Lean Enterprise Self-Assessment as a Leading Indicator for Accelerating Transformation in the Aerospace Industry

by ***Cory R. A. Hallam***

Bachelor of Mechanical and Aerospace Engineering (1996)
High Distinction, Carleton University (Canada)

Master of Engineering, Aeronautics and Astronautics (1997)
Massachusetts Institute of Technology

ISU SSP, Space Systems Architecture (1997)
International Space University

Master of Science, Technology and Policy Program (2001)
Massachusetts Institute of Technology

Submitted to the Technology, Management, and Policy Program in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Technology, Management, and Policy at the Massachusetts Institute of Technology
May 2003 [June 2003]

Signature of Author ______________________
Technology, Management, and Policy Program
May 16, 2003

Certified by ______________________
Dr. Deborah J. Nightingale
Professor of the Practice of Aeronautics and Astronautics, and Engineering Systems, Doctoral Committee Chair

Certified by ______________________
Dr. Thomas J. Allen
Howard W. Johnson Professor,
Sloan School of Management, and Engineering Systems

Certified by ______________________
Dr. John J. Deyst
Professor of Aeronautics and Astronautics

Certified by ______________________
Dr. Joe H. Mize
Regents Professor Emeritus, Oklahoma State University

Approved by ______________________
Dr. Daniel E. Hastings
Professor of Aeronautics and Astronautics, and Engineering Systems
Co-Director, Technology, Management and Policy Program
Chair, Committee on Graduate Studies

This page intentionally left blank.

Lean Enterprise Self-Assessment as a Leading Indicator for Accelerating Transformation in the Aerospace Industry

by

Cory R. A. Hallam

Submitted to the Technology, Management, and Policy Program on May 16th, 2003 in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Technology, Management and Policy

ABSTRACT

The research contained in this thesis explores leading indicators of lean enterprise transformation in the aerospace industry, as part of the greater body of work associated with MIT's Lean Aerospace Initiative (LAI). Arguments from literature are made in support of the assumption that a lean enterprise can outperform a less lean enterprise, permitting the research to focus on identifying potential means for achieving and accelerating lean enterprise transformation in the aerospace industry. Senior enterprise leaders and their leadership committees from thirty-one enterprises in the US and UK aerospace industry utilized the LAI Lean Enterprise Self-Assessment Tool (LESAT) as a means for measuring their current state of leanness in leadership/transformation processes, lifecycle processes, and enabling infrastructure. Cross-sectional LESAT data, two-period time series LESAT data, and directed interviews and site visits were utilized to formulate the conclusions drawn in this thesis.

There are four primary empirical findings of this research. First, the aerospace industry as a whole exhibits lowest maturity in practices related to establishing and deploying a lean enterprise vision, even in the presence of high maturity in lean production. Second, enterprises exhibiting high lean enterprise maturity in leadership/transformation processes also exhibit high maturity in lifecycle processes and enabling infrastructure. Third, strong leadership commitment (LC) correlates highly with setting a lean enterprise change environment (CE), which then correlates highly with lean change activities in practice (CP). Finally, there is evidence that the highest lean maturity enterprises have established formal information feedback mechanisms that allow the enterprise to strategically build on the lean capabilities of the enterprise, while prioritizing lean improvement activities within the context of enterprise strategic needs.

From the perspective of industry, this research suggests that there must be a formal decision to pursue the lean enterprise as an operational strategy in order to achieve successful transformation. This decision will be founded on strong leadership commitment, which if established, can help support the leadership/transformation practices as a means for improving lifecycle processes and enabling infrastructure. The LAI Transition-to-Lean (TTL) roadmap provides a logical sequencing of lean enterprise transformation activities, to which formal information feedback mechanisms should be added based on the model proposed in this thesis for accelerating lean enterprise transformation. Most importantly, this model suggests a new mode of operating, not a one-time improvement effort. Further research is needed to empirically validate the model as a means for accelerating lean enterprise transformation.

ACKNOWLEDGEMENTS

Completing this work has been challenging and exciting and would not have been possible without the support of numerous organizations and people. I would like to take this opportunity to thank them.

First of all, my doctoral committee consisting of Dr. Deborah J. Nightingale, Dr. Thomas J. Allen, Dr. John J. Deyst, and Dr. Joe H. Mize has been invaluable in helping craft my line of thought in the area of lean enterprise transformation, and has continuously challenged me to push my thinking to a new level. I am grateful for the financial and intellectual support the Lean Aerospace Initiative has provided during my Doctoral studies. I am also grateful for the financial support the LAI receives from industry and government, and the opportunities afforded me by having access to industry data that served as the basis for this research. I must also give thanks to the UK LAI for providing additional data for my research. Finally, I would like to express my gratitude to my family and friends, and especially Sara for supporting my work habits during this time.

Executive Summary

Research overview

The research herein covers lean enterprise transformation in the aerospace industry, conducted under the auspices of the Massachusetts Institute of Technology's (MIT) Lean Aerospace Initiative (LAI). Leading indicators of lean enterprise transformation, as measured by the Lean Enterprise Self-Assessment Tool (LESAT), are studied as a means for informing management decisions for achieving and accelerating the transformation process. Arguments from literature are made in support of the assumption that a leaner enterprise can outperform a less lean enterprise. This study uses cross-sectional and time series LESAT data, along with directed interview data, to disprove the null hypotheses associated with each of the following primary hypotheses, namely:

H1) Enterprises that exhibit a greater value of lean enterprise Transformation and Leadership Process maturity will exhibit a greater value of lean Lifecycle Process maturity

H2) Enterprises that exhibit a greater value of lean enterprise Transformation and Leadership Process maturity will exhibit a greater value of lean Enabling Infrastructure Process maturity

H3) Enterprises that exhibit a greater value of lean Enabling Infrastructure Process maturity will exhibit a greater value of lean Lifecycle Process maturity

LESAT data was collected from a total of 31 enterprises from the US and UK aerospace industry. Each enterprise data set consisted of an average of eleven individual assessments conducted by senior enterprise leadership committee members. Enterprises in this study were considered to be business units, divisions, or sites that had profit and loss (P&L) accountability for some set of aerospace products or services.

Main Findings

The LESAT tool was not designed to be a benchmarking tool, and as such no average industry lean enterprise maturity data is reported in this thesis. The data does, however, allow for the rank ordering of lean enterprise practices. This ranking provides several insights into the current state of lean enterprise transformation maturity in the aerospace industry. First, the industry exhibits its lowest maturity in practices related to crafting and deploying the lean enterprise vision, even though it does exhibit high maturity in lean production. Second, integration of lean in strategic planning (LESAT practice I.A.1) ranked highly, suggesting that enterprise strategic planners are considering lean as one of their operating tools. Yet, leveraging lean capability for business growth (LESAT practice II.A.1) and impacting enterprise strategic planning (LESAT practice I.G.5) ranked low. This suggests that the actual benefits realized with lean are not informing the strategic planning process. This would indicate a potential open-loop management system that "considers" lean in strategic planning, but does not strategically build plans based on the gains that lean is actually providing the enterprise.

The empirical data in this thesis supports the three primary hypotheses by showing strong correlations in each of the three proposed relationships (H1, H2, and H3). Additional evidence suggests that the causal inference associated with these hypotheses may exist. The implications for industry are that lean enterprise change efforts must have mature leadership/transformation processes in order to improve the maturity of lifecycle processes and enabling infrastructure. Maturity in these processes will lead to improved P&L results and better enterprise stakeholder value delivery, all else being equal.

A subdivision of the leadership/transformation variable indicates that leadership commitment (LC) is an essential prerequisite for establishing a lean change environment (CE), which in turn enables detailed lean change activities to occur in practice (CP). These variables represent the three major cycles of the LAI Transition-to-Lean (TTL) roadmap, namely the entry/reentry cycle, the long-term cycle, and the short-term cycle. Empirical evidence supports the causal inference between these variables. Further analysis also suggests that the current structuring of the TTL is a logical way to organize and prioritize lean enterprise transformation activities, and should produce better results than an ad-hoc improvement process.

The new knowledge associated with this thesis suggests that the creation of formal management information feedback, associated with lean enterprise change activities, is necessary for achieving lean enterprise transformation. Furthermore, the structuring of improvement activities within this information feedback model, as shown in Figure 1, may lead to the acceleration of the lean enterprise transformation compared to an enterprise that does not establish the information feedback loops. The recommendation for enterprises attempting lean enterprise transformation is to begin by establishing leadership anxiety or desire for lean enterprise transformation. This will help establish strong leadership commitment. Next, a lean office or group should be established. If there is an existing continuous improvement office, then the lean group should be incorporated as part of this office. Lean transformation efforts need to be supported as part of regular enterprise operations. If the lean office is considered a separate entity working on the sidelines, and not viewed as a strategic resource, then the transformation efforts will face serious resistance as they inherently cross functional, process, and corporate management boundaries. The Transition to Lean (TTL) Roadmap, or a modified version thereof, should be used as a guide for organizing and sequencing lean enterprise transformation activities. Finally, the lean enterprise transformation information feedback connections identified in Figure 1 must be established and managed as part of normal enterprise operating procedures. These feedback mechanisms will ensure that there is continued awareness and support for the transformation, and that the gains associated with the transformation are utilized to the enterprise's best strategic advantage. Enterprises operating in this manner will be better positioned to outperform their competitors.

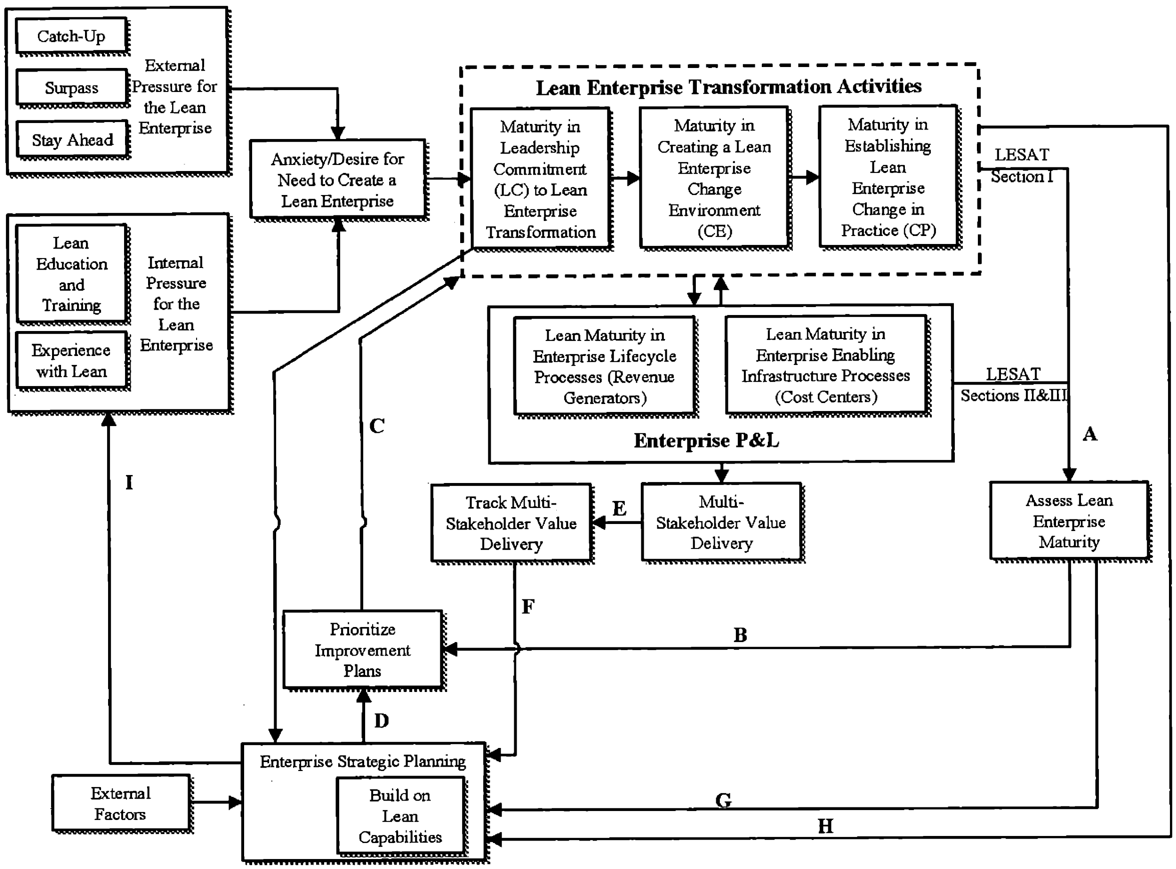


Figure 1 - Proposed lean enterprise transformation information feedback model.

Barriers to Adoption

The most obvious barrier to adopting this model for lean enterprise transformation is that it requires leadership commitment. While there is evidence that local lean efforts may succeed at improving local performance metrics, there is no evidence that lean enterprise transformation can occur without leadership support, as the change efforts necessarily cross functional, process, and corporate management boundaries. The "islands of success" discussed in this thesis highlight the fact that a major limiting factor in expanding local lean improvement efforts has been the need to go beyond the management authority of the local leader.

The next barrier is that successful lean implementation will require the establishment of a lean change office (or a lean team within a continuous improvement office). This necessarily means the allocation of scarce resources to lean efforts. This team must then manage, track, and provide information feedback to enterprise leadership that enables them to make strategic decisions with respect to the lean capabilities of the enterprise. If the lean efforts are viewed as a "flavor of the month" improvement program, establishing these feedback mechanisms as part of routine enterprise operations may have little support. In the event that the management environment is supportive of lean enterprise transformation, the lean change team must be adequately prepared to understand and deploy lean, and have the ability and authority to help change organizational behavior at all levels of the enterprise. This is perhaps the single hardest element of the transformation puzzle, especially as it means redefining employee attitudes, roles, duties, incentives, and even promotion paths. All of these efforts will encounter resistance to change, and unless that resistance can be overcome, the change efforts will not take hold.

Finally, if lean transformation is viewed as a pure cost cutting initiative, it will encounter serious resistance from the workforce and will not lead to any long-term strategic improvements for the company. Recognizing that the gains achieved with lean transformation can help produce long-term capabilities and returns for the enterprise may be the most fundamental piece of knowledge that leadership needs to embrace in order to enable and accelerate lean enterprise transformation.

Table of Contents

1 CHAPTER 1 - INTRODUCTION 18

1.1. RESEARCH OBJECTIVES 18

1.2. MOTIVATION FOR THIS RESEARCH 18

1.2.1. Fit of Research within TMP *22*

1.3. DISSERTATION OVERVIEW 25

2 CHAPTER 2 - DEFINING LEAN 30

2.1. THE MEANING OF LEAN 30

2.2. THE HISTORICAL ROOTS OF LEAN IN TOYOTA 34

2.2.1. The Tenets of Lean *44*

2.3. EVIDENCE OF SUCCESS WITH LEAN MANUFACTURING OUTSIDE OF THE AUTOMOTIVE INDUSTRY 50

2.3.1. Lean in Other Manufacturing Industries *50*

2.4. LEAN MANUFACTURING IN THE AEROSPACE INDUSTRY 52

2.4.1. Success with Lean Manufacturing in the Aerospace Industry *56*

2.5. OPEN ISSUES WITH LEAN IN AEROSPACE 61

2.6. CONCLUSIONS 63

3 CHAPTER 3 - THE LEAN AEROSPACE ENTERPRISE IMPERATIVE 64

3.1. DEFINING THE LEAN AEROSPACE ENTERPRISE 64

3.2. THE IMPORTANCE OF THE LEAN AEROSPACE ENTERPRISE PERSPECTIVE 76

3.2.1. The Enterprise as a System of Systems *77*

3.2.2. Cost and Time outside of Manufacturing *84*

3.2.3. The Multi-Stakeholder Focus of the Lean Enterprise *88*

3.3. CONCLUSIONS 99

4 CHAPTER 4 - THE STRATEGIC VALUE OF THE LEAN ENTERPRISE 100

4.1. STRATEGY AND BUSINESS 100

4.1.1. Types of Strategy in a Business Environment *102*

4.1.2. Factors Affecting Strategy *104*

4.2. THE LEAN ENTERPRISE AS AN OPERATIONAL STRATEGY 107
4.3. THE STRATEGIC VALUE OF KNOWLEDGE AND THE ECONOMICS OF INFORMATION 112
4.3.1. Non-Zero Marginal Cost of Acquiring New Knowledge 114
4.3.2. Absorptive Capacity for Understanding New Knowledge 115
4.3.3. Organizational Behavior Change for Exploiting New Knowledge 117
4.4. SHORT-TERM VERSUS LONG-TERM STRATEGIC THINKING FOR THE LEAN ENTERPRISE 120
4.5. CONCLUSIONS 122

5 CHAPTER 5 - HYPOTHESIS FORMULATION AND EXPERIMENTAL METHODS 124

5.1. MEASURING THE EXTENT OF LEAN ENTERPRISE TRANSFORMATION.................... 124
5.1.1. The Lean Enterprise Self-Assessment Tool (LESAT)................................. 125
5.2. OPERATIONALIZATION AND TEST OF HYPOTHESES 136
5.2.1. Leadership and Leading Indicators of Enterprise Transformation............. 136
5.2.2. Major Hypotheses.. 140
5.2.3. Hypothesis Tests 141
5.2.4. Exploring the Leading Lean Transformation Indicators in Greater Detail. 148
5.2.5. Sub-Hypothesis: Variability as an Indicator of Lean Maturity.................. 152
5.2.6. Measure of the State of the Industry... 152
5.3. DATA COLLECTION PROCEDURES 153
5.3.1. Observing the Effectiveness of the LESAT... 154
5.4. THREATS TO EXPERIMENTAL VALIDITY 155
5.5. CONCLUSIONS 158

6 CHAPTER 6 - ANALYSIS AND RESULTS 160

6.1. DESCRIPTION OF THE SAMPLE POPULATION... 160
6.2. HYPOTHESIS TESTS.. 161
6.2.1. Primary Hypotheses.. 161
6.3. EXTENSION OF THE LEAN TRANSFORMATION HYPOTHESES 184
6.3.1. Sub-Categories of Leadership/transformation Transformation Measure 184
6.3.2. Exploring the Sequencing of TTL Elements.. 190

6.4. VARIABILITY IN ASSESSMENT RESULTS AS AN INDICATOR OF ENTERPRISE MATURITY 192
6.5. INDUSTRY AVERAGE DATA 197
6.5.1. Highest Ranking Industry Practices *198*
6.5.2. Lowest Ranking Industry Practices *200*
6.6. OBSERVING THE LESAT IN USE 203
6.6.1. LESAT Beta Test Case Studies *203*
6.6.2. Models of how Enterprises Act on their LESAT Results *205*
6.7. CONCLUSIONS 211

7 CHAPTER 7 - CONCLUSIONS AND DISCUSSION 212

7.1. CONCLUSIONS FROM LITERATURE AND THEORETICAL WORK 212
7.2. CONCLUSIONS FROM EMPIRICAL RESULTS 223

8 CHAPTER 8 - RECOMMENDATIONS AND FUTURE RESEARCH 240

8.1. AN INTEGRATIVE MODEL FOR LEAN ENTERPRISE TRANSFORMATION 241
8.1.1. Step 1 - Creating Leadership Commitment (LC) *241*
8.1.2. Step 2 - Following the TTL to Establish CE and CP *244*
8.1.3. Step 3 - Improving Lean Maturity In Enterprise Processes *245*
8.1.4. Step 4 - Closing the Transformation Management Loop *247*
8.2. POTENTIAL FOR FURTHER RESEARCH 258

APPENDIX A - SOME OF THE MATHEMATICS DESCRIBING THE GAINS ACHIEVABLE WITH LEAN PRODUCTION 260

APPENDIX B - STAKEHOLDER VALUE TAXONOMY 270

APPENDIX C - LEAN ENTERPRISE SELF-ASSESSMENT TOOL (LESAT) 276

List of Figures

Figure 1 - Proposed lean enterprise transformation information feedback model. 8
Figure 2 - Research phases of the Lean Aerospace Initiative 20
Figure 3 - LAI enterprise tool triad 21
Figure 5 - Japanese share of world automotive production from 1955 to 1989 43
Figure 6 - Activity reduction and lead time improvement from Kaizen event lean transformation 51
Figure 8 - Trends in DOD program development time 54
Figure 9 - Enterprise stakeholders. 72
Figure 10 - Defining the boundaries of the core enterprise and extended enterprise. 73
Figure 11 - Composition of aircraft Total Ownership Cost (TOC) 85
Figure 12 - DOD budget authority by lifecycle phase over the past two decades 86
Figure 15 - LAI lean enterprise tool triad 126
Figure 16 - Representation of interdependency of LESAT processes 132
Figure 17 - Enterprise Transition to Lean (TTL) Roadmap 134
Figure 18 - Proposed relationships in enterprise process lean maturity, as measured by the LESAT. 141
Figure 20 - Grouping of leading variables in the Enterprise Transition to Lean (TTL) Roadmap 148
Figure 22 - Histograms and 3-D plot of the LSM data at t_1 (n=31). 163
Figure 23 - Plot of data for hypothesis H1: LSM_2 increases with LSM_1 (t_1, n=31). 165
Figure 24 - Plot of data for hypothesis H2: LSM3 increases with LSM1 (t_1, n=31). 166
Figure 25 - Plot of data for hypothesis H3: LSM_2 increases with LSM_3 (t_1, n=31). 167
Figure 26 - Histograms and 3-D plot of the LSM data without outlier (t_1, n=30). 171
Figure 27 - Plot of data for hypothesis H1: LSM_2 increases with LSM_1 (t_1, n=30). 172
Figure 28 - Plot of data for hypothesis H2: LSM_3 increases with LSM_1 (t_1, n=30). 173
Figure 29 - Plot of data for hypothesis H3: LSM_2 increases with LSM_3 (t_1, n=30). 174
Figure 31 - Plots of cross-time differential LSM data (dLSM) according to primary hypotheses (n=6). 180
Figure 32 - Cross-panel LSM data representing the three primary hypotheses (n=6). 182
Figure 33 - Cross-panel correlations for six enterprises reporting LESAT data at t_1 and t_2. 184
Figure 34 - Lean change environment (CE) as a function of leadership commitment (LC) measured at t_1 (n=30). 186
Figure 35 - Lean change in practice (CP) as a function of lean change environment (CE) measured at t_1 (n=30). 186
Figure 37 - Cross-panel correlation analysis of leadership/transformation sub-variables across two time periods (n=6). 189
Figure 38 - Enterprise Transition to Lean (TTL) Roadmap 190
Figure 39 - Average lean practice maturity versus assessment variance (n=1008). 194
Figure 40 - Average lean section maturity versus average variance of lean practice scores in the section (n=57). 195

