Information Speed:

The Driving Force and Source of Supernormal Shareholder Returns

“That I may recognize what holds the
Earth together in its inmost essence,
behold the driving force
and source of everything,
and rummage no more in empty words”

Goethe, *Faust*

As translated by Frederick Reif in *Statistical Physics*

Definition of Supernormal Returns

"A Supernormal return earns a return that is greater than that earned on investments of equivalent risk. The existence of these excess returns acts as a magnet, attracting competitors to take on similar investments. The excess returns dissipate over time; depending on the ease with which competition can enter the market and provide close substitutes"

Applied Corporate Finance, Aswath Damodaran, chapter 5

The Source of Supernormal Returns

- Supernormal Returns in Shareholder Value are maintained for greater than 10 years by less than 10% of companies[1]
- Thesis: the *Driving Force and Source* of supernormal returns is *maintaining* Information Speed much greater than Competitors, defined as:

$$\text{Information Speed} = \frac{\text{Value Creating Variety of Offerings Demanded by Market}}{\text{Lead Time to supply that Variety to the Market}}$$

- 1. e.g.,Foster, Richard *Creative Destruction.* Christensen*, Innovators Solution,*see page 7 for formula for shareholder value

Variety Demanded by the Market: the natural emergence of Entropy

Assume a company produces A and B in quantities $N_A + N_B = D$ per unit of time, $N_A = N_B$ in sequences demanded by the market like:

AABABBAABBBABBAB

BABBABBAAABAABAB, etc.

Essentially there are D Choices per unit of time of either A or B. The number of distinct sequences or “messages” is

$$m = \frac{D!}{n_A!\,n_B!} = \binom{D}{n_A} = \frac{D!}{n_A!\left(D - n_A\right)!}$$

Emergence of Shannon Entropy

Demand Variety=Information,
The Numerator of Information Speed

- Let $p_A \to \frac{n_A}{\mathrm{D}}$ etc
- Using Stirling's Approximation

$$\mathrm{logm} \cong \text{-}\mathrm{D}\sum_{i=A}^{B} p_i \mathrm{log} p_i = \mathrm{DH} \to \left(\frac{\text{Choices}}{\text{Unit of Time}}\right)\left(\frac{\text{Bits}}{\text{Choice}}\right) \to \frac{\text{Bits}}{\text{Unit of Time}}$$

- And for M products from the Market

$$\mathrm{H_M} = -\sum_{i=1}^{M} p_i \mathrm{log} p_i \to \text{Shannon Entropy}$$

Information speed supplied $=$ $\mathrm{DH_M}$ bits per unit of time by the Market

But what products should we supply? Those that create the greatest shareholder value

Market Information of Shareholder Value

Assuming constant growth of g% per year in Economic profits, the perpetual annuity formula yields the shareholder value for any company based on its current year's (year zero)Economic Profit:

$$\text{Shareholder Value} = \text{BookValue} + \frac{\text{Economic Profit}_0}{\text{WACC\%} - \text{g\%}}$$

- Book Value = Total Assets-Total Liabilities (assuming Economic Profit≥0)
- Economic Profit = (ROIC% - WACC%)(Invested Capital)
- ROIC = Return on Invested Capital = (Profits after Tax)/(Invested Capital)
- Invested Capital (IC)= Total Assets – Current Liabilities
- Assets= Inventory + Accounts Receivable + Fixed Assets + Cash& Securities
- Liabilities= Accounts Payable + Notes Payable + Accruals
- WACC = Weighted Average Cost of Capital ~ 10%
- g% = Growth in Economic Profits per year or Revenue if ROIC is fixed

Those goods/services for which ROIC%>WACC% have positive Economic Profits will add to the shareholder value. On the other hand, the goods/services for which ROIC<WACC will destroy shareholder value.

[i] McTaggert, Stern, Copeland, op cit

[ii] For finite and supernormal valuation formulae, see J Fred Weston,*Takeovers, Restructuring..* These formulae avoid the singularity at WACC=growth

Value Creating Variety: Information supplied by Economic Profit (EP) distribution of the M products in the Market

- Products with negative EP add no value information and are eliminated
- $Log(EP)=log(\Sigma EPi)=H(EP_i)+Ex(log(EP_i))$[1]
- $H(EP_i)$ is the variety needed to generate Economic Profit
- When Model T accounted for

% Total EP	Variety needed to earn Economic Profit
90%	0.67 bits
30%	2.25
0%	2.00
Uniform Dist	2.32

1.Ex(log(EP)) is expectation of logEP, see also Appendix 1 and 3

Requires solution to the "Ill posed inverse problem"

Each company should select a subset R of M, present or potential, for which $H_R \cong H_M$ the R selected such that the company can maximize Economic profit using MaxEnt[1].

From the time that variety H_R is demanded by the market, the question is: how long will it take to supply it?

