Sloan Industry Studies – 2007

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LEAN TRANSFORMATION IN THE U.S. AEROSPACE INDUSTRY:

APPRECIATING INTERDEPENDENT SOCIAL AND TECHNICAL SYSTEMS

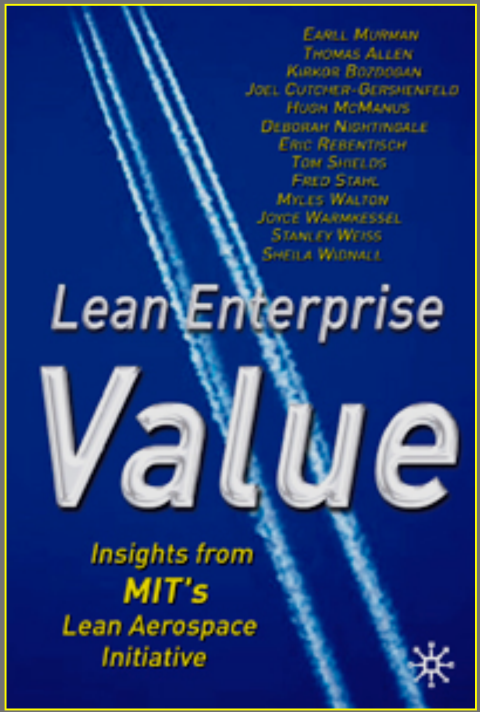
Joel Cutcher-Gershenfeld

University of Illinois, Urbana-Champaign

Overview

- Lean Enterprise Value Challenge for the Aerospace Industry
- National Aerospace Facility Survey
- Lean Implementation Analysis

> *"Becoming 'lean' is a process of eliminating waste with the goal of creating value"*



"Islands of Success"

C-130J production

- Throughput of extrusion shop from 12 days to 3 minutes

Automatic code generation

- 40% reduction in time
- 80% improvement in quality

Military electronic modules from commercial lines at TRW

- 73% cost reduction

F-16 Build-to-Print Center

- 75% cycle time reduction

777 floor beam

- 47% assembly time reduction

P & W General Machining Center

- 67% reduction in lead time

Delta IV launch vehicle

- 63% reduction in floor space

GE Lynn aircraft engine facility

- 100% on time deliveries

Joint Direct Attack Munition (JDAM)

- 63% reduction in unit cost

Source:
Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative, Earll Murman, Thomas Allen, Kirkor Bozdogan, Joel Cutcher-Gershenfeld, Hugh McManus, Deborah Nightingale, Eric Rebentisch, Tom Shields, Fred Stahl, Myles Walton, Joyce Warmkessel, Stanley Weiss, Sheila Widnall (Palgrave, 2002)

Initial Evidence of Enterprise Transformation

- F-16 maintained sales price and decreased order-to-delivery time by up to 42% while production rate decreased 75%
- C-17 unit priced decreased from $260M to $178 M for final 80 aircraft of 120 aircraft buy.
- Northrop Grumman ISS lean enterprise implementation reduced throughput times for major systems by 21 to 42%.
- F/A18-E/F EMD completed on time, within budget (without rebaseline) while meeting or exceeding performance requirements.
- Raytheon realized $300M FY 2000 bottom line benefits from its enterprise wide Six Sigma program

Source:
Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative, Earll Murman, Thomas Allen, Kirkor Bozdogan, Joel Cutcher-Gershenfeld, Hugh McManus, Deborah Nightingale, Eric Rebentisch, Tom Shields, Fred Stahl, Myles Walton, Joyce Warmkessel, Stanley Weiss, Sheila Widnall (Palgrave, 2002)

2002 National Facility Survey: Overview and Process

- **Overview:**
  - **A nationally representative sample of aerospace facilities to examine instability, new work systems, skills & capability, intellectual capital, and related matters**
- **Process:**
  - **Sample drawn from national aerospace directory**
  - **Mailed survey to approximately 2500 facilities**
  - **Special panel established for respondents to 1999 National Facility Survey – drawn from same source**
  - **Second mailing and follow-up telephone calls**
  - **Data presented based on 362 responses**
    - ***Note: Approximately 300 returned as "not in the aerospace industry" or returned to sender as bad addresses***
- **Note:**
  - **1999 survey responses: 194**

- Cross-sectional data – longitudinal results in some cases
- Single respondents from facilities
- Post 9/11– a major discontinuity
- Hypotheses examined first bi-variate and then muliti-variate
- Causality not always clear

Profile Data on Facilities and Respondents: 2002 Survey Data

Facility Profile

- **Average Number of Employees:**
  - **558 employees**
- **Average Year Began Operations:**
  - **1976**
- **Average % Sales to Largest Customer:**
  - **30%**
- **Average Number of Major Government Programs:**
  - **5.4 Programs**
- **Average Number of Major Commercial Programs:**
  - **8.9 Programs**
- **Product Volume – Primary Product:**
  - **Low: 60% Med: 32% High: 8%**
- **Unionization Among Respondents:**
  - **15%**

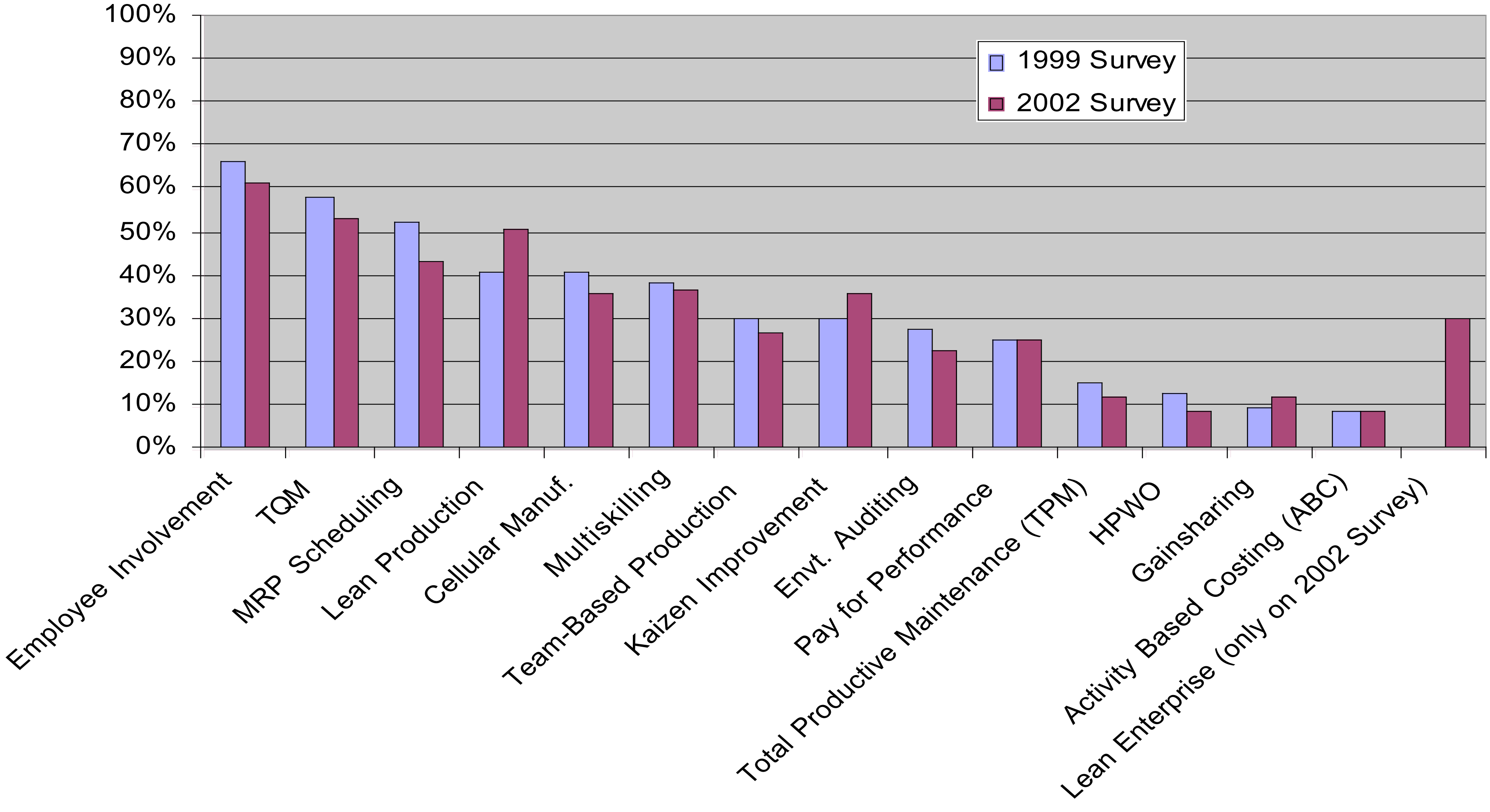
Industry Sector Distribution

- **Aircraft Frames/Structures: 24%**
- **Aircraft Engines: 13%**
- **Avionics: 15%**
- **Spacecraft and Missiles: 6%**
- **Other (mostly suppliers): 42%**

Respondent Profile

- **Average Years of Experience in Aerospace:**
  - **24 years**
- **Average Age Range:**
  - **46–55 years**
- **Average Education Level:**
  - **Undergraduate Degree and some Graduate Education**

Organizational Change Initiatives: 1999 and 2002 Survey Data



There are a broad range of change initiatives found across the industry, with Employee Involvement and TQM being the more common and the most growth in Lean and Kaizen Improvement Efforts.

