Lean Aerospace Initiative

web.mit.edu/lean

Enterprise Value: The New Lean Horizon

Managing Intellectual Capital for the Long Haul

March 27, 2002

Presented By:
Eric Rebentisch
MIT

Research Sponsored By SDM program sponsor

Overview

- Intellectual capital (IC) defined
- LAI-related research on IC
- Evolution of IC in design projects
- Observations from IC research
- Some ways of framing IC investment decisions
- Conclusions

Intellectual Capital Defined

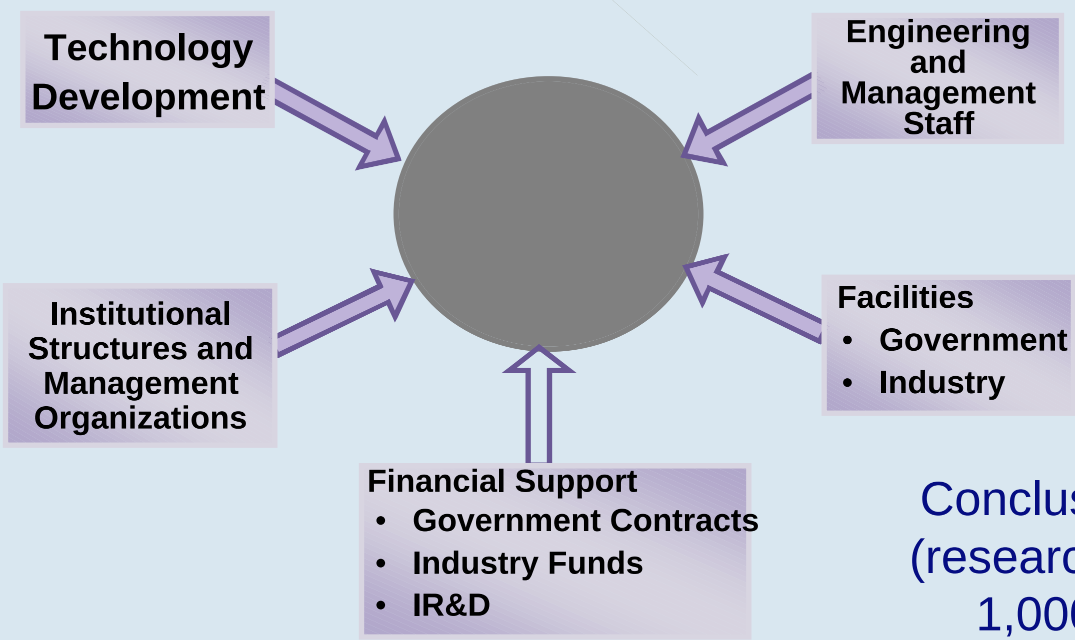
- IC is intellectual material -- knowledge, information, intellectual property (IP), and experience -- that can be put to use to create wealth and value
- Includes:
  - employees' skills
  - patents & trade secrets
  - an organization's technologies, processes, and experience
  - info about customers and suppliers

Assertion: IC, like other forms of capital, can be made more productive through proper management

LAI Intellectual Capital Management Research

- The Link Between Design Problems and Intellectual Capital Loss in Aircraft Development
  - Investigate examples of increased problems in design for possible links to intellectual capital degradation (Andrew)
- Intellectual Capital Management in the Multi-project Environment
  - Model and identify key factors affecting development and sustainment of intellectual capital associated with project assignments in a multi-project environment (Herweg & Pilon)
- Assessing and Measuring Intellectual Capital
  - Develop an assessment tool to support management of and investment in intellectual capital (Seigel)

1992 RAND Study: Maintaining Aircraft Design Team Capability



Conclusion: Need $100M annually (research and technology funding), 1,000 technical staff to maintain adequate aircraft design team capability

Study conclusions based on historical experience unlikely to be repeated; What are the realistic solutions to IC challenges potentially occurring in a significantly different future context?