1.See Golan, Judge *Maximum Entropy Econometrics*

Impact of Customer Lead Time on Required Information Velocity of Supply

$$\text{InformationSpeed}_{\text{Demand}} = DH_R = \frac{H_R}{\left(\frac{1}{D}\right)} \text{ bits per unit of time}$$

$$\text{Natural Period/unit of product} = \left(\frac{1}{D}\right) \text{ units of time/choice}$$

But if customer will accept lead time $t=\tau$ for a choice to be satisfied then required information velocity of the process is reduced to:

$$\text{InfoSpeed}_{\text{Supply}} = \frac{H_R}{\tau} \text{ bits per unit of time/choice}$$

For a unit of product of product supplied to the customer

To use this equation , we must review the formula for lead time τ

Lead time τ of Internal Processes to supply Variety

The *Denominator* of Information speed

- Little's Law[1]: Lead time τ of any process

$$\tau = \frac{\text{Units of Work In Process=WIP}}{\text{Completion Rate in Units/Time=D}} = \text{Lead Time}$$

- Little's Law leads[2] to a formula for WIP

$$\text{WIP}=\text{e}^{\text{H}_{\text{IntProcess}}} \text{ units of Work In Process}^{3}$$

$$\text{Lead Time to supply variety} = \tau = \left(\frac{1}{D}\right)\text{e}^{\text{H}_{\text{IntProcess}}} \text{ in units of time}$$

1. Hall, *Queueing Methods,*Hopp *Factory Physics*
2. George, *On the Entropy of Business Processes,* George, Patell, et al, *On the WIP of a Business Process*
3. *See appendix 2 and 3 for a derivation and an expression for $H_{IntProcess}$*

Drivers of Shareholder Value: Fundamental Equations of Information Speed

$$\text{Information Speed} = \frac{\text{Variety of Market Demand}}{\text{Lead Time to Supply that Variety}}$$

$$\text{Information Speed} = \frac{H_R}{e^{H_{IntProcess}} / D} = \frac{DH_R}{e^{H_{IntProcess}}} = \frac{(\text{units}/\text{time})(\text{bits})}{\text{units}} = \frac{\text{bits}}{\text{time}}$$

$$\text{Information Speed} = DH_R e^{-H_{IntProcess}}$$

and the rate at which a company accelerates is $\frac{d}{dt}(\text{Speed})$:

$$\text{Information Accelleration} = e^{-H_{IntProcess}} \left\{ \frac{d}{dt}(DH_R) - DH_R \frac{d}{dt}(H_{IntProc}) \right\}$$

Achieve and maintain supernormal returns by maximizing all 3 sources of Information Speed

1. Increase the rate of change of the offering H_R, in response to H_M:

$$+\frac{\mathrm{d}}{\mathrm{dt}}\left(\mathrm{DH_R}\right) \to D\frac{d}{dt}\mathrm{H_R}$$

to prevent commoditization and complexity destruction of margins

2. Increase rate of reduction of the entropy of internal processes

$$-\frac{\mathrm{d}}{\mathrm{dt}}\left(\mathrm{H_{IntProc}}\right)$$

to reduce lead time, complexity and cost

3. Increase D to attain economies of scale (Wal-mart)

$$+\frac{\mathrm{d}}{\mathrm{dt}}\left(\mathrm{DH_R}\right) \to \mathrm{H_R}\frac{d}{dt}D$$

Product Development, Marketing, etc

- It has been shown[1] that, for non mfg processes:

$$H_{IntProcess}=\log\left(\frac{\rho^2}{1-\rho}\right)+\log\left(C_P{}^2+C_A{}^2\right)-\log 2-\log K$$

- Where[2]

