The Economic and Scientific Context of Quality Improvement and Six Sigma

By
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Overview

1. Economic Context
   - A. Innovation
   - B. Information
2. Scientific Context
   - A. Role of Deduction and induction
   - B. Role of statistics and experimentation
   - C. Management of change
3. Quality improvement and Six Sigma
   - A. DMAIC for existing products, services and processes
   - B. DFSS for new products, services and processes
4. Statistical research
5. Conclusion

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1. The Economic Context

A. Innovation

B. Information

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Schumpeter On *Innovation*

- Joseph Schumpeter:
  - *The fundamental impulse that sets and keeps the economic engine in motion comes from the innovation of new products, new methods of production or transportation, new markets,new forms of industrial organization*
  - *The primary reason for profits is as a premium for the risk of innovation*

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Today's Economic Realities:

- An abundance of new competing products and technologies
- Competitors with similar products and technologies invade markets
- Shorter product life cycles — bigger market pressure
- Learning effects: competitors world wide learn faster to execute better, faster and cheaper
- Competitors in other countries emerge with significantly different cost structures
- World wide communication technology and logistics make the market global and extremely competitive

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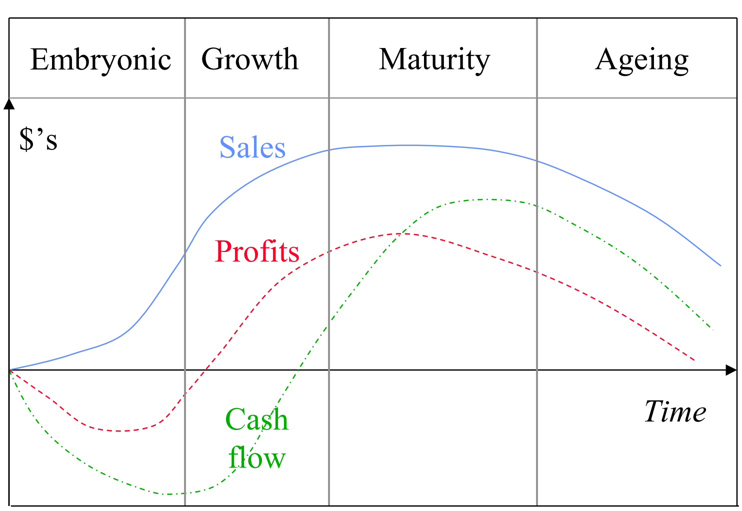
Product Life Cycle Model



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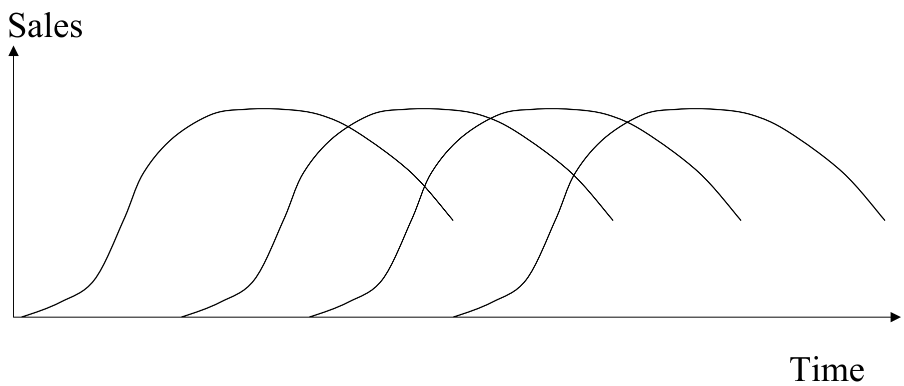
The Necessity of Innovation to Sustain Profitability



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The Innovative Process

- Quality is not just about quality!
- It's about innovation!
  - Product innovation, process innovation, radical and incremental innovation!
- Radical innovations: entirely new products, processes and services
  - Example: the light bulb, wireless communication,
- Incremental innovations: the adaptation, refinement and enhancement of existing products, processes and services
  - Example: next generation of a micro processes, next years automobile model,…
- Modern society needs innovations to stay competitive, growth and prosper!

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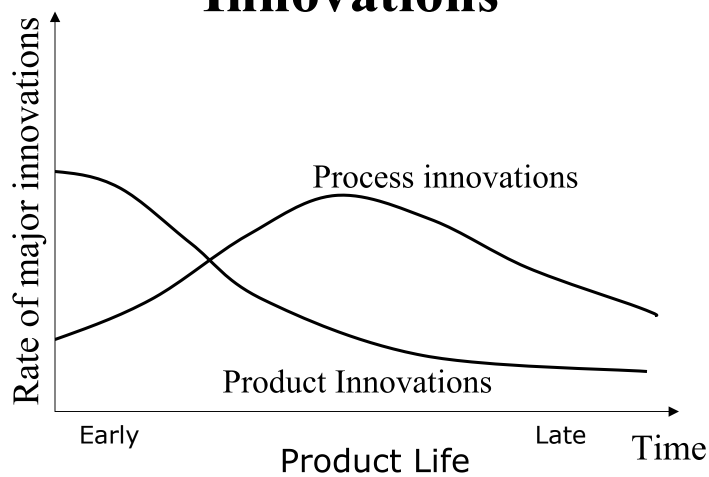
Changing Character of Innovations



Adapted from Abernathy and Utterback (1978)

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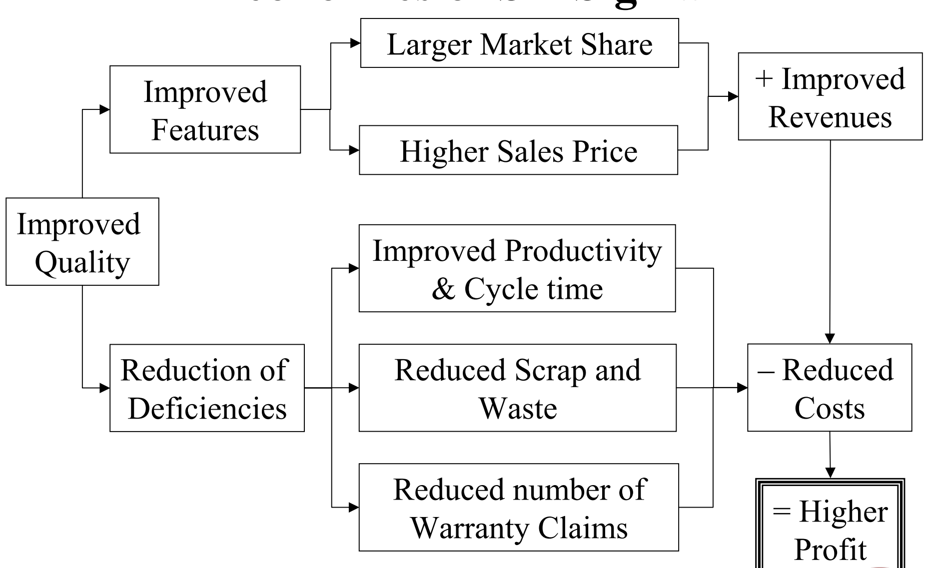
Economics of Six Sigma