Lean Scale

- Simultaneous/concurrent engineering
- Minimal "in-process" inventory
- Reducing cycle times
- Flexible job assignments
- Scheduling on a "pull" basis driven by customer orders
- Preventative maintenance
- Tightly integrated suppliers
- High trust between management and employees
- In-process inspection
- Job rotation
- Continuous improvement
- "Flow" of material or design ideas — no wasted steps
- Engineering organized by integrated product or process teams (IPTs)
- High levels of worker responsibility on the job
- Extensive formal group process training

Scale Construction:	*1 & 2 = Not found at all in this facility*
	3 & 4 = Partly true of this facility
	5 & 6 = Completely true of this facility
Scale Reliability:	*Alpha = .88*

Conceptual Model:
Causes and Consequences

Control Factors Explaining Degree of Lean Practices

- Sector of the Industry
- Product Volume
- Facility Age
- Facility Size
- Union Status

Lean Scale

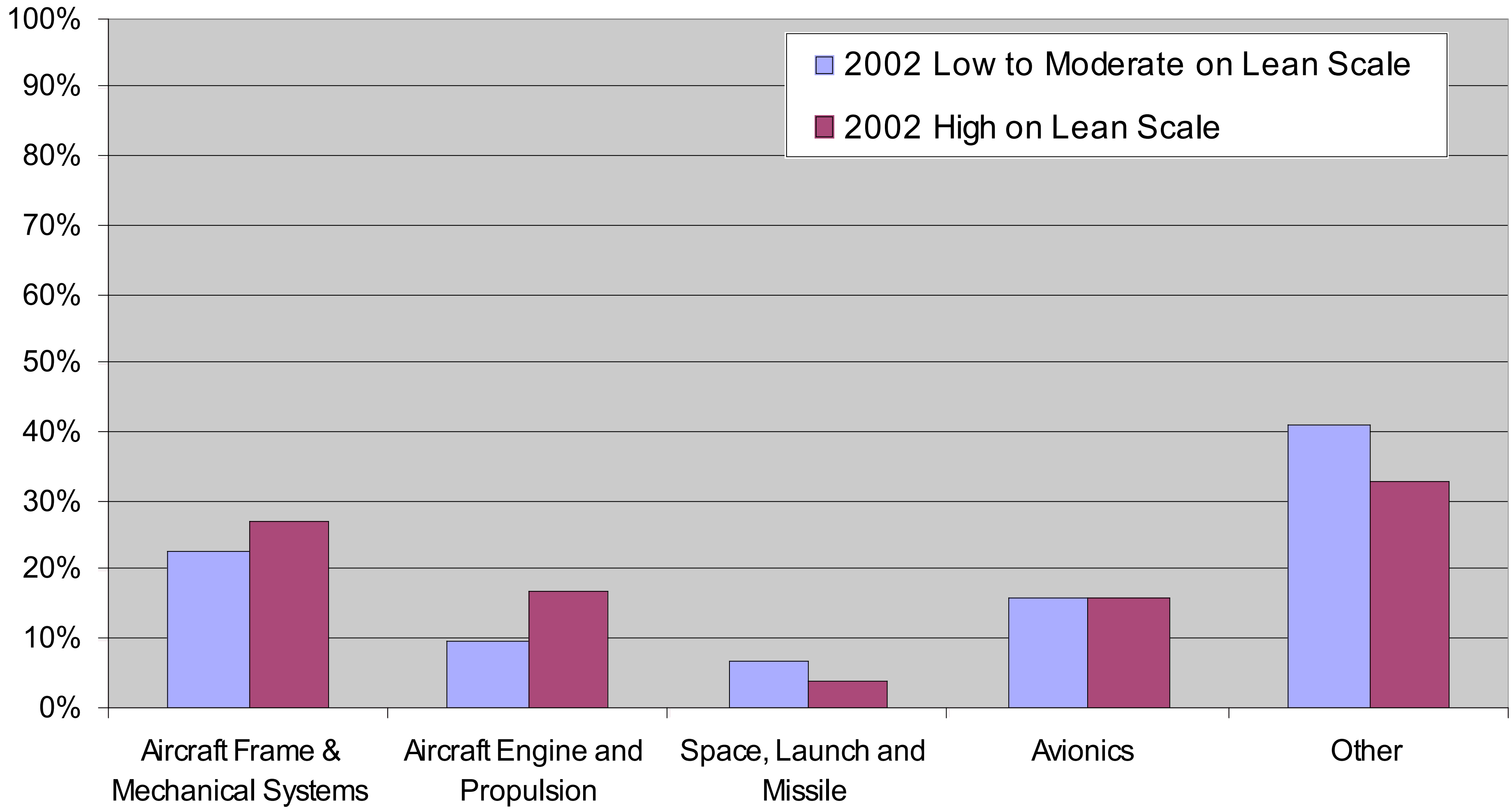
Impact of Lean Practices

- Use of Temporary / Contract Workers
- Use of Overtime
- Use of Outsourcing
- Loss of People with Critical Skills
- Scope of Worker Responsibility
- Worker Satisfaction
- Turnover
- Absenteeism
- Employment
- Productivity
- Quality Performance
- Schedule/Delivery Performance
- Profitability

