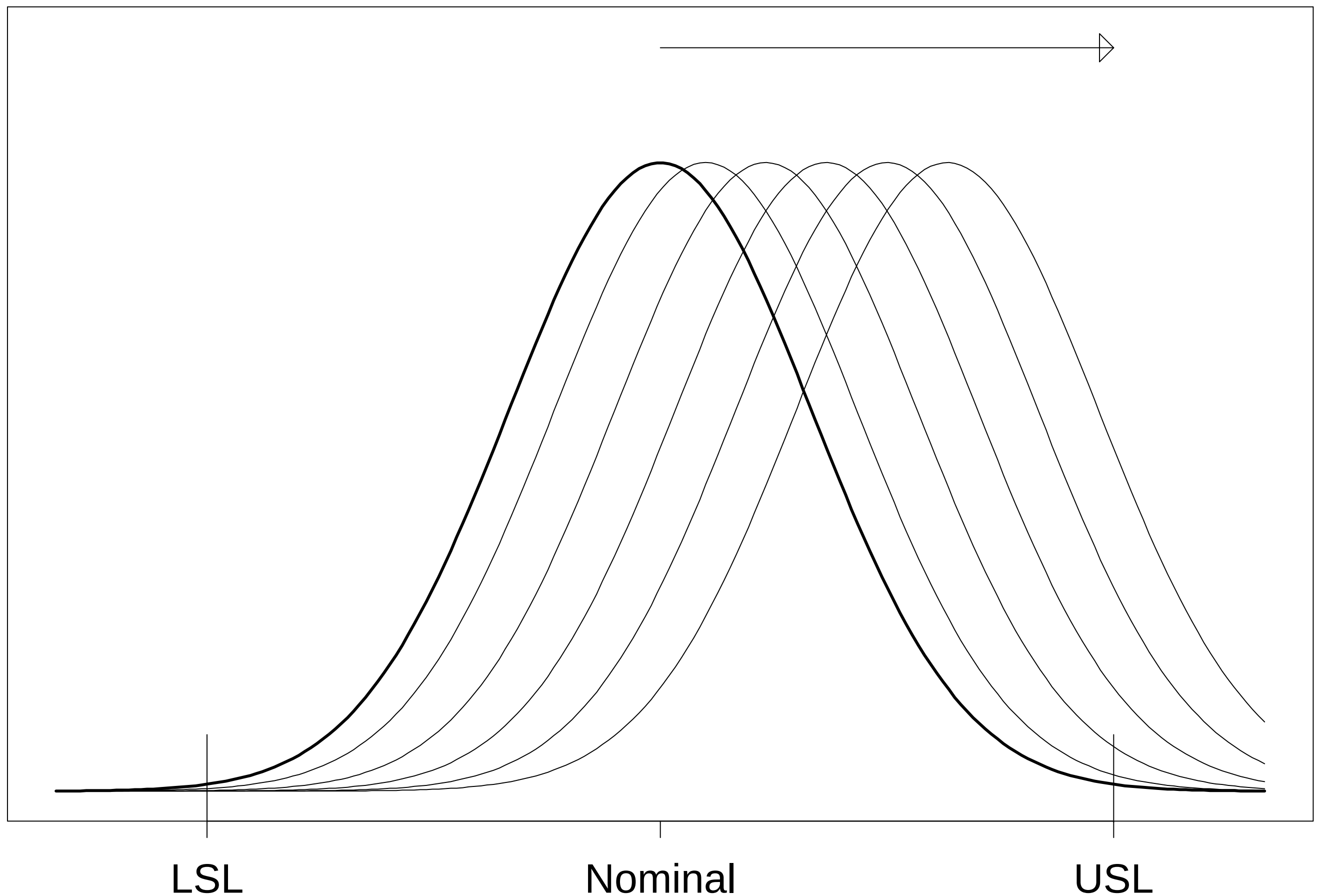
What Is the Source of Quality & Reliability Problems?

- Variability is everywhere.
- There will always be variability in a process.
  This is well said by Nelson in his statement: **Failure to understand variation is a top problem in USA industry.**
- We can tolerate variability if
  - The process in on target.
  - The process variability is small when compared with the process specification (**capability**).
  - The process is stable.