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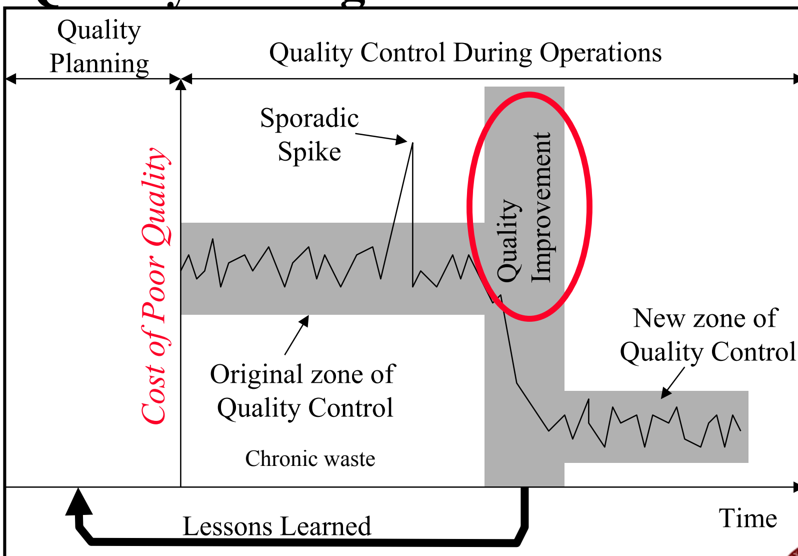
Quality Management in a Nutshell



Adapted from Juran

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Quality, Economics, Information, Knowledge Generation and Learning

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Transaction Costs

- Ronald Coase -- Transaction costs: Like friction in mechanical systems
- Defects, rework, snags and delays are frictions
- Improving delivery quality is about reducing certain transaction costs
- But to be competitive long term, we must also improve the design quality
- Whether improving design or delivery quality, it is achieved through *knowledge and information*.

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Information and Knowledge

- We need to generate information and knowledge about
  - Who the customers are,
  - What is the value proposition; what is value to the customers
  - How we can meet and possibly exceeds their needs and expectations
- And learn
  - How to improve processes
  - How to develop products that satisfy the customers

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Hayek on Information

- Friedrich von Hayek: "the … problem [of economic success]… is mainly one of rapid adaptation to changes … ultimate decisions must be left to people who are familiar with these circumstances…."

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The Invisible Hand & Local Knowledge

- The knowledge we need to generate is *"local knowledge"*
- Decision-making local to where the action is, is more effective than centralized decision-making
- …Much the same way as the invisible hand of the market decisions has proven to be more effective than a centralized plan economy

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Local Decision Making

- To support decision-making and help employees ─ from factory floor worker to the CEO ─ we need local knowledge
- Knowledge needs to be generated where it is needed, where it can be interpreted and understood and where it intelligently can be acted upon
- But to generate information and to learn, we need skills in the application of scientific method

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2. The Scientific Context

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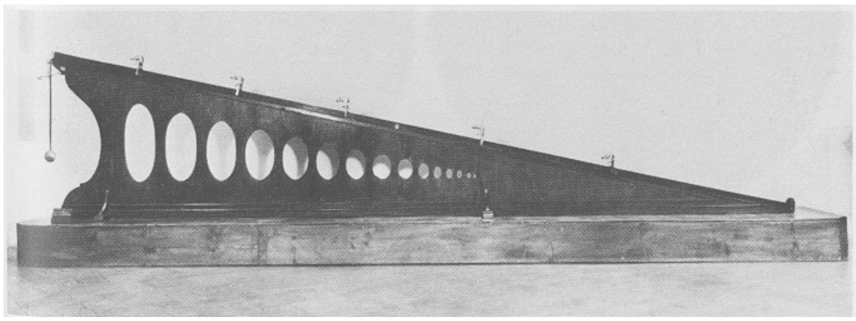
Good Science is Inductive <u>and</u> Deductive



A replica of Galileo's apparatus made in 1775 for the Grand Duke of Tuscany.
Instituto e Museo di Storia della Scienza, Florence
in: Harré, Rom, Great scientific experiments. Oxford University Press, Oxford/New York 1981, p.121

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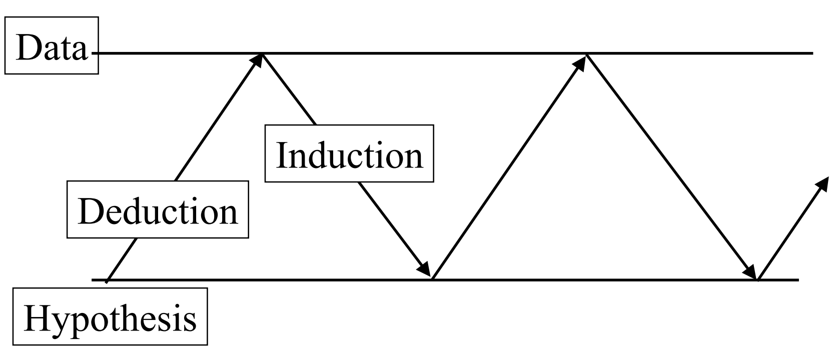
Iterative Process of a Scientific Investigation: We Need *Induction* <u>*and*</u> *Deduction*



Adapted from Box, Hunter and Hunter (1979)

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An Empirical Foundation

"For the best and safest method of philosophizing seems to be, first diligently to investigate the properties of things, then establish them by experiment, and then to seek hypotheses to explain them."

Sir Isaac Newton

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Six Sigma: A Systematic Programmed Innovation Approach

- A successful program spearheaded by companies such as General Electric and Allied Signal
- Originated at Motorola as their quality improvement program
- Different from traditional TQM and ISO 9000; really about systematic innovation in general, not just quality control

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What is Six Sigma?

- A program for near elimination of defects from every product and process
- A disciplined quantitative approach for improvement of defined metrics aligned with the overall strategy
- Can be applied to all business processes: manufacturing, transactions, finance and services
- Focused on carefully selected Projects
- *In a nutshell: Six Sigma is the application of scientific method to improve processes and products*

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DMAIC: A Simple Problem Solving Discipline

- Define: Select relevant problems to work on
  - » Stating a problem in measurable and actionable terms
- Measure: measuring the variation of the performance data of the problem
- Analyze: finding the sources of variation to the performance data
- Improve: eliminating or enhancing the highest drivers of the performance data variation
- Control: establishing controls to manage the gains of the problem solution

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The Six Sigma Strategy

Phase 0: Define
- Scope and Boundary
- Define Defects
- Develop Team Charter and Select Champions
- Estimated $ Impact
- Get Leadership approval

Phase 1: Measure
- Map the process and Identify Inputs and Outputs
- Make Cause and Effects Matrix
- Establish Measurement System Capability
- Establish Process Capability Baseline

Phase 2: Analyze
- Perform Multi-vari Analysis
- Develop Input-output relations
- Identity Critical Process Inputs
- Develop FMEA