Lean Aerospace Initiative

Digging Deeper Into "Design Team Capability"

- Recent LAI study on role of IC in aircraft design:
- Setting: new commercial aircraft designs over a generation of change in the industry
  - Same target markets
  - Company-funded development
  - Same FARs, certification requirements
  - Mature multi-product firms (with significant military business)
- Data based on interviews and extensive archival document search

Year	70s Era	90s Era
Case Studies	"A70" "B70"	"A90" "C90"

Data Used to Assess Design Team Capability

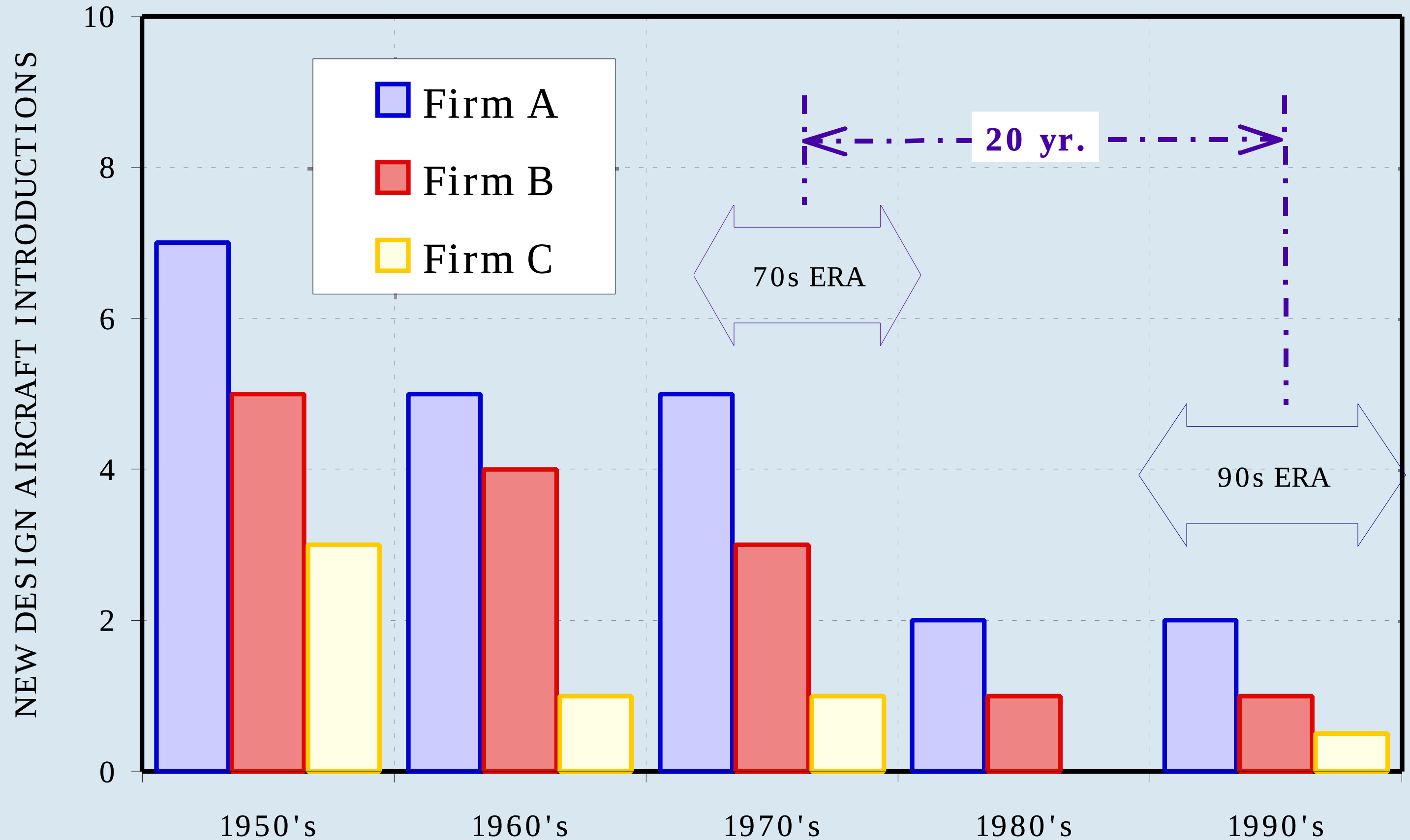
- Examined detailed aircraft and program performance metrics and their stability over the life of the development program:
  - Design effectiveness: W_e; Useful load; payload; MTOGW; Range; Altitude
  - Design quality: Spec changes, flight test hours
  - Program milestones: First flight, Type certification (VFR & IFR), Initial delivery
- IC metrics (including):
  - New aircraft designs in past 10, 20 years
  - Design team staffing stability
  - Individual engineering and managerial experience
  - Type of experience (demonstrator vs. production a/c)
  - Use of modern design tools and knowledge capture