Preliminary Hypotheses on Control Factors

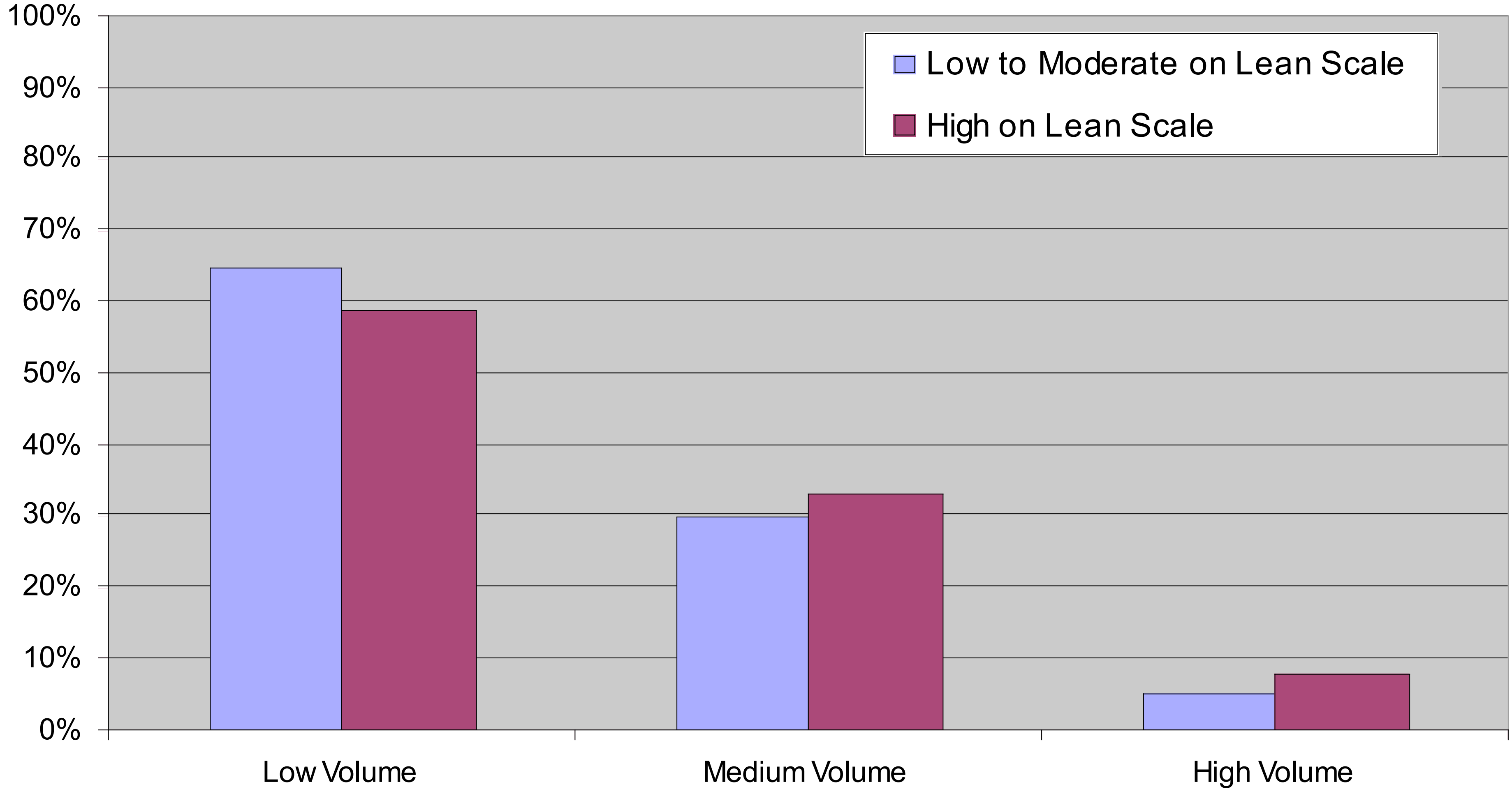
- **H1a – Sector**
  - *Lean practices will be least common among suppliers and the space sector of the aerospace industry*
- **H1b – Volume**
  - *Lean practices will be more widely used in high volume operations; least widely used on low volume operations*
- **H1c – Age**
  - *Lean practices will be more widely used in newer operations; least widely used in older operations*
- **H1d – Size**
  - *Lean practices will be more widely used in medium sized facilities; least widely uses in small or large facilities*
- **H1e – Union Status**
  - *Lean practices will similarly practiced in unionized and non-union facilities*

Industry Sector and Lean Practices: 2002 Survey Data



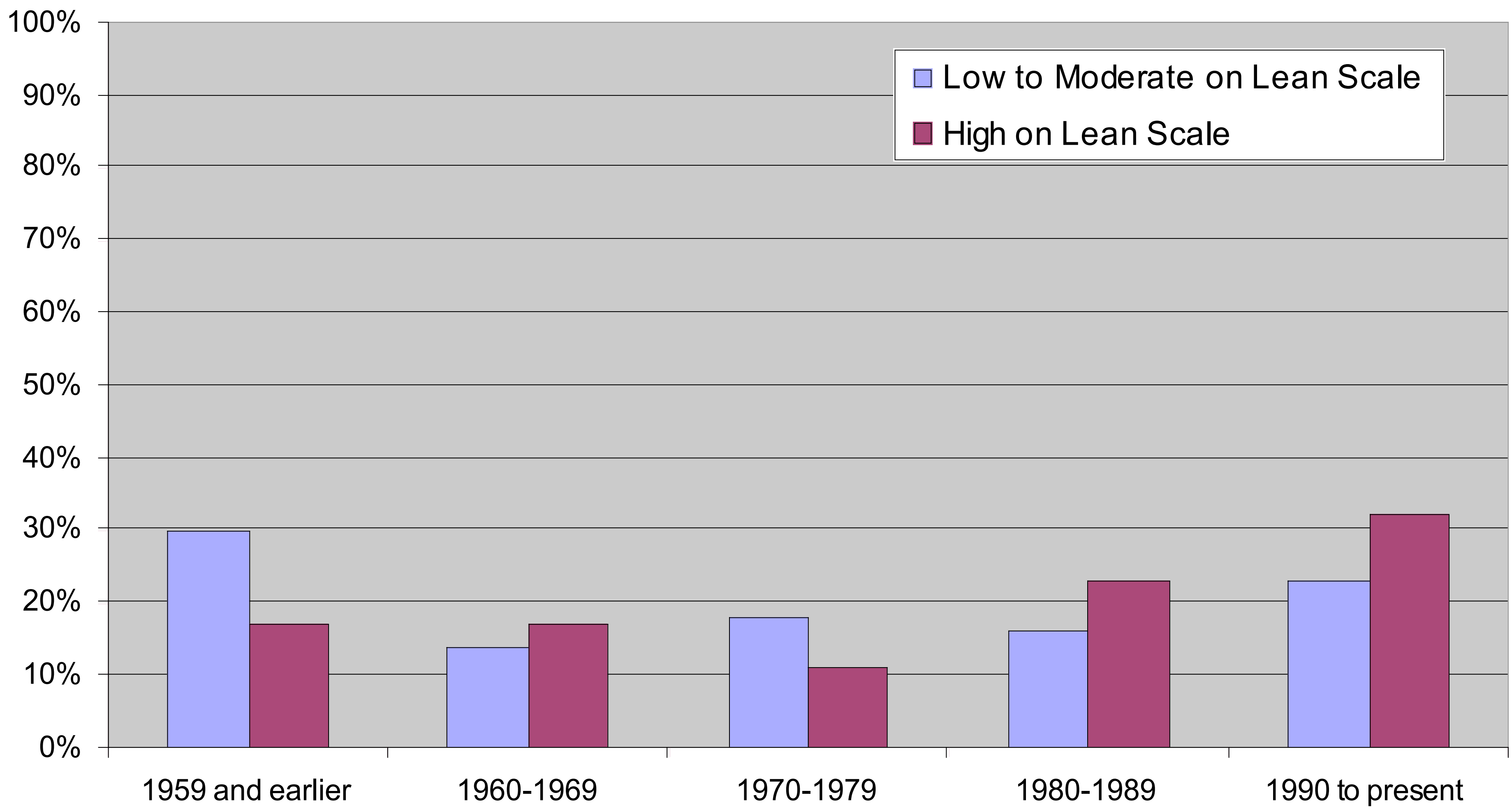
Preliminary support for H1a: Lean practices will be least common among suppliers and the space sector of the aerospace industry

Product Volume and Lean Practices: 2002 Survey Data



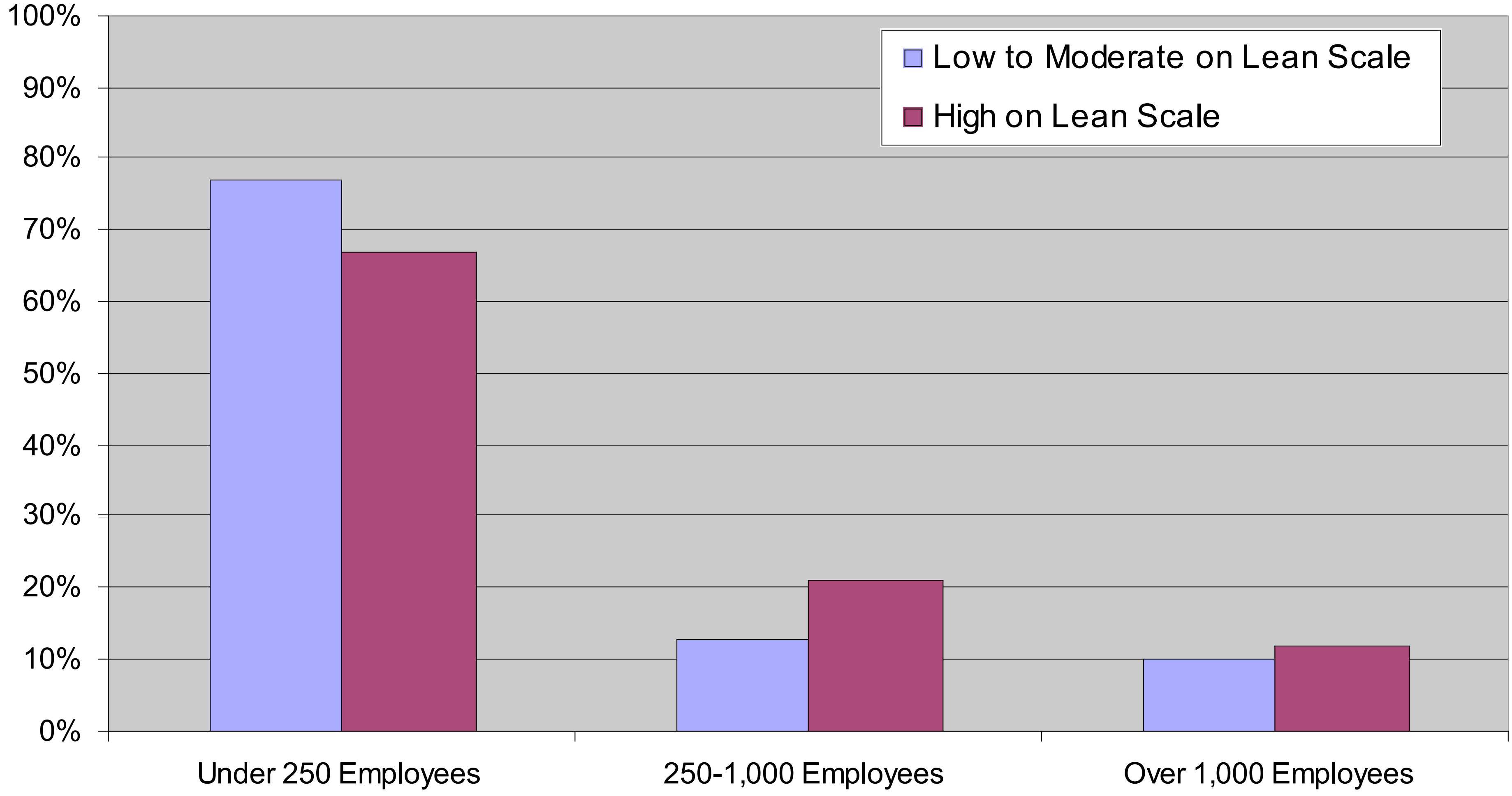
Preliminary support for H1b: Lean practices will be more widely used in high volume operations; least widely used on low volume operations