Figure 41 - Average enterprise maturity versus average of lean practice maturity variances. 195
Figure 42 - Average of lifecycle process and enabling infrastructure practice maturity versus average variance in leadership/transformation practices. 196
Figure 43 - Open loop control. 206
Figure 44 - Dissociated closed-loop control. 207
Figure 45 - Integrated closed-loop control. 208
Figure 46 - Categorization of enterprises based on management information feedback. 210
Figure 47 - Development of leadership commitment (LC) in the lean enterprise transformation information feedback model. 242
Figure 48 - LAI Transition-to-Lean (TTL) Roadmap 244
Figure 49 - Leadership commitment (LC) as the starting point of lean enterprise transformation activities. 245
Figure 50 - Building lean enterprise maturity in lifecycle and enabling infrastructure processes. 247
Figure 51 - Fully integrated closed-loop lean enterprise information feedback transformation model.......248
Figure 52 - Prioritization of lean enterprise improvement areas based on lean maturity and strategic value. 250

List of Tables

Table 1 - Performance measures in the world auto industry 40
Table 2 - Performance measures of Toyota as compared to world automotive market in 1993-1994 41
Table 3 - Characteristics of craft, mass, and lean producers 44
Table 4 - Comparison of Womack and Jones' lean transformation taxonomy to Ohno's pillars of the TPS. 47
Table 5 - Mapping of Ohno's lean philosophies to lean tools and techniques. 49
Table 6 - Documented results from lean transformation efforts in other manufacturing industries 52
Table 7 - Performance improvements accredited to implementing lean principles and practices in work cells 56
Table 8 - Best performance improvements seen in U.S. aerospace production systems as visited by LAI members 57
Table 9 - Performance improvements attributed to applying lean in 24 production cells at Lockheed Martin Aeronautics 58
Table 10 - Lean enterprise process management team structure 69
Table 11 - Difference in realtionships between traditional and lean suppliers 90
Table 12 - Performance improvements at supplier due to coordination with downstream customer........... 92
Table 13 - Major categories of stakeholder value.. 95
Table 14 - Twenty-eight enterprise leadership process practices in the LESAT. 129
Table 15 -Eighteen life cycle process practices in the LESAT. 130

Table 16 -Eight enabling infrastructure process practices in the LESAT. 131
Table 17 - Generic LESAT Capability Maturity Matrix level definitions. 133
Table 18 - Example of lean practice maturity definitions for practice 1.B.3 - Lean Enterprise Vision 134
Table 19 - Three main hypotheses defined in terms of the test statistics. 144
Table 20 - Hypothesis tests using partial correlation coefficients. 145
Table 21 - Hypotheses defined in terms of test statistics at time t_2 145
Table 22 - Hypotheses defined in terms of longitudinal test statistics across $^{\Delta}t$. 146
Table 23 - Cross-time correlation analysis tests. 147
Table 24 - Lean enteprise change variables for testing leadership. 149
Table 25 - Leadership sub-variable correlation analysis at t_1. 150
Table 26 - Test of causal inference in TTL Roadmap as measured by the LESAT at t_1. 151
Table 27 - Hypotheses defined in terms of the correlation test statistics. 164
Table 28 - Results of LSM correaltion anaylsis at t_1 (n=31). 164
Table 29 - Results of LSM partial correaltion anaylsis at t_1. 170
Table 30 - Results of LSM correaltion anaylsis at t_1 (n=30). 176
Table 31 - Results of LSM correaltion anaylsis at t_2 (n=6). 178
Table 32 - Differential LSM data for enterprises reporting second set of LESAT data at t_2 (n=6). 179
Table 33 - Results of dLSM correaltion anaylsis (n=6). 179
Table 34 - Cross-panel correlation results (n=6). 183
Table 35 - Counter hypotheses in cross-panel analysis (n=6). 183
Table 36 - Definition of leadership/transformation sub-variables. 185
Table 37 - Leadership sub-variable correlation analysis test statistics. 185
Table 38 - Leadership/transformation sub-variable correlation analysis at t_1 (n=30). 187
Table 39 - Leadership/transformation sub-variable correlation analysis at t_2 (n=6). 188
Table 40 - Leadership/transformation sub-variable differential correlation analysis (n=6). 188
Table 41 - TTL block correlation analysis at t1 (n=30). 191
Table 42 - Bivariate correlations amongst LESAT leadership/transformation variables aggregated at the LESAT X.X level (aka TTL block level, t_1, n=30). 191
Table 43 - TTL block correlation analysis at t2 (n=6). 192
Table 44 - Bivariate correlations amongst LESAT leadership/transformation variables aggregated at the LESAT X.X level (aka TTL block level, t_2, n=6). 192
Table 45 - Results of correlation analysis between in lean maturity and variance in lean maturity scores. 194
Table 47 - Numerical measure associated with categorization of observed enteprise management control style. 209
Table 48 - Ten lowest-ranking LESAT practices in the industry. 223
Table 49 - Ten highest-ranking LESAT practices in the industry. 226

Nomenclature

6σ	- Six Sigma
AC	- Absorptive Capacity
AIA	- Aerospace Industries Association
AFB	- Air Force Base
AFCAA	- Air Force Cost Analysis Agency
AMRAAM	- Advanced Medium-Range Air-to-Air Missile
AOP	- Annual Operating Plan
ASC	- Aeronautical Systems Center
ATD	- Advanced technology Demonstrator
BCAG	- Boeing Commercial Airplane Group
BPR	- Business Process Reengineering
BVR	- Beyond Visual Range
CI	- Continuous Improvement
CMM	- Capability Maturity Matrix
CVF	- Customer Value Function
DFF	- Design for Flow
DFL	- Design for Lean
DFMA	- Design for Manufacture and Assembly
DOD	- Department of Defense
EI	- Employee Involvement
EQFM	- European Forum for Quality Management
ERP	- Enterprise Resource Planning
FAF	- Fire and Forget
GDP	- Gross Domestic Product
GE	- General Electric
HR	- Human Resources
I	- Inventory
IMVP	- International Motor Vehicle Program
IPPD	- Integrated Product and Process Development
IPT	- Integrated Product Teams
IS	- Information Systems
JDAM	- Joint Direct Attack Munition
JIT	- Just in Time
JSF	- Joint Strike Fighter
LAI	- Lean Aerospace Initiative
LCV	- Life Cycle Value
LEM	- Lean Enterprise Model
LESAT	- Lean Enterprise Self-Assessment Tool
LEAP	- Lean Effects on Aerospace Programs
LP	- LESAT Practice
LMCO	- Lockheed Martin Corporation
LM21	- Lockheed Martin 21st Century (continuous improvement program)
LPM	- Lean Practice Maturity
LSM	- Lean Section Maturity
MIT	- Massachusetts Institute of Technology
N/A, n/a	- Not Applicable
NAICS	- North American Industrial Classification
NAPCS	- North American Product Classification System
NASA	- National Aeronautics and Space Administration

NC	- Numerically Controlled
NG	- Northrop Grumman
NRO	- National Reconnaissance Office
NVA	- Non-Value Added/ing
NVAN	- Non-Value Added but Necessary
OB	- Organizational Behavior
OE	- Operational Effectiveness
OMB	- Office of Management and Budget
O&S	- operations and Support
OSHAct	- Occupational Safety and Health Act
PDCA	- Plan-Do-Check-Act (a.k.a. Deming Cycle, Shewhart Cycle)
P&L	- Profit and Loss
P&W	- Pratt and Whitney
POU	- Point of Use
ppm	- parts per million
R&D	- Research and Development
RDTE	- Research, Development, Test and Evaluation
RFP	- Request for Proposal
RMS	- Root Mean Square
ROI	- Return on Investment
SAC	- Strategic Air Command
SIC	- Standard Industrial Classification
SIGINT	- Signal Intelligence
SMED	- Single Minute Exchange of Dies
SPC	- Statistical Process Control
SPO	- System Program Office
S&P	- Standard and Poors
t_{TK}	- Takt Time
t_C	- Cycle Time
t_T	- Throughput Time
t_L	- Lead Time
t_Q	- Queue Time
TMC	- Toyota Motor Company
TOC	- Total Ownership Cost
TPM	- Total Productive Maintenance
TPS	- Toyota Production System
TQM	- Total Quality Maintenance
TQM	- Total Quality Management
TTL	- Transition to Lean (guide and roadmap)
UCAV	- Unmanned Combat Air Vehicle
UK	- United Kingdom
U.S.	- United States
U.S.A.	- United States of America
U.S.A.F.	- U.S. Air Force
U.S.S.R.	- Union of Soviet Socialist Republics
VA	- Value Added/ing
VBM	- Value Based Management
VSM	- Value Stream Mapping
VSMA	- Value Stream Mapping and Analysis
WIP	- Work in Progress
WWII	- World War II

Chapter 1 - Introduction

1.1. Research Objectives

The current mission of MIT's Lean Aerospace Initiative (LAI) is to research, develop and promulgate knowledge, principles, practices, and tools to enable and accelerate the envisioned transformation of the greater U.S. aerospace enterprise through people and processes. This dissertation has four primary objectives intended to support this mission, namely to:

1. Develop a formal empirical understanding of leadership's role in lean enterprise transformation.
2. Identify important management implications for accelerating lean enterprise transformation.
3. Validate and improve upon LAI enterprise transformation tools, including the Transition to Lean (TTL) Roadmap and Lean Enterprise Self-Assessment Tool (LESAT).
4. Propose new research based on this work.

1.2. Motivation for this Research

During the early 1990's the aerospace industry and the federal defense acquisition environment shifted mindset amidst declining defense spending and rising system acquisition costs and development lead-times. In this changing operating environment the industry experienced a shift from "performance-at-any-cost" programs to "total-system-affordability". Building on the work of MIT's International Motor Vehicle Program (IMVP) which introduced the concepts of "lean" in the *"The Machine That Changed The*

World", the LAI was established in 1993 to work on the application of lean manufacturing principles and practices to the aerospace community.

Since its inception, the LAI has worked to study and deploy lean principles and practices in the aerospace industry through the identification and codification of best practices in the Lean Enterprise Model (LEM), the establishment of an information sharing community and annual conference on the subject matter, and the deployment of lean implementation tools. The LAI has also promoted collaboration by operating as a consortium composed of the U.S. Air Force, government, MIT, labor unions, aerospace businesses, the UK LAI, and more recently other academic institutions as part of the educational network.

Over time, the LAI's thinking about 'value' and 'enterprise' has evolved directly from efforts to apply lean principles and practices in the aerospace industry. While there has been much success in implementing lean principles and practices in production, it appears that a much greater impact can be made by extending lean throughout the enterprise by incorporating lean into the operating, technical, business and administrative elements of aerospace enterprises. The growth of LAI thinking into a multi-stakeholder value perspective extends lean beyond a pure customer focus, and is promulgated in the following definition of the lean enterprise:

> *"A lean enterprise is an integrated entity that efficiently creates value for its multiple stakeholders by employing lean principles and practices"* (Murman et al. 2002, pp.144).

The early years of LAI focused on benchmarking lean best practices and understanding lean in the aerospace context. This work influenced many of the "low-hanging fruit" projects in industry that aimed to improve the poorest performing areas in various production systems. These efforts yielded great local improvements quantified by such metrics as reduced lead-time, reduced inventory, and improved quality. As Figure 2 shows, these efforts began with a focus on reducing waste, and culminated in the development of the Lean Enterprise Model.

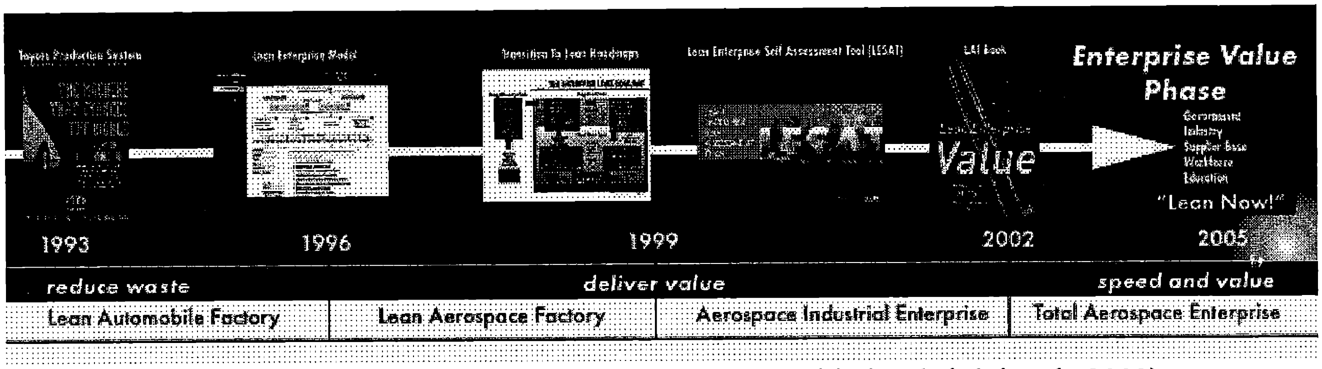


Figure 2 - Research phases of the Lean Aerospace Initiative (Nightingale 2003).

The next phase for LAI concerned itself with performing focused research on specific areas of lean implementation in the aerospace industry. There was a concerted effort to look deeper into the theory behind lean and the application of lean to areas of the enterprise beyond manufacturing, such as product development and the supply chain. This phase saw the beginning of work aimed at the establishing connections between some of the lean areas and ended with the development of the Transition-to-Lean (TTL) roadmap and guide-book for industry to use as a means for organizing their lean transformation efforts.

The third phase of LAI marked the beginning of enterprise research aimed at many of the systems issues associated with creating lean enterprises. This phase also marked the transition to a "value creation" focus in addition to the waste minimization efforts traditionally associated with lean. As this phase progressed it became clear that in addition to the LEM and TTL, a tool was needed to measure the state of leanness of the enterprise. A team from industry, government, and academia (including the UK LAI) jointly developed the Lean Enterprise Self-Assessment Tool (LESAT) as the third element of the LAI tool triad, as shown in Figure 3.

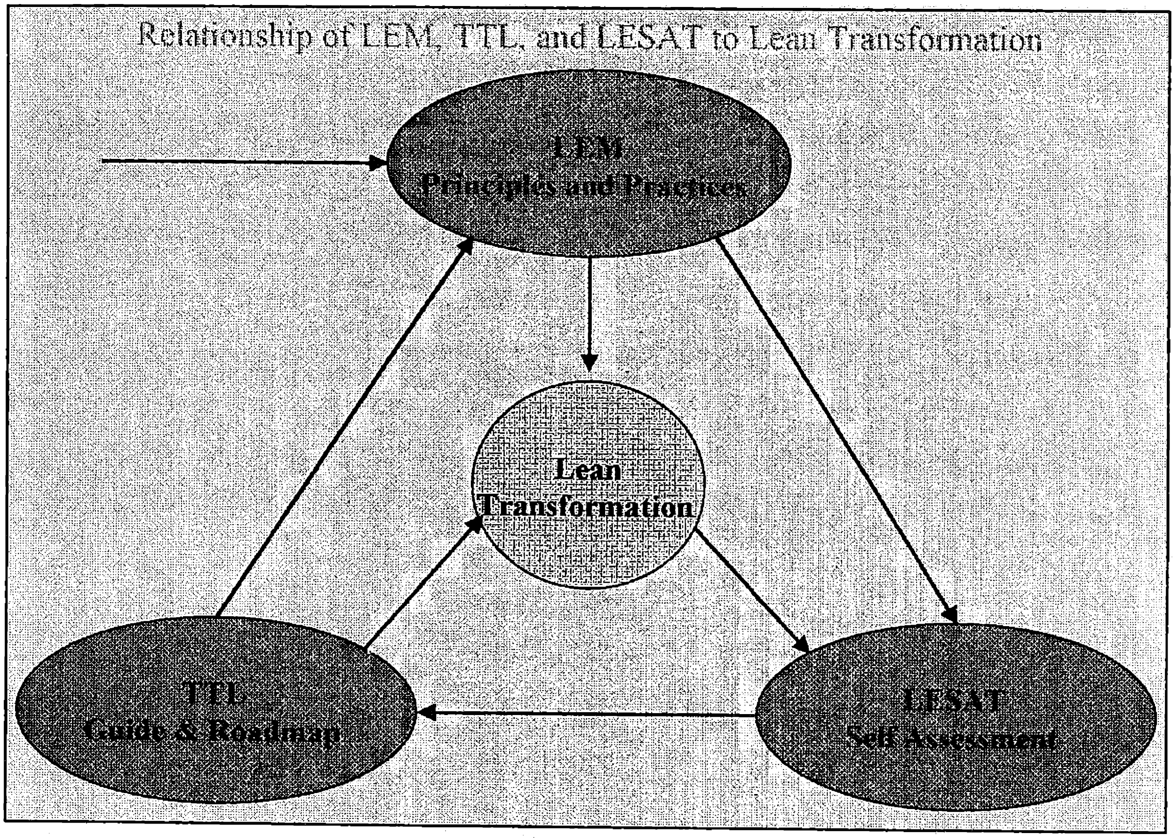


Figure 3 - LAI enterprise tool triad (Nightingale et al. 2001).

This thesis grew out of the third phase of the LAI and was formulated during the time the LESAT was in its Alpha test phase. At the time there was a belief amongst LAI researchers that there were no truly lean enterprises in the aerospace industry, as qualified by the definition promulgated earlier in this chapter. Rather, it was felt that there were enterprises attempting the transformation that were at various stages of maturity in the transformation process. It was felt that a concerted effort was needed to address the topic of lean enterprise transformation from a formal, methodological, and scientific perspective. This approach was intended to provide new insight into lean enterprise transformation and produce new knowledge for industry to use as a means for achieving and accelerating their transformation processes.

Building on the potential data available with the LESAT, this thesis looks at identifying meaningful relationships amongst lean enterprise leadership/transformation practices and enterprise lifecycle and enabling infrastructure practices as leading indicators of lean enterprise transformation. Literature reviewed in this thesis points to the ability of a lean enterprise to outperform a less lean enterprise along multiple stakeholder value metrics. Combined with this knowledge and the necessity to limit the scope of the research, the focus is on the lean enterprise transformation element and not the lagging outcome indicators. Formally, the following three hypotheses are tested:

H1) Enterprises that exhibit a greater value of lean enterprise Transformation and Leadership Process maturity will exhibit a greater value of lean Lifecycle Process maturity

H2) Enterprises that exhibit a greater value of lean enterprise Transformation and Leadership Process maturity will exhibit a greater value of lean Enabling Infrastructure Process maturity

H3) Enterprises that exhibit a greater value of lean Enabling Infrastructure Process maturity will exhibit a greater value of lean Lifecycle Process maturity

It is believed that the establishment of data supporting these hypotheses will help create the imperative for senior leadership support of lean enterprise transformation in the aerospace industry and potentially influence the allocation of scarce resources to key lean transformation efforts. Furthermore, this research identifies potential transformation models and further research questions that can influence the next phase of the LAI which aims to *"do for the rest of the enterprise what lean has done for manufacturing"* (Nightingale 2003).

1.2.1. Fit of Research within TMP

From the perspective of the Technology, Management, and Policy there are many important management and policy deployment issues associated with lean enterprise transformation that are highlighted within this thesis. Some of these issues are addressed in some detail within the text, while others are highlighted as potential issues of interest for further research.

First, it appears that creating a lean enterprise is a choice that must be made by senior enterprise leadership, and will not grow from localized improvement efforts as it requires changing procedures and practices across management boundaries. However, while the top down support and deployment of the lean enterprise approach appears necessary for successful transformation, it is important to remember that all employee behaviors must change to operate the enterprise in a lean manner. This requires education and training, and the deployment of management policy that will create the necessary structure and incentives to enable lean operations. Employees must also be disincentivized from returning to their original non-lean behavior patterns. Furthermore, the lean enterprise is considered an operational strategy that is intended to allow an enterprise to outperform its rivals based on the manner in which it organizes and executes its activities, which is based primarily on employee behaviors. Thus, the potential for imitation will be limited by the ability of a rival to change its behaviors in a similar manner.

