Effective Innovation

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ESD 33, MIT
July 2004

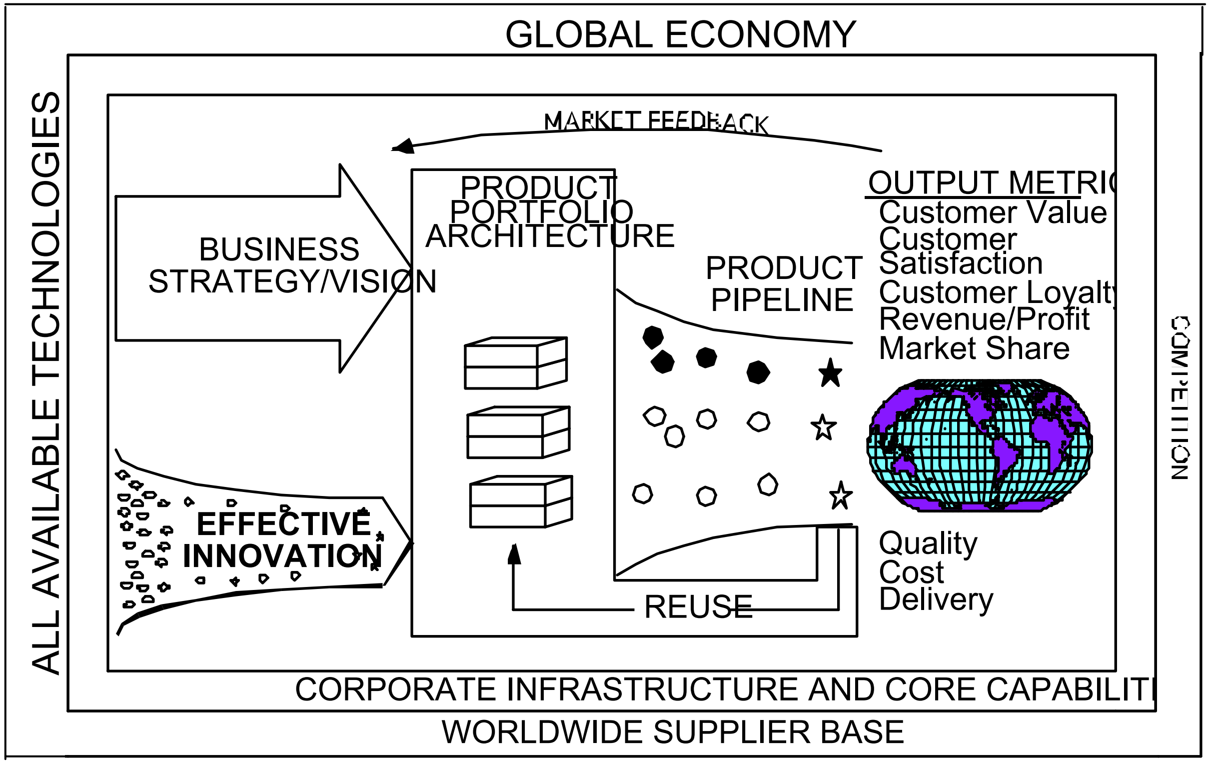
Three types of innovations

- Launch
- Growth
- Library

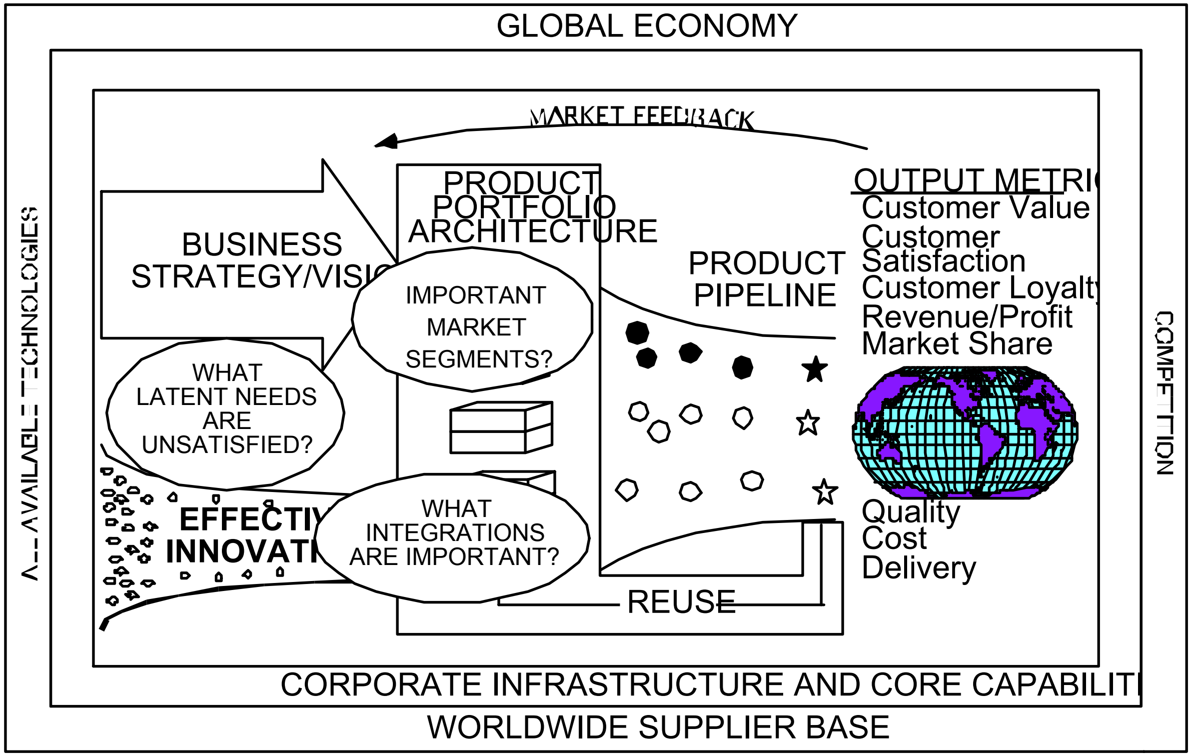
Enterprise Processes

INTEGRATION & DIRECTION

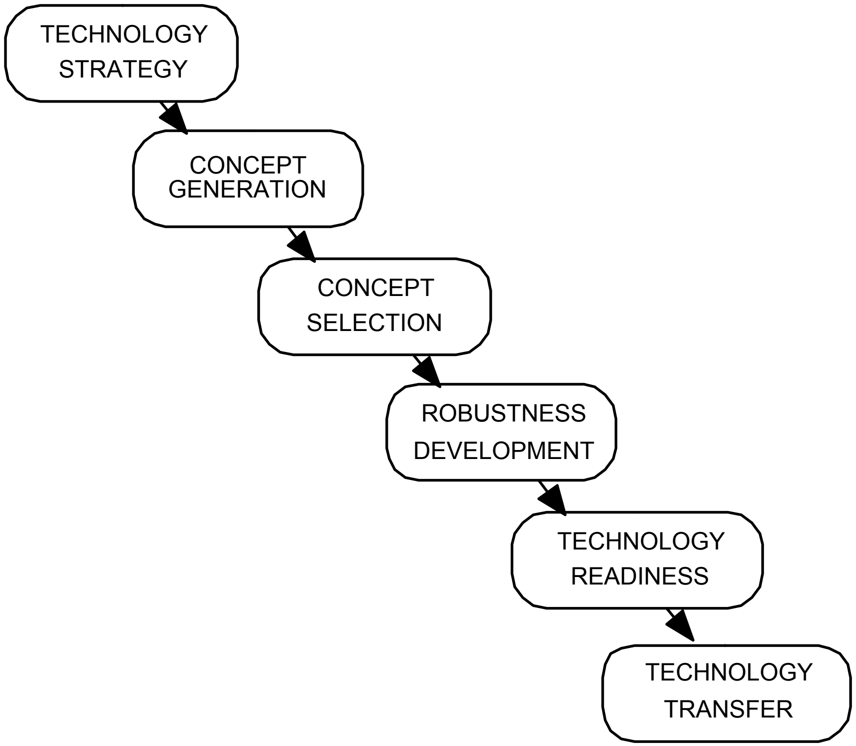
Product acquisition process



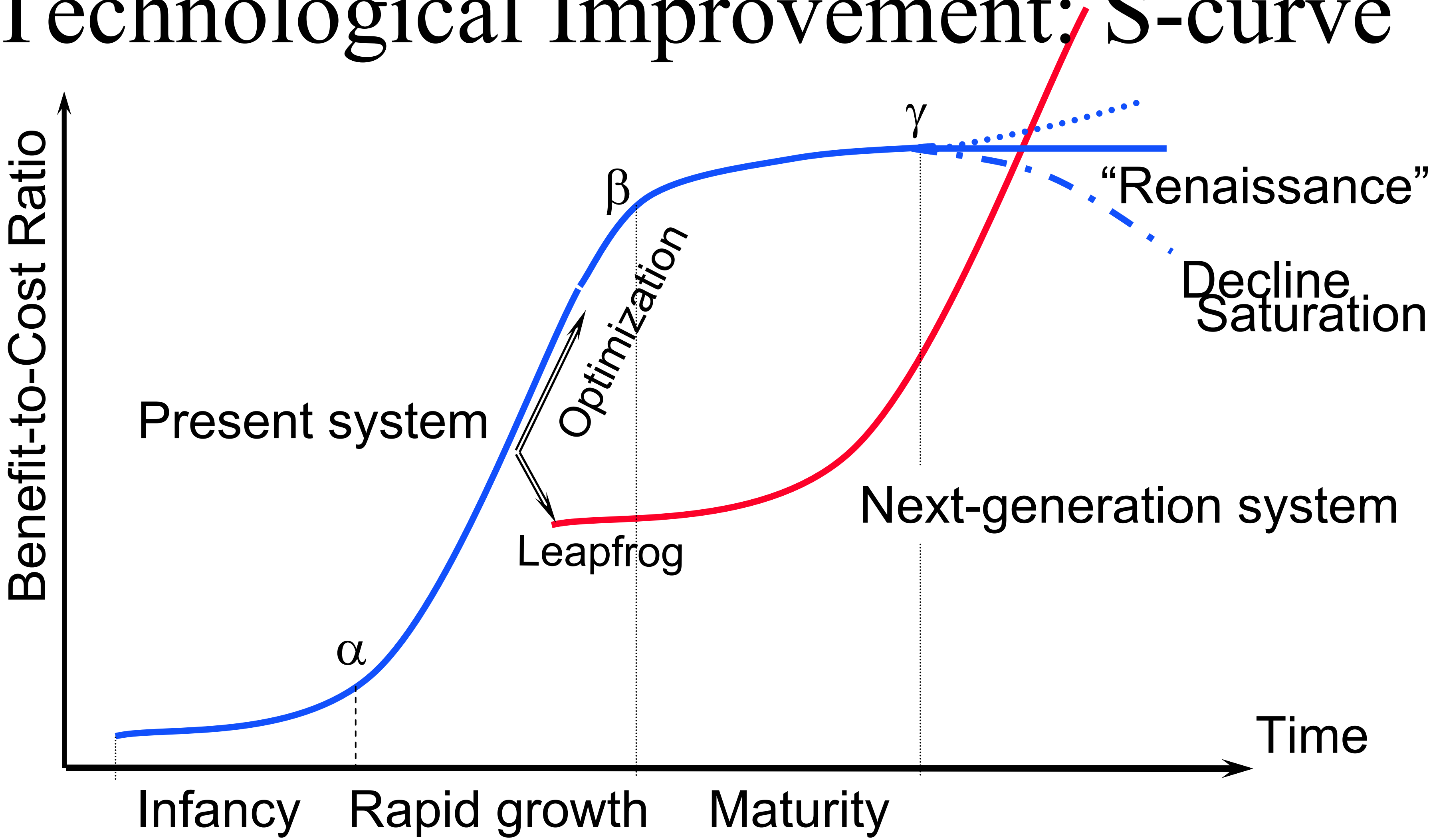
Three important interactions



Effective innovation process



Technological Improvement: S-curve

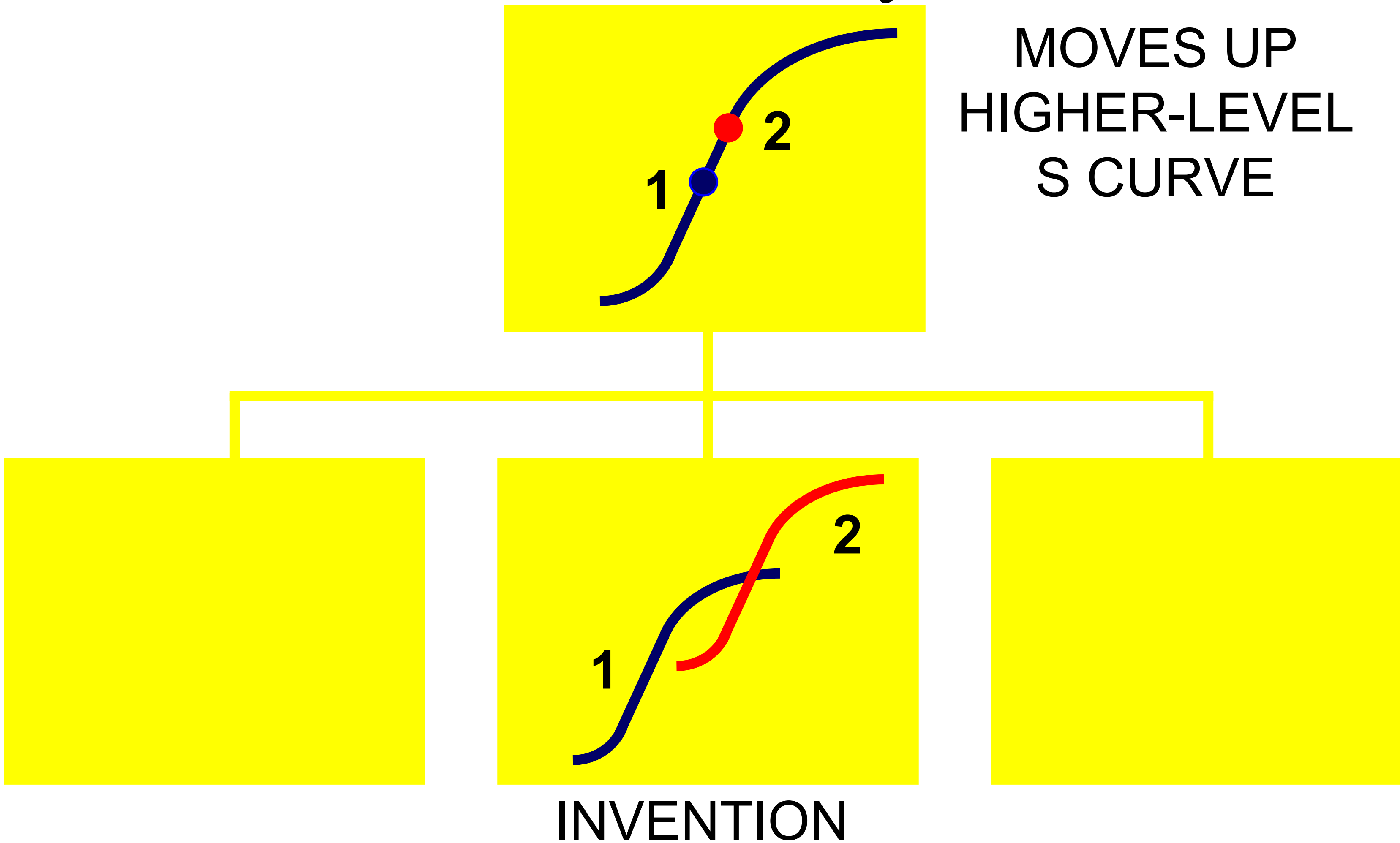


Typical steps of evolution of technological systems can be illustrated by an S-shaped curve that reflects changes of the system's benefit-to cost ratio with time since the inception of the system. In the infancy phase the system's development is relatively slow. The next phase is characterized by fast