ρ=% of maximum capacity utilization

C_P=Coeff of Variation of Processing time

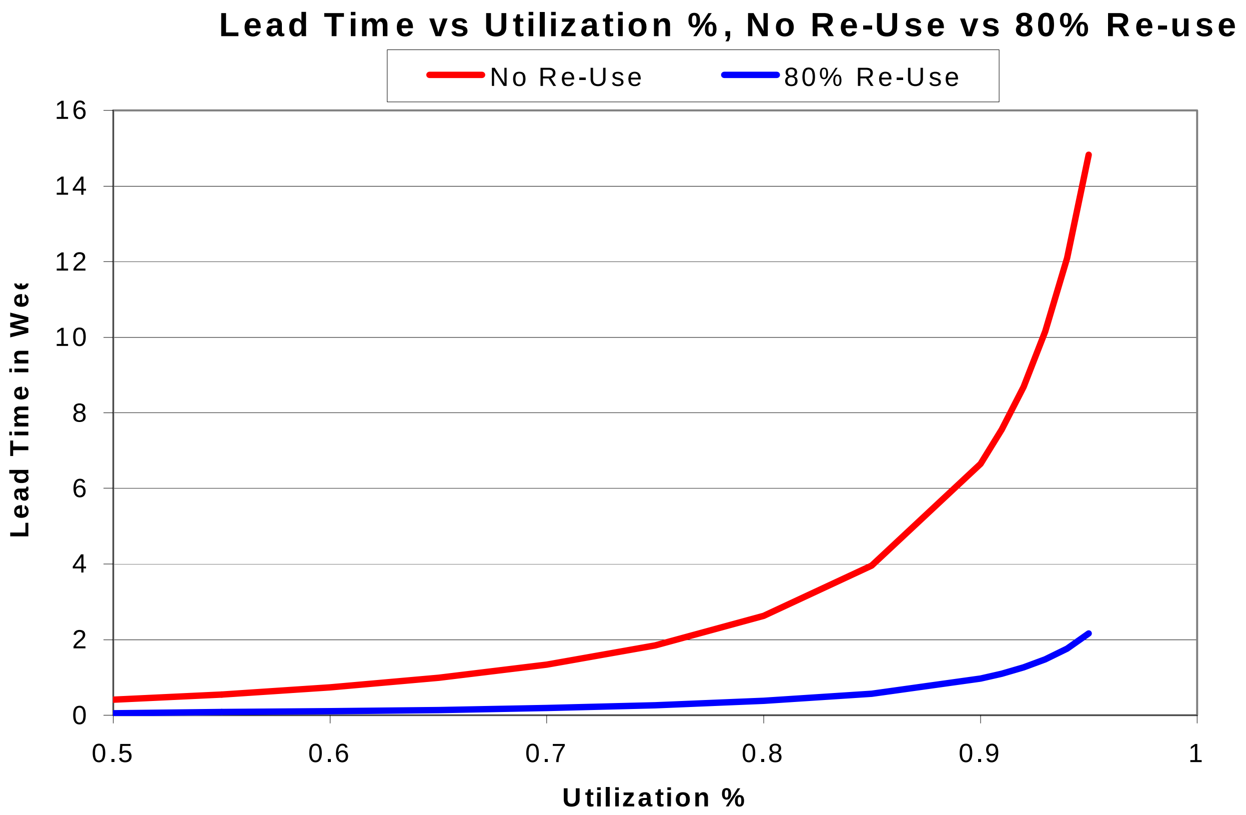
C_A=Coeff of Variation of Arrival time

K=number of cross trained personnel

1. George, *On the Entropy of Business Processes.* George et al, *Fast Innovation*
2. Hall, *Queueing Methods*

Toyota vs "Big 3" development times 2-3 times as fast

Reuse: Approximately 65% of all internal components N are common to Toyota platforms reducing $\log\left(\frac{\rho^2}{1-\rho}\right)$ and $\log\left(C_P^2 + C_A^2\right)$



Isn't Information Speed an obvious way to maintain supernormal returns?

- That 90% of companies cannot maintain supernormal returns argues to the contrary.
- We assert that a significant gap in Information Speed is a necessary and sufficient condition to maintain supernormal returns
- Let us test this assertion with empirical examples

Comparative Examples of Information Speed: Henry Ford vs. GM

- Ford only produced one model from 1908-1927, hence each workstation only produced 1 item, N=1,complexity=0, and hence there was no setup, S=0. Thus per App 2A

$$H_{IntProcess} \cong \log(1) + \log\left(\frac{(0)DA}{(1\text{-}X\text{-}PD)} + A\right) = \log A$$

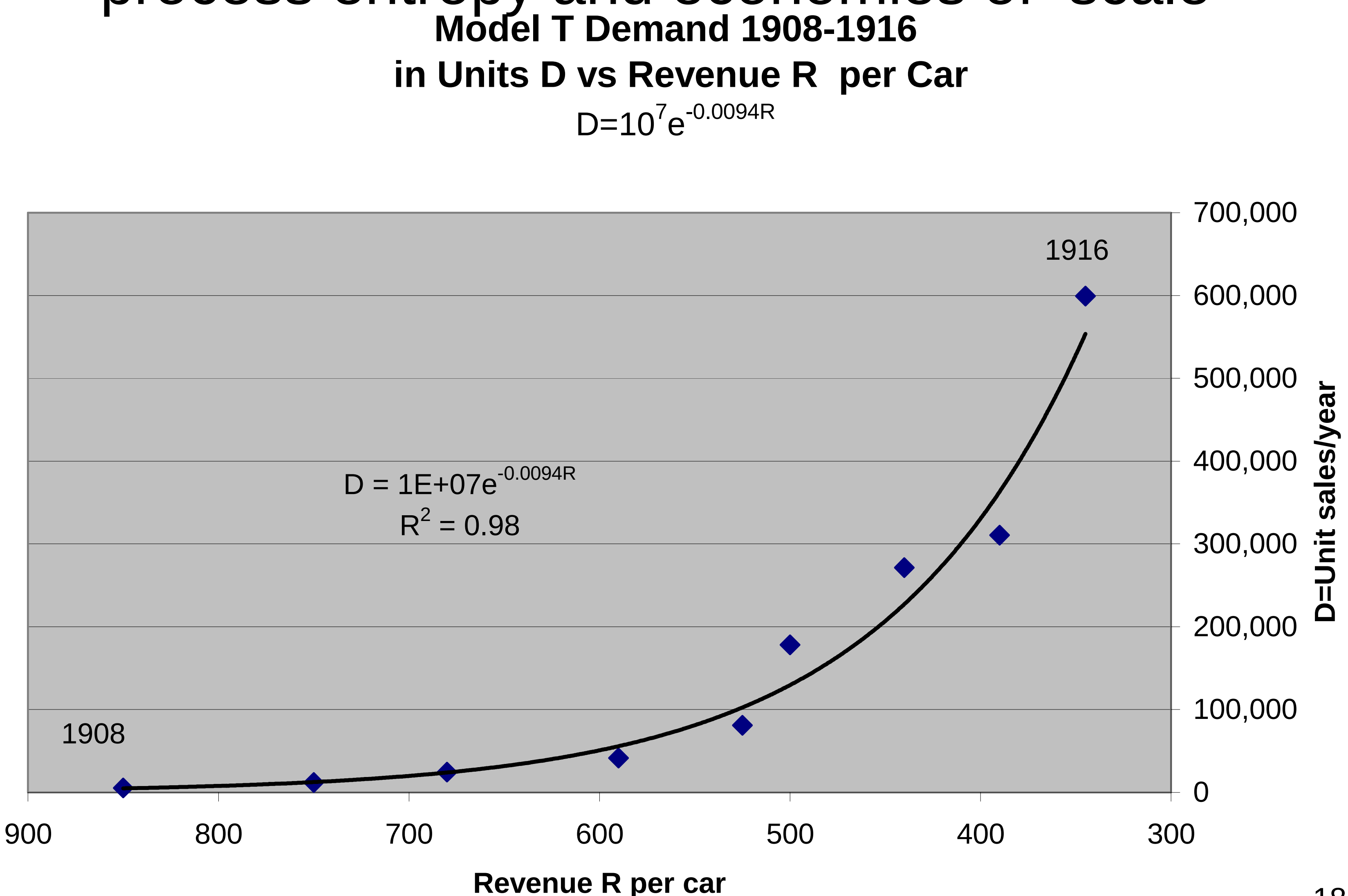
$$H_R = \log(1) = 0$$

- Hence

$$\text{Information Speed} = \frac{0}{e^{\log A}} = \frac{0}{A} = 0$$

Henry Ford fell victim when H_M market demand increased from near zero for utility transportation to near logR, the variety offered by GM. Ford's share falling from 65% in 1921 to 0% in 1927, transferring Ford's supernormal returns to GM