Second, the lean enterprise looks beyond the realm of a single function or process, as has been the case with much of the previous work in lean. This perspective looks at multiple functions, processes, programs, and even companies in the extended enterprise as an operating system (or system of systems) that is intended to deliver a product, which is typically a system that must operate over its lifetime within a larger system. This perspective highlights the potential existence of systemic-level wastes within and beyond the enterprise. Internally there are localized decision functions that managers attempt to optimize based on their incentive structures (i.e. reduce costs, increase profits, reduce lead-times, maximize resource utilization, etc.). Many of these local optimization functions are not created with the enterprise's global optimization function in mind. As a result, they often lead to local decisions that decrease overall enterprise value delivery. External to the corporation, the supply chain, customer, end user, and operational maintainer all contribute to the overall lifecycle value of the system being produced. A view of the enterprise as a continuous flow of activities over time identifies wastes and the potential for increased value delivery that would otherwise not exist under traditional economic market forces between each layer of the supply chain. This raises questions about how to structure relationships and contracts for identifying and removing these wastes, and for improving value delivery. This is an interesting area of study, especially when the improvement efforts of an upstream supplier are only realized as gains by a downstream customer or end user at some later point in time. There is a definite potential for study in the area of enterprise-centric decision rules that flow down to local decision points to drive behavior that increases lifecycle value delivery, and the necessary contracting environment for such decision systems when they cross corporate boundaries.

The third area of interest with the enterprise perspective is that it introduces the notion of multiple stakeholder value delivery as a measure of enterprise performance. This is a move from the more traditional financial view of the firm, as it considers the many stakeholders as both delivering and receiving value from the existence of the enterprise. The multi-stakeholder focus considers that market conditions for stakeholder value such as labor, investment capital, and customers makes a pure financial focus a potentially less optimal operating point, as all three need to receive a certain level of value to be willing to participate in the enterprise. The trade-offs and interdependencies present amongst these values raise issues of increased enterprise value delivery and sustainability, especially with the existence of mutually reinforcing value exchange propositions.

Finally, it is of significant interest that the industry is evenly divided between commercial and government customers. The commercial side tends to operate as an open "market" type of economy on a world scale, but also exhibits some oligopolistic characteristics in certain product areas (i.e. heavy lift launch vehicles, large capacity commercial passenger aircraft) where there are only a small number of sellers that supply the entire world market (Lipsey et al. 1991, G-12). The government side of the U.S. aerospace industry is essentially a monopsony, as there is one buyer (the government) who can select from multiple sellers (Lipsey et al. 1991, G-11). Some may argue that the government is not really a monopsony, since it consists of many buyers. However, the purchase of aerospace systems, especially for the DOD, has historically been one in which single acquisition executive offices contract for customized products that were not useable or requested by other government services and/or agencies (i.e. SAC heavy bombers, NRO

SIGINT satellites, etc.). Even in light of recent moves towards the purchase of products that are useable by multiple services (i.e. JSF), the government is essentially issuing a combined contract (i.e. a single source of demand) on behalf of all of the services. In this case there is not open competition amongst the buyers, and as such the market still looks like a monopsony. While not the focus of this thesis, it is also important to realize that the government's involvement in the lifecycle of the aerospace industry is important, as it plays many roles, including system acquirer, system user, and regulator of the purchased system and of the larger system in which it operates. There are a myriad of issues that arise as the lean principles and practices extend throughout the enterprise and extended enterprise, as they often highlight the need for systemic changes. When these systemic changes appear in the realm of the government, the ability to change and improve becomes cloudier as the source of responsibility and authority for change is not always obvious.

1.3. Dissertation Overview

Chapter 2 is intended to provide an introduction to lean, from its inception through to its use in the aerospace industry. The origins of lean manufacturing are traced from the history of the Toyota Production System (TPS). During the late 1980's the term "lean" was coined, yet many of its underlying philosophies and techniques have been in development for almost a century. This chapter explores lean manufacturing and its underlying principles and practices. Evidence of the benefits firms have experienced from going lean is presented, starting with the original studies of Japanese automobile manufacturing. The empirical evidence of firm performance associated with lean manufacturing is then explored in other industries. A discussion of the applicability of lean manufacturing in the aerospace industry ensues, with empirical data showing the successes from the past decade of LAI-associated research efforts in this area.

The lean aerospace enterprise perspective is introduced in Chapter 3. The literature and data discussed in Chapter 2 suggests that there are significant gains to be achieved from implementing lean in aerospace manufacturing. However, the literature also leads one to consider that the enterprise perspective may provide the potential for larger gains from the implementation of lean beyond manufacturing. Furthermore, this enterprise perspective can directly affect and improve the value delivered to multiple enterprise stakeholders above and beyond direct customers. This Chapter explores the formal definition of the lean aerospace enterprise, the lifecycle cost and time imperative for looking beyond manufacturing, and the potential evidence that multiple stakeholder enterprise value exchange is a non-zero sum game.

In Chapter 4 arguments are introduced that support the strategic value of the lean enterprise. The previous chapters introduced the concept of lean, first in manufacturing, and then in the aerospace industry. The data seems to support that leaner companies are able to deliver products and services faster, better, and cheaper than their less lean competitors. This chapter explores the literature surrounding the lean enterprise as a source of a competitive advantage. An overview of strategy in the business context is provided, followed by a discussion of lean as an operational strategy that can lead to competitive advantage. This discussion leads to organizational behavior change as a major factor in creating and maintaining the competitive advantage over some finite period of time. A discussion of both short-term and long-term competitive advantage follows, along with some of the difficulties and issues associated with a lean enterprise operational strategy and the decisions that rest with the senior enterprise leaders for capitalizing on this operational strategy.

Chapter 5 provides the detailed description of the experiment aimed at testing the major hypotheses introduced earlier in this chapter. Sub-hypotheses are also introduced that aim to explore the leadership/transformation variable in greater detail and investigate the validity of the proposed TTL model. Chapter 6 provides an overview of the sample population and the results and analysis of the data. The major hypotheses are not disconfirmed by the data, and the results of interviews are introduced to provide further information about the lean enterprise transformation process.

Chapter 7 provides a summary of the conclusions derived from this research effort. The conclusions are divided into two sections, those derived from the literature and theoretical work, and those derived from the empirical results of the study. Each of the conclusions is followed by a brief discussion of the supporting evidence, a discussion of the implications of the conclusion for industry, and a select few potential research issues associated with the conclusion. The main conclusions of this thesis are as follows:

Conclusions from Literature and Theoretical Work

- Conclusion #1 - A firm with a lean production system has the potential to outperform a firm with a less-lean production system (i.e. mass or craft), as it can deliver greater customer value with equal or fewer resources.
- Conclusion #2 - A lean enterprise has the potential to outperform a firm with only a lean manufacturing function, as it can deliver greater lifecycle value to more enterprise stakeholders with equal or fewer resources.
- Conclusion #3 - The multi-stakeholder focus of the lean enterprise, versus a pure customer focus, is a source of improved enterprise value delivery.
- Conclusion #4 - The lean enterprise is an operational strategy that can lead to competitive advantage.

Conclusions from Empirical Results

- Conclusion #5 - The aerospace industry has yet to create a lean enterprise.
- Conclusion #6 - Observed maturity in some lean enterprise practices can be attributed to other business initiatives familiar to the Aerospace Industry.
- Conclusion # 7 - The transformation to a lean aerospace enterprise can be accelerated by first maturing lean Leadership/Transformation practices. Increasing maturity in lean Leadership/Transformation practices will enable the improvement in lean maturity in Lifecycle Processes and Enabling Infrastructure.
- Conclusion # 8 - Of the lean Leadership/Transformation practices, Leadership Commitment (LC) is necessary for creating a successful lean Change Environment (CE). The creation of a successful lean Change Environment (CE) is then necessary to allow lean Change in Practice (CP) to permeate the enterprise.

- Conclusion # 9 - The Transition to Lean (TTL) Roadmap in its current logical sequencing is a practical and effective means for organizing and prioritizing the lean enterprise transformation process.
- Conclusion #10 - The Lean Enterprise Self-Assessment Tool (LESAT) can be an important part of lean enterprise transformation and management.

Finally, Chapter 8 provides a recommended integrative lean enterprise transformation information feedback model that builds on the TTL and the work contained in this thesis. This thesis highlights many of the issues associated with the lean enterprise and lean enterprise transformation. Furthermore, evidence is presented that suggests there exists a means to formally and logically accelerate lean enterprise transformation by creating leadership commitment and following the TTL, versus following a random-path improvement process. This chapter will present a recommended integrative information feedback model for lean enterprise transformation that builds on the TTL and the work contained in this thesis. Even though this model is derived from research conducted in the aerospace industry, the methodology is considered generic enough to apply to most industries that deliver a product and/or service. The model does remain a proposition, however, and can only be validated with further study as recommended at the end of the chapter.

This thesis does not promulgate the lean enterprise as the answer to all business woes, however, it does promote it as a viable means of conducting business operations. While some worry that this is a "flavor of the month" improvement effort, it was felt worthwhile to end this overview with this recent note from Jim Womack discussing the current state of Toyota that might indicate otherwise (Womack 2003):

> *More than twenty years ago Dan Jones and I made an important discovery. On a trip to Japan we concluded that there was really no "Japan, Inc." or standardized way of doing business. Instead there were many companies pursuing a variety of approaches, some very good and some mediocre. Most important, we concluded that best of the best was Toyota. This company, rather than anything generically "Japanese", became our image of the business system to copy or exceed.*

In the years since we reached this conclusion, we've often wondered what would happen to the lean movement if Toyota faltered. Fortunately, we've never found out because Toyota has marched from victory to victory over the past twenty years while sharing its business system freely with the world.

In the mid-1990s, Toyota set a goal of a 10% market share in the global motor vehicle market by 2000 and in 2000 Toyota's share was 10.01%. Last year Toyota announced a new vision to achieve a global motor vehicle market share of 15% by 2010, which will push Toyota past GM and Ford as the global market share leader. This is not being done at the expense of profits, which have been rising steadily in step with growing market share. In the 2003 fiscal year ended March 31, Toyota will report profits of about $10 billion US on about $125 billion in sales."

Perhaps lean is not the "flavor of the month" but rather the "strategy of the century"? Only time will tell.

Chapter 2 - Defining Lean

The origins of lean manufacturing can be found in the history of the Toyota Production System (TPS). While the term "lean" was coined during the late 1980's, many of its underlying philosophies and techniques have been in development for almost a century. This chapter looks at the origins of lean manufacturing and its underlying principles and practices. Evidence of the benefit to firms from going lean is presented, starting with the original studies of Japanese automobile manufacturing. The empirical evidence of firm performance associated with lean manufacturing is then explored in other industries. A discussion of the applicability of lean manufacturing in the aerospace industry ensues, with empirical data presented from the past decade of LAI-associated research efforts in this area.

2.1. The Meaning of Lean

The literature that forms the basis for the use of the term "lean" in industry originates from the work of the International Motor Vehicle Program (IMVP) at the Massachusetts Institute of Technology (MIT) in benchmarking the state of the world's car manufacturing industry. This work is summarized in "The Machine that Changed the World" (Womack et al. 1990). Some of the research findings in "The Machine" were first documented in a Master's thesis written by John Krafcik at the MIT Sloan School of Management in 1988 entitled "Comparative Analysis of Performance Indicators at World Auto Assembly Plants" (Krafcik 1988).

A review of Krafcik's research reveals cases of superior manufacturing practice in the automobile sector, as observed through a comparative assessment of thirty-eight automobile manufacturers in thirteen countries. Krafcik's thesis promulgates that automobile manufacturers compete on the strength of their product portfolio and manufacturing capability. Further, it is proposed that manufacturing capability characterized by high productivity, high quality, and high product flexibility can lead to competitive advantage. Krafcik's work found that the type of production management policy in use in automobile manufacturers was a significant predictor of manufacturing performance. This result refuted an existing notion that there was a "country" explanation for high performance, since wide performance variations were found in each of the major study areas (Europe, Japan, and North America). The research indicated that corporate culture and ownership were primary reasons for manufacturing plant efficiency. There was also a strong indication that the Toyota Motor Company was doing something entirely different with respect to how it ran its manufacturing business, which resulted in significantly better performance than any of its international competitors.

In Womack et al's work, it was reported that Toyota demonstrated the ability to manufacture cars with one-third of the defects, built in half of the factory space, and using half of the labor hours of its international competitors (Womack et al. 1990). Represented as a resource utilization efficiency ratio of production output divided by input resources, Toyota was achieving a much higher ratio than its international competitors, all the while delivering higher quality vehicles in greater variety, but at lower total volume. Looking at these results, John Krafcik is credited with having anointed such companies with the title of "lean", as it appeared they were "doing more with less" (Womack et al. 1990, pp.13).

When coined, it appears the term "lean" was meant to represent the state of a manufacturing operation based on a comparison of output/input ratios amongst common product producers (in Krafcik's case, automobile manufacturers). However, the fact that one manufacturer has a better ratio than another in itself is not a clear indicator of success, other than potentially for a single point in time. Consider the fact that the numerator of the equation, the output, can be improved by many means, some of which do not necessarily lead to sustainable manufacturing performance (i.e. making employees work faster with fewer breaks, ignoring defects when shipping products, etc.). One could consider a manufacturing company that has made enormous labor cuts in a short-term view of becoming lean, yet actually becomes anemic by eliminating the intellectual capital that creates the potential for future performance or innovation. Thus, the focus on only the lean output/input ratio metric, or the state of the firm, should not lead one to predict the type of sustained automotive manufacturing superiority observed by Krafcik (Krafcik 1988).

Since first being coined, the term "lean" has been promulgated more loosely by consultants, academia, and industry to refer to manufacturing businesses that utilize an underlying set of manufacturing principles and practices that are assumed to lead to a leaner state. In effect, the same term has been used to refer to four aspects of the manufacturing firm, namely the operating philosophy, the tools, the activities, and the state of the manufacturer. Some confusion has crept into the literature on the subject, as people often refer to "lean" manufacturing companies as either those embracing the lean philosophy, those utilizing tools and techniques seen in the TPS, those exhibiting state characteristics that appear to be lean, or some combination of these. The problem with this kind of terminology is that people attempting to adopt the lean manufacturing paradigm may not clearly understand the transformation they are trying to achieve. Do they attempt to emulate the end-state by any means necessary or do they simply mirror the methodologies of "lean" role models and wait for the end-state to emerge? It could be argued that the proper delineation of the terminology should actually contain three terms, one to describe the end state, one to describe the process the achieve the end state, and one to describe the tools used to execute the process. Yet literature on the subject has somehow merged the three terms under the umbrella of a generic term called "lean".

In its literal definition, the term "lean" is an adjective that means *"thin, containing little or no fat"* (AHD_WWW 1996). This then begs the question "what is the fat in non-lean manufacturing systems?" As will be discussed later, this "fat" has been identified as waste in manufacturing systems (Ohno 1988). It is argued that companies that eliminate this fat, or waste, exhibit the characteristics of a lean manufacturer. However, "how to eliminate waste" is the key question one needs to ask in order to understand the process necessary to transform into a lean manufacturer. The researchers studying automotive manufacturing and management identified the underlying principles and practices of what is now called the Toyota Production System (TPS) as the cause of the lean end-state (Krafcik 1988), (Womack et al. 1990). The literature shows that the process employed and the tools used to become a lean manufacturer form an intricate web of activities and organizational behaviors attributable to the TPS. Furthermore, it is reported that the successful execution of the transformation to a lean manufacturer can result in the firm performance observed in the Krafcik studies (Krafcik 1988), (Womack et al. 1990).

The term "lean" in its own right is not readily defined in many publications, but there are many examples of authors defining lean manufacturing or lean production. For example, Baudin sates that lean production is *"the pursuit of concurrent improvement in all measures of manufacturing performance by the elimination of waste through projects that change the physical organization of work on the shop floor, logistics, and production control throughout the supply chain, and the way human effort is applied in both production and support tasks"* (Baudin 1999). While this definition is generic and broad, hinting at the use of some form of the improvement initiative and some set of waste reduction projects, there is little that actually leads one to understand the meaning of "lean". However, the definition does lead one to consider that the application of the "lean" strategy may affect the supply chain and has implications on human resource utilization.

Exploring other definitions in literature we find that Hines and Taylor describe lean as *"A consumer-focused approach to the provision of effective solutions involving the consumption of a minimum of resources"* (Hines and Taylor 2000b). This definition includes an argument about utilizing a minimum of resources while satisfying customer needs. While correct in the assessment of the state of a lean company, it does not define the causality clearly. It is in fact the consumer-focus, or more particularly the focus on delivering value to the customer, that provides a means for reducing resource utilization (Ohno 1988), (Womack and Jones 1996), (Hines and Taylor 2000b). A truly lean manufacturer removes all activities from the production system that do not deliver value to the consumer, resulting in a production system that requires fewer resource inputs to achieve a given unit of output.

This thesis will utilize the term "lean" in the following fashion: A lean firm or enterprise will be one that operates with the Toyota Production System (TPS) philosophy as described in Section 2.2, utilizing the underlying set of TPS-derived lean principles and practices. Specific lean tools and practices will be called by specific names and identified as lean tools and/or lean practices. The process to become lean will be referred to as "lean transformation." Referring to a lean manufacturer, lean production cell, and the like, will indicate that the philosophy of the TPS and some of its tools and practices are being used in the entity described.

The term "lean" as it applies to manufacturing first appears in the literature of the 1990's. Yet the management practices and production philosophy described in these works are based on decades of developments within the Japanese manufacturing sector, resulting in what is now called the "Toyota Production System" (TPS) (Ohno 1988), (Womack et al. 1990), (TMC_WWW 2001). The next section will take a brief look at this history.

2.2. The Historical Roots of Lean in Toyota

The history of lean, as it has been popularized in the management literature of the 1990's, is rooted in the world of the Toyota Motor Company (TMC) and its method of manufacturing cars, which it calls the Toyota Production System (TPS). The current understanding of the origins of lean indicate that it stems from a mix of interacting business pressures, production problems, and operating ideas that have slowly evolved into a philosophy for doing business, as exemplified by the TPS.

Taiichi Ohno calls "Autonomation" and "Just-in-Time" (JIT) the two main pillars of the TPS (Ohno 1988). The first pillar, autonomation, refers to automation with a human touch. While automation simply refers to the mechanization of a process, autonomation implies that human intelligence is somehow transferred to, and imbedded in a machine, activity, or process. The creation of this concept is accredited to Sakichi Toyoda.

In 1888 Sakichi Toyoda studied his grandmother at her loom to understand how the weaving process worked (Ohno 1988). Sakichi felt that the key to making a better loom would be to create one that was both powered and automatic (AIN_WWW 2000). His enthusiasm for this idea led to the development of Japan's first powered loom in 1897 (TMC_WWW 2001). In 1903, Sakichi completed a series of innovations that included a shuttle device that would automatically supply the weft (horizontal) yarn, and a device that automatically stopped the cutting of weft and warp (vertical) yarn (AIN_WWW 2000). All of these developments improved the automation aspect of the loom. The human touch, autonomation, came with the addition of a device that automatically stopped the machine in the event that a warp thread broke or a weft thread ran out (Ohno 1988, pp.77). This mechanized intelligent decision process prevented the production of defective goods.

While simple in concept, the idea of adding decision capability to a machine seemed to have been missed by the creators of mass production systems, whose machines would continue to operate until a post-production inspection process found the defects (Womack et al. 1990). During the inspection process, the mass producer would still be producing defective products until the source of the defect introduction could be found and rectified. Any defective products not identified in inspection would end up in the hands of the customer, resulting in unhappy customers and a potential loss of future sales. Any defects that were found prior to sale would either have to be reworked to meet specification, or scrapped if they could not be reworked. These latter two activities are a pure waste of labor and resources, and increases the overhead costs to the company with no increase in sales. Both result in decreased profitability.

From the stories of Sakichi Toyoda, it is told that he made all of the devices necessary for the automated loom himself and repeatedly tested them (AIN_WWW 2000). In January of 1918, Sakichi Toyoda established the Toyoda Spinning & Weaving Co., Ltd. (TMC_WWW 2001). Sakichi's son, Kiichiro Toyoda, eventual founder of the Toyota Motor Company (TMC), joined his father in 1920, and in 1924, the two completed a flawless automatic loom that implemented all of Sakichi's patents. To start producing the

Toyota Type G auto-activated loom, Sakichi established Toyoda Automatic Loom Works, Ltd. in 1926. The result of the autonomation was a machine that was 15 times more productive than existing looms (AIN_WWW 2000), (TMC_WWW 2001).

The second pillar of the TPS according to Taiichi Ohno is "Just-in-Time" (JIT) (Ohno 1988), (Ohno and Mito 1988b). JIT is defined in manufacturing as the arrival of parts for use in a process at exactly the time they are needed and in exactly the amount they are needed (Ohno and Mito 1988b). In 1910 Sakichi Toyoda visited America at a time when the automobile industry was beginning to take shape and the Ford Model T had been on the market for two years. Upon his return to Japan, he often said that the world was now in the era of the automobile (Ohno 1988). Kiichiro Toyoda was eager to learn the basics of automobile manufacturing from General Motors and Ford, and sought materials from the US manufacturers to compare with those the Japanese could produce. He then looked for ways the Japanese could produce them differently (Ohno 1988). In 1933 an Automobile Department was established within Toyoda Automatic Loom Works to look at producing a car indigenous to Japan (TMC_WWW 2001). Kiichiro Toyoda then announced his plan to develop domestically produced cars for the general public:

> *"We shall learn production techniques from the American method of mass production. But we will not copy it as it is. We shall use our own research and creativity to develop a production method that suits our own country's situation"* (Ohno 1988, pp.91).