Comparing the Programs

- 70s programs had the following in common:
  - Same period of execution, competing head to head in the same market
  - Workforce new design aircraft experience base is high
  - Predominantly Paper & Mylar design tools
  - Physical representations (e.g., prototypes, powered wind tunnel models) for design validation
  - Functional Organization with "heavy weight" project managers
- 90s programs had the following in common:
  - Overlapping periods of execution, overlapping market segments
  - Extensive use of computer aided design tools and information technologies
  - Increased reliance on simulation for design validation
  - Use of IPTs

Frequency of New Design Aircraft Introductions in Study Firms

Lean Aerospace Initiative



Trends in each firm were similar and mirrored the rest of this industry sector

Lean Aerospace Initiative

Illustrative Findings: A70 Performance at type certification

Metric	Deviation
We (lb)	+7%
MTOGW (lb)	+3.1%
We/MTOGW	+3.6%
Useful Load (lb)	+2%
Range (nm)	+4 %
First Flight	+9 mo.
Type Certification	+6 mo.
Initial Delivery	+8 mo.
Major Specification Changes	3

Some deviation from plan observed, but overall the best-performing program

Comparing the 4 Programs

- Ranked performance across all 4 programs:
  - Design effectiveness (i.e., weight, range, etc.)
  - Design quality (i.e., ECPs, etc.)
  - Program performance (i.e., milestones)
  - Intellectual capital (e.g., # new designs in prior 10, 20 years, management depth, skills)
- Sum scores and check for correlation

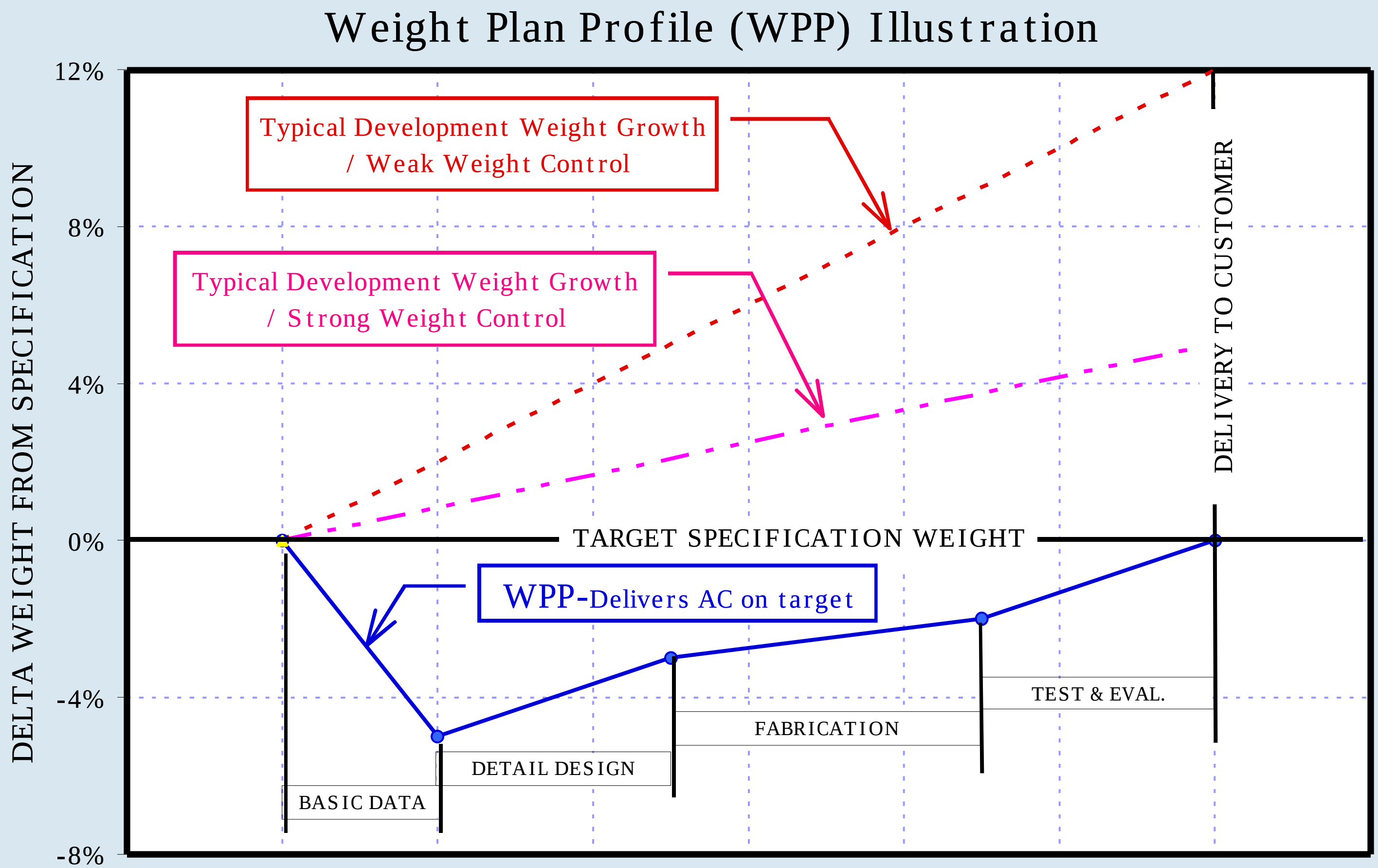
Depth of IC is positively correlated with design and program performance