Henry Ford exploited an $H_M \cong 0$ Market with low process entropy and economies of scale



General Motors

Internal Process entropy very large compared to Ford due to long setups S, poor quality X, long process paths A, and lack of standardization N. Per App 2A:

$$H_{IntProcess} \cong \log N + \log\left(\frac{SDA}{(1\text{-}X\text{-}PD)} + A\right) = \log N + \log\left(A\left(\frac{SD}{(1\text{-}X\text{-}PD)} + 1\right)\right)$$

$$H_{IntProcess} \cong \log N + \log A + \log\left(\frac{SD}{(1\text{-}X\text{-}PD)} + 1\right)$$

Third term very large. General Motors built 5 distinct models and a multitude of submodels hence H_R>log5>Ford=0.

$$\text{Information Speed} = \frac{\log 5 +}{\left(\frac{NASD}{(1\text{-}X\text{-}PD)} + NA\right)} > 0 = \text{Henry Ford}$$

Hence, despite inefficient operations, because H_M~log5,GM enjoyed supernormal returns from 1924 to 1984. This model also describes Compaq and most other companies.,

Toyota vs. GM

Offers a product line comparable to General Motors, i.e., H_R>log5+ ,builds multiple products hence N≠1, but S→0+ε where ε can be made arbitrarily small at modest cost by continuous application of the Four Step Rapid Setup[1] method, etc. Hence according to App 2:

$$H_{\text{IntProcess}} \cong \text{logN+log}\left(\frac{(0+\varepsilon)\text{DA}}{\text{(1-X-PD)}} + A\right) \cong \log N + \log A$$

$$\text{Information Speed=}\frac{\text{log5+}}{\text{NA}} >> \frac{\text{log5+}}{\left(\frac{\text{NASD}}{\text{(1-X-PD)}} + NA\right)} \text{=General Motors}$$

$$\text{Toyota} \rightarrow \text{NA} \approx 10^4 << 10^6 \approx \left(\frac{\text{NASD}}{\text{(1-X-PD)}} \text{+NA}\right) \rightarrow \text{GM}$$

Thus the Information Velocity of Toyota is at least an order of magnitude larger than GM, driving GM market share from 51% to 25% and transferring supernormal returns to Toyota. Toyota External Market entropy comparable to GM,Toyota internal Process entropy approaching Henry Ford. Toyota model is also characteristic of Dell

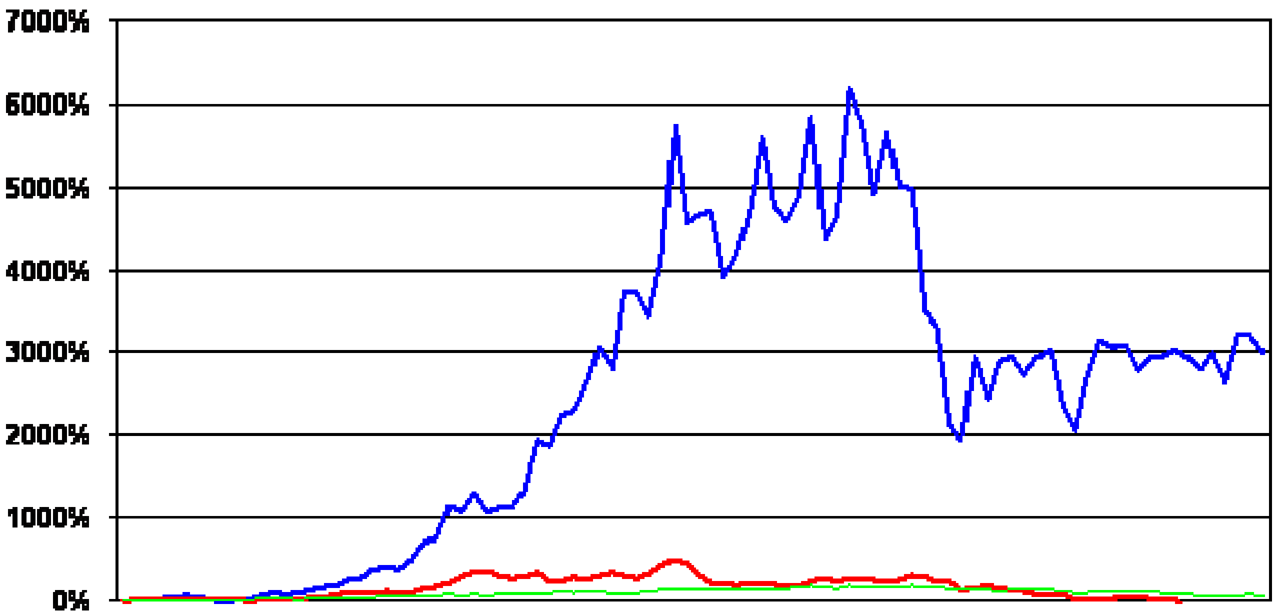
1 see George et al, *Lean Six Sigma Pocket Toolbook*

Intel vs AMD
Information speed:The Giant Killer

Intel enjoyed supernormal returns until it failed to supply the 64bit X86 chip, while AMD succeeded. AMD had never enjoyed supernormal returns, but superior information speed reversed their roles.