development, usually attributed to commercialization of the system and perfecting of the manufacturing processes. Then the system's evolution is eventually slowing down and stalls or even starts degrading. These segments of the system life curve are typical for its old age. In some cases the system undergoes "renaissance", which can be sparked by availability of new materials, of new manufacturing technology, and/or by development of new applications. When the present system is approaching the end phase of its development, usually a new system having a higher performance potential is already waiting in the wings.

On the other hand, some systems are deteriorating. An example is turntables for LP records, which are supplanted by CD systems, although some basic models of the turntables are still in production.

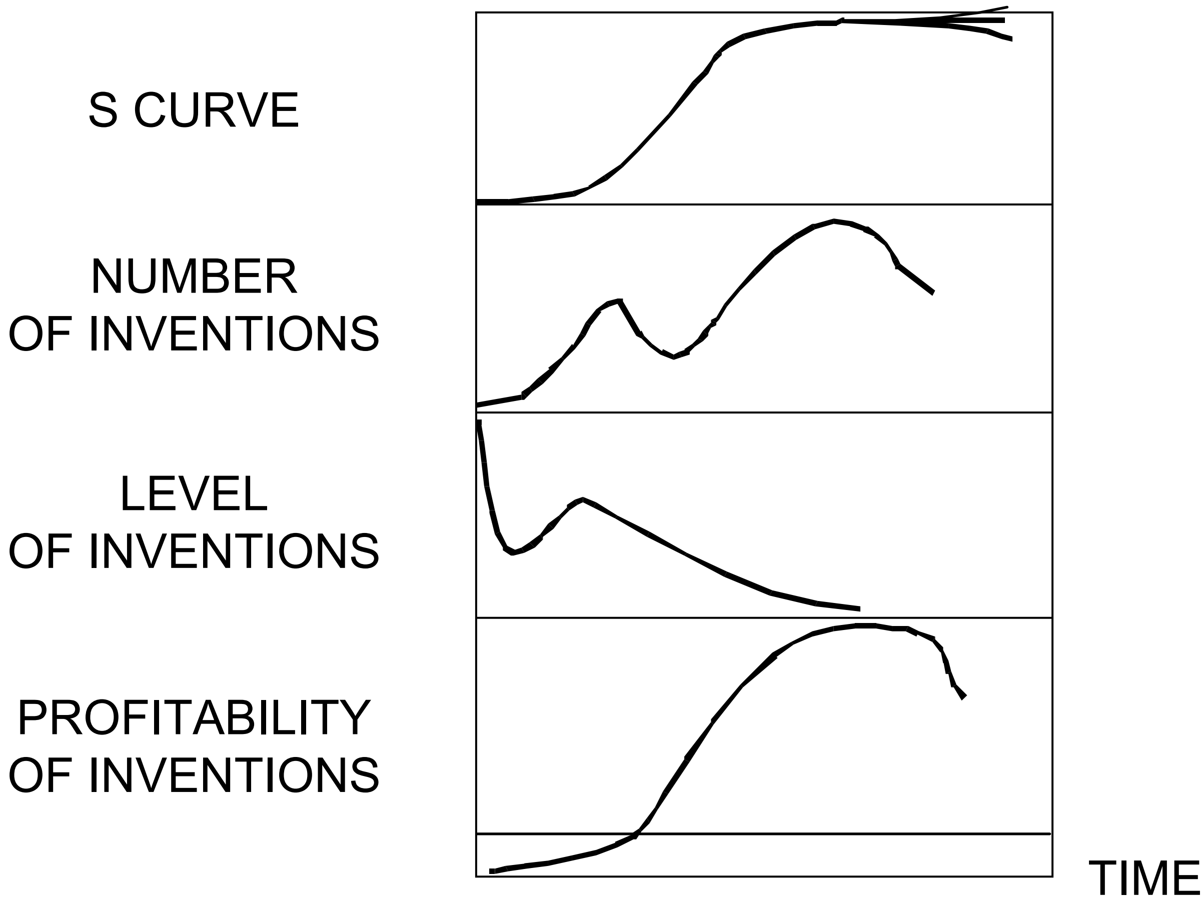
The length and slope of each segment on the life curve of the system depends, of course, not only on technical but also on economic and on human psychological inertia factors. While the common sense (in the hindsight!) suggests that a new system should start its fast development when development of the present system starts to slow down, frequently it is delayed by special interest groups, which have large investments, job security, etc., associated with the old system.

Invention at lower system level



The above is the basic S curve. The abscissa is time, or the amount of resources that have been applied. The ordinate is performance divided by cost. If the cost is relatively fixed, then the performance alone can be used. If the performance is relatively fixed, then the reciprocal of cost can be used alone.