Facility Age and Lean Practices: 2002 Survey Data



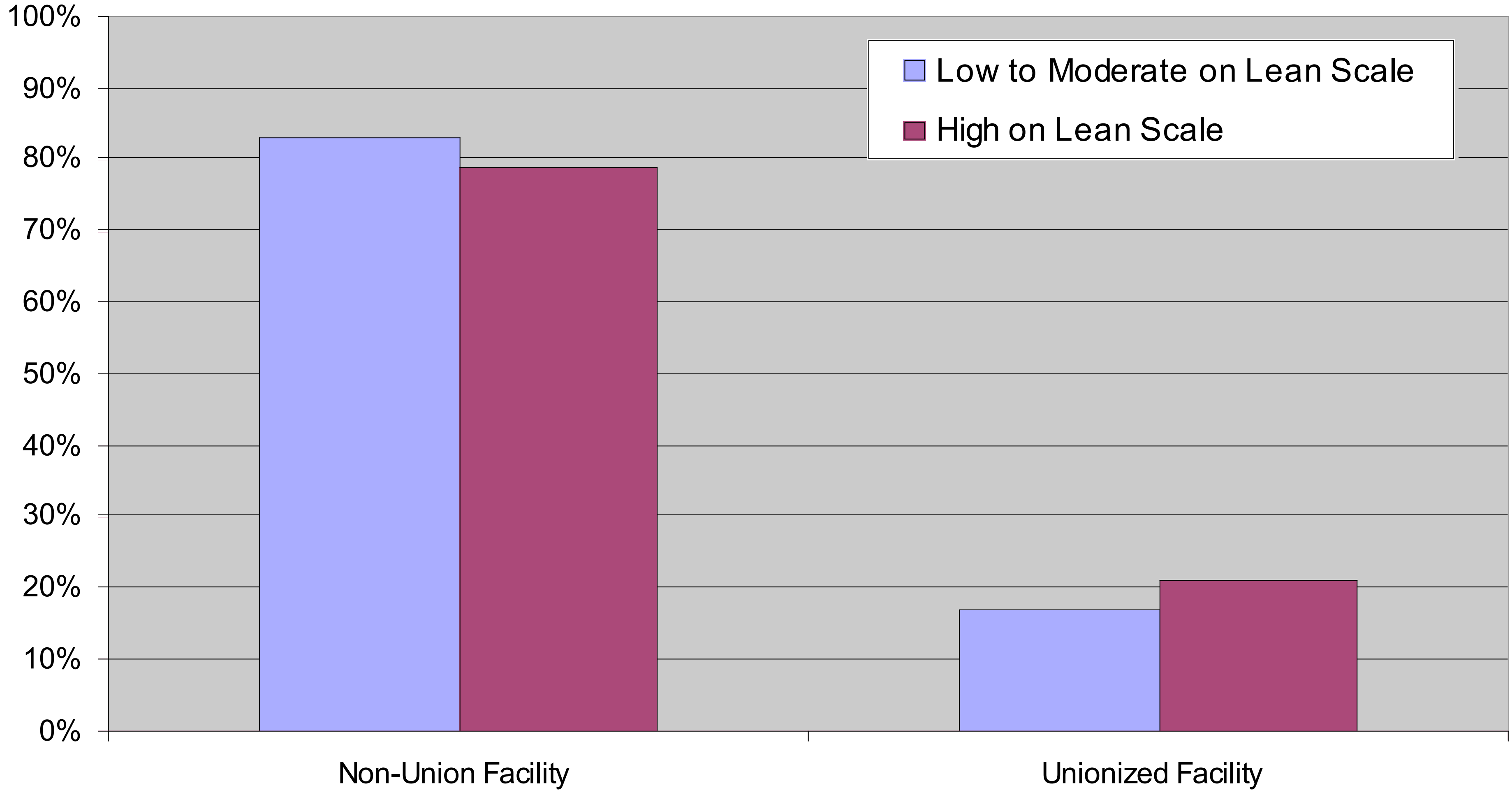
Preliminary support for H1c: Lean practices will be more widely used in newer operations; least widely used in older operations

Facility Size and Lean Practices: 2002 Survey Data



Preliminary support for H1d: Lean practices will be more widely used in medium sized facilities; least widely uses in small or large facilities (though large facilities are slightly higher)

Union Status and Lean Practices: 2002 Survey Data



Potential rejection of H1e: Lean practices will similarly practiced in unionized and non-union facilities (unionized facilities are slightly more likely to be higher on the lean scale)

Conceptual Model: Causes and Consequences

Factors Explaining Degree of Lean Practices

- Sector of the Industry
- Product Volume
- Facility Age
- Facility Size
- Union Status

→ **Lean Scale** →

Impact of Lean Practices

- Use of Temporary / Contract Workers
- Use of Overtime
- Use of Outsourcing
- Loss of People with Critical Skills
- Scope of Worker Responsibility