Dell vs Compaq Ten Year Return
Return of 1500% vs 0%

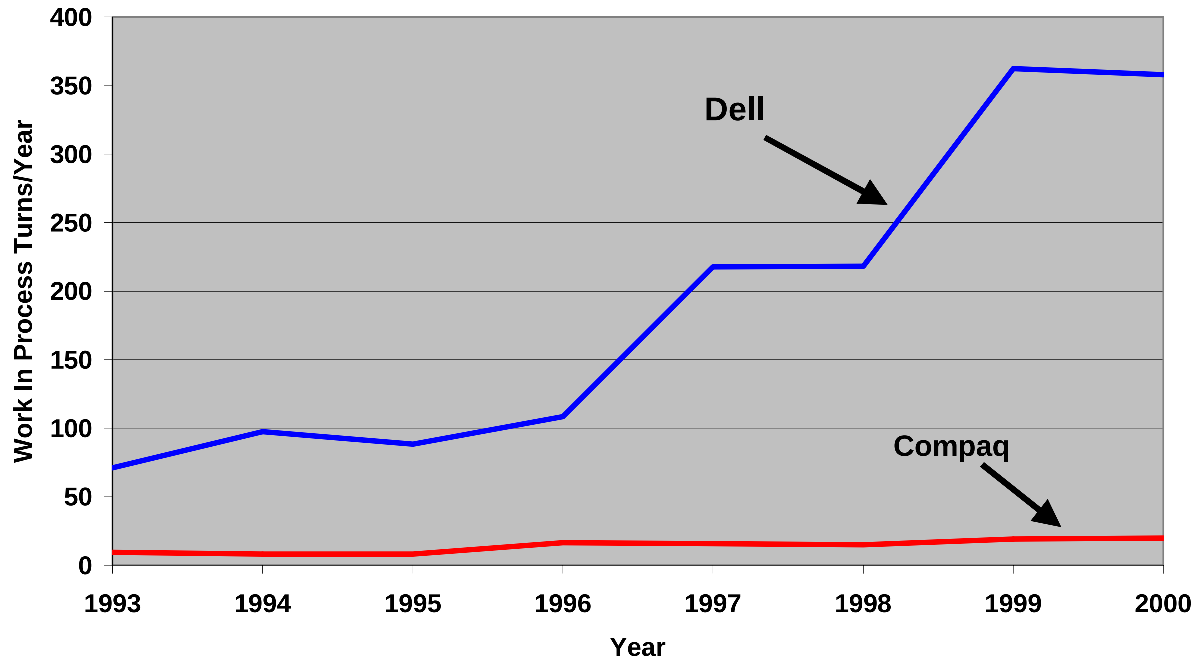
- Compaq created most innovations (high H_R), but had high $H_{IntProcess}$. Dell quickly copied Compaq and had comparable H_R, but very low $H_{IntProcess}$, hence much higher Information Speed



Dell Information Velocity 35 times greater than Compaq

WIP turns=1/τ, hence Dell Operational lead time and $e^{H_{IntProcess}}$ is 35 times smaller than Compaq. H_M is comparable for both firms $\therefore$,Dell information speed is 35 times greater than Compaq

Process/Business Model Innovation by Dell
Compaq fails to copy Dell…and is destroyed!