Evolution of inventive activity



Levels of invention

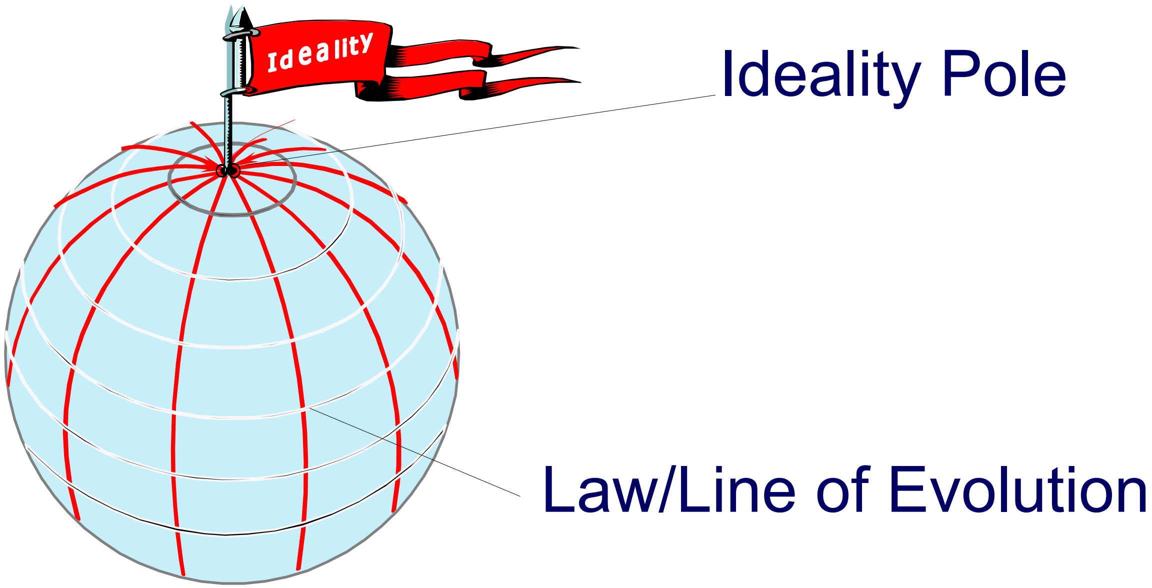
- 1. A component intended for the task is used
- 2. Existing system is slightly modified
- 3. At least one system component is radically changed or eliminated; within one discipline
- 4. A new system is developed; interdisciplinary
- 5. Pioneering invention, often based on recently-discovered phenomena

Laws of evolution

- Increasing ideality
- Non-uniform evolution of subsystems; e.g., bicycle
- Transition to a higher-level system
- Increasing flexibility of systems
- Transition from macro to micro level
- Shortening of energy flow path
- Harmonization
- Completeness
- Increasing controllability

Primary Law of Evolution

- The Law of Increasing Degree of Ideality is the central law of evolution of technology.
- Other Laws of Evolution are mechanisms for increasing the Degree of Ideality.



Increasing Degree of Ideality

$$\text{Degree of Ideality} = \frac{\text{Functionality}}{\Sigma \text{Costs} + \Sigma \text{ Problems}}$$

Costs = $, size, weight, part count, etc.

- In the course of evolution, degree of ideality of technological systems increases.
  - Systems with higher degree of ideality have much better chances to survive the long-run market selection process, i.e., to dominate the market.

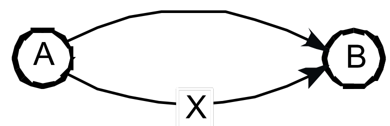
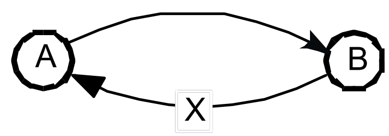
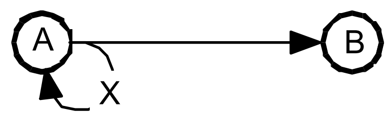
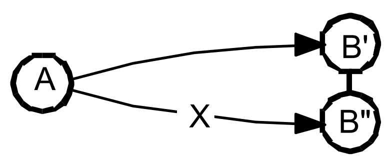
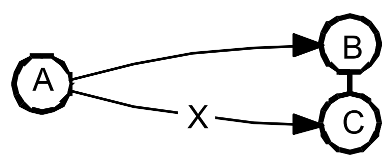
Analysis of the history of technology led Altshuller to the discovery and formulation of the primary law of evolution of technological systems — the *Law of Increasing Degree of Ideality*.

Degree of Ideality is defined as *a ratio of Index of Functionality* to *Index of Cost*, where cost can be expressed in dollars, or units of size or weight, etc. It is, essentially, the *Benefit-to-Cost* ratio. A truly ideal system in most cases is a virtual reality, it exists only in our imagination. This means that in the process of evolution either the system performing certain functions becomes less complicated/costly, or it becomes capable of performing its functions better or performs more functions. A combination of these evolutionary processes also often occurs.

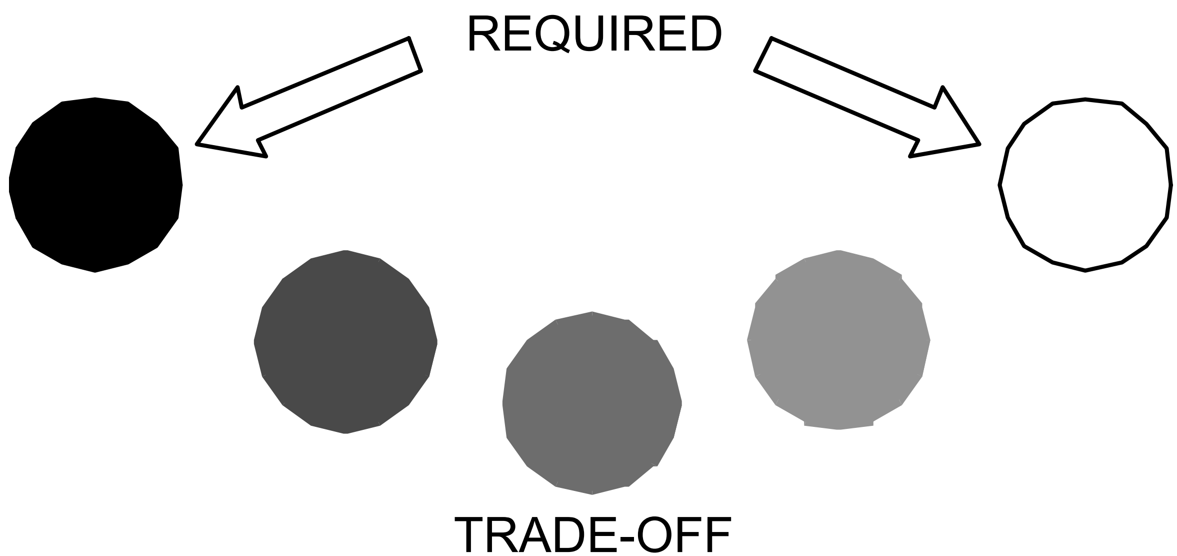
Bicycle

- 1813 Feet pushed on ground
- 1840 Pedals added, but no brakes
- 1845 Brakes added, wheels too weak
- 1860s Large metal wheels, effort too big
- 1870s Bearings added, height caused falls
- 1884 Chain added, wheels made smaller
- 1890 Pneumatic tires, pedals dangerous
- 1897 Overrunning clutch added, bike mature

Typical system conflicts

<table>
<tr><th>SYSTEM-CONFLICT DIAGRAM</th><th>DESCRIPTION</th></tr>
<tr><td>
</td><td>The useful action of A on B is accompanied by a harmful action of A on B.</td></tr>
<tr><td>
</td><td>The effect of A on B is useful, but the effect of B on A is harmful.</td></tr>
<tr><td>
</td><td>A acts usefully on B, but detrimentally affects itself.</td></tr>
<tr><td>
</td><td>The useful action of A on one part of B (B') is accompanied by a harmful action on another part of B (B").</td></tr>
<tr><td>
</td><td>The useful action of A on B is accompanied by a harmful action on the environment or an adjacent system C.</td></tr>
</table>

Conventional engineering approach



Compromise doesn’t satisfy either requirement.