Phase 3: Improve
- Verify Critical Process Inputs
- Optimize Critical Process Inputs
- Reduce variability

Phase 4: Control
- Develop Control Plan
- Implement Control Plan
- Verify Long Term Capability
- Transfer to operations
- Continuously Improve the Process

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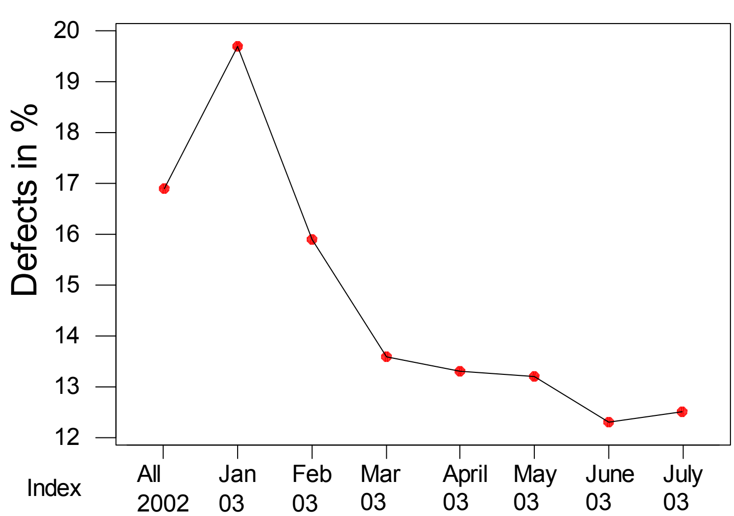
Is Six Sigma A Fad?



Not to the CEO of this company!!!

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Quality Improvement

J. M. Juran: *"All quality improvement takes place project by project and in no other way!"*

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Organization

Leadership:

- Champions
- Master Black Belts/consultant (MBB)
- Black Belts (BB)
- Green Belts (GB)

Key to Success: Select successful people, Not just "warm bodies"!!!

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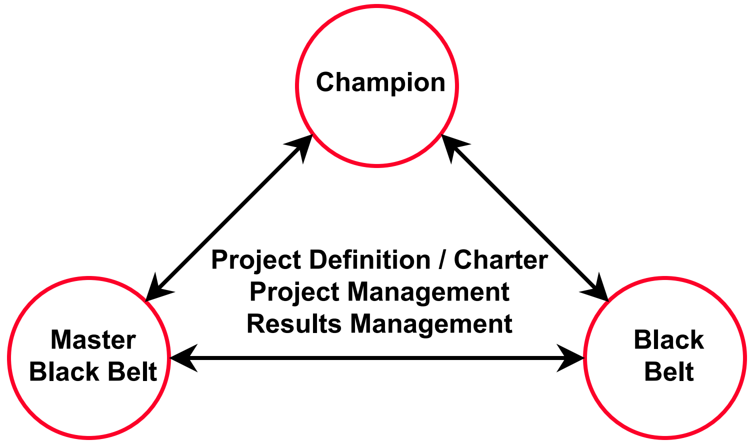
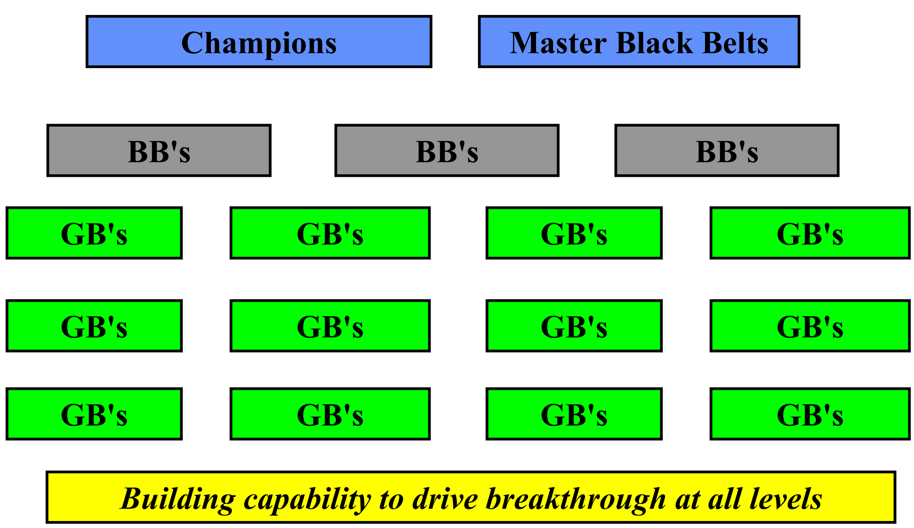
The Guiding Coalition



Organizational Structure:



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Design for Six Sigma (DFSS)?

- DFSS: The design of new processes, products and services from scratch:
  - Where a process, product or service does not previously exist
  - Where the existing process, product or service is not capable of being improved
- Focuses on systematically gathering the voice of the customer, prioritizing requirements, and building those requirements into new, processes, products or service
  - Identifies targeted customer requirements
- Focuses on *growth of the business*
- Not just for engineering – for all business areas

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The DMADV Road Map

Define
Identify the new (or modified) product

→ **Measure**
Plan and conduct research to understand customer needs

→ **Analyze**
Develop alternative design concepts, select a concept for high level design and predict the capability

→ **Design**
Develop the detailed design, evaluate its capability and plan a pilot test

→ **Verify**
Conduct the pilot test, analyze the results and make design changes as needed

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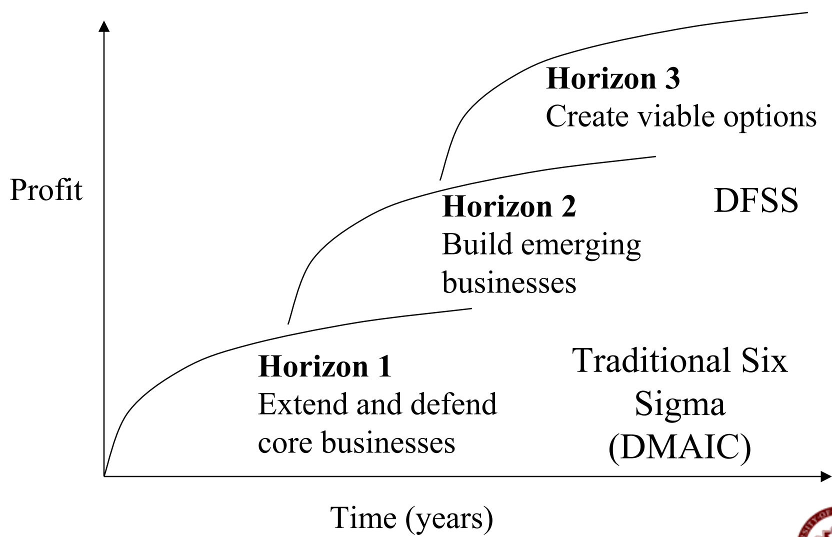
Strategy: Three Horizons*



*Adapted from Badhai, Coley and White (1999)

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Why Organizational Transformations Often Efforts Fail!