Lean Aerospace Initiative

Study Observations

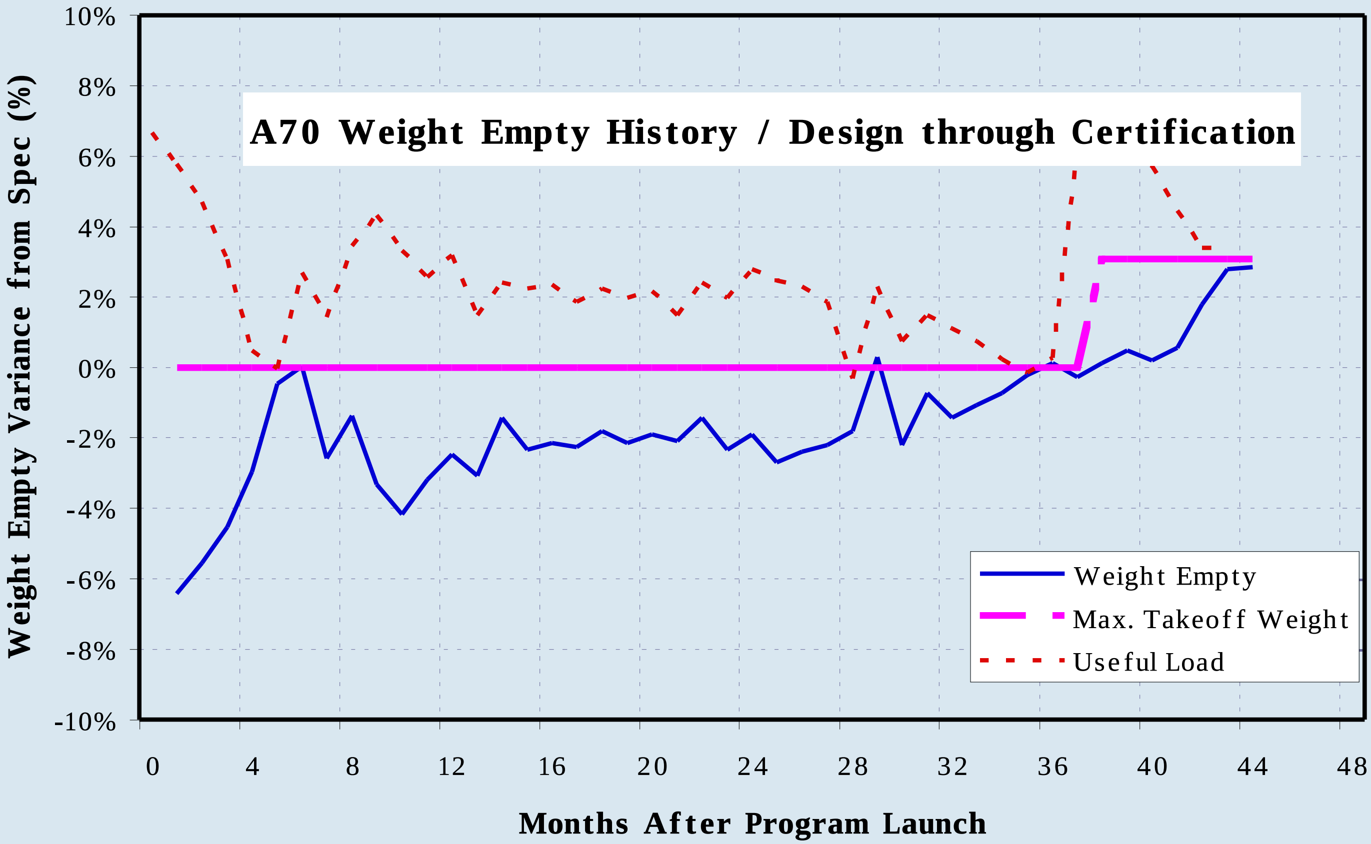
- Strong Linkage between IC metrics and Program Performance Metrics
- 70s-era design efforts outperformed the 90s-era efforts in meeting program/ performance objectives
  - Better weight, payload margins; closer to delivery milestones
- Performance extremes were in the same company—allowing convenient comparison
  - Can address evolution of in-depth through interviews with “graybeards” and documents
- Test phase an important downstream indicator of design performance and IC
  - Test personnel positioned to understand design system weaknesses through exposure to recurring problems

A Story About the Shelf Life of Explicit Knowledge



WPP resulted from attempt to codify lessons learned from a close military competition