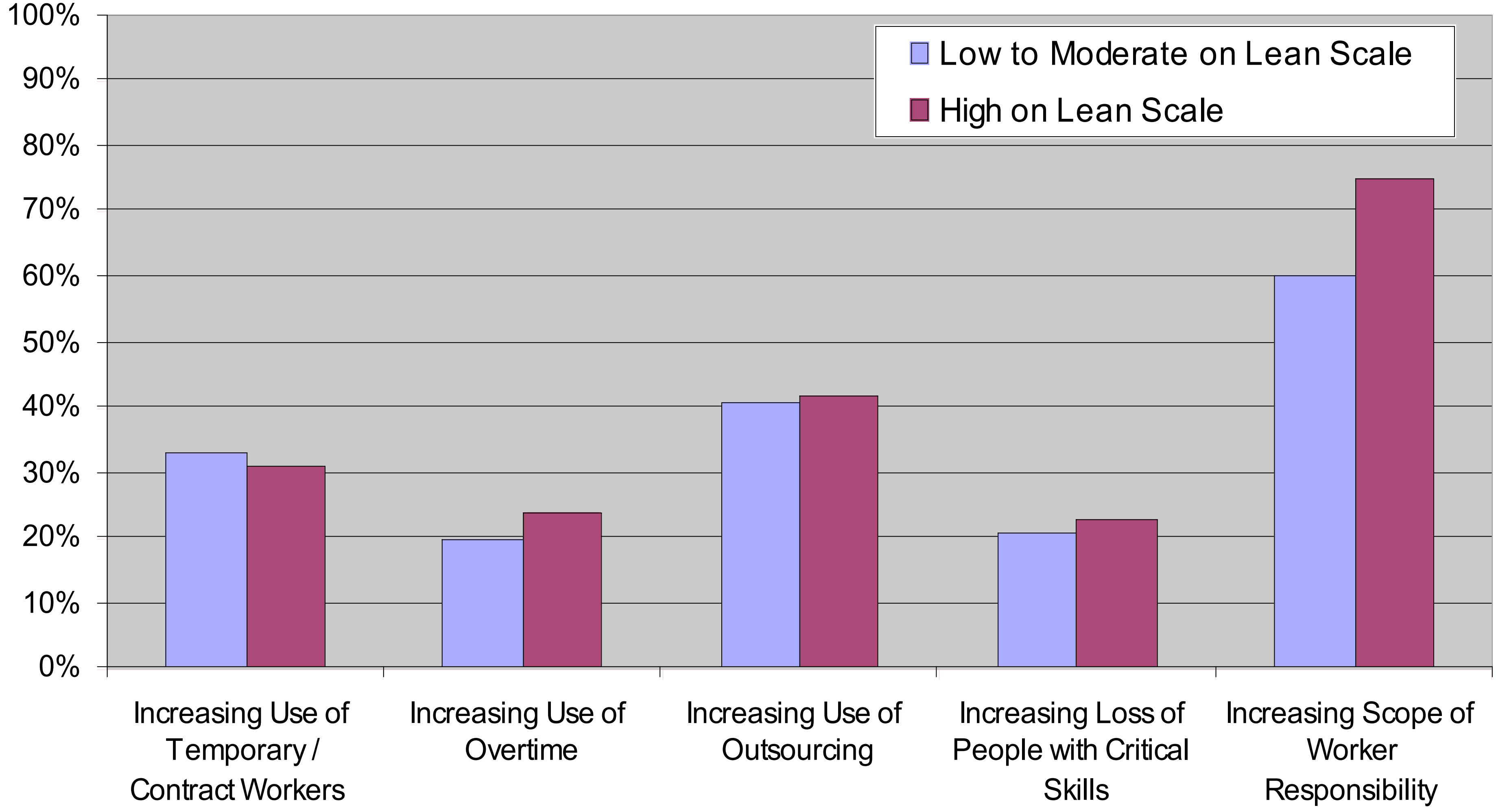
- Worker Satisfaction
- Turnover
- Absenteeism
- Employment

- Productivity
- Quality Performance
- Schedule/Delivery Performance
- Profitability

Preliminary Hypotheses on Context Factors

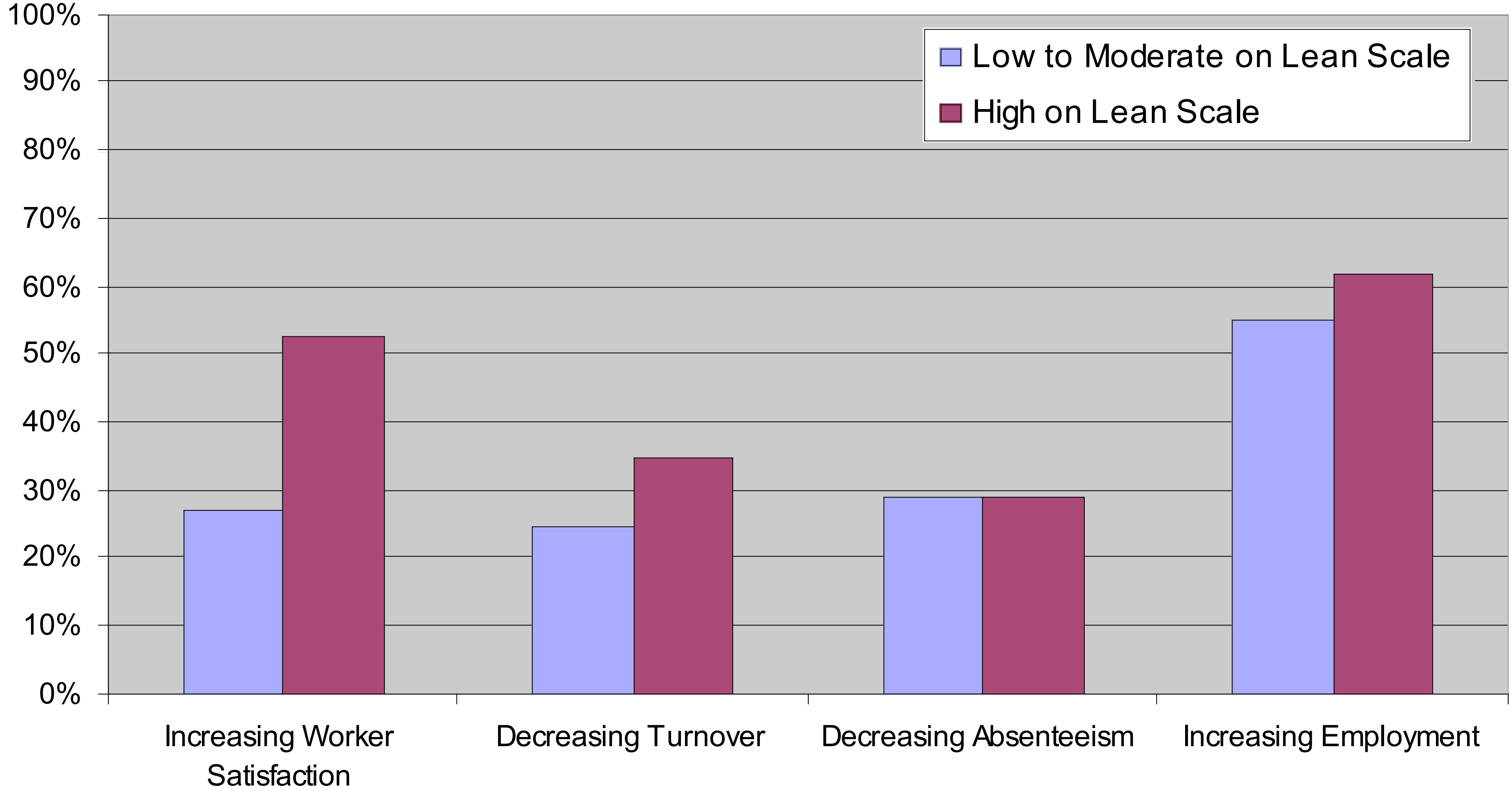
- **H2a – Use of Temporary / Contract Workers, Use of Overtime, Use of Outsourcing, Loss of People with Critical Skills, Scope of Worker Responsibility**
  - *The impact of lean practices on workforce operations will be indeterminate*
- **H2b – Worker Satisfaction, Turnover, Absenteeism, and Employment Workforce Outcomes**
  - *The impact of lean practices on employee outcomes will be indeterminate*
- **H2c – Productivity, Quality Performance, Schedule/Delivery Performance, and Profitability Economic Performance Outcomes**
  - *Lean practices will have a positive impact on all economic performance outcomes*
- **H2d – Components of Lean Scale and Outcome Measures**
  - *Different elements of the lean scale will be associated with appropriate workforce and economic performance outcomes*