Research show that eight common errors in managing change, two of which are:

1. Not establishing a sense of urgency
2. Not systematically planning for and creating **short term wins**

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Research Shows: An Effective Strategy…

1. Map out how the organization should look after a major change
2. Use a series of rapid cycle projects that provide the employees opportunities to develop their skills in managing change
3. As they learn to change, mount increasingly larger scale, more strategic efforts and move upstream
4. Periodically review and modify the overall strategic plan

Benefit: The projects pay for the program

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How to Get Started?

- Establish A Sense of Urgency
- Create a Guiding Coalition
- Evaluate strategic goals and "low hanging fruit" opportunities
- Develop team charters and select teams
- Just-in-time GB/BB training
- Manage projects for success: First wave *must* be a success
- Prepare for second wave …

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Schumpeter Again

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Statistical Challenges — Statistical Research

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The Importance of Practice for the Development of the Theory of Statistics

- Brewer/chemist/statistician W. S. Gosset working for Guinness Brewery in Dublin: Student's t-test
- R. A. Fisher at Rothamsted Experimental Station
- Henry Daniels working for the Wool Industries on variance components
- George Barnard working during WWII
- George Box at ICI: Response Surface Methods
- Gwilym Jenkins working on airplane design and time series analysis – collaborating with George Box to develop process control methods resulting in Box & Jenkins time series method used in econometrics
- John Tukey working for Bell Labs: Signal processing and exploratory data analysis
- Etc.

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Some Recent Inspirations for Research in Multivariate Process Control

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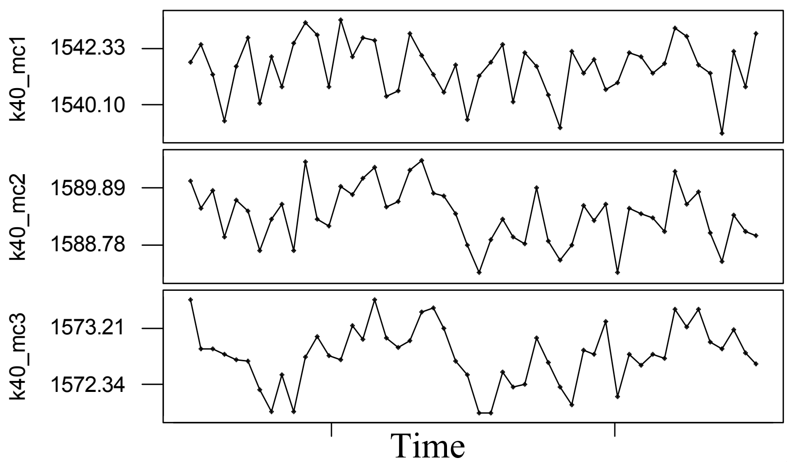
Three Time Series of Temperature Readings from a Chemical Process



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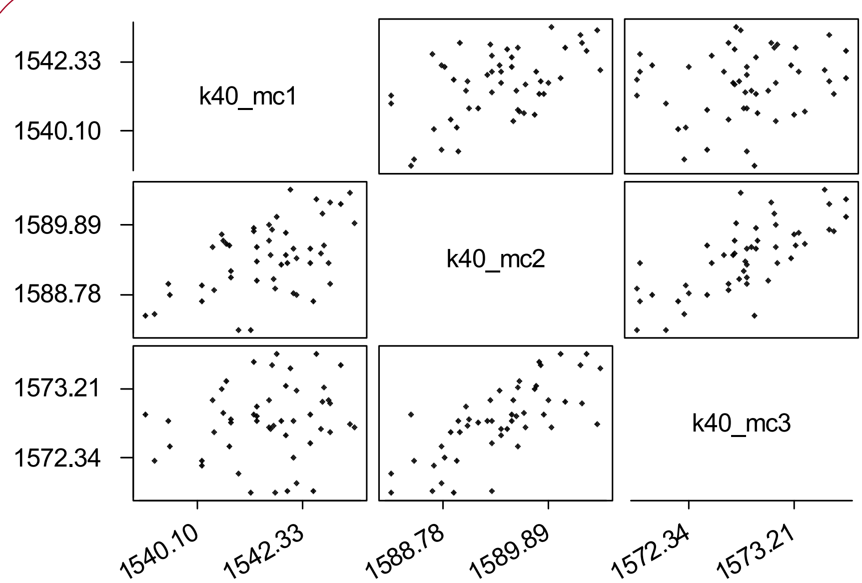

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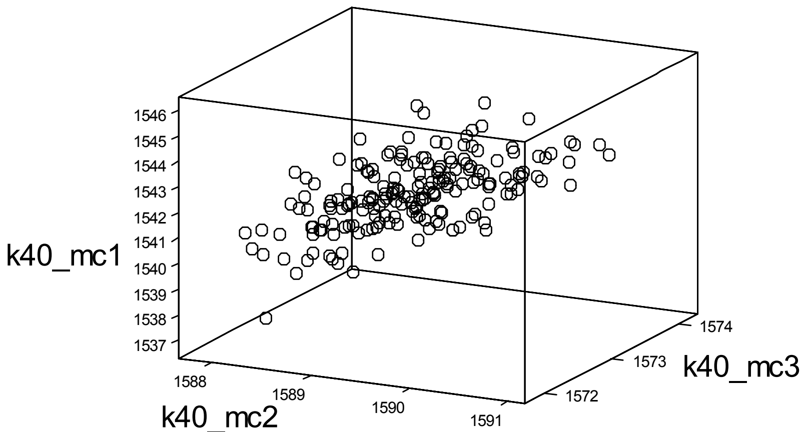
3D Plot of 3 Dependent Time Series: MC1, MC2 MC3



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Hotelling's T^2

p - Dimensions

$$T^2 = (\mathbf{x} - \overline{\mathbf{x}})\mathbf{S}^{-1}(\mathbf{x} - \overline{\mathbf{x}})$$