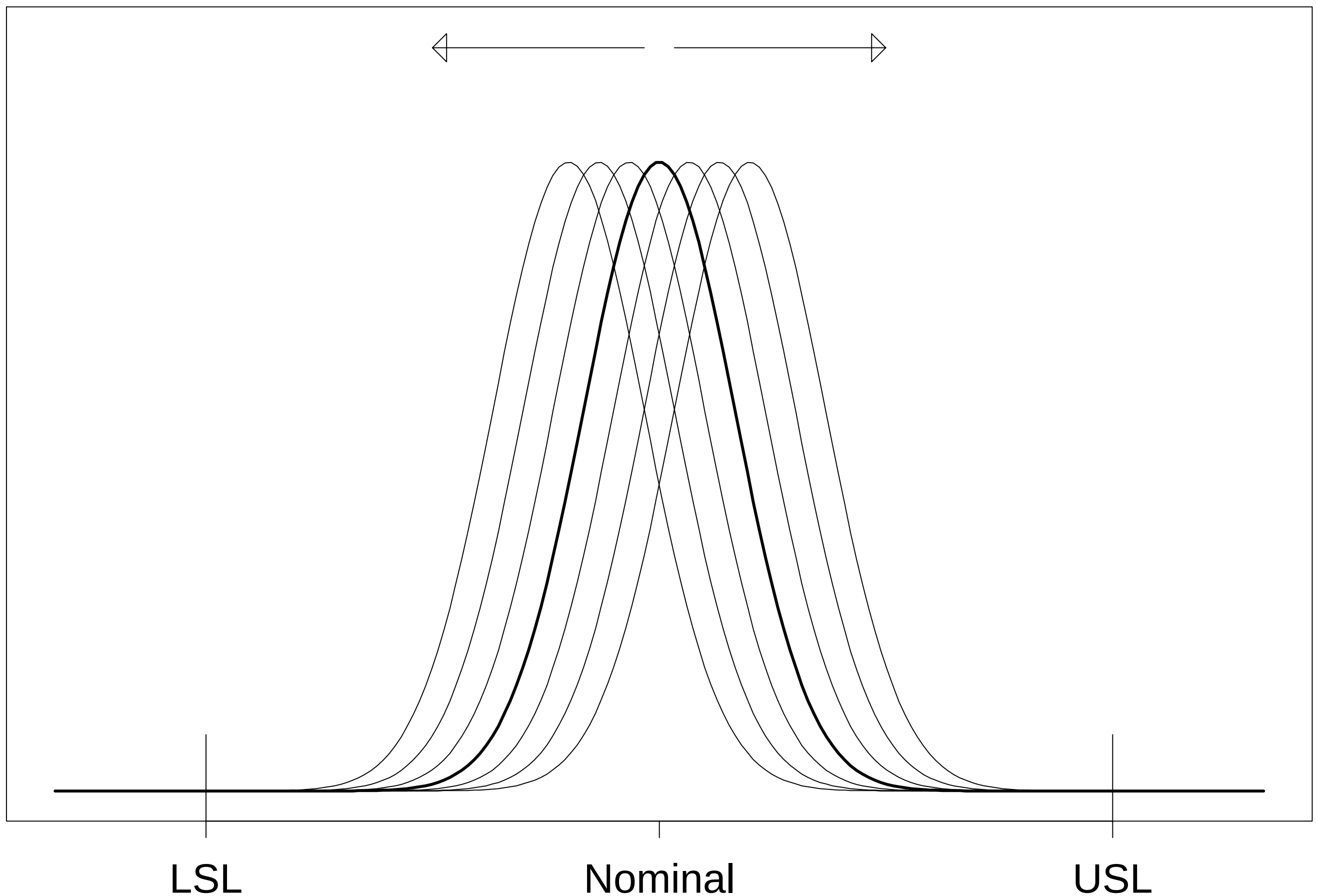
Three-Sigma Quality. Approximately, 2700 Defects per 10^6 Opportunities