Taiichi Ohno felt this was the start of Kiichiro Toyoda's thoughts on JIT. In 1937, the Toyota Motor Co., Ltd. (TMC) was established, by which point the G1 truck and Model AA passenger car had been created (TMC_WWW 2001). The goal with JIT was that each downstream production process would pull parts and material from upstream processes and suppliers when they were needed, in response to an actual order. This would result in matching production to sales, and all but eliminate work in progress (WIP) and inventory (I). Just-in-Time is contrary to the mass manufacturing approach that would produce large batch sizes of all parts and push them downstream to the next activity, irrespective of that activity's need for the parts. The result in mass manufacturing was large amounts of WIP and inventory accruing in the production system, as each activity operated at a different production rate. Accrual of WIP and inventory has several downsides. First, any part sitting on a shelf is money already spent, and is only of value when it is sold to the customer as a part of the final product and revenue is generated for the manufacturer. Large WIP and inventory results in large amounts of capital locked into the system, that could otherwise be used for other investments. Second, parts can get damaged or corrode from sitting around in the production system, leading to a need to scrap or rework the parts, thus adding cost to the system. Third, parts become obsolete if the product undergoes design changes or if the product is discontinued. Finally, there is a potential to produce a significant amount of defective parts, since the inventory acts as a buffer between the activity creating the part and the activity using the part. Since the defects will not be discovered until the part is used, the time required to work through the inventory until the defective parts are discovered can be long, all the while the upstream activity is still producing the defective parts. JIT alleviates these problems as it intends to produce parts at the rate they are needed, theoretically resulting in only the amount of WIP that is necessary to meet sales with no inventory.

While JIT outperforms mass production techniques by avoiding (or at least attempting to minimize) the WIP and inventory issues just described, an even more powerful effect of employing JIT emerged at Toyota - improved quality. The JIT approach required a part to be delivered from activity to activity in single piece flow with no waiting or storage in between. The next activity had to use the part immediately upon receipt, thus any defects that were not identified by autonomation in the previous activity would be immediately identified by the user in the next activity. The source of the defect could then be identified and the problem rectified, resulting in no defects propagating throughout the system. The result was the production of products with far fewer defects.

Taiichi Ohno Joined Toyoda Spinning and Weaving in 1932, shortly after his graduation from Nagoya Technical High School (Ohno 1988). In 1942, Toyoda Spinning and Weaving was in the process of being dissolved and in 1943, Taiichi Ohno was transferred to Toyota Motor Company where he worked on automobiles for the Japanese war effort. For Japan, World War II (WWII) ended on August 15th, 1945, with the declaration of a cease-fire by the Americans a day after an imperial conference accepted the allied terms of surrender (TST 1992). At that point, Kiichiro Toyoda gave his workers the ultimatum to "*Catch up with America in three years. Otherwise, the automobile industry in Japan will not survive*" (Ohno 1988, pp.3). Thinking back to 1937, while at Toyoda Spinning and Weaving, Taiichi Ohno remembered hearing that German workers could produce three times as much as Japanese workers, and American workers could produce nine times as much. The notion of nine Japanese workers being required to produce the same as one American worker made the idea of surpassing the American automobile industry in three years seem impossible. However, Ohno felt that the notion of American workers exerting ten times the physical effort of Japanese workers was impossible. Instead, he felt that the Japanese were wasting something. If he could eliminate this waste, then surely productivity could rise by a factor of ten. Ohno's idea marked the start of his quest to eliminate waste, a fundamental element of the TPS (Ohno 1988, pp.3).

Ohno states that the Toyota production system is fundamentally based on the absolute elimination of waste. By asking "Why is waste generated in the first place?" Ohno contends we are asking why people work and what is the meaning of profit, which is the condition for a business's continued existence (Ohno 1988, pp.18). When thinking about the absolute elimination of waste, Ohno claims the following two points must be kept in mind:

1) Improving efficiency makes sense only when it is tied to cost reduction. To achieve this, only the things needed must be produced, using minimum manpower.
2) Look at the efficiency of each operator and each line, then look at the operators as a group, and then at the efficiency of the entire plant (all lines). The efficiency must be improved at each step and at the same time for the plant as a whole.

Ohno reasoned that if only the activities needed to produce the product is defined as real work, and the rest is defined as waste, then the following equation would hold true whether considering individual workers or an entire production line:

Present capacity = work + waste Equation 1

Following this equation, Ohno describes true or absolute efficiency to be achieved when zero waste is produced and all remaining activities contribute to the production of the product. Furthermore, he states that the complete elimination of these wastes can improve the operating efficiency of the firm by a large margin. Ohno created a taxonomy that defines seven types of waste in manufacturing as (Ohno 1988, pp.20):

- Overproduction
- Waiting
- Transportation
- Processing
- Inventory Storage
- Movement
- Production of defective parts

According to Ohno, any of these activities can be removed from a production system without a loss of product value to the customer, while increasing the productivity and decreasing the expense associated with the production line.

The combination of the two pillars of the TPS, JIT and Autonomation, along with Ohno's quest to eliminate waste, act interdependently to create a new type of production system that ultimately outperformed rival mass manufacturing systems. Autonomation made the production system intelligent so as not to produce defects, which reduced production time, cut rework and scrap costs, reduced the necessary labor per vehicle produced, and delivered a higher quality vehicle to the customer. The quest for the removal of all waste helped remove unnecessary activities from the production system, thus reducing costs and labor required per vehicle, and decreased the lead-time from order to delivery. The establishment of production flow in a Just-in-Time manner, utilizing a series of signaling and tracking tools, reduced the lead-time per vehicle, increased productivity, removed much of the inventory from the system, and helped identify sources of production and quality problems. These problems would then be rectified so as not to occur again. This greatly increased the quality of the vehicles produced and reduced the overhead associated with rework and scrap costs.

The description of what the TPS was intended to do seemed to indicate a much better way of operating. Outcome measures of firm performance would ultimately make the case for lean by validating the TPS. The IMVP program at MIT, discussed earlier in this chapter, collected empirical evidence of disparities in company performance in the world automotive industry. The data showed that there were significant performance differences between the types of manufacturers, with the lean manufacturers concentrated in Japan, and the mass and craft producers in America and Europe. Table 1 shows a summary of the data reported in the work of Womack et al (craft producers are denoted as "specialist").

Performance Measure	**Japanese Auto Manufacturers**	**American Auto Manufacturers**	**European Auto Manufacturers**
Productivity (hrs/vehicle)	16.8 in Japan 21.2 in US	25.1	36.2
Quality (assembled defects/100 cars)	60.0 in Japan 65.0 in US	82.3	97.0
Inventory (days for 8 sample parts)	0.2 in Japan 1.6 in US	2.9	2.0
Engineering hours per new car (million)	1.7	3.1	2.9 volume 3.1 specialist
Development Time per new car (avg. months)	46.2	60.4	57.3 volume 59.9 specialist
Time to return to normal quality after new car introduction (months)	1.4	11	12
Number of products[1] in production (1989)	58	50	30
Annual sales volume per product (1000's)	73	219	18

Table 1 - Performance measures in the world auto industry (summarized from Womack et al. 1990).

[1] Womack et al define a product as "a vehicle selling more than 1000 units in the U.S. market annually that shares no external panels with and has a different wheelbase from any other in the producer's portfolio" (Womack et al. 1990, pp.125).

While some had argued that country differences were the cause of the variability in firm performance (Krafcik 1988), data for Japanese companies in the US also showed marked gains over other American firms. This data, along with Krafcik's work, supported the notion that there was a "management system" explanation as opposed to a "country" explanation for the observed performance heterogeneity. The shining example of success with a different "management system" was with Japan's first automotive producer - Toyota. As Table 2 shows, Japan as a whole outperformed the world automotive producers, yet Toyota outperformed the other Japanese producers as well. Heightened performance was also seen to extend through Toyota's supply chain, which Toyota had been training in its production methodologies since 1965 (Ohno 1988). Even though the country explanation was refuted by Krafcik's work in favor of a "management system" explanation, the underlying historical and socio-economic circumstances of Japan, and the foresight and abilities of a few remarkable individuals, are the main reasons for the development of the lean system at Toyota (Ohno 1988), (Womack et al. 1990), (Murman et al. 2002).

	Toyota (in Japan)	**Japan (Average)**	**USA (Average)**	**Europe (Average)**
Productivity Index (Toyota = 100)				
Assembly	100	83	65	54
1st-tier suppliers	100	85	71	62
Quality[1] (# delivered defects)				
Assembly defects (per 100 cars)	30	55	61	61
1st-tier suppliers (ppm)	5	193	263	1373
2nd-tier suppliers (ppm)	400	900	6100	4723
Deliveries (% late)				
1st-tier suppliers	0.04	0.2	0.6	1.9
2nd-tier suppliers	0.5	2.6	13.4	5.4
Stocks (1st-tier suppliers)				
Hours	n/a	37	135	138
Stock Turns per year	**248**	**81**	**69**	**45**

Table 2 - Performance measures of Toyota as compared to world automotive market in 1993-1994 (recreated with modifications from Table 10.1 in Womack and Jones 1996, pp.239).

The data presented in Table 1 and Table 2 highlighting the performance differences between lean production and non-lean production is striking for four major reasons. First, the Japanese firms, and Toyota in particular, significantly outperformed the other firms in terms of productivity, quality, cost (taking reduced engineering hours in development as a measure of cost reduction), and time for new designs. These results led to better customer satisfaction and increased profitability, all else being equal, in comparison to the mass (and craft) manufacturing methods of Toyota's international competitors.

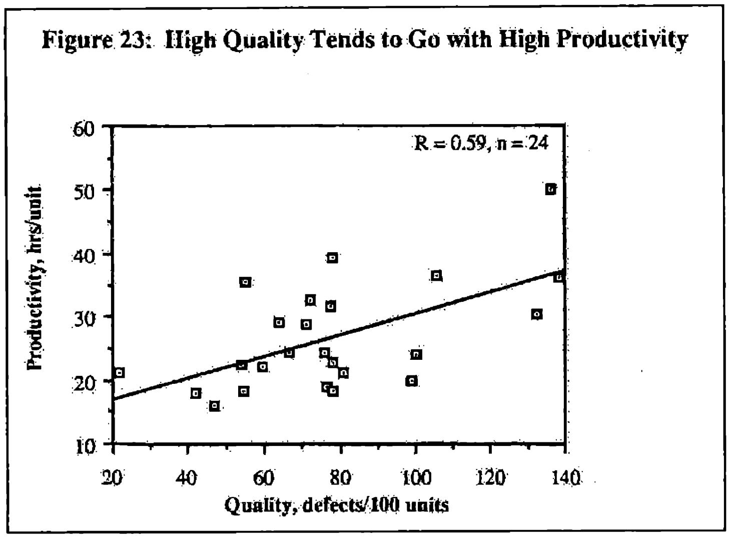


Figure 4 - Correlation of quality and productivity in the world automotive industry (Krafcik 1988, pp.19).

Second, the Japanese firms exhibited both increased quality and increased productivity, a characteristic elusive to many of the mass manufacturers that often sacrificed quality to increase output in response to market demand (Reid 1990). Some manufacturers had historically argued that higher quality would decrease productivity (Reid 1990), yet the IMVP research seemed to show the opposite. Figure 4 is a plot of the raw data for 24 companies that Krafcik studied, which shows a moderate to strong correlation between quality and productivity. Note that by Krafcik's choice of axes, the better performing firms are in the lower left hand corner of the graph while the poorer performers are in the upper right hand corner of the graph.

The third point of interest is that the work of Toyota, in teaching and extending its operating practices to its supply chain partners, appears to have resulted in a win-win situation. The high-level of performance seen at Toyota is also exhibited in its supply-chain partners, as compared to other producers' suppliers. These observations suggested that the operating philosophy of the TPS, when applied beyond the corporate boundaries of a single member of the supply-chain, can have systemic effects that improve the performance of all supply chain members. The TPS supply-chain operating philosophy was in stark contrast to many mass manufacturing firms that used their buyer power to extract cost savings from their suppliers, or in some instances, create a local lean operation by pushing all inventory costs to the upstream suppliers (Stallkamp 2001).

Finally, the fourth element that is surprising from the IMVP data is that the performance of the Japanese firms was achieved while delivering greater product variety in fewer numbers than other producers. An ability to perform in this manner is counter to the mass manufacturing mentality that assumes greater productivity is attainable with larger and longer production runs. The capabilities of the TPS-style production led to the Japanese capturing a third of the world automotive market by the 1980's, as shown in Figure 5. Market circumstances beyond the control of the world's automotive manufacturers, such as the oil crisis of the 1970's that had small Japanese cars better positioned against the gas guzzling American vehicles of the era, also contributed to this change in market share.

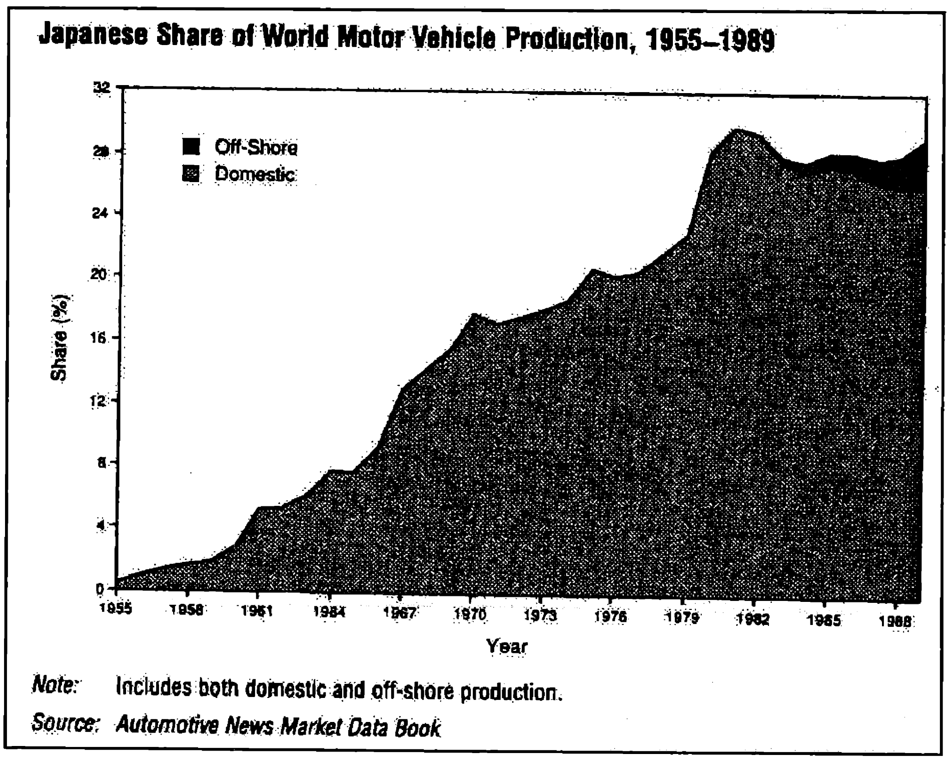


Figure 5 - Japanese share of world automotive production from 1955 to 1989 (Womack et al 1990, pp.69).

Ultimately, the work of the IMVP helped identify the existence of a new type of production system that was neither craft production nor mass production in nature. Table 3 highlights the main differences between these three types of systems. A discussion of the first two types of production systems within the context of the automobile industry is presented in "The Machine that Changed the World" for those who wish to learn more about the other two systems (Womack et al. 1990).

	Craft Production	Mass Production[2]	Lean Production
Focus	Task	Product	Customer
Operations	Single item	Batch and queue	Synchronized material flow with customer demand
Overall Aim	Mastery of Craft	Reduce cost and increase efficiency	Waste elimination and value creation
Quality	Integration (part of the craft)	Inspection (additional step after production)	Prevention (designed into products and built into systems)
Business Strategy	Customization	Economies of scale and automation	Flexibility and adaptability efficiently utilizing resources
Improvement Efforts	Master-driven	Expert-driven periodic improvement	Workforce-driven continuous improvement

Table 3 - Characteristics of craft, mass, and lean producers (Murman et al. 2002, pp.97).

2.2.1. The Tenets of Lean

From the perspective of Toyota, lean is a way of operating, using the philosophies of JIT, Autonomation, and Waste Elimination, all within an organization that promotes employee involvement (EI). A collection of tools and techniques are required to make the system work, but adopted and applied individually are not sufficient for becoming a lean manufacturer. In fact, Ohno claims that the current tools of lean are a stopgap measure

---

2 Within the U.S. it is notable that mass production did not start with Henry ford, but was actually started over a century earlier by Eli Whitney. Whitney developed a system for manufacturing muskets which would permit an unskilled laborer to turn out a product that would be just as good as one made by a highly trained machinist by using standardized parts and processes (EWM_WWW 2002). This idea would form the core of Ford's mass production system.

until the system operates perfectly, and will either evolve into new tools over time, or will be eliminated completely as the system approaches perfection. Understanding this aspect of lean was a sticking point for many early lean transformation efforts outside of Toyota, where the adopters thought the tool was the key. In these cases, the tools were adopted and implemented without addressing the need to change operating patterns and behaviors. In the worst of these cases, the manufacturer claimed to be lean because they had done a one time event and used a lean tool, but ultimately never experienced any of the gains attributable to lean, as the philosophy of the TPS was never adopted (Koenigsaecker 2003b).

In their 1996 publication "Lean Thinking", Womack and Jones attempt to classify the transition to being a lean manufacturer as a series of five steps (Womack and Jones 1996), namely:

- Step 1 - Specify customer value by product
- Step 2 - Identify the value stream for each product
- Step 3 - Make the value flow without interruption
- Step 4 - Let the customer pull the value from the producer
- Step 5 - Pursue perfection

The first four steps are designed to progress sequentially in order to transition to a lean manufacturer. The final step is intended as a reminder that the process of transitioning to lean should never end, and that the steps can be repeated to gain further improvements, with perfection as the ultimate (albeit unattainable) goal.

Specifying customer *value* is the first step in the process. Womack and Jones claim that value can only be defined by the customer (Womack and Jones 1996, pp.16). By their definition, value is created by the producer in the eyes of the customer, and is only meaningful when expressed for a specific product or service at a given price and time. According to Womack and Jones, it is up to the producer to work with customers to consciously define the value metrics in terms of specific products with specific capabilities offered at specific prices (Womack and Jones 1996, pp.19).

The next step Womack and Jones propose is the identification of the *value stream.* The value stream is defined as the set of all actions required to bring a specific product from concept through design (problem-solving task), order-taking to delivery (information management task), and from raw input material or goods to final output product (physical transformation task) (Womack and Jones 1996, pp.19). In their view, the entire value stream must be mapped, even up and down the supply chain, to understand what activities are involved in delivering value to a customer. The activities in the value stream are then classified as either value adding (VA), or non-value adding (NVA), according to the definition of customer value developed in the first step. The end objective of this step is a process improvement effort aimed at eliminating the activities that are non-value adding. This effort will result in greater productivity, less expense, and shorter product lead times, as no resources will be committed to non-value adding activities.

The third step, creating *flow*, is a major step in becoming a lean manufacturer. The idea is to make the remaining value-adding activities operate as a seamless sequence that has eliminated all batch-production. The intended result is single-piece product motion through the value stream. Suffice it to say, it is an incredibly dramatic change from the mass-production mentality of many U.S. companies, as Womack and Jones forewarn *"please be warned that this step requires a complete rearrangement of your mental furniture"* (Womack and Jones 1996, pp.21). Ultimately this type of production system will operate with single-piece-flow and utilize just-in-time (JIT) parts delivery. This step eliminates most of the firm's inventory and WIP, thus releasing previously unavailable working capital, and significantly reduces the lead-time for producing products. It also has the benefit of identifying sources of defect introduction in the production system, and thus helps improve quality.

The fourth step, establishing *pull,* is intended to capitalize on the gains achieved from creating flow. With reduced lead-times, the lean-producer is in a better position to produce and deliver to customer demand, rather than producing to forecast and pushing inventory onto the customer (Womack and Jones 1996, pp.24). This step also involves attempting to work with customers to understand their true demand. Pull is extremely important for producers further up the supply chain, as they are susceptible to demand amplification that can result in their production being significantly higher or lower than the true market demand for their products, otherwise known as the "bullwhip" effect (Sterman 2000). Communication with the customer and linking the supply chain into true customer demand are major parts of creating flow, and depend heavily on effective information exchange.

Perfection, the fifth step, is considered the end goal one attempts to pursue en route to transforming into a lean manufacturer. Pursuing perfection involves continuously revisiting the first four steps, and utilizing the tools and techniques associated with them, to create a system that delivers more and more value with less and less waste. The most important aspect of this step is the realization that becoming lean is not a one-time set of events or analyses. It is a continuous process of systemic change and improvement activities that are intended to be the modus operandi of the organization.