$$UCL = \frac{p(n+1)(n-1)}{n(n-p)} F_{(p,n-p)}(1-\alpha)$$

$$LCL = 0$$

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```
MTB > %tsquared c1-c3 c7
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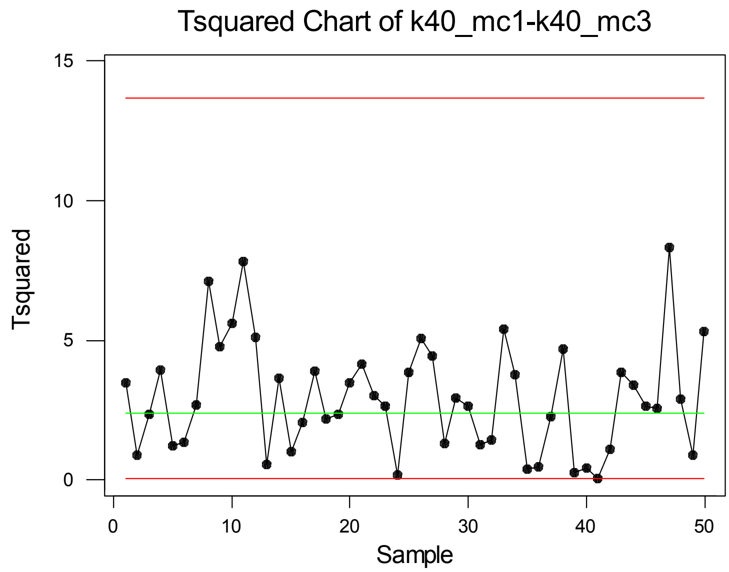
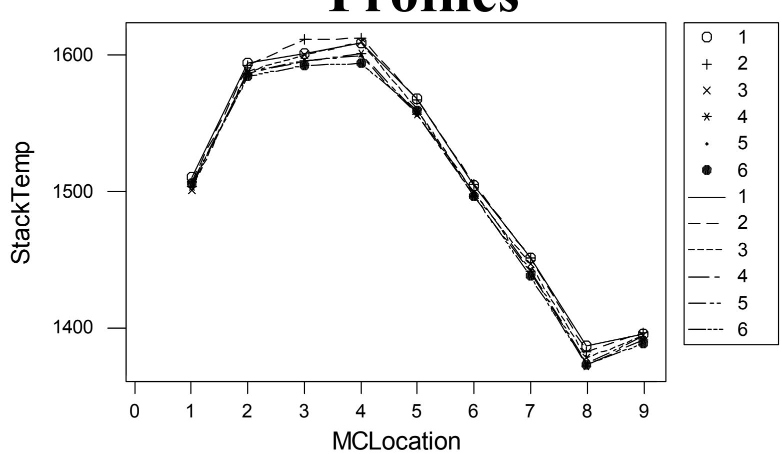


Profiles



Data July 2002 : `MCTEMPPROFILE2.MPJ`

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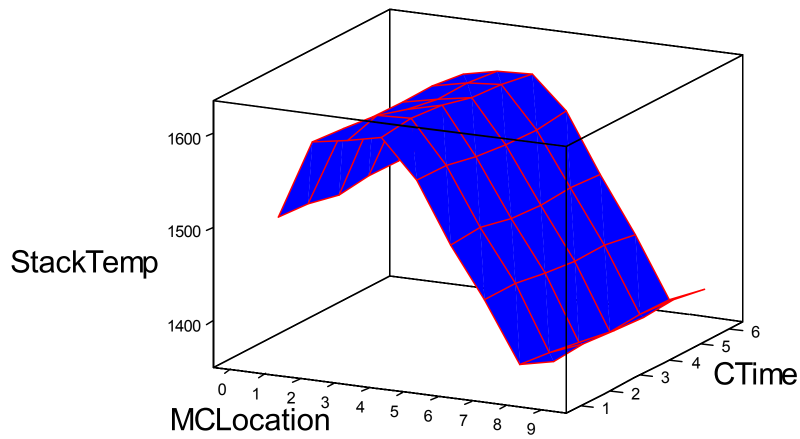

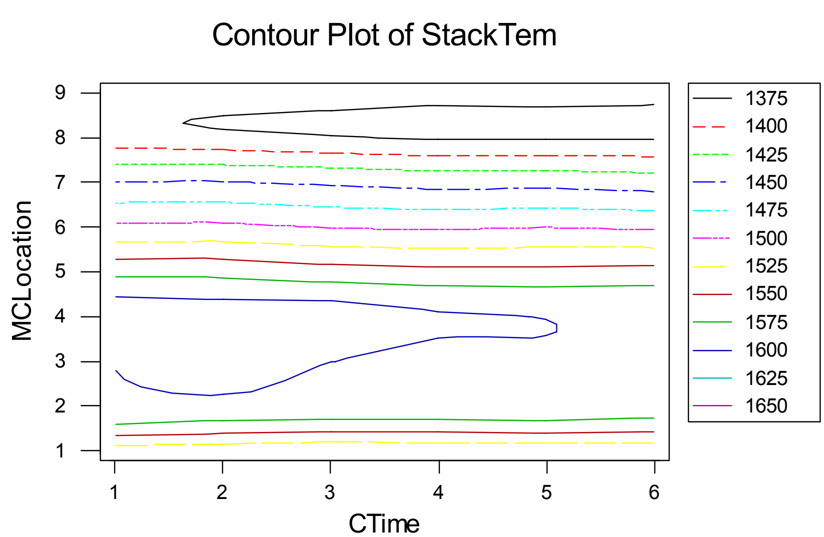

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Principal Component Analysis: PCA

Data matrix: *k* dimensions, *n* observations

$$\mathbf{X} = \begin{pmatrix} \mathbf{X}_1 \\ \vdots \\ \mathbf{X}_k \end{pmatrix} \Rightarrow \mathbf{X}' = \begin{pmatrix} x_{11} & \cdots & x_{k1} \\ \vdots & & \vdots \\ x_{1n} & \cdots & x_{kn} \end{pmatrix}$$

$$D(\mathbf{X}) = \mathbf{\Sigma}_{k\times k}$$

$$\mathbf{P} = (\mathbf{p}_1, \ldots, \mathbf{p}_\mathbf{k})$$

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$$\mathbf{Y} = \begin{pmatrix} y_{11} & \cdots & y_{1n} \\ \vdots & & \vdots \\ y_{k1} & \cdots & y_{kn} \end{pmatrix} = \begin{pmatrix} \mathbf{Y}_1 \\ \vdots \\ \mathbf{Y}_k \end{pmatrix} = \mathbf{P}'\mathbf{X}$$

or

$$\mathbf{Y}' = \mathbf{X}'\mathbf{P}$$

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Spectral Decomposition

$$\boldsymbol{\Sigma} = \lambda_1 \mathbf{p}_1 \mathbf{p}_1' + \cdots + \lambda_n \mathbf{p}_k \mathbf{p}_k'$$

$$\mathbf{Y}_1 = \mathbf{p}_1' \mathbf{X}, \ldots, \mathbf{Y}_k = \mathbf{p}_k' \mathbf{X}$$

$$\mathbf{Y} = \mathbf{P}' \mathbf{X}$$

$$\mathbf{Y} = \mathbf{P}' \mathbf{X} \Leftrightarrow \mathbf{X} = \mathbf{P} \mathbf{Y}$$

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Reconstruction of X

$$\textit{Let } \mathbf{Y}^* = \begin{pmatrix} \mathbf{Y}_1 \\ \vdots \\ \mathbf{Y}_m \\ 0 \\ \vdots \\ 0 \end{pmatrix} \textit{ then } \mathbf{X}^* = \mathbf{P}\mathbf{Y}^*$$

$$\Rightarrow D(\mathbf{X}^*) = \mathbf{P} D(\mathbf{Y}^*) \mathbf{P}'$$

$$= (\mathbf{p}_1, \ldots, \mathbf{p}_k) \begin{pmatrix} \lambda_1 & & & & & \\ & \ddots & & & & \\ & & \lambda_m & & & \\ & & & 0 & & \\ & & & & \ddots & \\ & & & & & 0 \end{pmatrix} \begin{pmatrix} \mathbf{p}_1' \\ \vdots \\ \mathbf{p}_k' \end{pmatrix}$$

$$= \lambda_1 \mathbf{p}_1 \mathbf{p}_1' + \ldots + \lambda_m \mathbf{p}_m \mathbf{p}_m'$$