Separation of physical conflicts

- Separation of opposite properties in time
- Separation of opposite properties in space
- Separation of opposite properties between the whole and its parts

These simple ideas lead to many inventions.

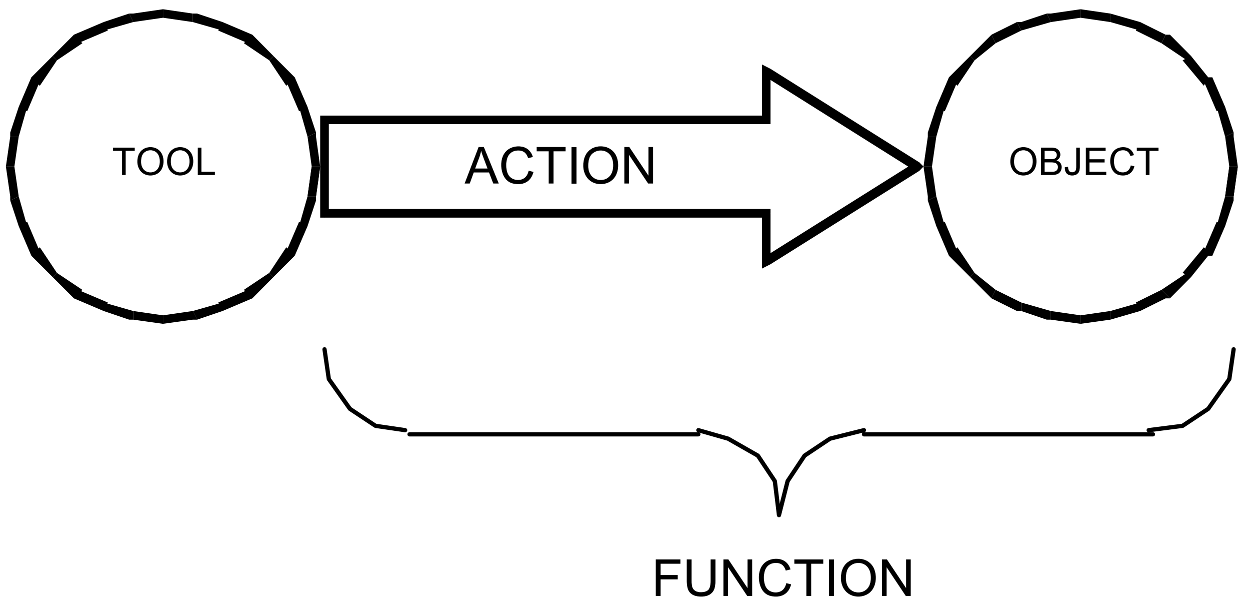
Separation in space

- Basic approach: apply one requirement in one place, and the conflicting requirement in another place
- Make front of armor plate from hard steel, back of armor plate from tough steel, bond together into one plate
- Invention came from separating the two requirements; one to front, second to back

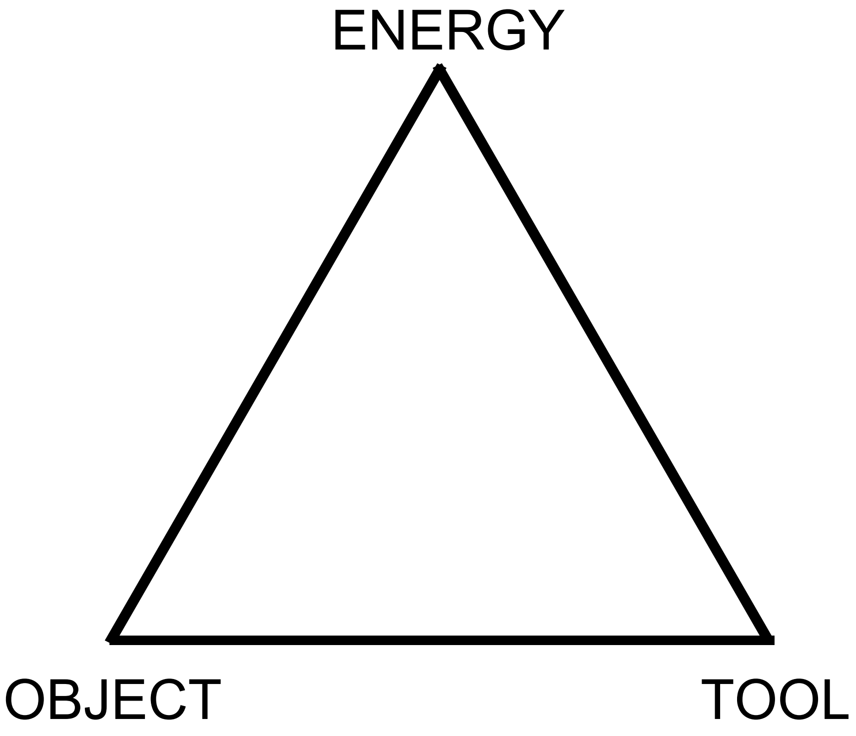
Role of science

- TRIZ laws suggest new “rooms” in which we might find a new invention
- Then use scientific data base to combine scientific effects with suggested pattern of invention
- Thousands of scientific effects; most people know less than 20
- Use extensive data base to find effects that can be used in conjunction with a TRIZ-identified pattern of invention