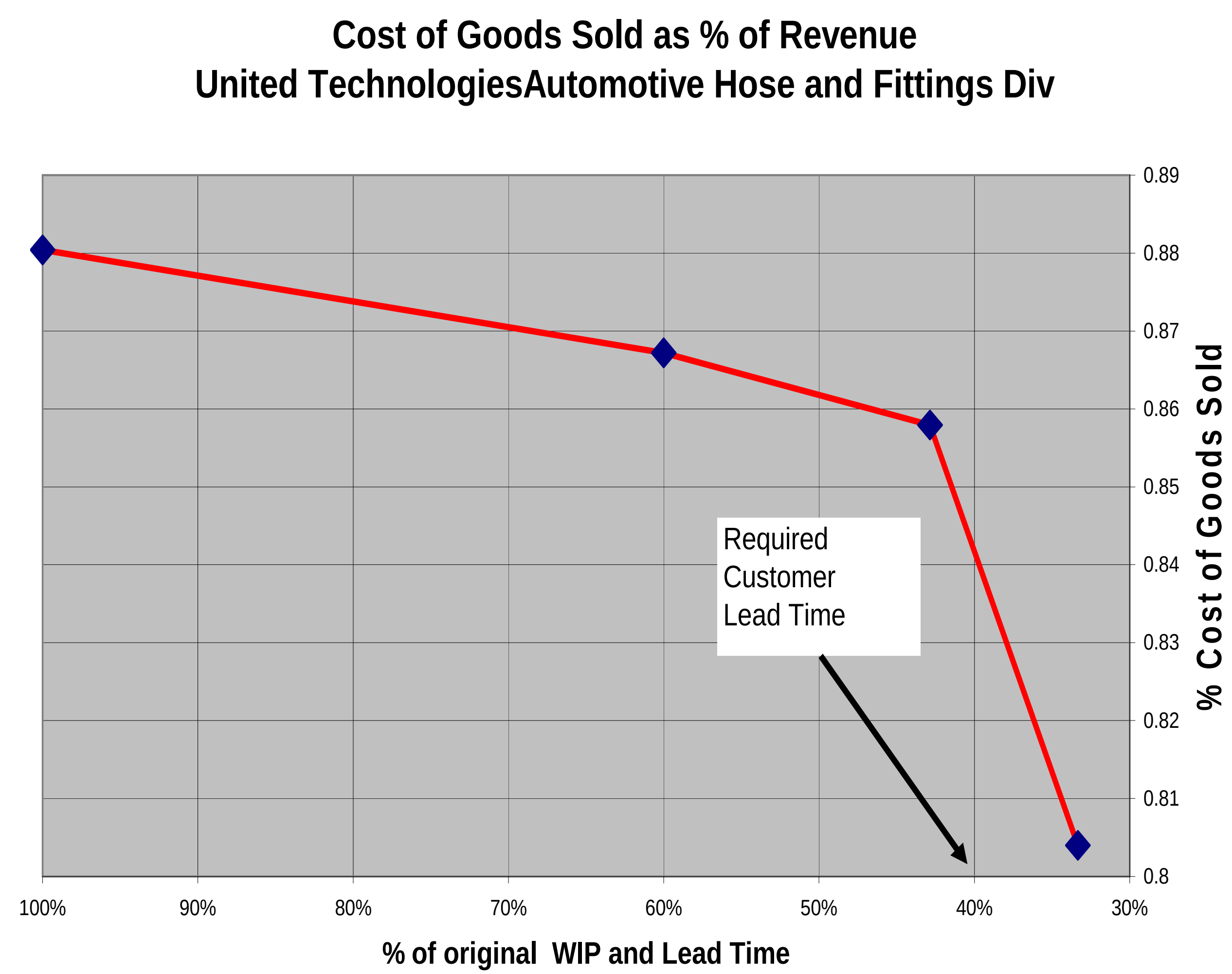


Why should companies reduce process lead time τ<<t=Customer Lead Time

- The perfect process has no waste cost, which is typically 10-20% of revenue
- Waste eliminated when all cost is value add
- In the perfect process $\tau \rightarrow$ Total Value Add Time
- Material is passed in lot size 1(setup time S=0, defects X=0%) from value add to value add tasks A_0<A, for a given R, internal Complexity is reduced from N to N_0
- Waste$\rightarrow\delta$ as

$$\text{Entropy}=\log\left(\text{WIP}\right)=\log\left(\frac{\text{NSDA}}{\text{1-X-PD}}+\text{NA}\right)\rightarrow\log\left(0+\text{N}_0\text{A}_0\right)\rightarrow 0+\varepsilon$$

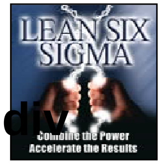
United Technologies Automotive Information Velocity 4 times that of Ford Climate Control



..resulting in Supernormal returns and increasing shareholder value by 225%

Results of Lean Six Sigma:

United Technologies Automotive Hose and Fittings div

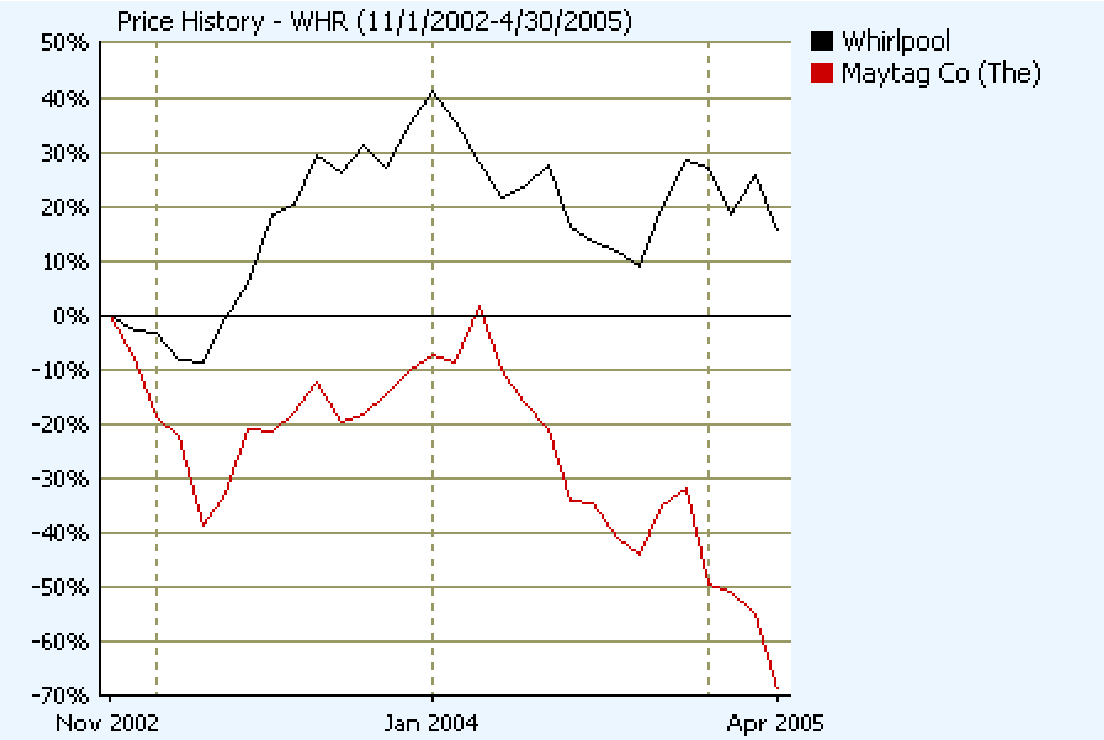


Customer Quality	
Quality Performance (External CTQ)	From 3σ to 6σ (regained Ford Q1)
On-Time Delivery	From 80% to >99.7%
Lead Time	From 14 Days to 2 Days
Inspection	Moved from Full Final Inspection to In-Process Inspections

Financial Results	
Operating Margin	From 5.4% to 13.8%
Capital Turnover	From 2.8 to 3.7
ROIC	From 10% to 33%
Enterprise Value	Increased 225%
EBITDA	Increased 300%
Economic Profit=ROIC% - WACC%	From –2% to 21%
Work-In-Process Inventory Turns	From 23 to 67 Turns per Year

Maytag vs Whirlpool
to the victor go the spoils!