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Building up X

$$Let\ \mathbf{Y}_m{}^* = \begin{pmatrix} \mathbf{Y}_1 \\ \vdots \\ \mathbf{Y}_m \\ 0 \\ \vdots \\ 0 \end{pmatrix} then\ \mathbf{X}_m{}^* = \mathbf{P}\mathbf{Y}_m{}^*, m = 1, \ldots, k_m$$

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Building up X

$$\mathbf{X}_m{}^* - \mathbf{X}_{m-1}{}^* = \mathbf{P}\mathbf{Y}_m{}^* - \mathbf{P}\mathbf{Y}_{m-1}^*, m = 2, \ldots, k$$

$$\mathbf{X}_m^{\delta} = \mathbf{X}_m{}^* - \mathbf{X}_{m-1}{}^* = \mathbf{P}(\mathbf{Y}_m{}^* - \mathbf{Y}_{m-1}^*)$$

$$= \mathbf{P}\left(\begin{pmatrix} \mathbf{Y_1} \\ \vdots \\ \mathbf{Y_{m-1}} \\ \mathbf{Y_m} \\ \mathbf{0} \\ \vdots \\ \mathbf{0} \end{pmatrix} - \begin{pmatrix} \mathbf{Y_1} \\ \vdots \\ \mathbf{Y_{m-1}} \\ 0 \\ \mathbf{0} \\ \vdots \\ \mathbf{0} \end{pmatrix} \right) = \mathbf{P} \begin{pmatrix} 0 \\ \vdots \\ 0 \\ \mathbf{Y_m} \\ \mathbf{0} \\ \vdots \\ \mathbf{0} \end{pmatrix}$$

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Building up X

$$Let\ \mathbf{X}_1^{\delta} = \mathbf{X}_1^{*}\ then:$$

$$\mathbf{X} = \sum_{m=1}^{k} \mathbf{X}_m^{\delta}$$

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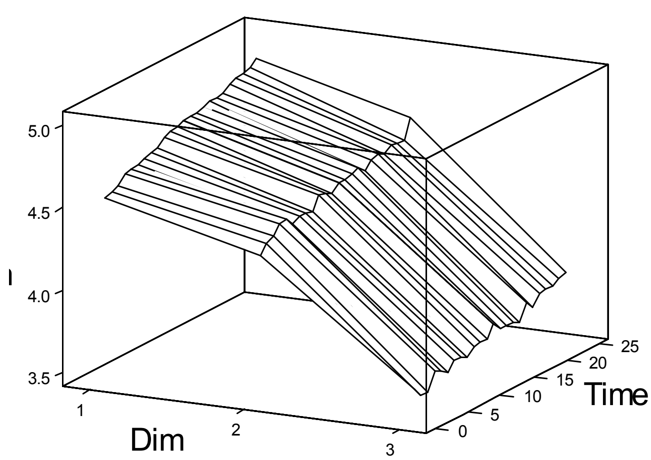
The Original Surface



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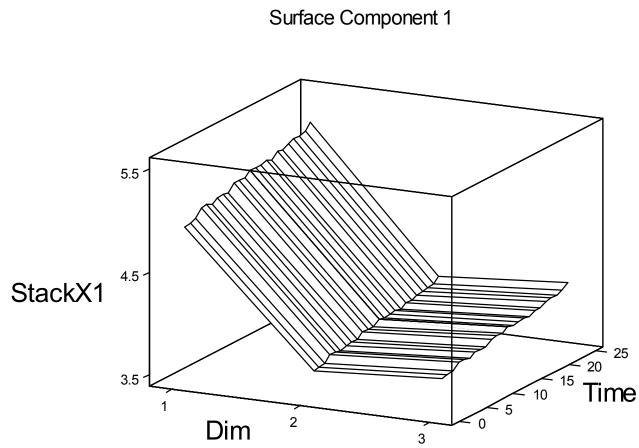

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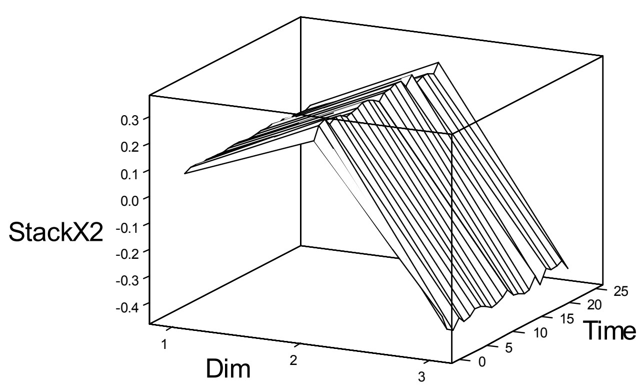
Component 2



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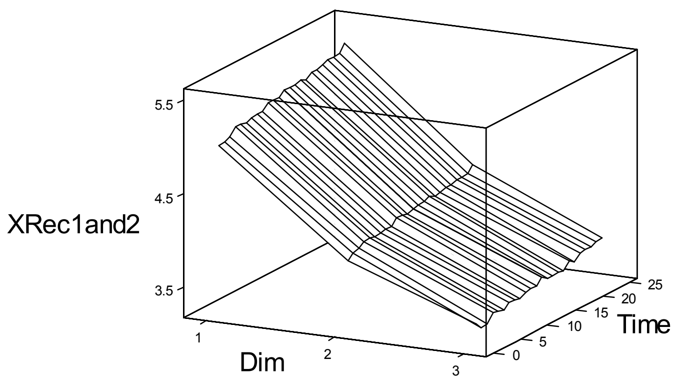
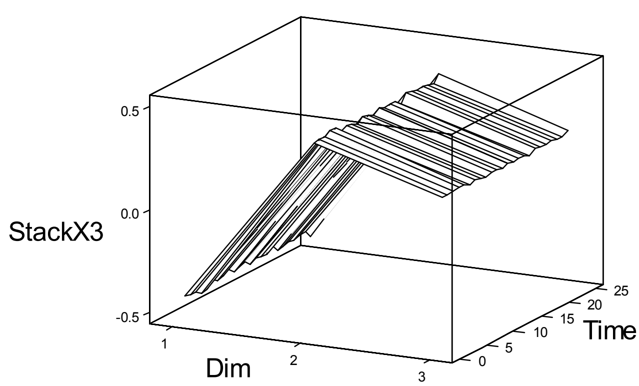
Surface 1 and 2