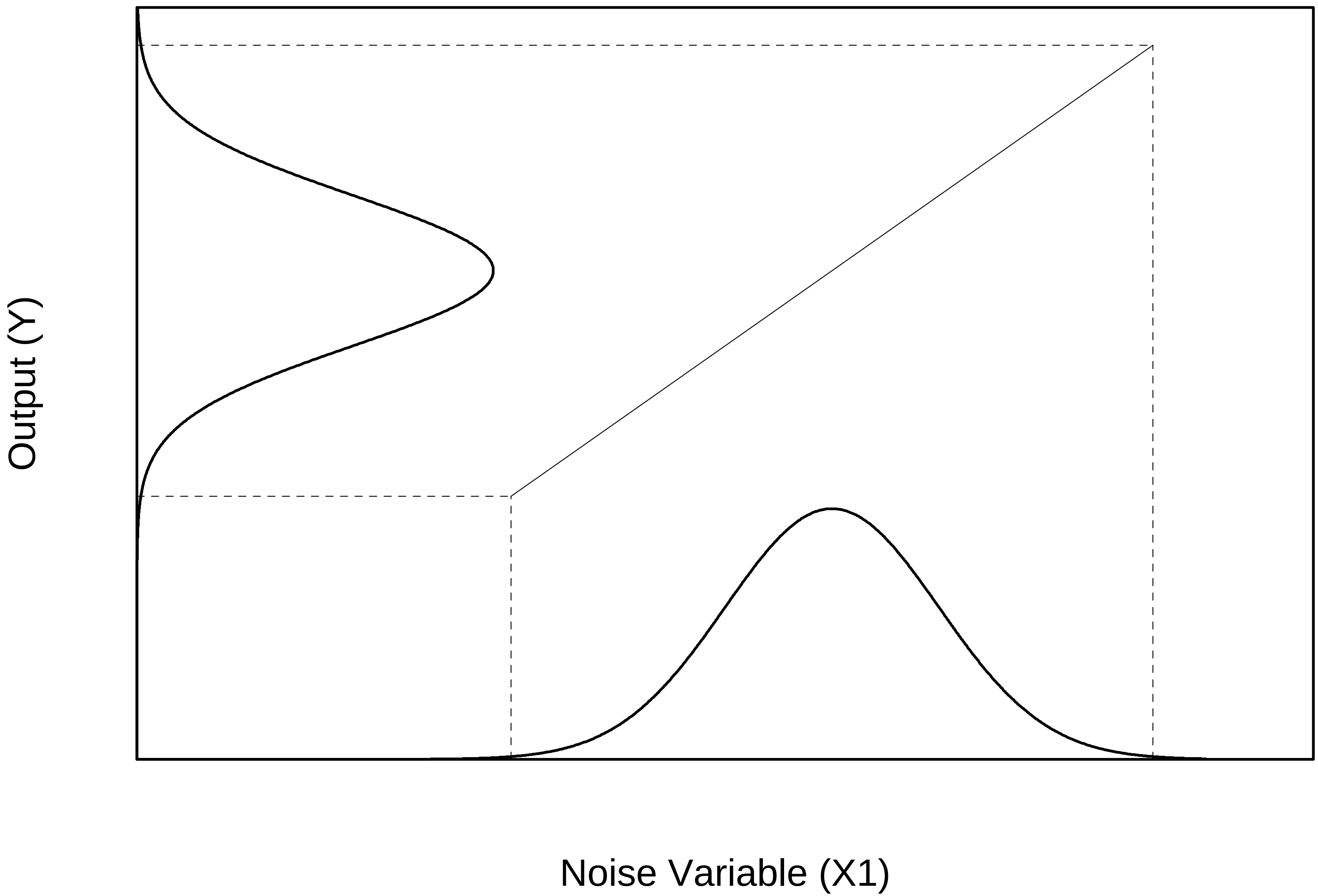
Drifting Three-Sigma Quality. Approximately, 67,000 Defects per 10^6 Opportunities