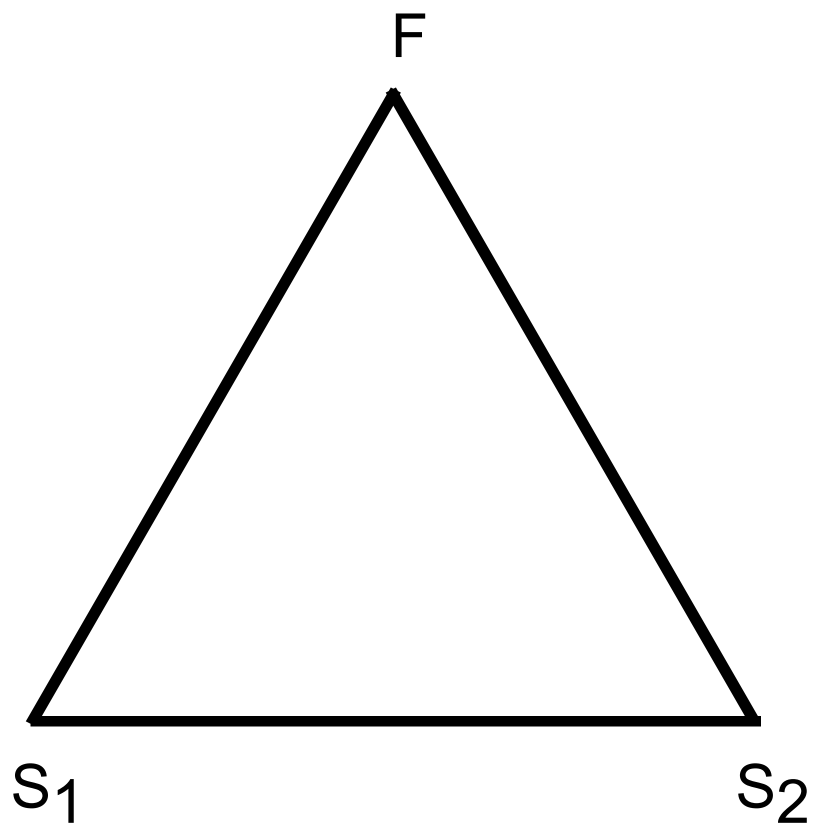
Functions lead to invention



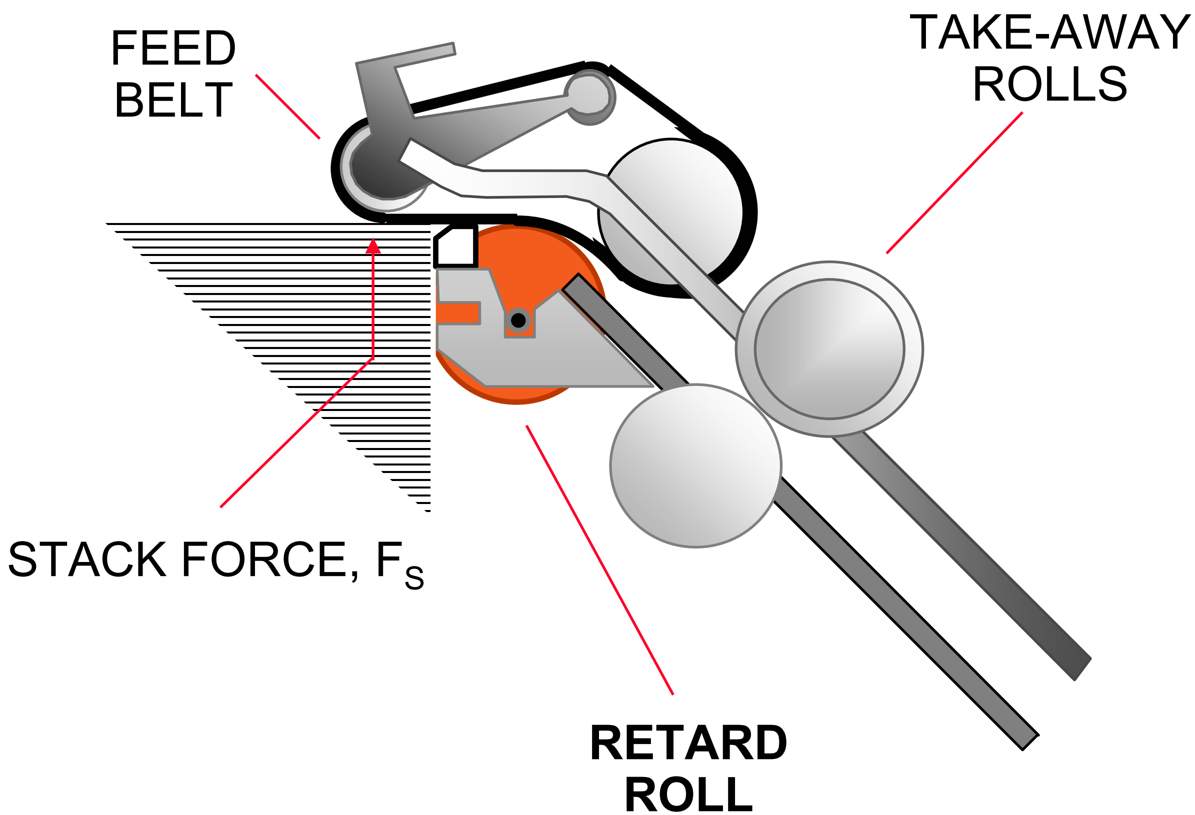
Sufield triad



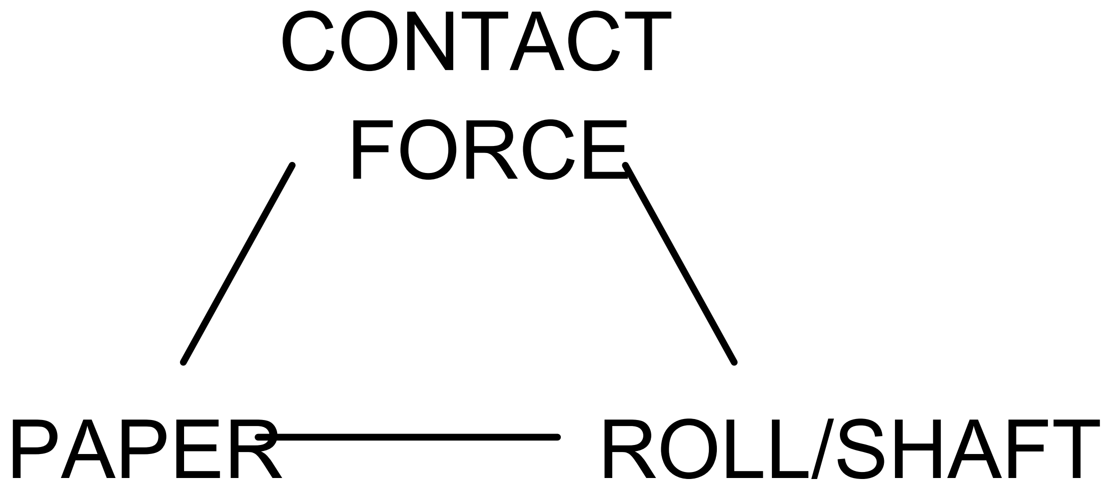
Sufield symbols



Paper feeder



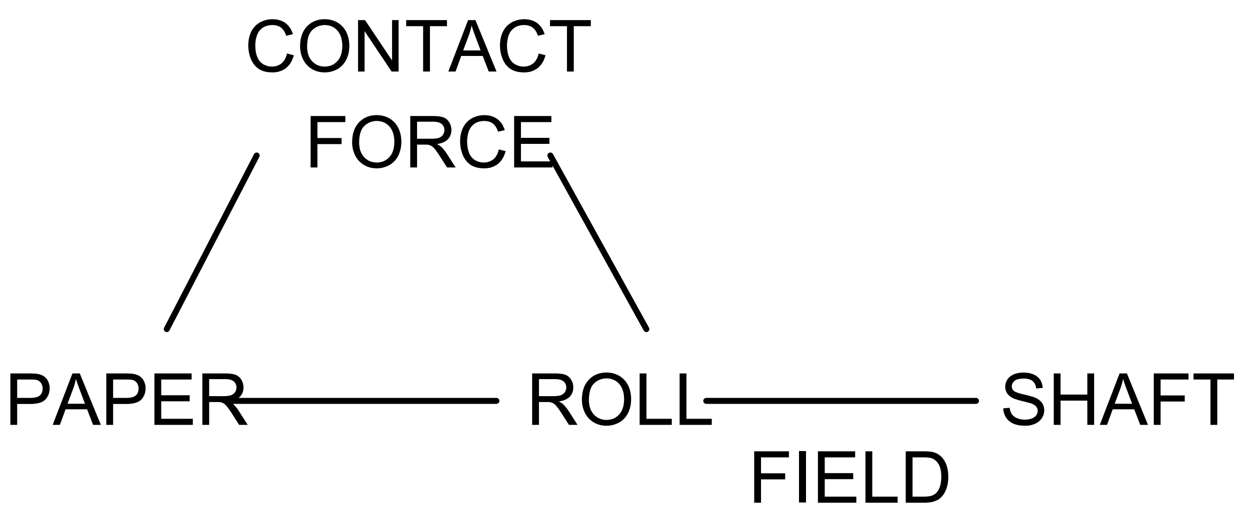
Sufield for retard roll



Types of changes to Sufields

- Structural changes to Sufield diagram
- Change the field
- Change the nature of the substance
- Apply the first three (above) for a specific purpose; e.g., mitigate a harmful effect