Impact of Lean on Workforce Operations: 2002 Survey Data



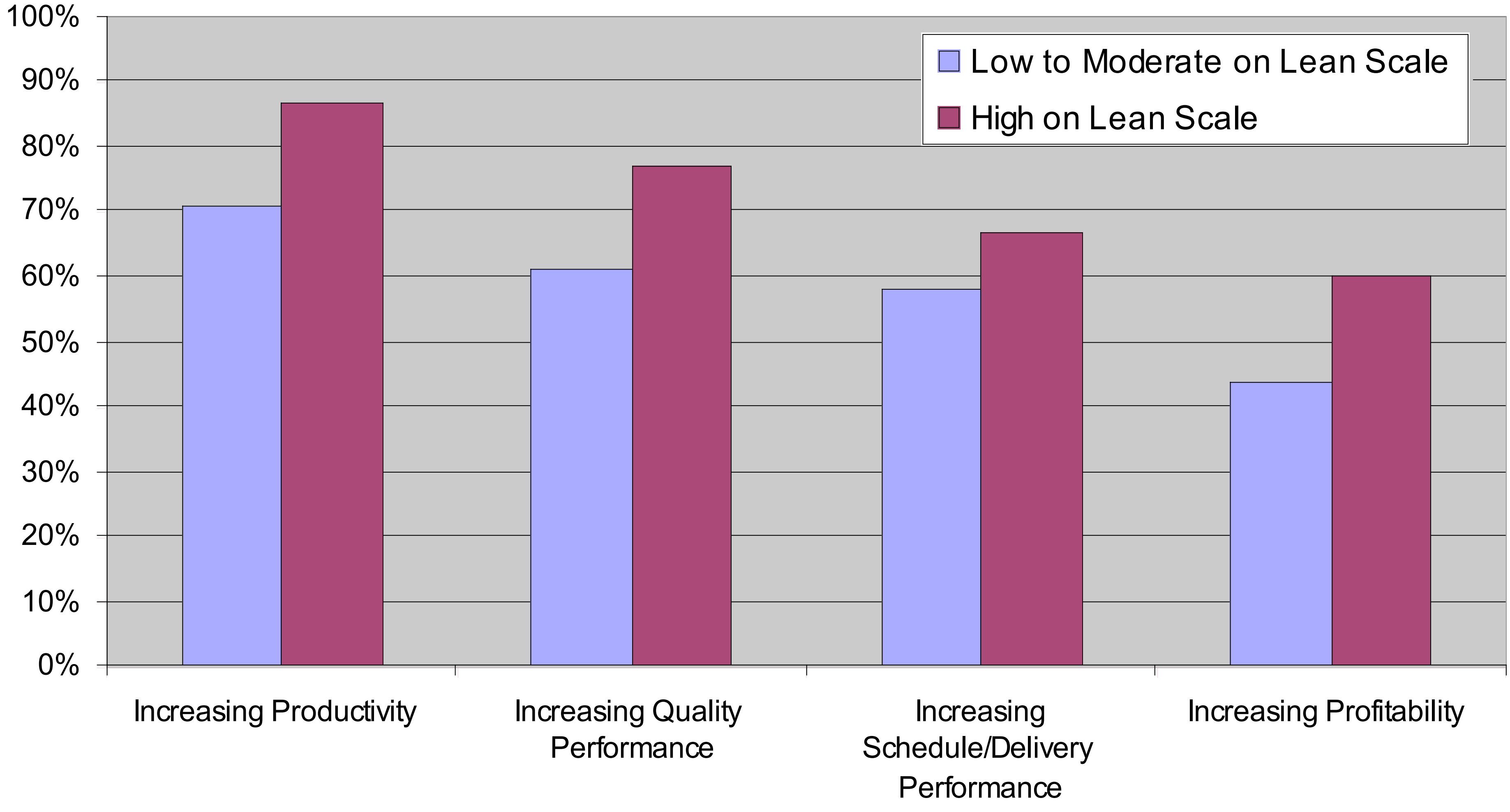
Preliminary support for H2a: The impact of lean practices on workforce operations will be indeterminate (with a potential effect on increasing the scope of worker responsibility)

Impact of Lean on Workforce Outcomes: 2002 Survey Data



Potential rejection of H2b: The impact of lean practices on employee outcomes will be indeterminate (facilities higher on the lean scale are, in fact, higher on three of the four workforce outcomes)

Impact of Lean on Economic Performance Outcomes: 2002 Survey Data



Preliminary Support for H2c: Lean practices will have a positive impact on all economic performance outcomes

Regression Analysis: Economic Performance

Variables	Productivity		Quality		Schedule/Delivery		Profitability	
	B	SE	B	SE	B	SE	B	SE
(Constant)	2.224	.281***	2.317	.251***	2.399	.343***	2.235	-.451***
a. Simultaneous Eng	-1.709E-02	.043	-5.609E-02	.039	-9.577E-02	.053	-5.899E-02	-.070
b. Minimal In-Process Inventory	2.999E-02	.050	5.495E-02	.045	6.512E-02	.062	3.105E-03	.081
c. Reduced Cycle Time	.167	.052 **	.102	.047 *	.158	.064 *	.114	.084
d. Flexible Job Assignments	6.978E-02	.054	2.865E-02	.048	6.109E-02	.066	2.859E-02	.086
e. Scheduling on a "pull" basis	-3.889E-03	.043	-.108	.039 **	-2.962E-02	.053	3.242E-02	.069
f. Preventative Maintenance	-7.436E-02	.046 *	2.203E-02	.041	8.766E-02	.057	.104	.073
g. Tightly Integrated Suppliers	-1.999E-02	.048	-5.080E-02	.043	2.827E-02	.058	-4.326E-03	.076
h. High Trust	8.564E-04	.050	7.350E-02	.044 *	-9.783E-03	.060	5.230E-02	.080
i. In-Process Inspection	1.710E-02	.044	1.848E-02	.040	-.107	.054 *	-6.673E-02	.071
j. Job Rotation	2.245E-02	.048	3.190E-02	.042	-1.351E-02	.058	-.192	.076 **
k. Continuous Improvement	.126	.066 *	4.868E-02	.059	.140	.080 *	2.794E-02	.105
l. Flow of Material and Ideas	6.011E-03	.064	.136	.058 *	-9.162E-02	.078	-1.699E-02	.103
m. Engineering IPTs	-1.752E-02	.041	-1.232E-03	.037	5.272E-02	.050	9.717E-02	.066
n. Worker Responsibility	6.653E-02	.060	.122	.053 *	2.765E-02	.072	6.094E-02	.096
o. Formal Group Process Training	5.033E-02	.050	-9.827E-02	.045 *	4.613E-02	.062	9.118E-02	.081

* Significant at the .1 level; ** Significant at the .01 level; *** Significant at the .001 level

Regression Analysis: Workforce Operations

Variables	Worker Satisfaction		Turnover		Absenteeism	
	B	SE	B	SE	B	SE
(Constant)	1.859	.262 ***	3.560	.329 ***	3.185	.277 ***
a. Simultaneous Eng	-4.976E-02	.041	-3.031E-02	.051	9.336E-03	.044
b. Minimal In-Process Inventory	-1.023E-02	.047	-6.636E-02	.059	1.142E-02	.049
c. Reduced Cycle Time	-1.060E-02	.049	3.887E-02	.061	-6.060E-02	.053
d. Flexible Job Assignments	-3.618E-02	.050	6.688E-03	.062	1.203E-02	.053
e. Scheduling on a "pull" basis	-1.940E-02	.040	2.385E-02	.050	.102	.043 *
f. Preventative Maintenance	5.343E-02	.043	-4.534E-02	.053	-.111	.045 *
g. Tightly Integrated Suppliers	2.948E-02	.044	-2.882E-02	.057	2.237E-02	.047
h. High Trust	.165	.046 ***	-.171	.058 **	-.116	.049 *
i. In-Process Inspection	-4.258E-02	.041	5.393E-02	.051	.108	.044 *
j. Job Rotation	-1.341E-02	.044	4.247E-02	.055	-2.019E-02	.048
k. Continuous Improvement	2.974E-02	.061	8.939E-02	.076	3.052E-02	.065
l. Flow of Material and Ideas	6.606E-02	.060	-6.608E-02	.075	-1.558E-02	.064
m. Engineering IPTs	-6.810E-04	.039	2.457E-02	.050	-9.508E-03	.043
n. Worker Responsibility	.150	.055 **	-6.530E-02	.069	-6.755E-02	.058
o. Formal Group Process Training	6.399E-02	.047	-3.975E-02	.059	-3.041E-02	.050

* Significant at the .1 level; ** Significant at the .01 level; *** Significant at the .001 level

Conclusions

Context findings (bivariate):

- **H1a – Sector variation – airframes and engines are more lean**
- **H1b – Volume variation – medium and high volume are more lean**
- **H1c – Age variation – newest facilities are more lean**
- **H1d – Size variation – medium and largest are more lean**
- **H1e – Union status variation – unionized facilities are more lean**