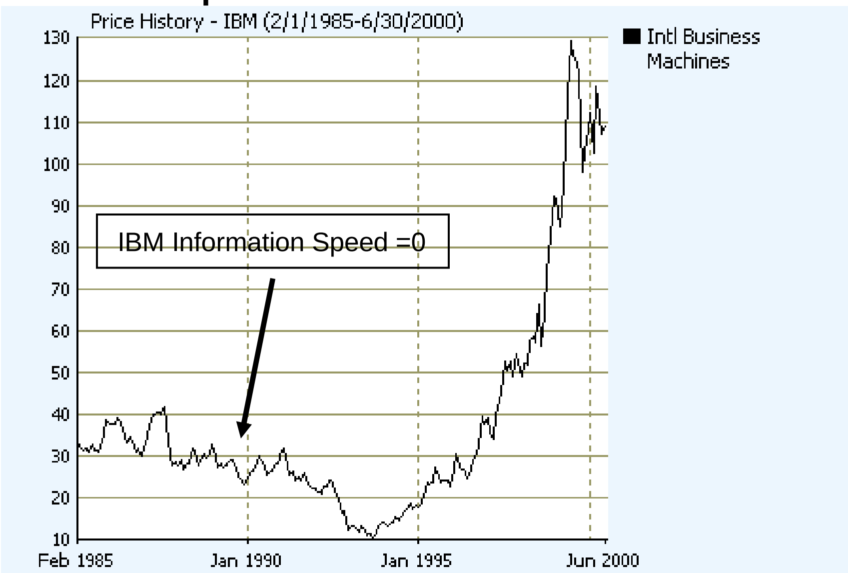
Maytag focused on reduction of the denominator of Information Velocity, reducing $H_{IntProcesses}$ in an effort to reduce cost and improve quality. Whirlpool chose a balanced approach, emphasizing highly differentiated innovation (dramatically increasing H_M) as well as lower $H_{IntProc}$. The duel ended with Whirlpool acquiring Maytag



IBM: riches to rags to riches

IBM maintained supernormal returns from 1922 to well into the 1980's.

In the 1990's, IBM management was in denial about the decline of main frames due to PC, Windows, UNIX servers, routers etc. The rate at which information was received by IBM management fell below the rate at which the information was transmitted by the market. Only by radical increase of Information Velocity to reposition the company(e.g. attack EDS, acquire PwC, withdraw from Hardware) to positive Economic Profit businesses was IBM able to return to supernormal returns.



Empirical Conclusions

Thesis: A company which maintains a significant gap in Information Speed will maintain supernormal returns as has Toyota and Dell. Had Compaq, IBM, Maytag, Ford Climate Control, GM, Henry Ford, and Intel applied management resources to monitor <u>*and*</u> accelerate Information speed, they would have maintained supernormal returns without interruption.

Corollary: If a competitor wishes to acquire and maintain the supernormal returns of a competitor it must first generate a gap in information speed.

The ***Driving Force*** *and* ***Source*** of Supernormal Shareholder Returns

- A company can only achieve and sustain supernormal shareholder returns if it maintains a superior gap in:

$$\text{Information Speed} = DH_{\text{Market}} e^{-H_{\text{IntProcess}}}$$

acquired by information acceleration

$$\text{Information Accelleration} = e^{-H_{\text{IntProcess}}} \left\{ \frac{d}{dt}\left(DH_R\right) - DH_R \frac{d}{dt}\left(H_{\text{IntProc}}\right) \right\}$$

- This conclusion is supported by all known empirical examples and provides a methodology for increase in shareholder value by management as well as a predictive tool for potential increase in share valuation.

Next Papers

- Application of Max Entropy principle for least biased estimate of source of competitive margins
- Impact of Noise on Market Information H_R and reduction of wealth doubling rate
- Application of Predictive Game Theory to determine outcome (distribution over mixed strategies, not a single equilibrium)

App 1 Entropy as a Measure of Variety Demanded to earn Economic Profit

Competitor	Economic Profit(EP)	% EP	log(%EP)	**Variety Demanded to earn Economic Profit**
	1921			
	EP	p	logp	-plogp
1	0.25	0.025	-5.32	0.13
2	0.25	0.025	-5.32	0.13
Ford	9	0.9	-0.15	0.14
4	0.25	0.025	-5.32	0.13
5	0.25	0.025	-5.32	0.13
Total	10	1		**0.67**
	1925			
	EP	p	logp	-plogp
1	1	0.1	-3.32	0.33
2	2	0.2	-2.32	0.46
Ford	3	0.3	-1.74	0.52
4	2	0.2	-2.32	0.46
5	2	0.2	-2.32	0.46
Total	10	1		**2.25**

Economic Profit(EP)	% EP	log(%EP)	**Variety Demanded to earn Economic Profit**
1927			
EP	p	logp	-plogp
2.5	0.25	-2.00	0.50
2.5	0.25	-2.00	0.50
0	0	0.00	0.00
2.5	0.25	-2.00	0.50
2.5	0.25	-2.00	0.50
10	1		**2.00**
uniform distribution			
EP	p	logp	-plogp
2	0.2	-2.32	0.46
2	0.2	-2.32	0.46
2	0.2	-2.32	0.46
2	0.2	-2.32	0.46
2	0.2	-2.32	0.46
10	1		**2.32**