Womack and Jones Characterization of Lean Transformation	Ohno's Description of the Pillars of Lean
Step 1 - Specify Value Step 2 - Eliminate Waste	Waste elimination (of which autonomation is a part)
Step 3-Make Value Flow Step 4- Pull value	Just-in-Time production and delivery
Step 5- Pursue Perfection	Continuous improvement in the right organizational environment

Table 4 - Comparison of Womack and Jones' lean transformation taxonomy to Ohno's pillars of the TPS.

Upon reflection, one can see how Womack and Jones' lean transformation classification system maps to Ohno's writings about the pillars of the TPS, as shown in Table 4. Table 5 further expands Ohno's pillars of lean into the tools utilized to implement and operate in a lean manner. The first two steps identified by Womack and Jones deal with Ohno's quest for waste elimination. The third and fourth steps deal with JIT. Finally, the fifth step deals with a continuous improvement cycle. However, Ohno goes one step further than

Womack and Jones' statement that continuous improvement is needed in pursuit of perfection. Ohno discusses at great length how an organization needs to operate and behave in a manner that embraces the lean philosophy and continues to implement and use its tools and techniques in an evolving manner (Ohno 1988), (Ohno and Mito 1988).

Ohno's Pillars of Lean	Tools to Become Lean	
	Name	**Function**
Waste Elimination		
	7 Wastes	Identify the activities to remove from the system
	5S	Clean environment to avoid waste
	SPC	Avoid out of tolerance production
	Autonomation	Avoid producing defects
	Baka Yoke, Poka-yoke	Avoid introducing production errors
	Use Good Equipment	Avoid introducing production defects
JIT		
	Kanban	Trigger mechanism for flow and pull
	Point of Use (POU) delivery	Introduces parts when and where needed, no overhead for receiving, handling, storage, etc
	Andon	Warn of pending problems in the system
	SMED	Allows quick changeover for multiple products to be made on same machine and/or in same line
	Multi-machine operation	Distribute labor across multiple machines
	Workload leveling	Single piece flow
	Work standardization	Workload leveling, allows scientific improvement
	Right sized equipment	Single piece flow
	Mixed Production	Multiple products on same line
	Load Chart	Matches mixed production to mixed demand, reducing inventory, WIP build-up, and lead-time
	Supermarket	Fills in the gap where flow must stop
	Demand Leveling	Eliminate large fluctuations in production demand
	TPM	Keep the system operating normally
Continuous Improvement in the Right Organizational Environment	Kaizen	Structured improvement event
	Solve problems at lowest point in organization	Use all intelligence in organization, things get fixed faster, distributed decision making
	Employee Involvement	All brains are better than one, make employees feel more valuable, use their knowledge
	Teamwork	Working together solves problems
	Management by Ninjitsu	Employees coached by management
	Stand on shop floor	See how things actually work, change not dictated from an office
	kaikaku	Radical improvement, a.k.a. breakthrough kaizen
	Cross-training	Employees have wider assortment of skills and daily activities, increase job satisfaction
	Scientific Improvement	All improvements must be run like an experiment with metrics for success established *a priori*
	5 Why's	Root cause analysis of problems

Table 5 - Mapping of Ohno's lean philosophies to lean tools and techniques.

2.3. Evidence of Success with Lean Manufacturing Outside of the Automotive Industry

From the data presented earlier in this chapter, it is evident that Toyota has outperformed its mass manufacturing competitors in the automotive business as a result of its methods of operation (i.e. lean, TPS). The logical question to ask next is "does lean apply to other industries, or is it an automotive and/or Toyota-specific anomaly?" The following section will look at the application of lean in other manufacturing sectors.

2.3.1. Lean in Other Manufacturing Industries

The discussion of lean philosophies, practices, and tools sounds impressive in the automotive world, however a measure of its generalizability as a new operating model is its application and success in other industries. Womack and Jones claim that as a rule of thumb, lean improvements in any manufacturing industry can do the following (Womack and Jones 1996, pp.27):

- Increase productivity 200%
- Reduce production throughput time 90%
- Reduce inventories 90%
- Reduce defects to customers 50%
- Reduce scrap and rework 50%
- Reduce job-related injuries 50%
- Reduce time-to-market for new products 50%

Additionally, they claim that lean companies in any industry can produce a larger variety of products using product families with only a marginal cost increase, and the capital investment needed will be modest to negative if freed-up space and equipment are sold. Finally, they contend that continuous efforts at improvement over a two to three year period using additional kaikaku and kaizen events will lead to another doubling of productivity, and a halving of inventories and lead-times. Koenigsaecker presents data that supports this continuous improvement effect from his experience leading the transformation of Jake Brake into a lean manufacturer (Koenigsaecker 2001). For example, Figure 6 shows the improvements achieved in reducing the number of activities and lead-time in a process after multiple kaizen events.

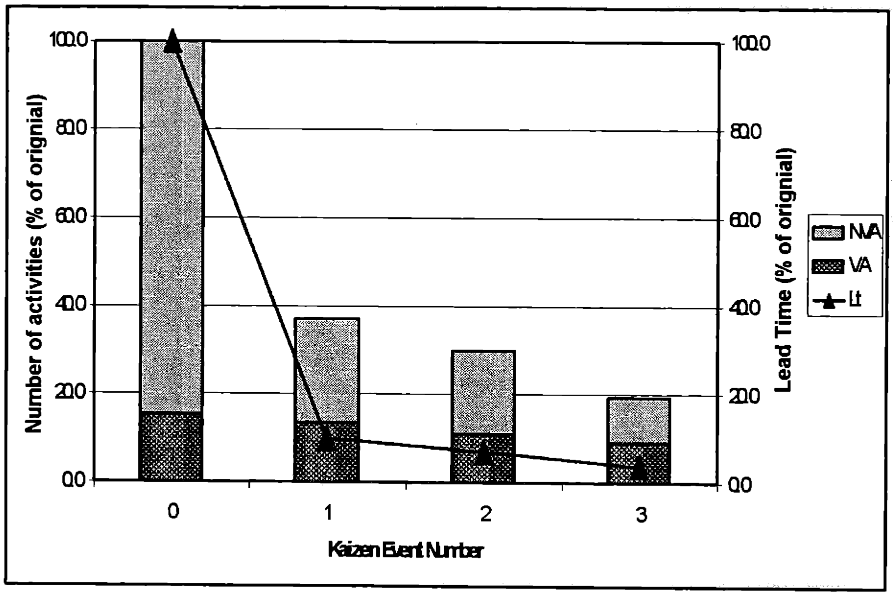


Figure 6 - Activity reduction and lead time improvement from Kaizen event lean transformation (created from data in Koenigsaecker 2001, pp.17).

A quick survey of existing case studies on lean improvement initiatives shows that the efforts do return significant results, albeit with varying degrees of success and impact. Table 6 highlights the results of documented lean change efforts in a number of companies. The efforts are characterized by varying levels of product complexity (from simple part to large assembly), different time scales (from months to years), and varying organizational scopes (from manufacturing cells to complete product lines).

In all of the improvement cases the results were positive, showing some form of improvement in productivity, quality, and/or lead-time. All else being equal, the results of these changes should manifest themselves in increased customer satisfaction and better financial performance for the firm. This data, along with other studies in the area of lean improvements, suggest that the lean philosophies underlying the TPS that resulted in the performance improvements exhibited in the automotive industry are applicable and can be successful in other industries. But does this make sense? A look at some of the math underlying these results helps shed some light on why there are performance differences between lean firms and non-lean firms, as explained in Appendix A. The relationships discussed in Appendix A highlight the fact that achieving higher quality leads to less costly operations and better lead-time. While achieving higher quality might cause some short-term disruptions in the production system, the end result is better performance than a firm that does not make the improvement efforts.

Product	Description	Time (years)	Productivity Change	Lead Time Change	Inventory Change	Quality Change	Financial Return
1	Gasket and seals), (Womack et al, 1996, pp.91)	3	+991%				
2	Chain Products (Feld, 2001, pp.172)	1/3		-63%			
3	Wood pedestal (Czarnecki, 2001)	1	+33%	-8%			
4	Turbine Blades and Guides (Womack et al, 1996, pp.179)	3		-99.5%	-99%		
5	Truck Brake Kits (Koenigsaecker, 2001)	3	+86%	-75%	-80%	+80%	Sales +190%, EBITDA at 30% from 13% after 11 years
6	Window and Door assemblies (Siekman, 2000)	7		-60%	-71%		
7	Uninterruptable Power Supplies (Feld, 2001, pp.151)	1	+15%	-24% to -54%	-41%		
8	Plastic Wrapping Equipment (Womack et al, 1996, pp.121)	4	+100%	-75% to -80%	-27%	+90%	
9	Turbo charger and parts (Darlington, 1999)	4	+202%				
10	Water Jet and Industrial Parts Cleaning Systems			-90%		+80%	Cost reduction of 18.4%, 416% ROI
11	Motorcycles (Reid, 1990)	7	+50%		-75%	+68%	US Revenue +80% Int'l Revenue +177% US Market Share +97%
12	Sports car (Womack et al, 1996, pp.213)	6	+37% +62% pdc	-93%	-81%	+99% s +75% p	

Table 6 - Documented results from lean transformation efforts in other manufacturing industries (pdc = post design change, s = supplied, p = produced).

2.4. Lean Manufacturing in the Aerospace Industry

Up to this point, Chapter 2 has introduced the foundations of the Toyota Production System as the reason for the success of Toyota in the world automobile industry. It is also apparent that the principles and practices of the TPS are transferable to other manufacturing industries producing everything from simple gaskets, to electronics, to high performance automobiles in niche markets. Furthermore, these improvements occurred in manufacturers that had once relied on a mix of mass and/or craft production techniques. The question for this chapter remains, "does lean work in the aerospace industry?" The reader might wonder why this question is important. A brief look back at the early 1990's and the state of the aerospace industry will answer this question.

The cold war, a time spanning the end of WWII to the early 1990's, was a time of immense investment in the U.S. military-industrial complex (Murman et al. 2000). The aerospace professionals and military leaders who were educated and worked during this time period experienced an environment of immense government investment in research and development (R&D). While the commercial aerospace market was growing during this time, the government investment was aimed at the development of aerospace technologies and systems that would ensure the United States' capabilities were superior to those of its sworn enemy on the geopolitical landscape, the U.S.S.R. The cold war period was celebrated as a time of incredible technological achievements, including commercial jet transportation, supersonic flight, instantaneous global satellite communications, human space-flight, and the robotic exploration of the solar system (McDougal 1997), (Hughes 1998), (Murman et al. 2000). The emphasis in aerospace during the cold war was primarily on performance at any cost.

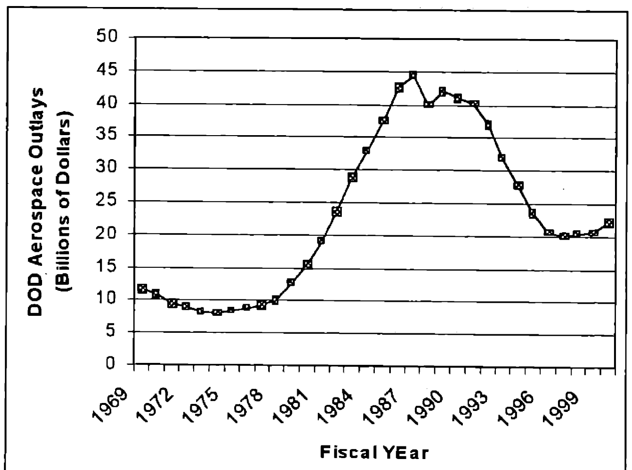


Figure 7 - DOD outlays for aerospace products and services (AIA 2001).

As the 1990's dawned on the U.S. aerospace industry, the world's geopolitical environment was changing drastically. With the dissolution of the U.S.S.R., the cold war was declared over in 1991 (GME 1997). Suddenly, the imperative for Department of Defense (DOD) spending on ultra-high performance projects seemed to be vanishing, and total system affordability seemed to be growing in the minds of the acquisition community. Figure 7 shows the sharp decrease in DOD outlays for aerospace systems in the early 1990's.

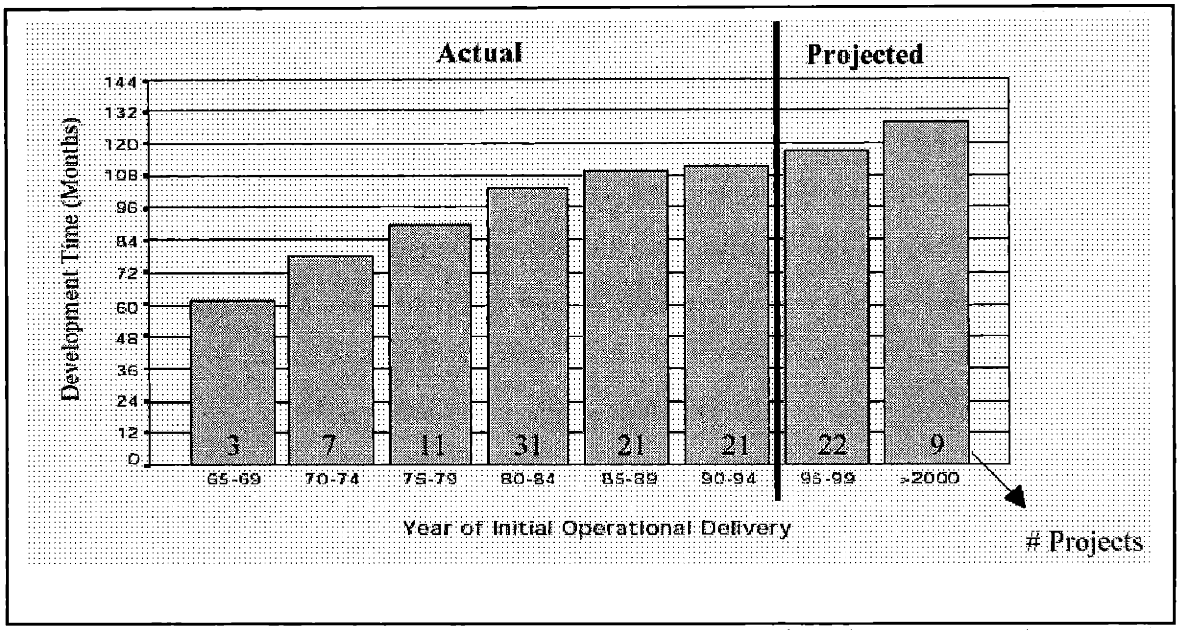


Figure 8 - Trends in DOD program development time (McNutt 1998).

In a time of decreasing spending, the lead-time and cost of defense systems were rising. Figure 8 shows the average lead-time to field new DOD systems as reported by McNutt (McNutt 1998). This data shows that during the cold war the development time until first operational delivery increased by approximately 80% over a period of thirty years. Murman et al note that some may argue increasing system complexity may be the cause for increasing delivery lead-time (Murman et al. 2000). However, commercial systems in some instances were being developed in less time even in an environment of increasing product complexity. For example, the Boeing 777 was fielded in five years, from launch in 1990, until delivery and operation in 1995 (Boeing_WWW 2003). Murman et al suggest that besides complexity, other inefficiencies in the acquisition, design, engineering, and manufacturing processes spawned in the cold-war operating environment have led to the poor performance of contractors on delivering aerospace defense systems (Murman et al. 2000).

The post cold war defense spending cuts were compounded by a stagnant commercial market in the aerospace industry. These cuts resulted in a very depressed business market for the industry (Murman et al. 2002, pp.xiv). The industry was at a crossroad that required it to look at its business models and practices and question its future as a significant employer and contributor to the U.S. balance of trade.

In 1992, Lt. General Thomas R. Ferguson Jr. was the commander of the Air Force's Aeronautical Systems Center (ASC) at Wright Patterson Air Force Base (AFB). At that time, the ASC was responsible for acquisition of all aircraft systems. Having just read *"The Machine that Changed the World"* (Womack et al. 1990), and confronted with rising costs in a time when budgets were being drastically reduced, the Lt. General explored the idea of applying the concepts uncovered in the IMVP study to the defense aerospace business (Murman et al. 2002, pp.xv). A quick overview study was undertaken in 1992, and the results indicated that the aerospace industry was essentially a craft industry with a mass production mindset (Murman et al. 2002). Acting on these results, MIT and a consortium of aerospace companies, in partnership with the U.S. Air Force (USAF) and other government agencies, established the Lean Aircraft Initiative in 1993. The research group defined a charter:

> *"to help bring about fundamental change in both industry and government operations in defense aerospace in order to achieve greater affordability of systems, increased efficiency, higher quality, enhanced technological superiority, and a stronger US defense industrial base."*

This charter was later expanded to include *"enhancing the effectiveness of the national workforce"*, and with the addition of the space sector of the industry into the consortium in 1998, the name was changed to the Lean Aerospace Initiative (Murman et al. 2002). With an imperative for change, the industry attempted to work towards the introduction of lean in aerospace manufacturing.

2.4.1. Success with Lean Manufacturing in the Aerospace Industry

Through the 1990's, there was a concerted effort to introduce lean manufacturing in the aerospace industry. A review of reports and research on the lean implementation and transformation efforts reveals some of the outcomes that were achieved, as will be discussed in the following section.

A Rand report covering the issue of future aircraft cost estimation models was undertaken for the Assistant Secretary of the Air Force (Acquisition), as part of Project Air Force's Resource Management Program. The report was tasked with determining whether current cost estimating tools for new aircraft could be adjusted to account for current lean production impacts (Cook and Graser 2001). Data from this study showed that for a sample of 20 production cells, there seemed to be quantifiable improvements in each of the performance measures as shown in Table 7 (Cook and Graser 2001, pp.77).

Performance Measure	Average Improvement	Minimum	Maximum
Direct Labor Hours	36%	5%	85%
Cycle Time	44%	13%	93%
Floor Space	24%	0%	61%
Part Travel Distance	61%	25%	95%
Worker Travel Distance	55%	23%	94%

Table 7 - Performance improvements accredited to implementing lean principles and practices in work cells (Cook and Graser 2001, pp.77).

Cook and Graser, the authors of the report, noted that the data tended to show an inverse relationship between the size of the effort and the percentage savings achieved (i.e. smaller pilot projects tended to get much larger improvement percentages). Furthermore, they pointed out that two potential selection biases may have affected their sample. First, only companies achieving significant results may have been responding to the study, as there is a tendency to report successes rather than failures. Second, companies may have selected their least efficient cells to improve first. The literature refers to these cases as the "low-hanging-fruit". This would result in much more impressive improvement gains than would have been seen with improvement efforts in already efficient cells (Cook and

Graser 2001, pp.78). These biases notwithstanding, Cook and Graser do believe the results indicate that incorporating the principles and tools of lean manufacturing has the potential to reduce costs in aircraft production (Cook and Graser 2001, pp.79).

The LAI *"Evidence of Site Visits Interim Report"* (Cantrell et al. 1999) claimed that the companies participating in the site visits had, to some extent or another, shown performance improvements in various elements of their production system due to the use of lean principles and practices. The interesting aspect was that while they all had shining examples of success, that success did not cover all facets of the production system, nor did the success manifest itself in all of the performance criteria. Localized successes were apparent, but none that represented the whole production system. The report stated that a company exhibiting all of the best performance improvements seen in the industry could produce an aircraft or missile with a lead-time of less than a year and with half the current production costs. The best results seen in the study are shown in Table 8.

Production Performance Measure	Best Improvement
Assembly touch hours	49%
Non-conformance costs	70%
Assembly support labor	80%
Inventory	80%
Assembly Cycle Time	47%
Engineering Changes	60%
Fabrications costs	50%
Part lead-time	69%
DPMO	90%

Table 8 - Best performance improvements seen in U.S. aerospace production systems as visited by LAI members (Cantrell et al. 1999, pp.2).

In a presentation entitled *"From Lean Production to Lean Enterprises...a Key to Operating Performance"*, Bill Kessler reported on some of the results associated with Lockheed Martin (LMCO) Aeronautics' efforts at introducing lean manufacturing (Kessler 2001). Amidst the hundreds of improvement efforts claimed to have been undertaken at LMCO, the presentation provided a review of lean efforts in 24 production cells, the outcomes of which have been summarized in Table 9. The transformation included utilizing tools and techniques to improve flow and eliminate waste. Some of the tools and techniques utilized included parts kitting, seamless information flow, flexible modular tooling, design for manufacture and assembly (DFMA), and five-S to name a few. The data shows significant improvements as a result of the lean transformation initiatives. The return from these efforts was estimated to be an average of a four to one (4:1) return on investment (ROI), and some may have been as high as thirty to one (30:1) (Kessler 2001, pp.8).

Production Performance Measure	Improvement
Actual Hours	36% - 47%
Throughput Time	79%
WIP	68%
Space Requirements	56%
Parts Travel Distance	79%
Defects	50%

Table 9 - Performance improvements attributed to applying lean in 24 production cells at Lockheed Martin Aeronautics (Kessler 2001, pp.9).

While this summary data is interesting, a look at some of the specific cases provides some insight to the scale and scope of some of the lean transformation efforts in the aerospace industry and the results they have achieved.