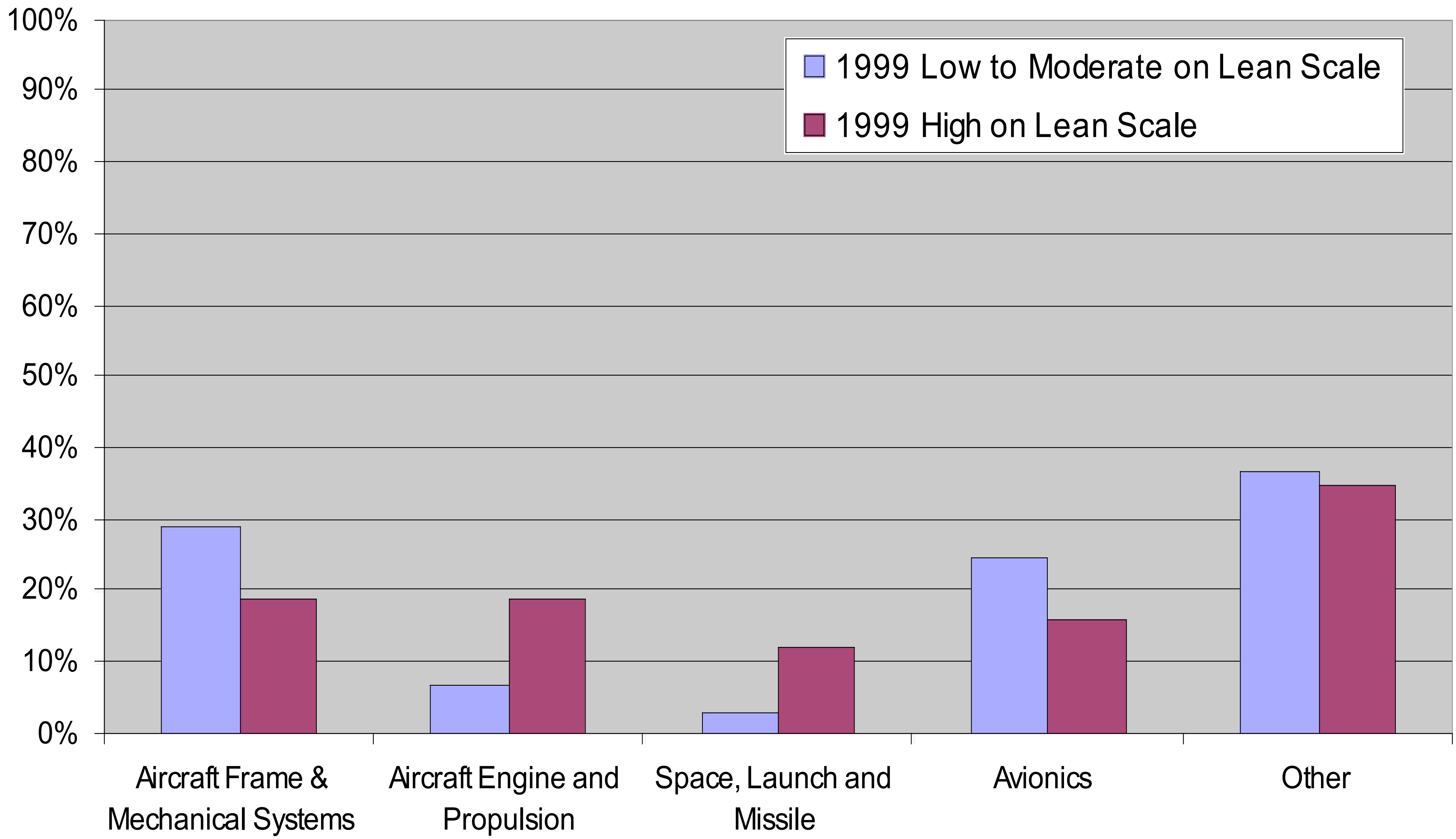
Multivariate findings (bivariate and multivariate):

- **H2a – HR Practices — Scope of Worker Responsibility is higher with lean**
- **H2b – HR Outcomes – Worker Satisfaction is higher, Turnover is lower, and Employment is higher with lean**
- **H2c – Economic Performance Outcomes – Productivity, Quality Performance, Schedule/Delivery Performance, and Profitability Economic Performance Outcomes are all higher with lean**
- **H2d – Components of Lean Scale and Outcome Measures – Trust in particular stands out**

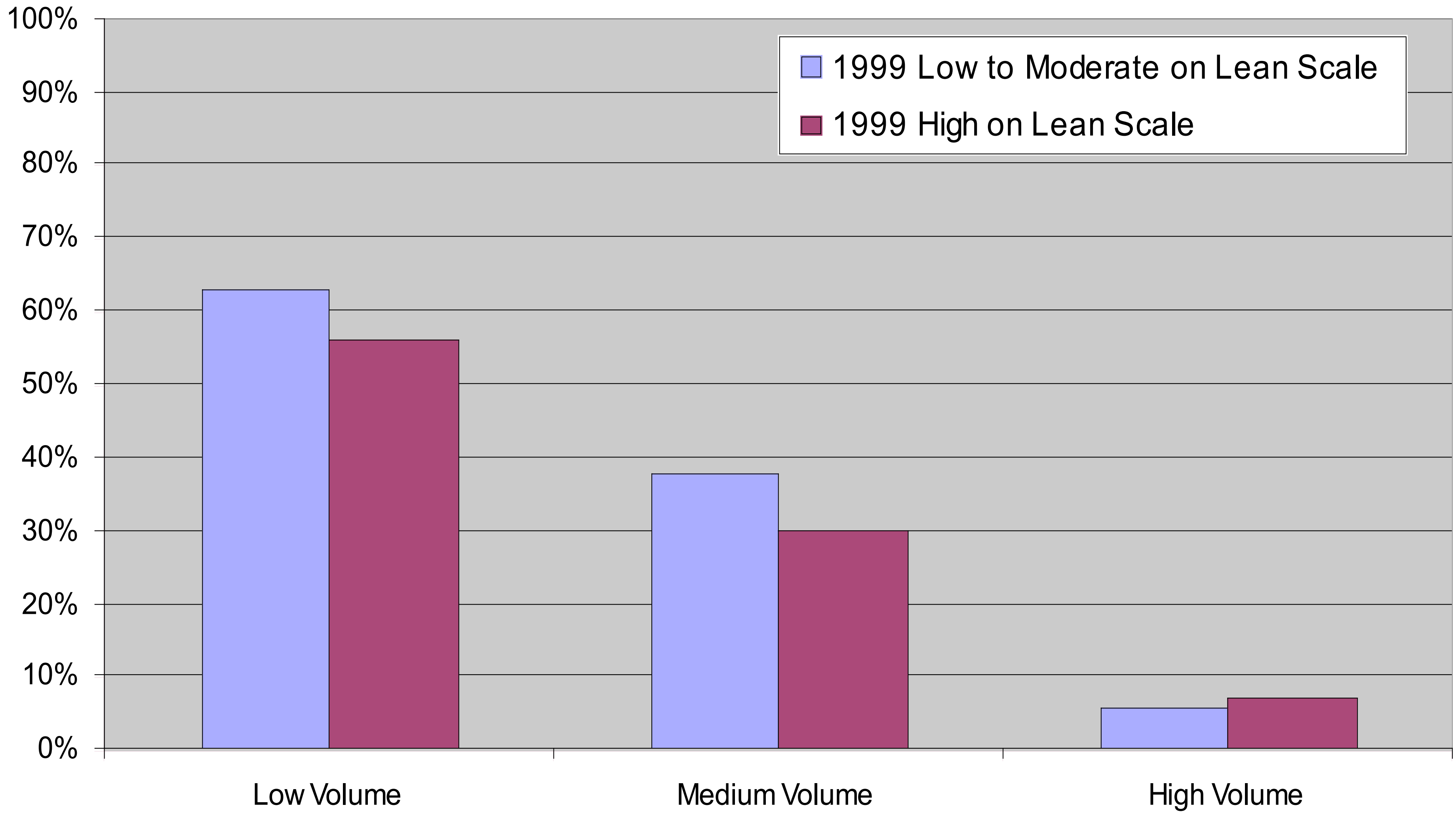
Appendix

- 1999 Industry Profile Data
- 1999 Outcome Data
- Aerospace industry publications (LERA Aerospace Industry Council and MIT's Labor Aerospace Research Agenda)