Drifting Six-Sigma Quality. Approximately, 4 Defects per 10^6 Opportunities

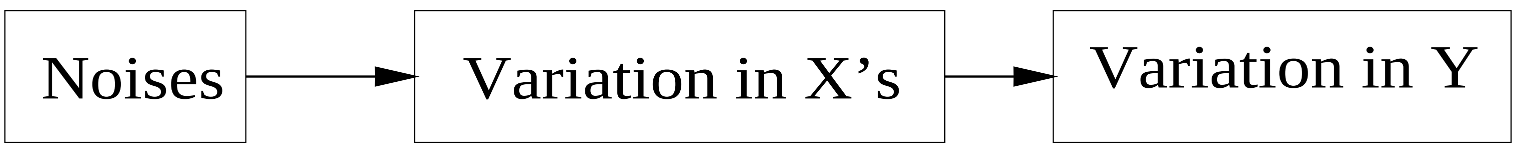


Transmission of Variability



Some Sources of Variability Affecting Product Reliability: Key Questions

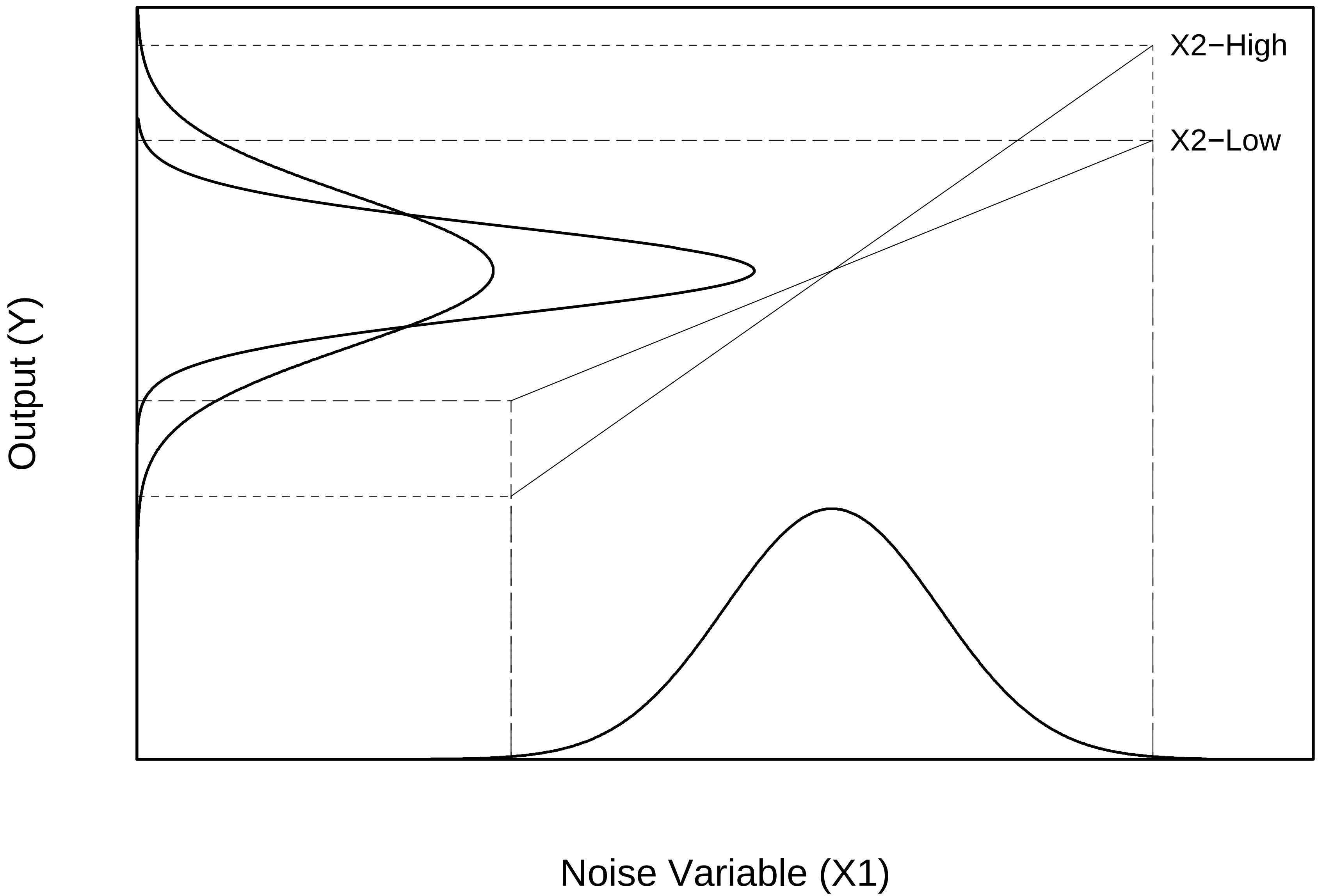
- What causes X and thus Y to vary?
- How much variability can we expect in X and Y?
- To what extent can we reduce the variability in X?
- To what extent can we reduce the transmission of variability in X?



In summary,

- Find the **important** X's that impact the **important** Y's.
- Use engineering, DOE, Robust design, and other engineering/statistical techniques to reduce variability in X and the transmission of variability to Y.

Reducing Transmission of Variability Using a Design Variable (X_2) by Noise (X_1) Interaction



Reliability Issues

- Causes (modes) of failure and degradation leading to failure.
- Environmental effects on reliability.
- Quality problems leading to early failure.

Failure Modes

	Anticipated	Unanticipated
Wear related	ALT/ADT	HALT
Defect related	QC/SPC	HALT

- **Robust engineering and Robust product design** can help in all cases.

Robustness: Ability to perform intended function under a variety of operating and environmental conditions.