In the late 1980's, the C-130J Hercules was the newest generation upgrade to the Hercules family of tactical airlifters which had been in production since the 1950's. The extrusion manufacturing shop at Lockheed Martin performed sawing, milling, routing, sanding, and deburring operations on standard extrusion stock for some 20 000 part numbers, many of which were for the C-130J. With efforts to bring lean into the factory, the shop had been redesigned into a "focused factory" by 1994, by grouping products into various sizes of extrusions and matching management authority, control, and facilities to the production of specific types of products. Using a random access delivery system for components and tooling, and a nightly scheduling system, the focused-factory approach led to an 83% reduction in throughput time and a 94% reduction in WIP (Murman et al. 2002, pp.119). In 1997, the operation was transformed into a one-piece-flow environment whereby the parts traveled through the production activities uninterrupted until the part was completed. The result was a production system that reduced throughput a further 99.98% and reduced WIP nearly 100% from its already improved levels achieved in the focused factory effort.

While piece part improvements worked for Lockheed, Boeing demonstrated an ability to affect significant performance improvements on entire assemblies. Boeing's Commercial Airplane Group (BCAG) in Wichita, Kansas, worked on improving the delivery of the 737 fuselage. Between 1996-2001, BCAG Wichita provided lean basics training to 80%-90% of the personnel in the division, trained 100% of its first-wave change agents in the Lean Production Systems Academy, and trained 100% of the management team in Standard Operations (Ferdowsi 2002). A concerted effort was made to implement nine lean tactics, including value stream mapping and analysis (VSMA), line balancing, standardized work, visual controls, point of use staging, feeder/supply chain lines, process redesign, conversion to a pulse line, and conversion to a moving line (Blake 2002). The end result was that the fuselage unit cost was reduced 25% (which they expected to improve even further) and labor hours per unit were down 50% (Shah and Davidz 2002).

The lean efforts at Raytheon, which are now under the umbrella of their Six Sigma program, were applied to a complete flight system, the AIM-120 Advanced Medium-Range Air-to-Air Missile (AMRAAM). The AIM-120 AMRAAM is an active radar-guided air-to-air missile that allows an aircraft to launch multiple missiles at multiple targets from beyond visual range (BVR) in any weather in a fire-and-forget (FAF) mode (Davidz 2002). The AMRAAM program is a heritage system dating back to the 1970's and has gone through multiple design variants to reach its current state. It also had been extensively value engineered by the time Raytheon absorbed the former Hughes facility in Tucson Arizona and consolidated all AMRAAM production to the site. The AMRAAM team used a mix of principles and practices to go lean, including Integrated Product Teams (IPT), creating production flow, eliminating non-value-added activities, integrating suppliers with point-of-use delivery, and fostering an environment where the improvement decisions are made directly by improvement teams on the shop floor. Currently, 100% of workers participate in empowered teams. The end result after 7 years of improvement efforts (and consolidation difficulties) was a product whose cost had been reduced 75%, deliveries had doubled in a 12 month period, throughput time in production had decreased 71%, defects had dropped 48%, and the root-mean-square (RMS) reliability of the missile had been improved 300% over the contracted reliability (Davidz 2002b).

In a 2002 presentation, Robert Nelson, the corporate vice president for Business Strategy at Northrop Grumman, provided some insight into the results of lean implementation on some of their programs (Nelson 2002). For example, lean work had reduced the JSTARS aircraft assembly and modification cycle time by 28%. On new production of the E-2C aircraft, the throughput time (which Nelson called cycle time in his presentation) was reduced by 54%, from an original flow time of 42 months to a flow time of 19.5 months. In his opinion, this was partly attributable to the application of lean principles and practices to the subassembly and parts as well. In the case of a specific assembly for the E-2C, a material kitting system reduced travel distance 89%, reduced the number of trips by 89%, reduced defects 62%, all resulting in a cost saving $4 million to $5 million (Nelson 2002).

Even on a low production volume system like a launch vehicle, the effects of lean improvements were apparent. From 1995 to 2000 the Lockheed Martin Astronautics' Atlas launch vehicle program was able to reduce the throughput time by 34%, the travel distance by 54%, the labor hours by 34%, and hand-offs by 83% (Gass 2002). These performance gains were accomplished by lean and Six Sigma initiatives under the LM21 improvement program banner, and included activities such as kaizen improvement events, lean training for employees and suppliers, and finally organizing around product value streams (Hitchings 2002). From these cases it is clear that lean manufacturing does apply to the aerospace industry.

2.5. Open Issues with Lean in Aerospace

The data presented in the previous section seems to suggest that the positive results of lean efforts in the aerospace industry have been tremendous. Yet while local improvements in manufacturing cells can reduce WIP, lead-time, etc cetera, they do not necessarily affect the bottom line of the firm, or the top line of the customer. For example, consider inventory that is removed from a production cell by implementing single-piece-flow. If the cell receives its parts from a storage area at the end of the previous activity, and then ships its parts to a storage area in the start of the next activity, then the improvement may be a zero sum game at the production system level. Unless the inventory removed from the cell is removed from the whole production system, it will still be in the production system. Thus the overhead costs associated with storage and tracking will still be carried by the firm, resulting in no improvement to the bottom line. Cook and Graser comment that *"...the conclusion of this study [of lean in the aerospace industry] is that participating aircraft manufacturers have not provided adequate evidence to demonstrate they are producing in an entirely new way"* (Cook and Graser 2001, pp.134).

The improvement question with lean appears to be one of "systems of systems". Taiichi Ohno pointed this fact out when he said *"Look at the efficiency of each operator and each line, then look at the operators as a group, and then at the efficiency of the entire plant (all lines). The efficiency must be improved at each step and at the same time for the plant as a whole"* (Ohno 1988). Unless improvement efforts are done in the context of their impact on the production system as a whole, there are no real gains achieved. Ignorance of achieving systemic-level impact has been a major flaw of "kamikazee kaizens" - improvement efforts conducted with only a local view of improvement, irrespective of the result on the whole production system. With random local improvements there is no means to ensure that the results will benefit the customer and/or the firm. Frustration with this situation was expressed by Jacques Gansler, Under Secretary of Defense (Acquisition, Technology, and Logistics) when he said:

"I had hoped that after five years of lean in research under your belt we would have begun to see some significant impact on the top lines of our defense programs, i.e. the overall costs and schedules for weapons systems. I am sure you agree that your successes in specific elements of the production process must be extended and accelerated to all our programs and - most important - that we begin to see quantifiable data demonstrating the benefits of the lean approach at the weapon system level. So far we have just haven't been able to produce such data" (Gansler, 1999, quoted from Cook and Graser 2001, pp.22).

The strict focus on manufacturing does not address many other costs that are introduced into the design during program development, in the supply chain, or appear in the operational phase of the product. Cook and Gansler point out that many of the lean efforts they studied were focused on reducing direct labor hours in fabrication and assembly (Cook and Graser 2001, pp.135). In their opinion, this signals a very limited view of the lean approach, as some estimates put aircraft production costs due to direct labor at the prime manufacturer level in the 10% to 12% range. So even a savings of 50% of the direct labor would only translate into a 5% to 6% savings in production cost. The authors also suggest that a more conservative estimate of 20% savings is more appropriate due to the difficulty in creating a fully lean production system, and not just a few lean cells. In this case, the end result would be a savings of about 2% of the production cost (Cook and Graser 2001, pp.135). Cook and Gansler continue by saying *"For true lean implementation, contractors must focus on the other major cost areas as well, such as purchased materials and overhead. Purchased materials can make up two-thirds of an aircraft cost stream at the prime contractor level. Thus, focusing on generating savings throughout the supply cost stream offers considerably more opportunities for cost reductions. Similarly, a plan for cutting overhead can have significant cost reduction possibilities because overhead may constitute twice the value stream cost as manufacturing labor"* (Cook and Graser 2001, pp.135). Their observation raises questions about the value of lean manufacturing in aerospace and whether there is a better way to consider implementing its principles and practices.

2.6. Conclusions

From the literature on lean manufacturing and the history of the TPS, the term "lean" as it is used today represents a mix of operating philosophies, practices, and tools for running a manufacturing business in a manner other than observed in craft production or mass production systems. It is apparent that this alternative production methodology improves manufacturing costs, product lead-time, and product quality, all of which are important to customers. It is also apparent that leaner producers have higher productivity than less lean producers in the same business. The lower costs and higher productivity are essential operating factors of importance to the financial success of the firm.

The results of lean efforts in other industries has validated that the philosophies, practices, and tools of lean manufacturing are applicable to products other than cars, with equally impressive performance gains. Furthermore, efforts to implement lean manufacturing in the aerospace industry appear to have achieved comparable performance improvements, even though the aerospace industry is significantly different than purely competitive industries that deal in commodity products.

The literature suggests that a focus on localized manufacturing improvements may not result in large (if any) gains to companies. It is even suggested that more effective improvements with lean, that do affect the bottom line, lie outside the world of the manufacturing cell, or even manufacturing in general. There is thus a need to look at the systems-perspective of lean improvements to ensure that lean efforts manifest themselves in true performance gains. A systems-level perspective suggests looking at all of the business processes in a company beyond manufacturing, as well as the supply chain partners who help create the product, and the stakeholders who derive value from the business. This systems-level perspective is called the "enterprise" perspective and will be the focus of the next chapter.

Chapter 3 - The Lean Aerospace Enterprise Imperative

The literature and data discussed in Chapter 2 suggests that there are significant gains to be achieved from implementing lean in aerospace manufacturing. However, the literature also leads one to consider that the enterprise perspective may provide the potential for larger gains from the implementation of lean beyond manufacturing. Furthermore, this enterprise perspective could directly affect and improve the value delivered to multiple enterprise stakeholders above and beyond direct customers. This Chapter explores the definition of the Lean Aerospace Enterprise, the cost and time imperative for looking beyond manufacturing, and the consideration of multiple stakeholder enterprise value exchange as a non-zero sum game.

3.1. Defining the Lean Aerospace Enterprise

In its most basic definition, an enterprise is *"a business organization; an undertaking"* (AHD_WWW 1996). While brief, this definition provides little insight into the corporate boundaries and the scale of operations that may exist in an "enterprise". A more thorough definition is provided from legal sources as *"an organization or venture, especially for business purposes. One or more persons or organizations that have related activities, unified operation or common control, and a common business purpose"* (BLD 1999). The most notable element of the latter definition is that an enterprise is thought to comprise multiple (business) entities working towards a common business goal. This implies some form of cooperation or alignment of business practices across corporate divisions and even corporate boundaries. Thus, the idea of an "enterprise" view extends to the whole chain of activities, the associated companies (and/or corporate divisions), and the different stakeholders that are involved in delivering a product and/or service to a customer.

Womack et al proposed that a lean enterprise is a lean production company that has collectively applied the lean approach to finance, personnel management, and global coordination, in support of the lean production function (Womack et al. 1990, pp.192). This definition is primarily a firm-centric view of functional improvement. However, it does point out that the functions must be improved in view of optimizing some form of objective function with respect to production, suggesting that the authors were discussing functional process change as opposed to functional process efficiency. The efficiency argument would have meant that the processes in the functions were being optimized based on some local objective function. Thus, this view of the lean enterprise is one that involves changes in an organization's processes, structure and behavior.

Womack and Jones further expand on this early definition as *"the lean enterprise is a group of individuals, functions, and legally separate but operationally synchronized companies. The notion of the value stream defines the lean enterprise. The group's (lean enterprise) mission is collectively to analyze and focus a value stream so that it does everything involved in supplying a good or service (from development and production to sales and maintenance) in a way that provides maximum value to the customer"* (Womack and Jones 1994, pp.93). At this point we begin to see the view has shifted to one of interacting and interdependent business entities working towards the collective good of the end customer. Rather than a simple partnership or working agreement, Womack and Jones later define the lean enterprise as *"(The lean enterprise is) a wholly new way of thinking about the roles of firms, functions, and careers to channel the flow of value from concept to launch, order to delivery, and raw materials into the arms of the customer...A new concept - the <u>lean enterprise</u> - can move the whole value stream for products dramatically in the direction of perfection"* (Womack and Jones 1996, pp.12). In this last publication, Womack and Jones propose that the participants in the lean enterprise must treat others as equals, with *muda* as the joint enemy, and not each other. The recommended method of doing so is a conference of all of the firms in a given value stream, assisted by technical staff from lean functions, to make periodic analyses of the value streams and take quick-response corrective action (Womack and Jones 1996, pp.276). However, the view here is that there is still only one value stakeholder, the customer.

Hines et al define the lean enterprise as *"the extended supply chain responsible for effectively satisfying consumer requirements using a minimum of resources"* (Hines et al. 2000). The main point of interest in this definition is that the enterprise is proposed to include the extended supply chain, the contributors of subassemblies, parts, or services whose combined output yield a final product and/or service for a customer. The focus is still customer value, and the main performance metric for improved "leanness" is waste elimination in this definition.

Jordan and Michel consider the enterprise as including the entire company, the supply chain, and the customer base (Jordan and Michel 2001). The authors claim that manufacturing and business processes can be made lean, and once they are made lean the company by definition will be lean. The authors have created an interesting definition of the lean enterprise as it assumes that local lean functional optimization results in overall enterprise performance optimization (local versus global optimization will be discussed in more detail later in this chapter). Jordan and Michel contend that the main principles from lean manufacturing can be extended to the entire enterprise and can be summarized in the following five steps:

1) Focus on process intent
2) Eliminate those parts of the process that do not satisfy the intent
3) Examine the remaining parts to determine if they contribute to the value of the process
4) Eliminate those parts that do not contribute to value
5) Work continuously to lower the costs of the remaining parts, while making them timelier and improving the quality of their results

These five steps offer a new element to the lean enterprise perspective not seen in the previous definitions - process intent. The focus on process intent suggests that processes may be created and/or improved for some purpose other than simply customer satisfaction.

In *"Thinking beyond Lean"*, Cusumano and Nobeoka propose that multi-project management is beyond the tradition of lean which focuses on "heavyweight" program managers for single products (Cusumano and Nobeoka 1998). They propose that multi-project management can yield savings in development and production costs by creating new products that share key components, but utilize different development teams to ensure that each product differs enough to attract different customers. Their study suggests that the temporal overlap of engineering teams on the different products allows many products to be brought to market quickly using the latest technology. Furthermore, evidence is presented that firms that do this can achieve dramatic improvements in development costs (via reduced engineering hours per new product) as well as remarkable growth in sales and market share. This type of multi-product co-development strategy was used in the Boeing 737 Next Generation (NG) family of aircraft with some level of success (Proctor 1998). Even though Cusumano and Nobeoka do not use the term "lean enterprise", their view that performance improvements can be achieved by looking beyond a single product in manufacturing is a major consideration of the lean enterprise. The authors do try to distinguish multi-project management from lean, yet most lean principles and practices, if not all, apply to the multi-project management idea they put forward.

From an operating standpoint, much of the focus of the lean enterprise is on process management. The authors of "The Lean Enterprise" claim that with a process organization focus, the goal of the lean enterprise is to concentrate on how value is delivered (i.e. processes), and not on who delivers the value (i.e. individual positions in the organization hierarchy) (Dimancescu et al. 1997). In this definition of the lean enterprise, processes are defined as patterns of interconnected value-adding relationships designed to meet business goals and objectives. They claim that processes are in a continuous state of change, adapting to both expected and unexpected events. Furthermore, they say that the way in which information is communicated and knowledge is managed affects the quality of decision-making and innovation within a process (Dimancescu et al. 1997, pp.26).

In this model of the lean enterprise, the authors promote the use of core competencies and key suppliers as the basis for a process-focused operating strategy that delivers superior value to customers. Furthermore, they claim that those who understand the potential of a process-focused strategy realize that it can surpass the productivity of functionally structured organizations, and that a lean enterprise enables corporate agility by shedding bureaucracy and top-down decision-encumbering hierarchies. The authors propose a three-tiered system for becoming a lean enterprise:

1) Objectives and Rules - Decide on the business direction to take
2) Performance Gaps - Focus resources on biggest gain activities
3) Targeted Actions - Translate objectives into shop floor projects with performance improvement targets

The three-tiered system can be further divided into a matrix of teams and states where each tier is handled by a different team with the intention of solving a different stage of the lean enterprise transformation problem, as shown in Table 10. Above all else, Dimancescu et al claim that teaming around key processes starts at the top with the CEO and executive team who map a strategy and manage a portfolio of core processes to achieve business goals. The goals then flows down to sub-teams that eventually create and act on targeted actions. However, achieving this type of organization may not be very easy, as a study they quote showed that 80% of executives do not even understand what the key processes are in their organizations.

	Static	Motivational	Dynamic
Senior Team	Objectives/Rules	→	
Process Team		Performance Gaps	→
Action Team			Targeted Actions

Table 10 - Lean enterprise process management team structure (adapted from Figure 3.1,Dimancescu et al. 1997, pp.39).

The overarching lean enterprise transformation principles proposed by the authors are:

1) Processes driven by customer expectations
2) Maximize the opportunity for the interaction of people
3) Decisions made by those closest to the work
4) One time entry of data accessible by all who need to know

The authors claim that to achieve these transformation principles, and to act (behave) as a lean enterprise, requires a reflective and self-adjusting organization. This may not be the easiest environment to create given the historical management hierarchy and rigidity of the aerospace industry, as will be discussed in the next chapter.

In defining the lean enterprise, Donovan et al consider value-based management (VBM) an essential element of business success and growth in competitive times (Donovan et al. 1998). While they do not call their organization a "lean enterprise", it is fair to accept their work as a discussion of the lean enterprise, since defining and delivering value is the cornerstone of the lean enterprise. In their view, moving the concern for value from the boardroom of the company to all of the employees and the extended value stream members is the goal of the value enterprise. In this new enterprise, value is the focus of all employees and their business actions. Donovan et al's view of the enterprise is of interest because it brings into the definition a multi-stakeholder perspective of value stream members.

From the organizational perspective, Cooper defines the lean enterprise as a new organizational form, originating in Japan, that employs lean production methods such as just-in-time production, total quality management, team-based work arrangements, supportive supplier relations, and results in improved customer satisfaction (Cooper 1995). He contends that the lean enterprise is capable of producing higher-quality products economically in lower volumes, and bringing them to market faster than mass producers (Cooper 1995, pp.350).

Womack and Jones propose that the lean enterprise needs to look beyond the performance of any single firm in the value stream, but rather the performance of the whole value stream (Womack and Jones 1996). They claim the value stream is the only issue of relevance to the customer. In operating the lean enterprise, they contend that roles in the enterprise need to change. The supply chain must exhibit cost transparency to search out all waste. Contracting mechanisms must be in place to distribute gains across the supply chain, especially when upstream investments can improve downstream returns, implying that market conditions between supply chain tiers does not drive this kind of behavior in the first place. They claim that careers within the lean enterprise will no longer be functional, but will be a mix of experiences in teams to develop products and functions to develop skills. They also propose that promotion and career growth will be based on the difficulty of task handled by the individual, and not their hierarchical position on a functional organization chart. Womack and Jones further propose that the functions themselves will need to change their perspective to focus on enabling a lean production system, such as design for lean, quality for lean, and purchasing for lean.

Henderson and Larco contend that a lean factory alone does not make a lean enterprise (Henderson and Larco 2000). They argue that it is necessary to extend shop floor lean fundamentals throughout the entire company, and eventually to expand these practices outward to customers and suppliers - essentially to the entire value chain (Henderson and Larco 2000, pp.187). Similar to Womack and Jones, Henderson and Larco's philosophy in creating the lean enterprise is that the lean factory is the core of any manufacturing company, as it is the source of operating revenue. However, they also warn that in a lean enterprise there must be a rigorous balance among the key functions to ensure that a quality product can be produced at a competitive cost. It would seem that this approach in defining the lean enterprise applies to service companies as well. In their minds, the functions in a lean enterprise serve different purposes than in a mass manufacturing company. Design engineering must be capable of designing and introducing new products in a very short period of time, and it must ensure that its products can be manufactured in a lean production system.

Process engineering, or industrial engineering, is considered a critical element of the lean enterprise by Henderson and Larco. They believe that traditional manufacturing management looked at equipment utilization and efficient order quantities, whereas the lean enterprise process engineers will focus primarily on creating product flow (Henderson and Larco 2000, pp.194). In their view, the quality function changes from an inspection and control group to a "spiritual" leadership group aimed at helping inspire the workforce to design and build quality into products and processes. They also promote a concept of throughput cost accounting as opposed to standard cost accounting, which includes the complete elimination of WIP tracking, as it should be near zero in a lean system. Henderson and Larco propose that the human resources (HR) function take on new approaches in hiring team-appropriate employees, and in establishing team-based incentive systems as individual incentive systems are not considered compatible with a flow production system (Henderson and Larco 2000, pp.217). In their view, HR should also provide the appropriate training for creating a lean-enterprise workforce.

Henderson and Larco suggest that to establish true customer pull and flow, the sales and marketing force must sell "lean" to the customers so that they too can capitalize on the benefits of shorter lead-times, higher quality, and lower systemic cost. Finally, the purchasing function is touted as one of the most critical functions in the lean enterprise, since 35%-65% of product cost are in purchased materials. In the lean enterprise, purchasing agents need to become lean experts so that they can enable their internal lean production system by teaching and training their suppliers to operate in a lean fashion. This includes bringing suppliers in early in the product design process to capitalize on their skills and to set cost targets for the complete product (Henderson and Larco 2000, pp.224).