App 2 Entropy of a Business Process

Starting with Little's Law: $\tau = \dfrac{\text{Units of Work In Process=WIP}}{\text{Completion Rate in Units/Hour}} \equiv \text{Lead time in hours}$

we derive the velocity equation via inversion. Define

R=Revenue per Unit

C=Avg Cost per unit at a Workstation or Activity in the process including Material Mfg and SG&A Overhead, and Cost of Capital

A= Number of workstations or Activities which comprise the process

W=Work In Process (WIP) in units

$ =R-CA=dollars of Economic Profit per unit

D= Units per hour completed

Next, we obtain a relationship similar to the inverse of Little's Law: τ=W/D, so

. The process improvement tools reduce WIP W and hence increase velocity.

We differentiate the velocity equation to obtain an equation of acceleration. The *effective mass*[[i]] of the process is shown to be W^2, which results from the agreement of two independent derivations, one based on Feedback Control Theory, the other on Enthalpy.

$$\text{Force} = W^2 \frac{d^2\$}{dt^2} = WD\frac{d\$}{dt} - \left(D\left(\frac{dW}{dt}\right) - W\left(\frac{dD}{dt}\right)\right)\$$$

App 2(cont)Entropy of a Business Process

Since Force=Acceleration/Mass, by integrating the force of process improvement between an initial low process velocity vinitial (high WIP) and a desired higher final process velocity vfinal,(low WIP) and obtain an expression for the energy needed to accelerate process velocity:

$$\text{Energy}=\text{U}=\frac{1}{2}\text{D}^2\$^2=\left(\text{Economic Profit/Month}\right)^2$$

$$\text{d(Work)}=\text{dU}-\text{U}\frac{\text{dW}}{\text{W}},$$

$$\text{Work}=\int_{\text{Uinitial}}^{\text{Ufinal}}\text{dU}-\int_{\text{Winitial}}^{\text{Wfinal}}\text{U}\frac{\text{dW}}{\text{W}}$$

$$\text{Work}=\left(\text{U}_{\text{final}}-\text{U}_{\text{initial}}\right)-\int_{\text{Winitia}}^{\text{Wfina}}\$^2\text{D}^2\frac{\text{dW}}{\text{W}}\rightarrow\left(\text{U}_{\text{final}}-\text{U}_{\text{initial}}\right)+\text{f(logW)}$$

App 3 The Impact of Variety

- WIP W

For two different products $W=W_1+W_2$

$\log W=\log(W_1+W_2)=H(W)+Ex(\log W_i)$

logW=Entropy of Variety +Entropy of Process

- Economic Profit EP

For two different products $EP=EP_1+EP_2$

$\log EP=\log(EP_1+EP_2)=H(EP)+Ex(\log EP_i)$

logEP=Entropy of Variety + Entropy of Efficiency

App 3 (cont)Derivation of Impact of Variety

$$\log W = \frac{W_1 + W_2}{W}\log W = \frac{W_1}{W}\log W + \frac{W_2}{W}\log W = -\frac{W_1}{W}\log\frac{1}{W} - \frac{W_2}{W}\log\frac{1}{W}$$

$$\log W = -\frac{W_1}{W}\log\frac{1}{W} - \frac{W_2}{W}\log\frac{1}{W} + \left(\frac{W_1}{W}\log W_1 - \frac{W_1}{W}\log W_1\right) + \left(\frac{W_2}{W}\log W_2 - \frac{W_2}{W}\log W_2\right)$$

$$\log W = -\left(\frac{W_1}{W}\log\frac{W_1}{W} + \frac{W_2}{W}\log\frac{W_2}{W}\right) + \frac{W_1}{W}\log W_1 + \frac{W_2}{W}\log W_2$$

We can denote the probability that the jth item of WIP is p_j where:

$p_j = \frac{Wj}{W}$ and obtain:

$$\log W = -\sum_{j=1}^{N}\frac{Wj}{W}\log\left(\frac{Wj}{W}\right) + \sum_{j=1}^{N}\frac{Wj}{W}\log Wj$$

$$\log W = -\sum_{j=1}^{N} p_j \log p_j + \sum_{j=1}^{N} p_j \log W_j = H(W) + Exp(\log Process)$$

and for $pj = 1/N, Wj = W/N = ASD/(1\text{-}X\text{-}PD)$ from App2:

$$\log W = \log N + \log\{ASD/(1\text{-}X\text{-}PD)\} = \text{entropy of variety} + \text{entropy of process}$$

App3 (cont): $H_{IntProcess}$ manufacturing entropy

It has been shown[1] that, for a manufacturing process:

$$H_{IntProc} = \log W = -\sum_{j=1}^{N} p_j \log p_j + \sum_{j=1}^{N} p_j \log W_j = H(WIP) + E(\log PV)$$

$$W = e^{H_{IntProc}}$$

$H_{IntProc}$=Entropy of WIP+Expectation(log of Process Variables)

$H_{IntProc}$=Entropy of Variety+Entropy of Process

N=total number of different products produced

D=total demand per unit of time for all N products

W=Total WIP=$\sum_{j=1}^{N} W_j$, W_j=WIP of the j^{th} product, $\therefore$,$p_j = \frac{W_j}{W}$

per[1] $W_i \geq \left(S_i D / (1 - X_i - P_i D) + A\right) \rightarrow$ Process Variables

S=Setup Time, A=Number of steps in the process

P=Processing time per unit, X=Defect % Rate

1App 4.