70s Era Aircraft (A70) Design Experience



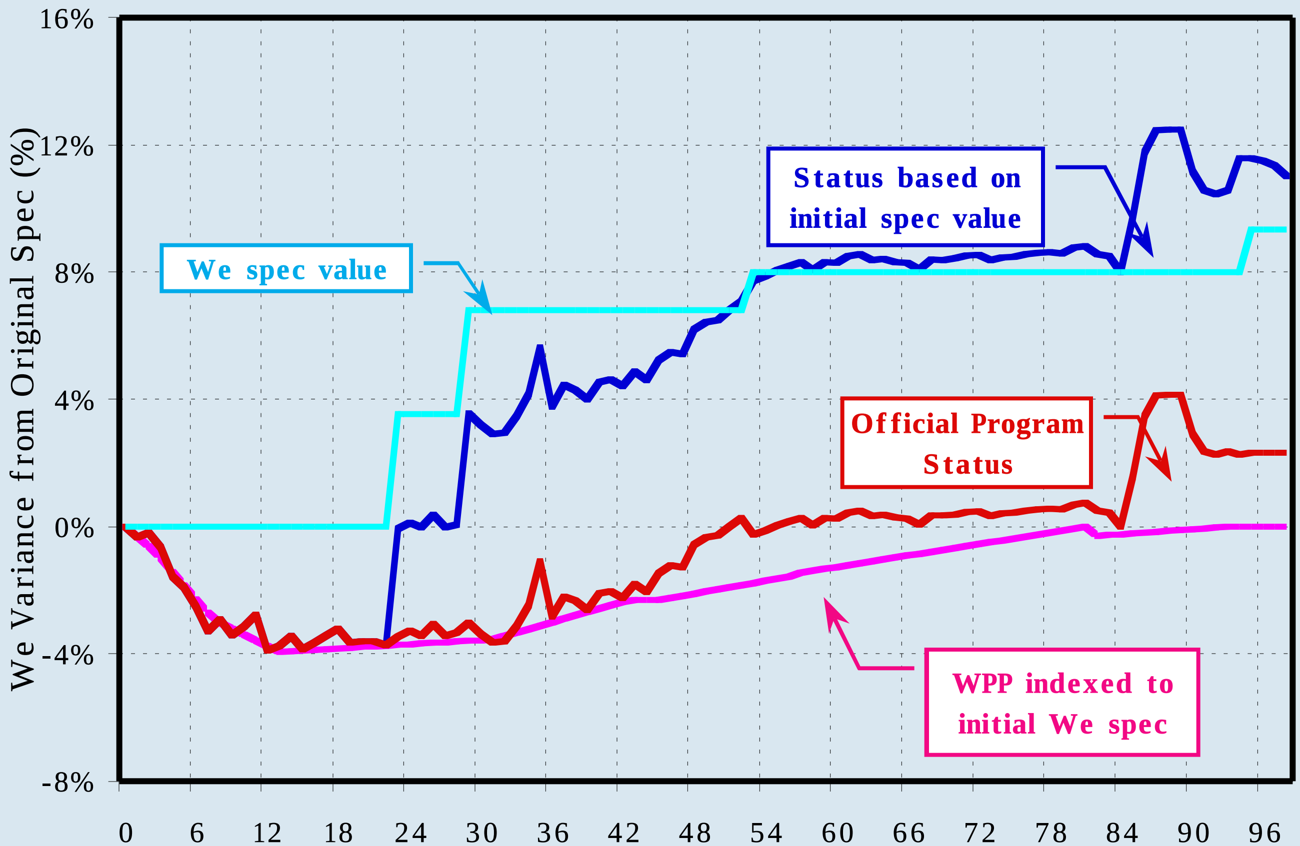
Aggressive use of WPP (and other lessons learned) by those who helped create it kept program on track

Footnote to A70 Design Experience

- Evolutionary derivative program 7 years later experienced greater difficulties
  - Delayed type certification
  - Reduced performance (poor weight control)
- WPP tool still existed, but originating team had moved on to new assignments
  - Discipline to use WPP methodology was not as strong as in original A70 program
  - Other codified lessons learned were circumvented

Perceived relevance of captured knowledge (WPP and others) was apparently affected by passage of time and turnover in workforce

90s Era Aircraft (A90) Design Experience



"Evolutionary" design strategy de-emphasized role of experienced air vehicle team members, with problems appearing in and corrected during developmental test

Contrasting the A70 and A90 Design Experiences

- **A70:**
  - **Management team built on senior engineering leadership emerging from a key military program competition victory**
  - **Hand-picked team of senior engineers with experience on multiple programs—"fully staffed" program**
  - **Aggressive use of lessons-learned and risk reduction strategies (employing familiar, common tools and concepts)**
- **A90:**
  - **1 prior major program from which to draw experiences (but housed in a separate facility**
  - **Program leadership experience primarily with legacy/derivative program; few key players (1-deep at times) from flight sciences**
  - **Manufacturing quality higher as a result of advanced design tools**
  - **Simulation tools graphically compelling, but underlying data deficiencies (in part due to reduced reliance on wind tunnel testing) lead to late design changes**

Summary Observations From This Research

- Knowledge capture and/or knowledge codification methods may be only partially effective if not backed up with experience in practice
- Prototype and experimental aircraft experience alone is inadequate to bring a new aircraft design through certification and rate production
- There must be adequate "critical mass" of intellectual capital—a few stars can't carry the entire team
- Use of modern design tools:
  - Modern computational tools did not fully offset impact of intellectual capital declines on program performance
  - Failure to refresh/support knowledge systems resulted in mis-prediction/rework that caused major delays
  - Modern computational tools can inhibit development of user tacit knowledge compared with predecessor analysis methods.