Component 3



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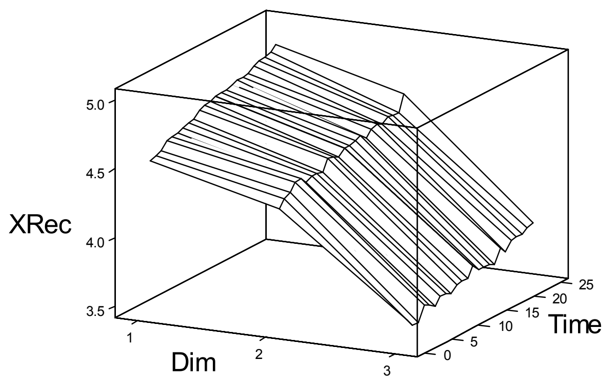
The reconstructed surface



Autocorrelation in Process Monitoring

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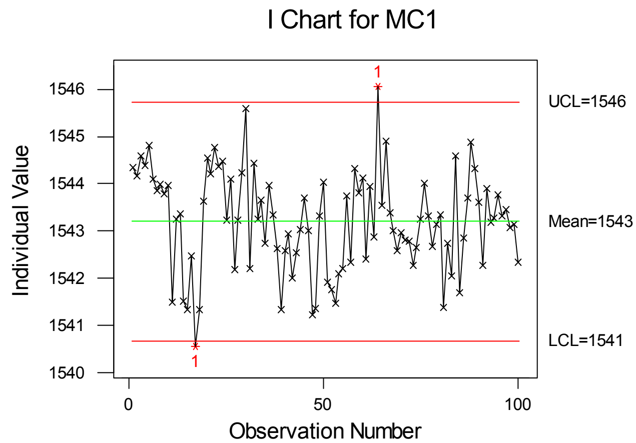
Example: Out of Control?



Descriptive Statistics: MC1

Variable	N	Mean	StDev
MC1	100	1543.2	1.1

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Effect of Autocorrelation

A simple autoregressive process

$$y_t = \varphi y_{t-1} + \varepsilon_t$$

$$\varepsilon_t \sim N(0, \sigma^2)$$

$$\rho_k = \phi^k$$

$$\sigma_y = \frac{\sigma_\varepsilon}{1-\phi}$$

$$\rho = autocorrelation$$

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A Simple Approach to Dealing with Positive Autocorrelation

- Positive autocorrelation means essentially that we don't have as much data as we think and that the estimated variability in small samples is smaller that it really is
- To compensate for this we can simply increase our estimate of sigma or widen the control limits to more than $\pm 3\sigma$
- Alternatively we can monitor the residuals from the time series fit with regular control charts

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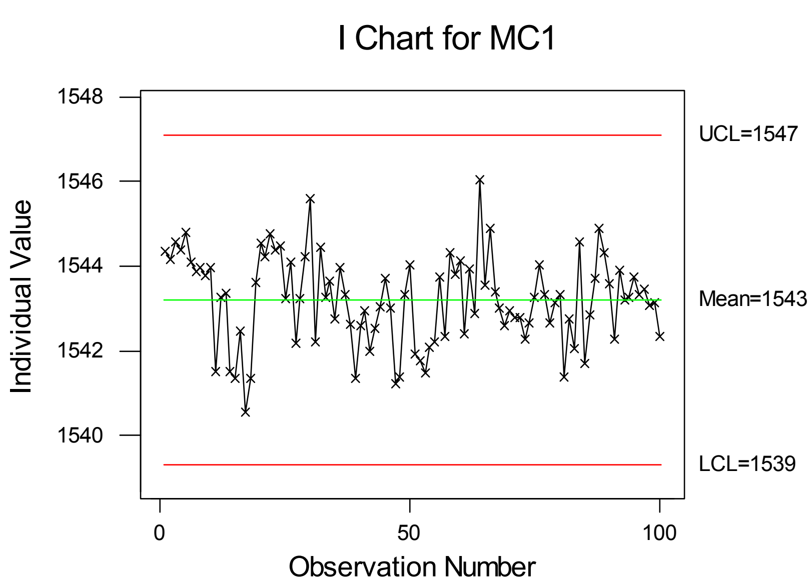

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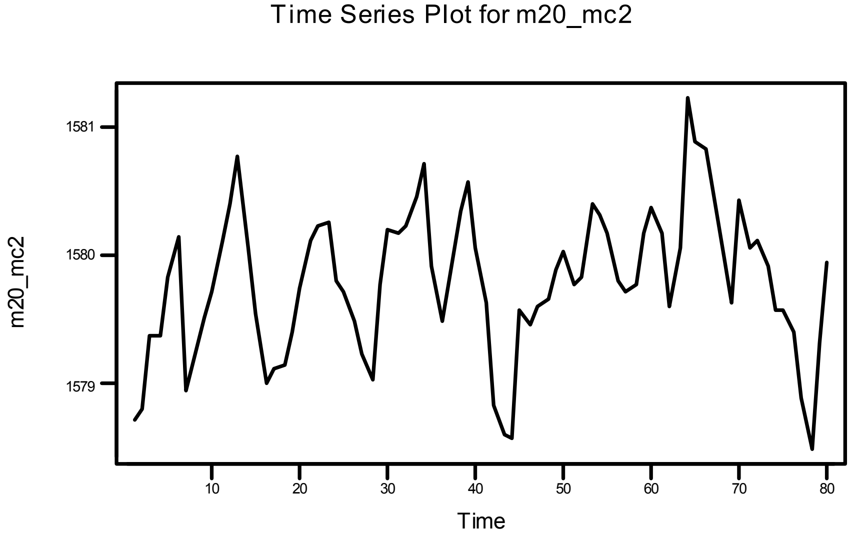
Another Time Series



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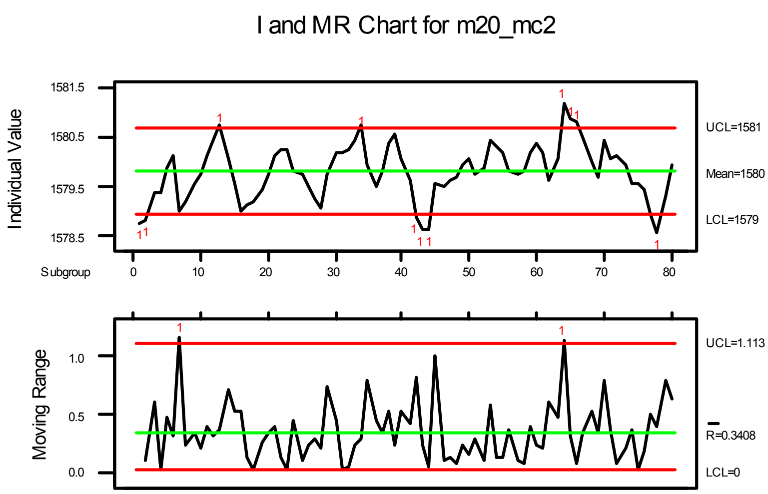