Structural change in Sufield



Changes to fields

- Change from one type of field to another
- Intensify
- Concentrate in a smaller region
- Vary strength of field with time
- Use waves
- Change frequence
- Use a traveling field
- Change the spatial distribution of the field
- Make the field more controllable

Some types of fields

MECHANICAL	ELECTRICAL
Contact	Monopole
Friction	Dipole
Adhesive	Line charge
Elastic	Line dipole
Pressure/shear	Sheet charge
Inertial	Traveling

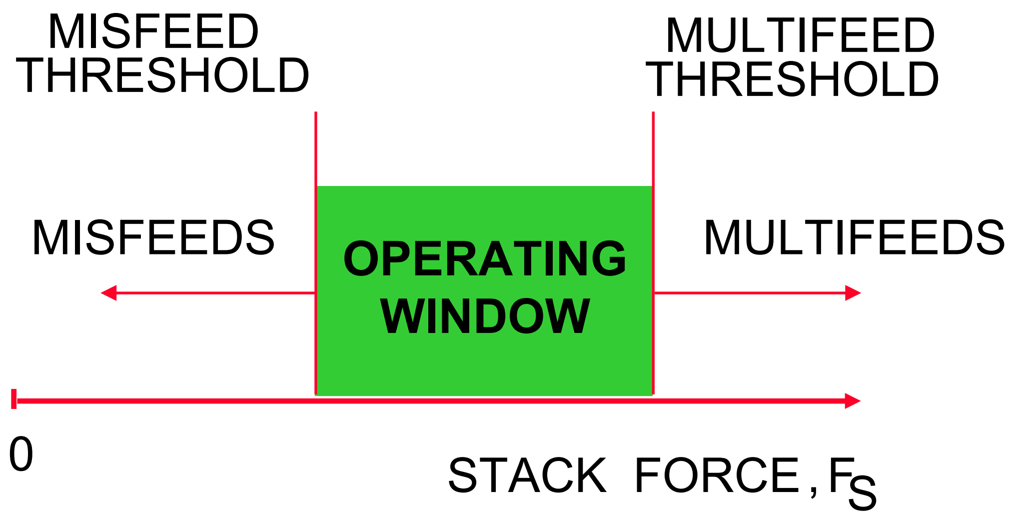
Changes to substances

- Phase changes
- Changes in electromagnetic properties
- Composite materials
- Introduction of voids
- Introduction of additives
- Replacement of solid with particles
- Combinations of two substances
- Form substance from the environment
- Separate two solidly connected substances

Concept selection

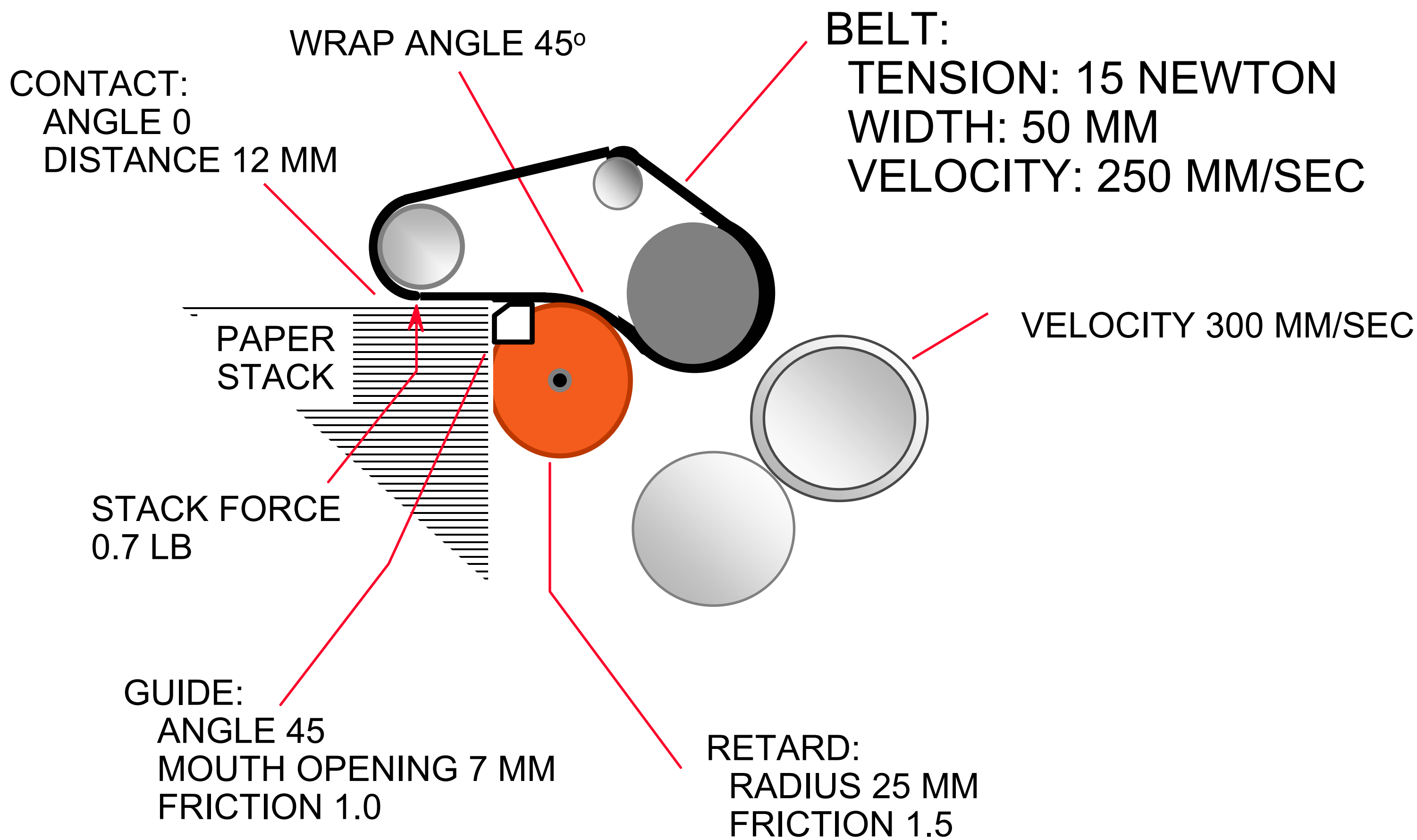
- Use Pugh concept selection process
- Use early to select innovations for further development
- Use for product portfolio architecture to select technologies