While all of the above descriptions of the lean enterprise consider value flow and customer focus, a shift in thinking about the enterprise perspective has occurred in the recognition of the multiple stakeholder value perspective, or *"how various stakeholders find particular worth, utility, benefit, or reward in exchange for their respective contributions to the enterprise"* (Murman et al. 2002, pp.178). Unlike previous work on the subject, the work of LAI recognizes two significant issues. First, LAI notes that multiple stakeholder values must be considered in the value delivery process, not solely the customer perspective. *"Enterprise, in this context, refers to every element of the organization, extending forward to the customer and reaching back into the supply chain"* (Nightingale et al. 2000, pp.3). Second, a waste elimination focus limits improvement potential, and should also be expanded to include a value creation focus. LAI has promulgated the multiple stakeholder perspective, shown in Figure 9, as a representation of all the entities that derive value from the existence of the enterprise, and also contribute value to the enterprise in which they participate (Mize 2002), (Murman et al. 2002), (Nightingale 2002b). This multi-stakeholder perspective is also shared by Jordan and Michel (Jordan and Michel 2001) and Donovan et al (Donovan et al. 1998) as a cornerstone of the lean enterprise.

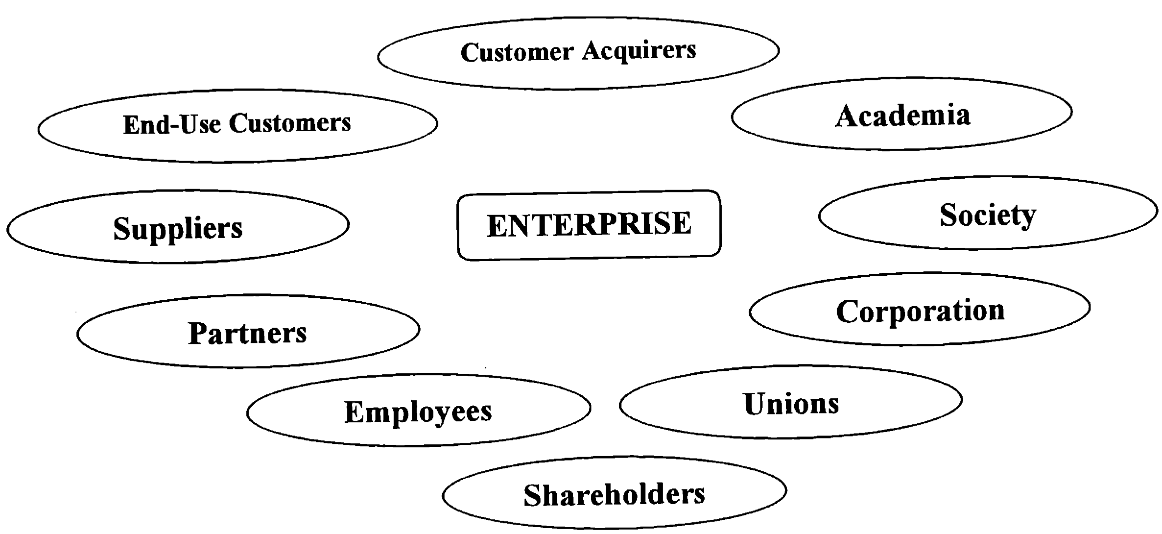


Figure 9 - Enterprise stakeholders.

Murman et al promulgate that *"A lean enterprise is an integrated entity that efficiently creates value for its multiple stakeholders by employing lean principles and practices"* (Murman et al. 2002, pp.144). Murman et al claim that lean enterprises systematically employ lean thinking throughout their organization and their value stream(s). Lean enterprises are considered to be dynamic, knowledge-driven, and evolving within the context of their operating environment. Furthermore, they continuously seek improvement and perfection within the changing landscape of their operating environment and changing stakeholders needs (Murman et al. 2002).

Two major definitions to consider in the enterprise context are also promulgated by Murman et al, namely the core enterprise and the extended enterprise, as shown in Figure 10. The *core enterprise* is defined as the group of entities that are tightly integrated through direct or partnering relationships (Murman et al. 2002, pp.162). *The extended enterprise* is composed of the less tightly coupled customers, suppliers, and government agencies - all of the entities along the value chain from the suppliers' suppliers to the customer's customers (Murman et al. 2002, pp.162).. The extended enterprise also includes all lifecycle phases of the product, including design, development, manufacture, certification, distribution, support, and disposal. The composition of stakeholders in the *extended enterprise* will change over time as certain activities in the product lifecycle are stopped or started.

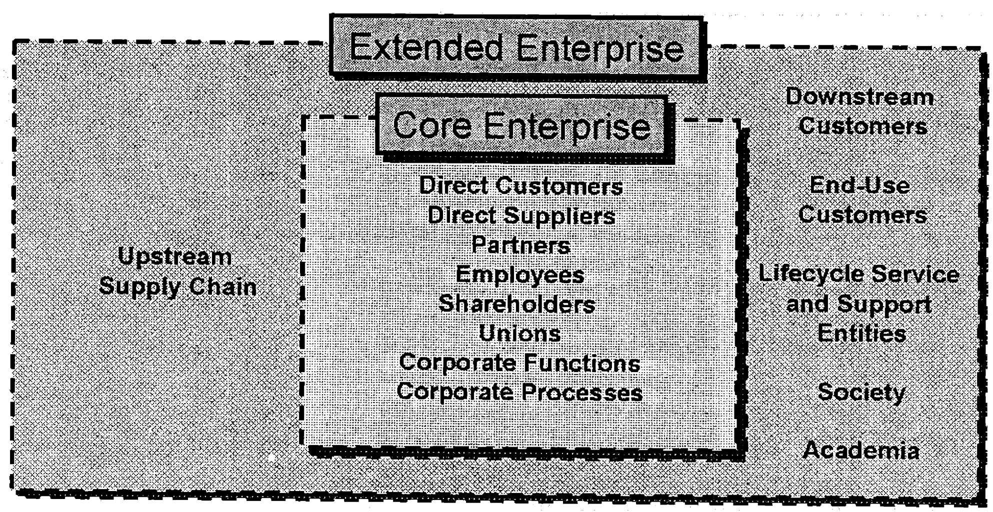


Figure 10 - Defining the boundaries of the core enterprise and extended enterprise.

Murman et al also define three types of Aerospace enterprises, namely the Program enterprise, the Multi-Program enterprise, and the National/International enterprise (Murman et al. 2002, pp.159). The Program Enterprise is considered the most elemental unit of aerospace business activity, and is defined as a collection of activities that produce a particular product. This definition should be expanded to include services as well. The program enterprise need not be the whole program, as defined by a System Program Office (SPO), but may be defined internally to an organization as a particular product or service that has a specific customer, whether internal or external to the organization. The businesses and government agencies that have responsibility for executing multiple programs are called Multi-Program Enterprises. The businesses in this definition are characterized as having profit and loss (P&L) accountability, while the government agencies are characterized as having budgetary authority for purchasing products/services (Murman et al. 2002, pp.160).

The collection of all entities and stakeholders that contribute to the creation and use of aerospace products, systems, and services at the national or international level is considered the National or International Aerospace Enterprise. The U.S. Aerospace Enterprise includes customers (airlines, general aviation, satellite service providers, civilian and military government agencies), government end users (warfighter and civil space resource users), manufacturers (prime contractors and sub-tiers of national and international suppliers), enabling infrastructure providers (airports, military bases, maintenance depots, and air traffic management), and related entities (universities, professional organizations, labor unions, laboratories, and support organizations) (Murman et al. 2002, pp.161). However, this definition should be expanded to include the regulatory elements associated with the enterprise, as they form a critical environmental factor in the aerospace industry.

Ultimately, the definition of an enterprise depends on perspective. An enterprise may be considered the people and entities involved in a single process in a company, or in multiple processes in a business unit, division, or corporation. Depending on the perspective, there can be interacting enterprises and nested enterprises. In all cases, the core of the enterprise involves some form of value creation process for a downstream customer based on inputs from stakeholders - this is the reason for its existence. The customer may be internal to a company, but may be external to the core enterprise of interest. For example, the employee training process could be considered an enterprise within the human resources (HR) function that serves two direct customers, the employees and the processes in which they work. The employees gain skills that make them more valuable by participating in the training process, and the processes in which they work become more effective because they have better trained employees. In the government sector, the core enterprise may be a system program office (SPO) with its prime contractor and direct DOD customer, while the end use customer (the warfighter) and the sub-assembly suppliers form part of the extended enterprise.

Having reviewed the meaning behind each of the words associated with the "Lean Aerospace Enterprise", it is now time to promulgate a working definition. We know that the definition will refer to the aerospace industry and will refer to the application of the principles and practices associated with the TPS (as well as other more contemporary research on business process improvements and innovations), as discussed in Chapter 2. Finally, the term enterprise will refer to the interaction of a group of stakeholders towards some common business objective, differentiated by their desired value contribution and extraction in the enterprise. Thus, it is proposed that a lean aerospace enterprise is *"a collection of entities utilizing lean principles and practices to create value for multiple stakeholders via the delivery of an aerospace product or service."* Murman et al propose a similar definition for the lean enterprise, as previously presented, to which one can simply add the terms "aerospace" and "in the aerospace industry" to create the following definition: *"A lean aerospace enterprise is an integrated entity that efficiently creates value for its multiple stakeholders by employing lean principles and practices in the aerospace industry."* These two definitions will be the basis for discussing the lean aerospace enterprise in the remainder of this thesis.

One can see that this definition in some form or other has started to permeate the aerospace industry. For example, the Boeing company's vision 2016 states that *"Our entire enterprise will be a lean operation, characterized by the efficient use of assets, high inventory turns, excellent supplier management, short cycle times, high quality and low transaction costs"* (Murman et al. 2002, pp.142 as quoted from the Boeing company, updated January 2001). However, the enterprise perspective associated with multiple stakeholder value delivery still seems to be missing. The quote from Boeing is indicative of traditional business thinking that is not lean. First, the quote states "excellent supplier management" which implies that the suppliers need to be controlled by Boeing, whereas a lean enterprise would be interested in "excellent supplier relations and involvement". The latter definition implies that the suppliers are valued for their capabilities and knowledge as well as their parts, sub-assemblies, and/or services. Second, there is no mention of the employees as part of the lean enterprise, even though "employee empowerment" is a cornerstone of much of the literature on lean. It is good to see that the words "lean enterprise" are beginning to enter the minds of industry leaders, however, the meaning of a lean enterprise promulgated in this thesis may not yet be pervasive in industry. As the imperative for a lean aerospace enterprise builds, this may change.

3.2. The Importance of the Lean Aerospace Enterprise Perspective

The lean aerospace enterprise perspective offers the chance for achieving greater benefits than simply focusing on lean manufacturing. The enterprise perspective proposes that there are systemic wastes and opportunities that require looking beyond the islands of success discussed in the previous chapter, and that a significant amount of cost and lead-time attributed to aerospace system delivery occurs outside of manufacturing at the prime contractor. Looking at the greater enterprise perspective, including the extended enterprise, offers the opportunity for greater lifecycle cost savings, quality improvements, and lead-time reductions. The multi-stakeholder focus of the lean aerospace enterprise also presents arguments that consideration for the value-exchange between multiple enterprise stakeholders throughout the product lifecycle can have a major positive influence on product lifecycle value, enterprise value delivery, and enterprise sustainability.

3.2.1. The Enterprise as a System of Systems

During the 1990's, the LAI undertook numerous research projects aimed at studying the improvements associated with implementing lean in manufacturing (Vaughn 2001). While all of these studies presented evidence of improvements in local performance indicators such as lead-time, inventory, productivity, and cost, the fact remained that many of these improvements had little or no significant effect on the bottom line of the business. The creation of a lean production cell or lean element of a production system created improvements in the local performance indicators, but had no visible effect on the production system as a whole. Murman et al describe this effect as creating an "island of success" (Murman et al. 2002).

In many instances, the success stories of implementing lean production cells using flow techniques, quality management, and statistical process control were often driven by local lean champions (Murman et al. 2002). Even with immense local success, these lean champions did not have the leadership authority to tackle the reorganization of the production system as a whole, or to extend lean beyond the manufacturing system, as this was not within their managerial purview. In essence, these efforts have failed to extend along entire value streams or across an entire enterprise.

However, the "islands of success" should not be considered as failures. Islands of success can be considered good demonstration tools for highlighting the kind of performance improvements that can be achieved in a production system if the lean concepts are extended beyond the island. Furthermore, they can be used as learning tools to help others see how lean works in practice and what is needed to create process flow.

Yet, even if one looks at the larger production system, composed of smaller manufacturing systems, each of which contains manufacturing activities, one encounters a "system of systems" issue. The production system itself forms part of the larger business system of the firm and the core enterprise, and it is also a part of the value stream system of the extended enterprise. Since there is an inherent interdependence amongst the enterprise elements, actions in local areas can limit improvements in others or even cause adverse effects. These interactions can also serve as constraints to lean improvement efforts. From the perspective of the firm, the production system interacts with other processes and functions within the organization, such as purchasing, sales, finance, engineering, human resources (HR), information systems (IS), and shipping and receiving amongst others. Each of these functions, and their inherent processes, are in some way coupled with the production system, thus there are limitations and constraints outside of production that affect its performance, especially in a lean context.

For example, purchasing influences the production system by its methods for contracting components with suppliers. Economic order quantities, while achieving the lowest piece part cost, do not take into account the systemic costs they introduce into the production system. Traditionally, economic order quantities meant large lot sizes to reduce the piece part cost by benefiting from the suppliers' economies of scale. However, large amounts of parts need to be logged upon receipt, identified with some form of tagging system, stored, managed, and retrieved prior to use. These activities add significant overhead to the production system in terms of warehousing, staff, information management systems, and transportation costs. They also add the potential for introducing more defects into the production system, as it takes longer to use parts from a large batch order, and thus there could be many bad parts in storage. The potential cost of obsolescence is also an issue if the time required to utilize the parts is longer than the mean time between design changes affecting that part in the product.

If a company's sales function operates separately from the other functions, then the potential for capitalizing on the lean improvements in the production system will limited. There is a need to sell the customer on the lean capabilities of the production system so that they understand the value of receiving a higher quality product or service faster. This is especially important when the time between purchases might be quite long (as is in the aerospace industry) and relying on the customer to learn of the lean capabilities of the production system from deliveries may take years. A sales force versed in the lean capabilities of the production system can use this knowledge as a means to educate clients and hopefully garner sales. Furthermore, lean is intended to align demand and production more closely to avoid high levels of under-production and over-production in the supply chain. To accomplish this task, sales must not be in a pure "push" mode that attempts to sell as much product to customers as possible. Aligning production to true customer demand requires establishing relationships that allow customers to pull product as needed. This also suggests the potential need for more formal information feedback mechanisms for the customers to the supply chain. This might suggest that the sales force also needs to be linked with the IS group as a means for helping create the formal information links between customers and suppliers. The "pull" idea could be extended to selling product development capabilities, for which the customer could pull new products in a shorter lead-time. A sales force focused solely on selling current product/services could miss out on the needs of the market and limit the potential for future product growth.

From the financial perspective, Kaplan and Norton argue that a company's success at implementing innovative capabilities cannot be measured nor motivated in the short-term by traditional financial measures (Kaplan and Norton 1996). It is their opinion that these measures, developed for trading companies and industrial age corporations track the results of past events, and not current efforts. A strict focus on financial outcome measures can have adverse effects on lean transformation. For example, a review of data for lean continuous improvement efforts in over twenty businesses revealed that in the short-term, the disruption of the processes led to decreases in performance while the system was changed (Nightingale 2001). Once changed, however, there were marked performance improvements. Had there only been a focus on the financial performance metric during the change, then management may have erroneously concluded that the effort was not working. Furthermore, financial accounting models report spending cutbacks as increases in reported income. Thus, the wrong focus of financial metrics can result in the cannibalization and lack of investment in firm capabilities as a means to make current financial performance look good at the expense of future performance (Kaplan and Norton 1996). There are, in fact, many elements of financial systems that focus on tracking information (such as WIP and inventory), versus enabling the right local decision making based on enterprise financial needs. The financial system in a lean enterprise may need to be a vehicle for communicating current and future operating needs throughout the enterprise, versus simply monitoring the results of past activities.

In engineering there is a tension between the push and pull of product development. Engineers traditionally worked to create new products that they felt would be sellable, resulting in a push of new products onto the market. Lean production, however, attempts to create a better link between new customer needs and new product development, resulting in the customer pulling a new product with the desired characteristics from the enterprise. The optimal approach may lie somewhere between a push and a pull, where the techno-centric engineering community identifies and develops innovative new technologies while the customer community identifies and requests new product capabilities and attributes. The resulting new product development process is then a mix of push from research and development (R&D) and a pull from customer needs. Beyond the customer interface, engineering in the aerospace community has slowly been adopting integrated product and process development (IPPD) practices that are intended to bring together representatives from multiple downstream lifecycle functions early in the product development process. For example, the consideration of design decisions on manufacturing and assembly can help to improve the production system efficiency (Ulrich and Eppinger 2000). Observations from site visits to lean manufacturers identified that even with the existence of IPPD practices, the lean efforts were seen as a post-product development improvement effort. Thus, when a new product was introduced into manufacturing, the lean improvement initiatives had to start all over again on the production line. This suggests that design for lean (DFL) or design for flow (DFF) considerations in the IPPD may lead to better operational performance versus considering the lean improvement efforts as a separate activity.

Human resources (HR) influences the production system by the type and quality of employees it can provide in response to labor needs. The change to a lean production system may require new employees that have different skills than existing employees and existing employees may need to be trained to acquire new skills for operating in the lean environment. If the HR function has set processes for hiring and training, a sudden shift in the needs of the production system may not be responded to until after a significant lead-time, during which the processes in HR are modified to adapt to the change in needs.

The information systems (IS) group is responsible for equipping and supporting the production system with its communication and information management systems. Existing IS capabilities can limit the flexibility of the lean transformation in the production system. In fact, the presence of an MRP or ERP system may require extensive configuration changes to support the lean production system change, and management policy that promotes the MRP or ERP system may prevent the production system from adopting its own set of information management tools. While new tools may add some capital and maintenance cost to the IS budget, as they do not fit within the "standard" set of supported tools, they could actually lead to larger cost savings through increased productivity and customer satisfaction from the production system. In some cases, a "right-sized" information management system might reduce the IS support costs because the production employees will maintain the system themselves.

The discussion in the preceding paragraphs raises the issue of the objective function. In management problems there is a desire to achieve some form of improvement level or optimality with respect to some set of variables and some set of constraints (Nagel and Neef 1990). The objective function constitutes the implementation of the problem to be solved and involves a mathematical representation of the variable(s) involved in the optimization problem. Whether explicitly stated, or implicit to management's mental model of a situation, decisions are typically based on achieving a goal with respect to optimizing some objective function. Within a traditional functional, hierarchical organization, each of the functions operates with a local objective function. Cost centers in companies have been operated based on minimizing their use of resources, whereas profit centers have been operated based on maximizing their profitability. The assumption has been that these local optimizations lead to the best performance for the firm. However, as discussed above, the decoupling of each of the local objective functions from the enterprise's overarching objective function creates a sub-optimal situation by introducing systemic costs and inefficiencies. A truly lean production system would be supported by all of these functions in a manner that maximizes the enterprise's objective function based on maintaining optimal value flow, and not on optimal cost recovery for each of its processes. By definition, this means that some of the local objective functions, defined in their pre-lean sense, would actually be operating less-optimally to achieve greater enterprise optimality. If the management and incentive system has created the local optimizations, then this would suggest a need to change management behavior and incentive structures to improve the enterprise's objective function.

As an example, consider shipping and receiving. Shipping and receiving attempts to minimize its costs by utilizing large shipments of many parts in large batches. This only requires a nominal number of deliveries per unit time using large vehicles and thus, the delivery cost per unit of product is reduced, with the delivery cost spread over a large number of parts. However, more storage is required at the end of the production system in order to accumulate enough product to fill the large shipping vehicle. This adds storage costs to the production system, increases the lead-time for orders, and may even create the need for more storage and all of its associated costs at the customer's end (unless they utilize their full shipment as soon as it arrives). The shipping and receiving department's objective function will look good (appear closer to optimality) on paper and probably be duly rewarded for keeping its transportation line item costs low. However, the added overhead costs to the production system might be larger than the cost savings realized due to large shipment sizes. The net result would be a decrease in the enterprise's performance. An increase in shipping costs with smaller, more frequent deliveries could actually decrease systemic costs in overhead by eliminating the need for significant storage systems, and could also reduce the product lead-time to the customer. The objective function for shipping might be at a less optimal operating point due to the more frequent shipments, since the shipping cost increases with more frequent and smaller deliveries. However, the systemic effect would be to reduce and/or eliminate all costs associated with storing and maintaining an inventory of finished goods. This would improve the performance on the enterprise's objective function by reducing firm overhead expenses. Be advised, however, that this is not an exhaustive discussion of shipping cost minimization, as there are other effects that need to be considered when determining the performance, including trading the lead-time needs of customers against shipment sizes.

From the extended enterprise perspective, the same interface problems arise as those between functions within the firm. Typically, firms aim to maximize their own profits, and economics says the market will work out the lowest costs (Pindyck and Rubenfeld 1998). Yet, when there are systemic costs introduced due to the transactions and information flow (or lack thereof) across organizational boundaries, there is a potential for achieving greater returns by eliminating systemic waste due to the interfaces. A focus on the enterprise-level objective function, and even the extended enterprise-level objective function, will cause the enterprise stakeholders to address real performance issues, rather than local performance issues, thus positively affecting the bottom line. Coordination of the supply chain via real-time information exchange can reduce demand amplification that traditionally arises from systemic information delays (Pindyck and Rubenfeld 1998), alleviating the waste of overproduction and avoiding lead-time delays from underproduction. The identification and removal of enterprise-level non-value added activities can reduce operating costs and the product lead-time. This effort can also remove systemic-level inventory such that working capital is made available to the enterprise.