Implications: Thinking About Investment in IC/KM Tools

NPVIC= discounted value of future net IC contributions to enterprise performance

$$= \sum_{I=1}^{N} \frac{\text{Productivity gains resulting from IC/KM projects}}{(1 + r)^i}$$

Investment in people and tools may increase net IC productivity and yield a return to the enterprise, but:

- **Organizational return from knowledge creation decays with time**
  - **Employee turnover, new requirements, forgetfulness, etc.**
- **Current productivity metrics make economic justification of IC/KM investment difficult**

IC/KM Investment Aided by Development of Better Metrics?

Two areas for development of practice/metrics:

- **Efficiency:**
  - **IC/KM reduces transaction costs by streamlining, improving knowledge flows**
  - **Enhances cycle time and cost outcomes**
  - **Need metrics and tools that can assess IC/KM impact on transaction costs (e.g., ABC/ABM)**
- **Effectiveness:**
  - **IC/KM allows creation/combination of the right of knowledge to create competitive advantage and superior products**
  - **Enhances competitive position for future business**
  - **Need metrics that can assess IC/KM impact on:**
    - **Relevance of captured/stored knowledge to tasks at hand**
    - **Ability to combine "network" knowledge into new forms to address new requirements**

Implications: Thinking About Investment in Knowledge Creation

Learning Curves

$$C_n = K N^s$$

Unit cost (C) declines with each additional unit produced by a rate (S)

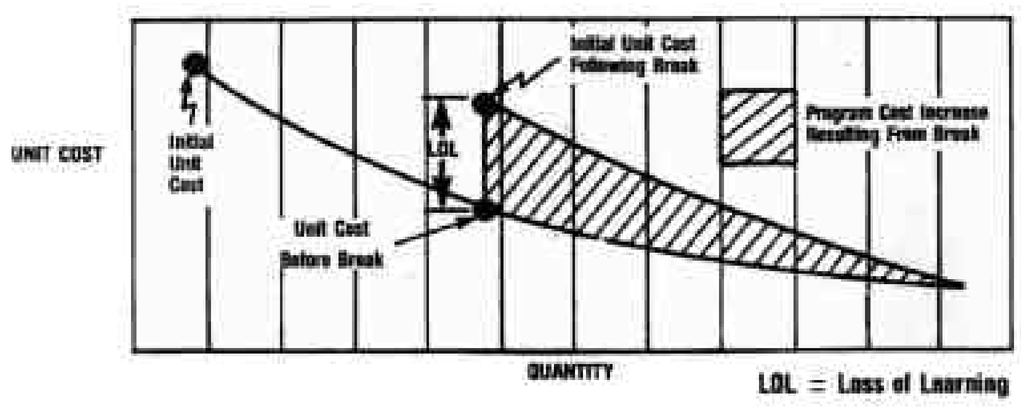


Figure 9-1. Production Break Impact on Learning Curve

- **"Production breaks" make the next unit more expensive because of "lost learning"**
- **IC analogy: years between exercise of design skills results in higher costs due to relearning or mistakes not avoided**
  - **Case studies showed that programs with broken or disrupted IC continuity with prior programs suffered in performance and programmatics**

Illustration from DoD 4245.7-M, 1985

Strategic Choices Around Knowledge Creation

Illustrative knowledge creation and capture investment strategies:

- **Short-term (periodic and predictable customer pull for new products):**
  - **Firm bridges gaps in knowledge creation activities through own investments in development of derivatives, IRAD, productivity enhancements**
- **Long-term (many years until next new design):**
  - **Externalize cost of knowledge creation by allowing customer to fund technology demonstrations, concept studies, and prototypes**
  - **Customer or firm adopts "spiral" or adaptive development process to "load level" design experience over several years**
  - **BUT–customer acknowledges and accepts potentially significant relearning penalties to develop follow-on new products if the break in knowledge creation activity stretches on too long**

Illustration from DoD 4245.7-M, 1985

Concluding Points

- Research on IC continuing
  - LAI: Development of model, framework, and tools to help assess IC vitality (June 2002)
  - LARA: current primary research thrust
  - Focus of LAI/LARA white paper to Presidential Commission on Future of Aerospace Industry (April 2002)
- Research scope and activity associated with KM expected to expand in LAI follow-on phase