The Interface Between Quality and Reliability

- Good quality is a **prerequisite** for high reliability.
- Like quality, reliability should be customer-focused.
- How can we assure **reliability?**
  - Robust product design from component to subsystem to system level.
  - Robust process design from operation to machine to plant level.
  - Process monitoring, where necessary.
  - **DFR:** Design for Reliability. Also, **Reliability by Design, Design for Six Sigma (DFSS),** and others.
  - **Objective** use of engineering knowledge, historic information, feedback from the field, etc.

Variability Reduction and Reliability Improvement

The idea is to improve reliability to decrease the cost attributable to poor reliability.

The general approach is:

- Reducing variation during the creation of products and services:
  - Reduce variation of factors that can be controlled.
  - Reduce product variation due to noise.
- Fixing processes so that they are nearly perfect. Controlling these processes so that they stay fixed.

Reliability Demonstration Versus Reliability Assurance

- Traditional reliability demonstration is essentially a statistical hypothesis test:

$$H_0 : \textbf{Reliability is smaller than the target.}$$

  Rejecting the null hypothesis provides a demonstration that the reliability target has been met.
- To demonstrate that reliability at time $20{,}000$ hours is 0.99, with 90% confidence, requires testing at least $n = 230$ units tested for $20{,}000$ hours with zero failures, where

$$n = \log(0.10)/\log(0.99) \approx 230.$$

- To have a 80% chance of passing the test, requires that the true reliability be approximately 0.999, i.e.,

$$\Pr(\text{passing test}) = (0.999)^{238} = 0.794 \approx 0.80.$$

A Feasible Reliability Demonstration

- Under certain circumstances, it is feasible to demonstrate reliability for a component with respect to a particular failure mode.
- Suppose that life has a Weibull distribution with a shape parameter of β, a zero-failure test that runs for $k \times$ 20,000 cycles requires a sample size of (see Meeker and Escobar 1998),

$$n \geq \frac{1}{k^{\beta}} \times \frac{\log(\alpha)}{\log(1-p)}.$$

- When $\beta = 2$, a zero-failure test that runs for $6.77 \times$ 20,000 cycles will provide the required demonstration with a sample size of only $n = 5$ units.
- Interesting $\Pr(\text{pass test}) \approx 0.80$ and it **does not** depend on β or n.
- For complicated systems, traditional reliability demonstration is usually not practicable. **Reliability assurance** is the alternative.

Reliability Assurance

Based on **reliability modeling and combining information**
Inputs:

- Engineering knowledge.
- Physical models.
- Previous experience (e.g., field data).
- Physical experimentation.
- Factors of safety.

Challenge: Assessing uncertainty.

Approach: Meaningful use of Bayesian methods (e.g., LANL PREDICT).

Distinguishing Features of Reliability Data

- Data are typically **censored** (bounds on observations).
- Models for **positive** random variables (e.g., exponential, lognormal, Weibull, gamma). Normal distribution not common.
- Model parameters **not** of primary interest (instead, failure rates, quantiles, probabilities).
- **Extrapolation** often required (e.g., want proportion failing by 900 hours but test runs for 400 hours).

Some Topics in Reliability Studies

- Single stress **failure times** studies.
- Accelerated **failure times** studies.
- Studies with **degradation data.**
- Studies with **recurrent data**.
- Studies with **warranty data**.
- Planning of life tests, ALT, and ADT tests.
- System reliability studies.

Useful references: Lawless (2002), Meeker and Escobar (1998), Nelson (2003), Rausand and Høyland (2004).

Some Trends in the Use of Statistics in Reliability

- More use of degradation data and models.
- Increased use of statistical methods for producing robust products and robust processes.
- More use of computer models to reduce reliance on expensive physical experimentation.
- Reliability on dynamic and heterogeneous environments. Including better understanding of the product environment (e.g., through the use of **smart chips**).
- More efforts to combine data from different sources and other information (through the use of **meaningful Bayes** methods).
- A better understanding of the counting process methodology and its applicability to problems of interest.

Concluding Remarks

- Reliability is an **interdisciplinary** field in which experimentation (perhaps using physical/computer models), engineering, statistics, and computational methods play an important role in improving quality.
- Some form of up-front **Design for Reliability** is probably necessary in today's competitive environment.
- The concept of **robustness** in product/process design is very important.
- Some general principles and tools are available, but many specifics of a Design for Reliability program will be product specific.
- There are opportunities for improving the current methodology and developing new methodology for relevant problems.
- Good and friendly software for reliability is (will be) in great demand.

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