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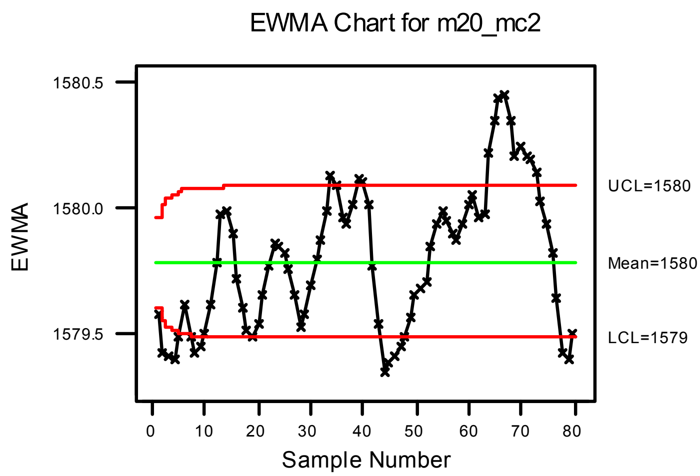

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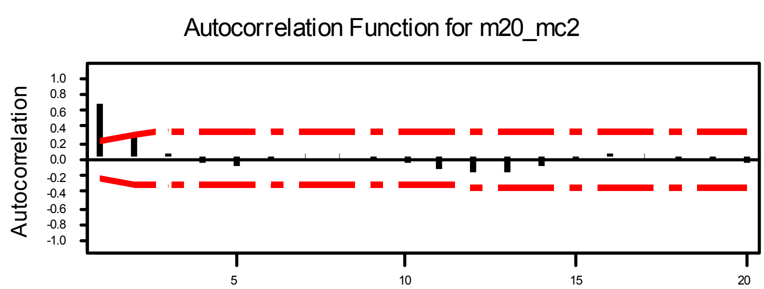

Lag	Corr	T	LBQ	Lag	Corr	T	LBQ	Lag	Corr	T	LBQ
1	0.69	6.20	39.94	8	0.02	0.13	49.11	15	-0.00	-0.00	59.77
2	0.31	1.95	47.79	9	-0.01	-0.05	49.12	16	0.05	0.31	60.07
3	0.06	0.35	48.08	10	-0.08	-0.46	49.65	17	0.01	0.06	60.08
4	-0.06	-0.39	48.43	11	-0.14	-0.83	51.43	18	-0.03	-0.19	60.19
5	-0.08	-0.50	49.02	12	-0.19	-1.14	54.91	19	-0.02	-0.14	60.25
6	-0.01	-0.06	49.03	13	-0.19	-1.12	58.44	20	-0.05	-0.30	60.56
7	0.02	0.13	49.07	14	-0.12	-0.67	59.77				

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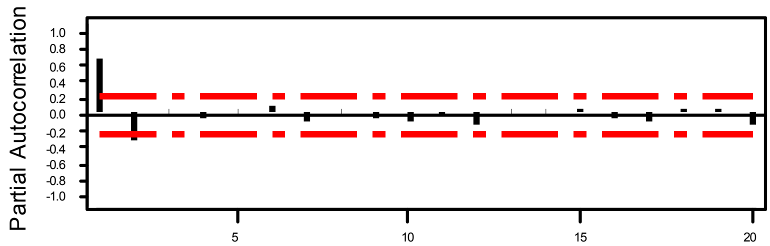
Partial Autocorrelation Function for m20_mc2



Lag	PAC	T	Lag	PAC	T	Lag	PAC	T
1	0.69	6.20	8	0.02	0.22	15	0.06	0.52
2	-0.34	-3.02	9	-0.05	-0.43	16	-0.04	-0.38
3	0.02	0.17	10	-0.09	-0.77	17	-0.10	-0.93
4	-0.05	-0.45	11	-0.04	-0.33	18	0.06	0.50
5	0.03	0.28	12	-0.12	-1.05	19	0.05	0.42
6	0.09	0.80	13	0.01	0.13	20	-0.13	-1.15
7	-0.08	-0.75	14	0.04	0.34			

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ARIMA (2,0,0) Model: m20_mc2

Final Estimates of Parameters

Type	Coef	SE Coef	T	P
AR 1	0.9824	0.1062	9.25	0.000
AR 2	-0.3722	0.1066	-3.49	0.001
Constant	615.836	0.042	14703.84	0.000
Mean	1579.79	0.11		

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AR(2) Process

$$\tilde{y}_t = \phi_1 \tilde{y}_{t-1} + \phi_2 \tilde{y}_{t-2} + a_t$$

Stationary!

Variance:

$$\sigma_y^2 = \left(\frac{1-\phi_2}{1+\phi_2} \right) \frac{\sigma_a^2}{\{(1+\phi_2)^2 - \phi_1^2\}}$$

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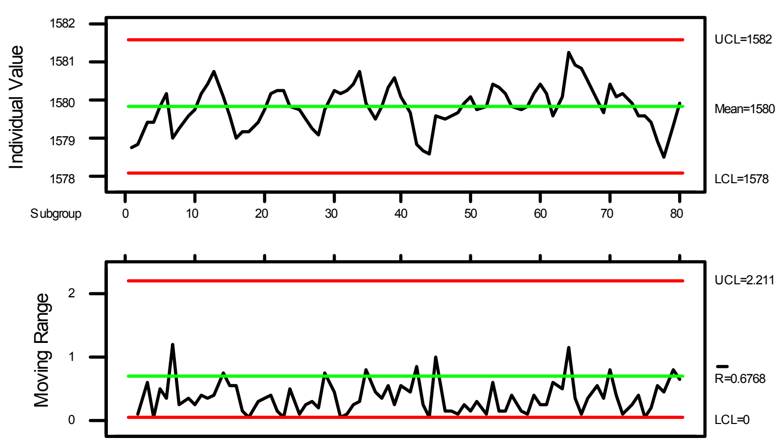
Using Expanded Limits

I and MR Chart for m20_mc2



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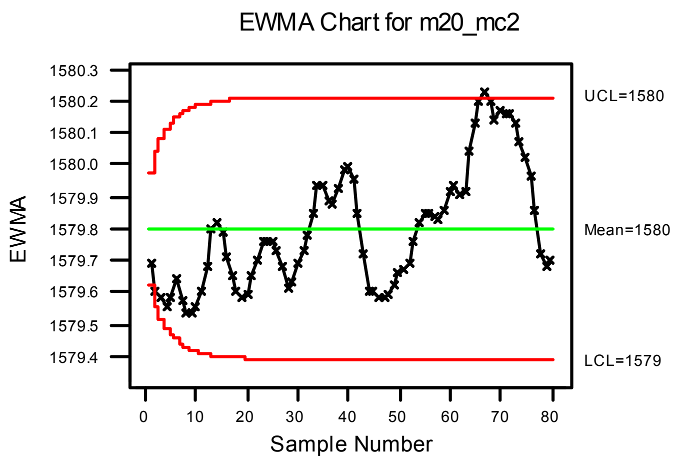
Using Expanded Limits



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Conclusion

- Schumpeter: The fundamental impulse that sets and keeps the economic engine in motion comes from innovation …
- Quality is about innovation – product and process innovation – service and manufacturing
- Hayek: Need local information and local decision making
- Statistics and scientific method play a key role

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