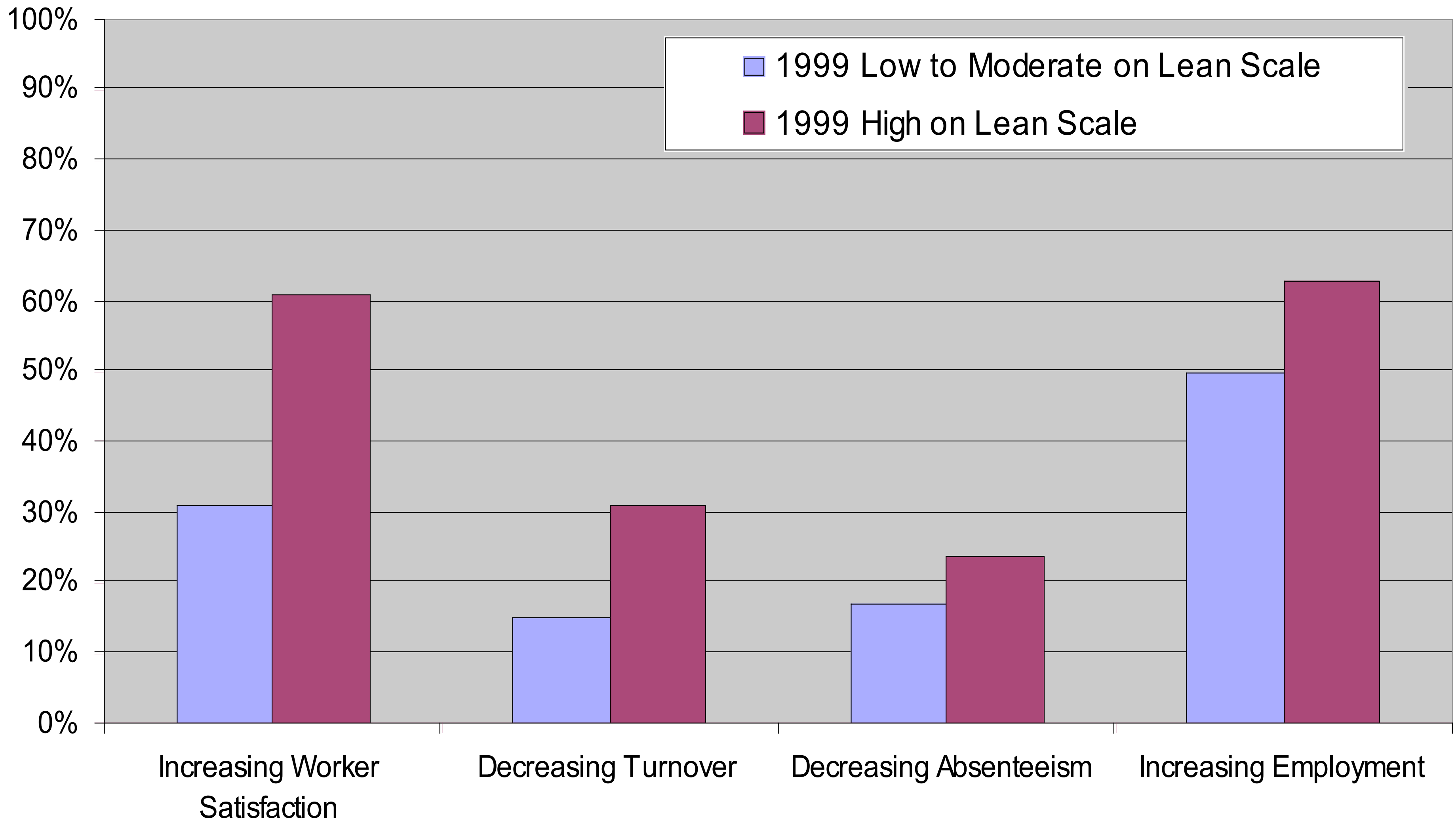
Industry Sector and Lean Practices: 1999 Survey Data



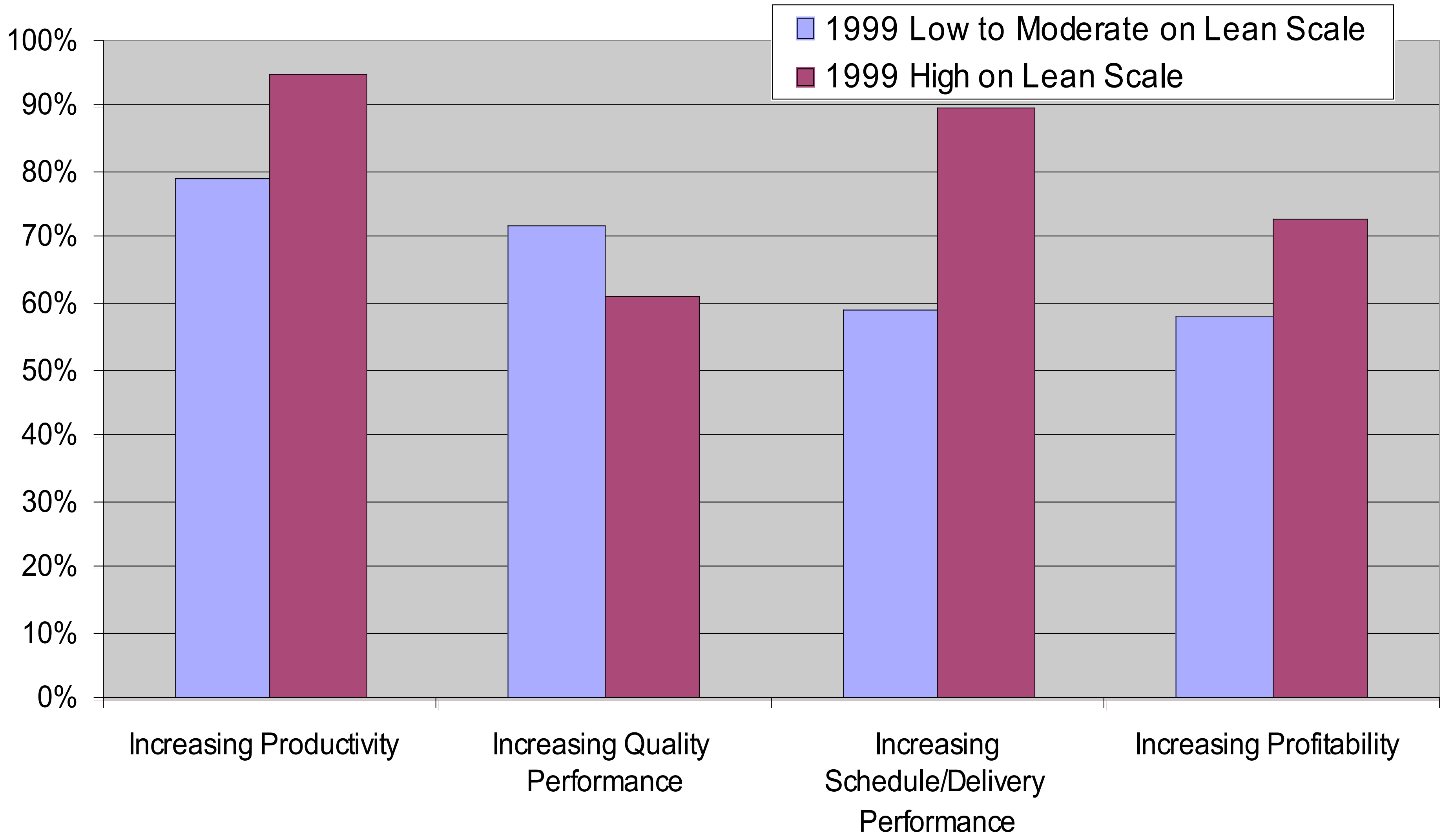
Product Volume and Lean Practices: 1999 Survey Data



Impact of Lean on Workforce Outcomes: 1999 Survey Data



Impact of Lean on Economic Performance Outcomes: 1999 Survey Data



Sample Aerospace Industry Publications

(available at http://www.lera.uiuc.edu/IndustryCouncils/aerospace/index.html)

Resource Guide:

- **Collective Bargaining in the Face of Instability: A Resource for Workers and Employers in the U.S. Aerospace Industry**

Case Studies:

- **A Decade of Learning**

  International Association of Machinists and Boeing Joint Programs

- **Transformation Through Employee Involvement and Workplace Training: The Challenge of a Changing Business Context**

  Rocketdyne Propulsion and Power and the United Automobile Workers

- **Employing Activity Based Costing and Management Practices Within the Aerospace Industry: Sustaining the Drive for Lean**

  Boeing Commercial Airplane Group, Wichita Division and the International Association of Machinists

- **Fostering Workplace Innovation and Labor-Management Partnership: The Challenge of Strategic Shifts in Business Operations**

  Pratt and Whitney (UTC) and the International Association of Machinists

- **Fostering Continuous Improvement in a Changing Business Context**

  Textron Systems

- **From Three to One: Integrating a High Performance Work Organization Process, Lean Production, and Activity Based Costing Change Initiatives**

  Boeing Commercial Airplane Group, Wichita Division and the International Association of Machinists

Note: Publications developed through MIT's Labor Aerospace Research Agenda; available through the Labor and Employment Relations Association's Aerospace Industry Council website