Operating window



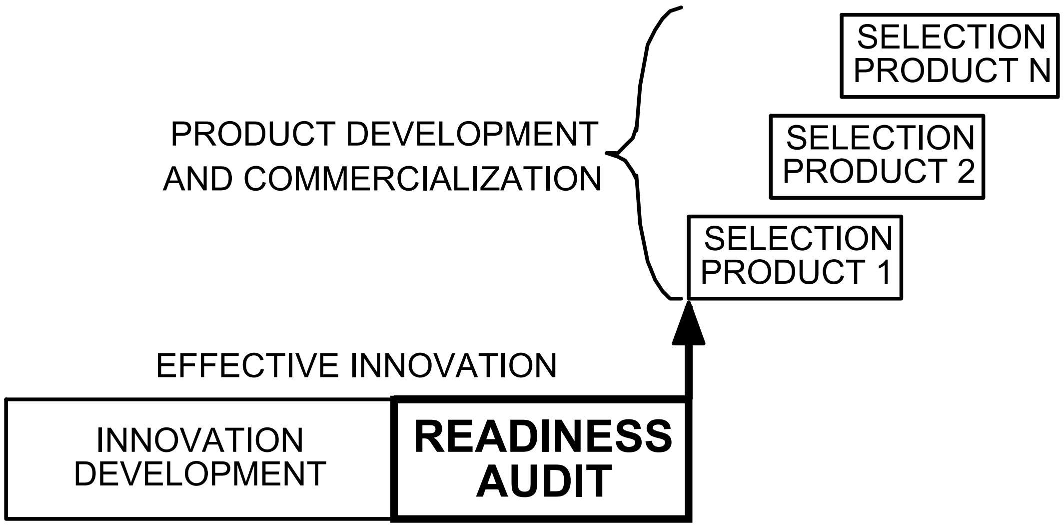
Broader window is more robust

Critical parameter drawing for paper feeder



Critical parameters guide the detailed design: assure robustness

Technology readiness



Readiness objectives

- Ensure that everything best done during the innovation cycle has been done
- After Readiness the remaining actions can be easily undertaken in the normal downstream commercialization process
- Commercialization people will clearly understand the requirements that flow downstream from Effective Innovation

Critical parameter management

- Assure robustness is achieved in production
- Provides:
  - Early specification maturity
  - Early technology readiness
  - Early identification of special manufacturing requirements
- Critical parameter drawing is key

Technology transfer

Effective technology innovation can only succeed
if it is accompanied by simultaneous
effective innovation of the total value chain

Maurice Holmes

Collateral failure

- Cylinder-valve paving breaker, 1959
- Great technical success, loved by customers
- But it required innovation by Sales
- Didn't happen; successful technical innovation blocked from market

Collateral success

- First Xerox copier
- Revolutionized copying in 1960
- But was very expensive
- Office managers would be reluctant to buy
- Leasing was innovative Sales approach; enabled huge commercial success of xerographic copiers

5 problems of EI management

- Innovation done ineffectively; EI process not followed
- EI not well integrated into PA
- EI not well integrated with other enterprise processes
- Spending on EI is at wrong level
- EI had wrong people

Management for success

- Right process
- Right people
- Right spending
- Right integration

New book

- Clausing, Don, and Victor Fey. *Effective Innovation: The Development of Winning Technologies.* American Society of Mechnaical Engineers, 2004. ISBN: 0-7918-0203-5.
- Available at ASME Press http://www.asme.org/pubs/asmepress/
- ISBN 0-7918-0203-5

Date		Subject	Reading	HW Out	HW Due
T 8 JUN		Course Introduction What is Systems Engineering?	Subject Information and Policies.pdf Argyris_Teaching Smart People How to Learn.pdf Schön_The Reflective Practitioner.pdf	#1	
R 10 JUN	**Frameworks**	INCOSE Model of Systems Engineering RCI model of Systems Engineering	INCOSE Systems Engineering Handbook ch 2.pdf INCOSE Systems Engineering Handbook ch 4.pdf Clausing_RCI Systems Engineering Process.ppt Clausing_Commercial Product Development.pdf	#2	#1
T 15 JUN		Lean Thinking Set Based Design	Womak_Lean Thinking Introduction.pdf Stanke_Murman_Lifecycle Value in Aerospace.pdf Ward_The Second Toyota Paradox.pdf		
R 17 JUN		Axiomatic Design Decision Based Design	Suh_Axiomatic Design Theory for Systems.pdf Frey_Cognition and Complexity.pdf Hazelrigg_Axiomatic Engineering Design.pdf Gigerenzer_Bounding Rationality to the World.pdf		#2
T 22 JUN		**Examination #1**	Brooks_No Silver Bullet.pdf	#3	
R 24 JUN	**Tools**	Quality Function Deployment	Hauser_Clausing_House of Quality.pdf Griffin_Evaluating QFD.pdf Olewnik_Lewis_Validating Design Methods.pdf		
T 29 JUN		Pugh concept selection	Pugh_Total Design ch 4.pdf	#4	#3
R 1 JUL		Effective Innovation (TRIZ, etc.)	No reading assignment		
T 6 JUL		Error Budgeting & Critical Parameter Mgmt.	Frey_Error Budgeting.pdf Crevelling_Critical Parameter Management.pdf	#5	
R 8 JUL		Design of Experiments	Thomke_Enlightened Experimentation.pdf Box_Statistics as a Catalyst p1.pdf Box_Statistics as a Catalyst p2.pdf Frey_One Factor at a Time.pdf		#4
T 13 JUL		Multi-Disciplinary Optimization / Isoperformance	DeWeck_Isoperforamnce.pdf	#6	#5
R 15 JUL		Use of physics-based models in SE	Senin_Wallace_Distributed Modeling.pdf Hazelrigg_Role and Use of Models.pdf		
T 20 JUL		Robust Design	Taguchi_Clausing_Robust Quality.pdf Ulrich_Eppinger_Product Design and Dev ch13.pdf		#6
R 22 JUL		Extreme Programming	Beck_Extreme Programming.pdf Williams_Pair Programming.pdf		
T 27 JUL		**Examination #2**			
R 29 JUL	**Case Studies**	Aircraft Engines (GE) Automobiles		#7	
T 3 AUG		Work on Aircraft Engines Assignment Project Oxygen	Steele_TBD.pdf		
R 5 AUG		NORAD Command and Control (Mitre)	Folk_TBD.pdf	#8	#7
T 10 AUG		Tactical Tomahawk	Cummings_TBD.pdf		
R 12 AUG		Course Summary / Feedback			#8

Next Steps

- Due date changed for HW #4
  - Due 8:30AM Thurs 8 July
- Reading assignment
  - Crevelling_Critical Paramter Management.pdf
  - Frey_Error Budgeting.pdf
- See you at the next session
  - 8:30AM Tuesday, 6 July
- Beware -- the course gets more technically challenging from this point