A truly lean enterprise is not one that has some islands of success in manufacturing. A truly lean enterprise needs to coordinate its internal processes and functions to enable a lean production system (the source of revenue for the firm). Local objective functions need to be restated in a form that represents their impact on value flow within the enterprise. The supply chain partners also need to look for ways to state their objective functions in a manner that aims to reduce systemic costs, while determining the means to share in the gains achieved by becoming leaner. This focus on redefining the objective functions within and external to the firm is one imperative for the enterprise perspective, as a properly defined objective function will expose the systemic costs previously hidden by discrete local objective functions.

3.2.2. Cost and Time outside of Manufacturing

The enterprise perspective, by definition, looks beyond manufacturing. One of the most compelling reasons for this are the costs and time associated with activities other than manufacturing at the prime contractor. For example, Cook and Graser claim that direct labor makes up only 10-12% of production costs at the prime contractor level (Cook and Graser 2001). There are, therefore, another 90% of production costs that lie outside of direct labor at the prime contractor. Hence, if all of this direct labor were removed from the prime contractor, there would only be a 10% cost savings in production costs for the product, assuming all else remains the same. In aerospace, it is estimated that up to two thirds of production costs are purchased from the supply chain. On the F-22 for example, the prime manufacturers each procure more than 60% of their contract value from their suppliers (i.e. LMCO Aeronautics 60%, Boeing 61%, Pratt & Whitney 70%) (Handell 2002). Furthermore, it is estimated that 60% of the supplier costs are also procured from sub-tier suppliers. As Handell points out, this puts over a third of the program costs (36%) in the sub-tier suppliers. Thus, there is more opportunity for savings in production costs in the supply chain than there are in the final assembly stage of the prime contractor.

Furthermore, the Air Force is operating in an era of "best lifecycle value", where total ownership cost (TOC) is of prime importance. Total ownership cost is a measure of owning the system over its entire lifetime, and includes the elements depicted in Figure 11 (Adamson 2002). In the past, systems were purchased based on procurement costs, but the realization that aerospace systems cost more to own and operate than to buy has led to a change in acquisition strategy.

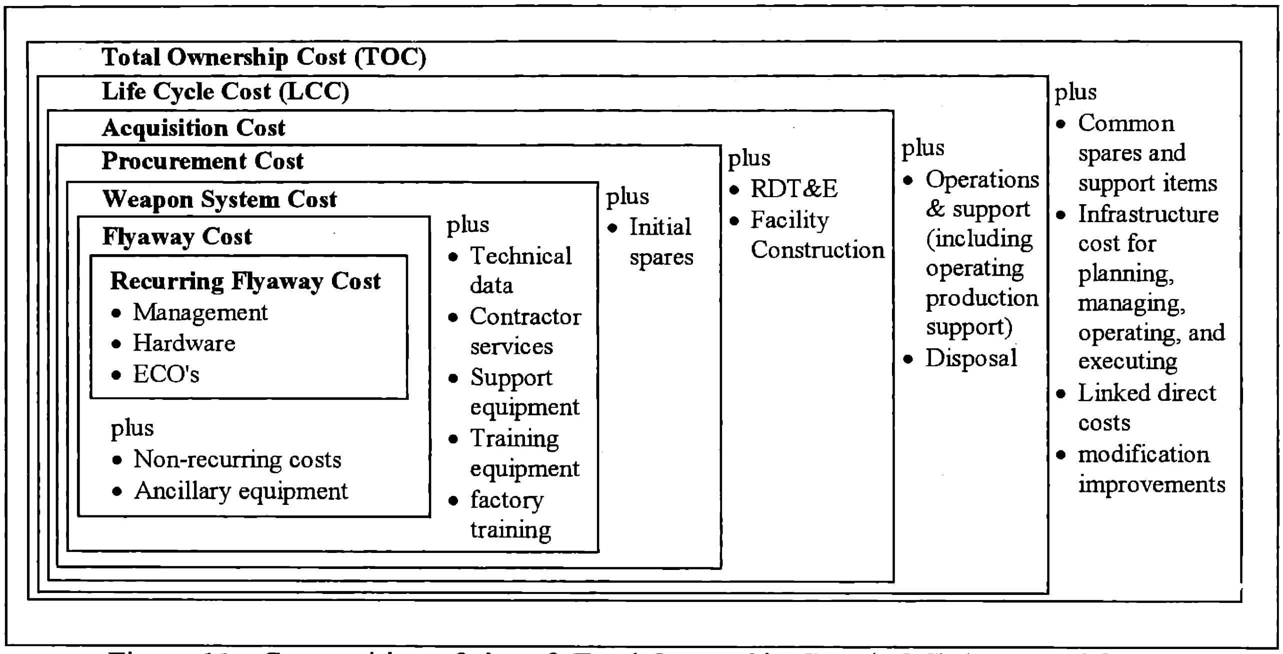


Figure 11 - Composition of aircraft Total Ownership Cost (TOC) (recreated from Adamson 2002).

As a rule of thumb, the life cycle cost of aerospace systems has historically been divided one third (33%) for acquisition and two thirds (66%) for operations and support (Haggerty 2002b). A general estimate of the breakdown of lifecycle cost is to look at DOD Budget Authority as it breaks down between (i) Research, Design, Tests and Evaluation (RDT&E), (ii) Procurement, and (iii) Operations and Maintenance (O&M). Data for the past 20 years shows that while procurement has remained relatively constant, and RDT&E has decreased, O&M has increased slightly, as shown in Figure 12. On average, Figure 13 shows that DOD spending is 35% RDT&E, 17% Procurement, and 48% O&M. For the most recent data (2001), the values were 28% RDT&E, 19% Procurement, and 53% O&M (Freidman and Pollack 2002).

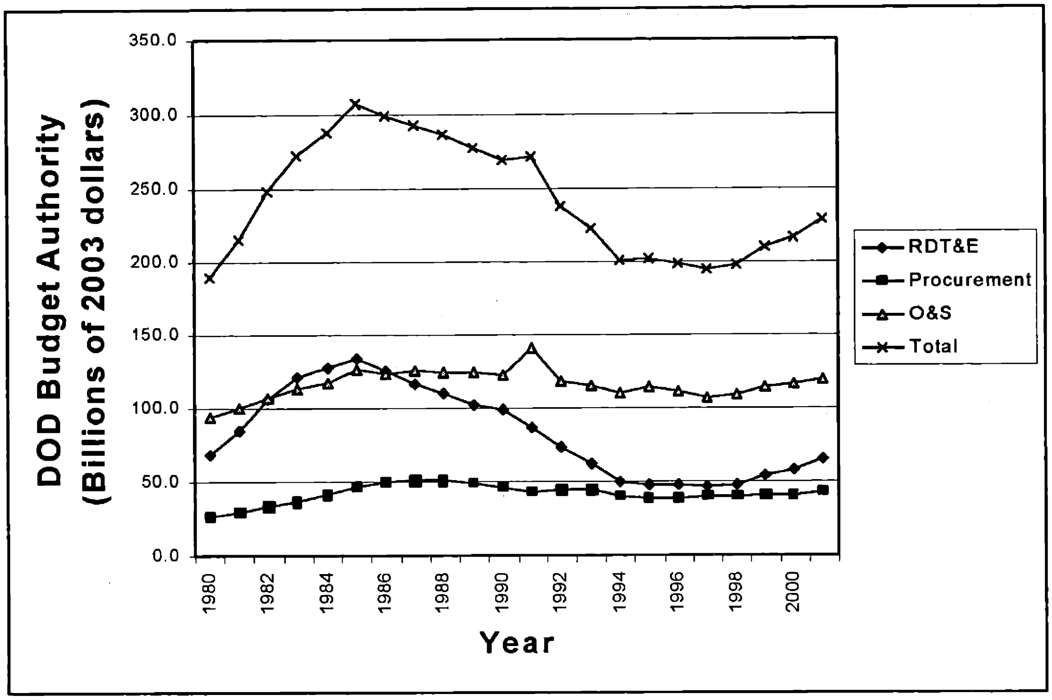


Figure 12 - DOD budget authority by lifecycle phase over the past two decades (Freidman and Pollack 2002).

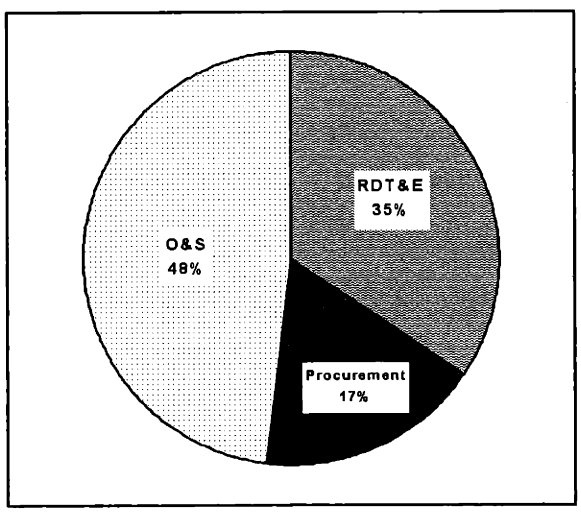


Figure 13 - Average DOD budgetary outlays by system lifecycle phase over the past two decades (Freidman and Pollack 2002).

For a typical fighter aircraft program spanning 15 years, data suggests the breakdown as 10% for development, 35% for procurement, and 55% for operation and support (Dhillon 1989, pp.217). For many of the existing aircraft systems, the actual ratios might change as development costs increase with system complexity and the life span for systems increase. For military aircraft engines, the numbers change to 40% for development, 23% for procurement, and 37% for support (excluding fuel) (Dhillon 1989, pp.223). Thus, the DOD spending data may be a reasonable approximation of average lifecycle cost breakdown for DOD systems.

Based on this discussion, if production only makes up 20% of the lifecycle costs, and direct labor only affects 10% of the production cost at the prime level, then the absolute maximum cost savings realizable from the elimination of labor at the prime is 2% of the lifecycle costs. Taking Cook and Graser's estimate that a 20% reduction in direct labor might be achievable if lean were applied across the whole production system at the prime manufacturer (Cook and Graser 2001, pp.134), this would only translate into a lifecycle cost savings of 0.4% on a program. However, the other aspects of lean, namely quality and lead-time should be considered in any lifecycle value analysis. For example, the customer may be happy with a marginal decrease in cost and a large decrease in lead-time. Furthermore, increased quality will lead to increased reliability, which should decrease maintenance costs and improve system availability during its O&S lifecycle phase. Thus the direct savings in acquisition costs due to lean might only be the lower bound of a potentially greater lifecycle cost savings and value improvement from the improved system quality.

This discussion seems to reinforce the lifecycle view of the lean enterprise, as there is a significant portion of cost associated with activities outside of procurement. Yet, there is also a temporal effect with the lifecycle, and it is important to differentiate between the time when costs are determined, versus when they are incurred in the program lifecycle.

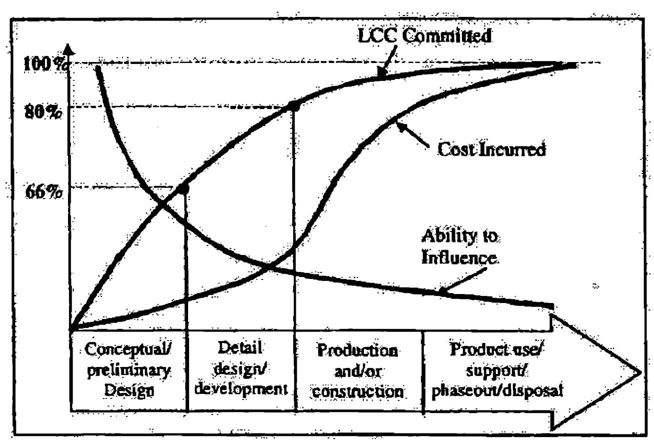


Figure 14 - Lifecycle cost lock-in versus emergence (Fabrycky 1991).

It is generally accepted that costs are locked-in early in the design and development phase, whereas the costs associated with the design decisions are incurred later in the lifecycle, usually during O&S. The Air Force Cost Analysis Agency (AFCAA) estimates that 80% of lifecycle costs are locked in at the end of R&D. A notional program cost-lock-in diagram is presented in Figure 14. Haggerty claims that 80% of a product's cost is decided by the end of the engineering phase in a program (Haggerty 2002, pp.12). Considering other elements of the enterprise beyond manufacturing at the prime contractor, as well as the temporal issues in the lifecycle, provide a much greater opportunity for improving system lifecycle value.

3.2.3. The Multi-Stakeholder Focus of the Lean Enterprise

The enterprise is considered to consist of stakeholders that both contribute value to, and receive value from, the activities that make up the processes involved in operating the enterprise. This value interaction provides three reasons for considering the multi-stakeholder perspective as a major element of the lean enterprise. First, the participation of multiple stakeholders in decision processes in various life cycle phases of the enterprise has the potential for improving lifecycle value (LCV) by building on the capabilities of all of the stakeholders. Second, there is evidence that the focus on multiple-stakeholders is not a zero-sum game when attempting to maximize enterprise value delivery. This would suggest that a pure customer focus (i.e. maximizing customer value delivery) may be a sub-optimal operating point for the enterprise. Finally, it is argued that enterprise sustainability is considered to depend on the multi-stakeholder perspective under open market conditions for labor, investment capital, and customer choice.

3.2.3.1. Building on Collective Capabilities

The participation of multiple stakeholders in decision processes during the various life cycle phases of the enterprise has the potential for improving lifecycle value (LCV) by building on the capabilities of all of the stakeholders. This proposition is not associated with each group in the enterprise having the right objective function, as discussed earlier. Rather, it promotes that even with the right objective function, the interaction of the stakeholders can create better LCV than if they worked alone. The implication is that information exchange both upstream and downstream amongst stakeholders can lead to the creation of better LCV.

The enterprise perspective involves utilizing the intelligence of the multiple stakeholders, rather than trying to independently make all decisions within the confines of one firm or function. This can lead to more creative and/or better performing solutions, faster decision processes (or iterations) that significantly reduce lead-time, and the ability to perform parallel activities in the development of new products, again reducing lead-time. In general, it is accepted that multiple individuals can usually develop a better solution to a problem than one individual. The downside to this belief is that the increase in number of individuals involved in the decision process can reach a point where the addition of further individuals to the process will diminish the results by slowing down the process (i.e. no decision can be reached).

From the design perspective, the inclusion of upstream suppliers in the downstream customer's design process acts to increase the capabilities of the enterprise. Suppliers have traditionally been utilized because they provided a product or service that the prime contractor did not possess, or did not wish to possess, in-house. Relations were historically arms-length, with the prime contractor producing product/service specifications, and using buyer power to extract cost concessions from the suppliers (Murman et al. 2002), (Ward et al. 2001), (Stallkamp 2001). However, design work devoid of supplier inclusion does not transfer the additional knowledge that the suppliers possess, of both product/service availability and process capability, to the enterprise's product development process. The inclusion of suppliers in the larger system design process expands the solution space and improves the lead-time. The partnering relationship with suppliers is also a source of agility (PDBPR 1998). Partnering instantaneously increases the core capabilities of the prime without adding to its overhead and without requiring the prime to spend time and money to invest in developing the capability internally. This saves product lead-time and permits to prime to utilize specific core capabilities outside of the firm when they are needed, while not being forced to sustain them when they are not agility (PDBPR 1998).

Bozdogan et al characterize the aerospace engineering industry as historically consisting of suppliers that manufacture to the specification of a prime contractor (Bozdogan et al. 1998). However, the authors go on to point out that architectual innovation in product design can be achieved by utilizing the expertise of suppliers, as they increase the virtual skill set of the company. Their research indicates that by bringing suppliers into the product development phase early there is a greater chance of innovation from the larger skill set, and as a result of the real-time collaboration, there are fewer design changes necessary as compared to design-to-specification products. Bozdogan et al note that the Japanese claim there is a decrease in produceability problems and increased learning of all supply chain partners by using this technique. Of forty military programs surveyed by Bozdogan et al, they found that 75% had suppliers involved in design work, 40% were involved in sub-assembly design, and 20% in part design. In the case of a program where the government mandated early teaming, the unit costs were reported to be 75% lower and the cycle-time was reduced by one third (33%), both of which are true systemic bottom-line results contractor (Bozdogan et al. 1998).

Characteristic	**Traditional Supplier Model**	**Lean Supplier Model**
Number and Structure	Many, vertical	Fewer, clustered
Procurement personnel	Many	Limited
Outsourcing	Cost-based	Strategic
Nature of Interactions	Adversarial, zero-sum	Cooperative, positive-sum
Relationship Focus	Transaction-focused	Value-creation focused
Selection criteria	Lowest price	Performance
Contract length	Short-term	Long-term
Pricing Practices	Competitive bids	Target Costing
Quality	Inspection-intensive	Designed in
Delivery	Large quantities	Small quantities, JIT
Inventory buffers	Large	Small
Communication	Limited, task-related	Extensive, multi-level
Information flow	Directive, one-way	Collaborative, two-way
Role in development	Limited, build-to-print	Substantial
Technology sharing	Limited to non-existent	Extensive
Mutual commitment	Limited to non-existent	High
Governance	Market-driven	Self-governance
Future expectations	No guarantee	Considerable

Table 11 - Difference in realtionships between traditional and lean suppliers (adapted from Bozdogan 2002, pp.4).

Bozdogan has characterized the lean supplier relationship as one that is markedly different from traditional prime-supplier relationships (Bozdogan 2002). It involves the supplier becoming lean itself (local perspective), and helping the supply chain also become lean (systemic perspective). Table 11 shows Bozdogan's comparison between traditional supplier relations and lean supplier relations. An important fact of supplier involvement is not only the core capabilities they intellectually bring to the design process, as discussed above, but also their understanding of the process capabilities that exist in the supply-base. The design process can benefit from this added knowledge of process capability in two ways. First, designers can work to design within the existing capabilities. Thus, once the design is ready, suppliers can begin the production process with little or no delay. This reduces lead-time and cost associated with changes in process capability. The second benefit involves designers identifying needs for new process capabilities during the design phase. Working together, the suppliers can develop the capabilities in parallel with the detailed design, thus reducing lead-time that would traditionally be associated with suppliers developing the new process capability after the design was released.

The understanding of supplier capabilities and early supplier involvement were credited as key lean engineering practices responsible for the affordability and short cycle-time of Boeing's Unmanned Combat Air Vehicle (UCAV) Advanced Technology Demonstrator (ATD) (Haggerty 2002). The Boeing team considered its suppliers as partners in the design process and their capabilities were considered when exploring the design space. The numerically controlled (NC) machining capabilities, fabrication capabilities, capacity, and process lead-time were considered as inputs to the design. Furthermore, the supplier was asked to suggest means for reducing the overall program cycle-time and participated in a collaborative request for proposal definition (RFP). The overall UCAV ATD program was able to release engineering and manufacturing data packages while still in the design phase. Combined with other lean engineering activities, the program produced a prototype that was approximately 50% less costly than production aircraft (measured in dollars per pound) and achieved a cycle time of 19 months from Phase 1 concept to containerized shipment (Haggerty 2002).

At the opposite end of the value-stream are the customers. Including customers in the design process helps to ensure that the proper user requirements are met. Customer coordination during manufacture and delivery can also help improve the performance of the enterprise. Bozdogan highlights an engine casings company that was able to improve its own performance by coordinating more closely with its downstream value stream customer (Bozdogan 2002). By coordinating its own flow to synchronize with the demand needs of its customer, the casing company was able to improve its performance, the value stream performance, and improve the lifecycle value of the product to the end-use customer. With efforts at implementing lean from 1992 to 1999, the company improved on-time delivery, productivity, quality, and cycle time, as shown in Table 12.

Metric	1992	1999	Improvement (as a % of 1992 state)
On-Time Delivery	68%	97.5%	43%
Cycle Time (days)	43.8	12	68%
Productivity	1.78	2.4	12%
Quality	85.2%	92.5%	8.6%

Table 12 - Performance improvements at supplier due to coordination with downstream customer (adapted from Bozdogan 2002).

In the case of government acquisition, the disconnect between supplier and customer cycle times can negate the potential creation of improved LCV. Government budgetary requirements and cycles that drive development schedules is major example of this type of issue. In a recent RAND study, users of 3-D wire-frame and solids design technology overwhelmingly supported the fact that the 3-D techniques were a dramatic improvement over previous techniques (Cook and Graser 2001, pp.43). However, the engineers suggested that the advanced tools were used to conduct more iterations of the design, since there was no means for changing the government's budgeting cycle. As a result, designs may end up being more refined than previous designs, with no change in cost or lead-time. The creation of a lean enterprise requires incorporating the knowledge of the industrial capabilities into the government acquisition process, creating a lean customer. This would enable delivering similarly capable products faster and with fewer labor hours. The current state of increased iterations in the same time and budget may only be producing design refinements that, due to diminishing performance returns from design effort, produce system performance gains that are negligible to the end user of the system.

In engineering, the multi-stakeholder perspective has slowly emerged in the aerospace industry in the form of integrated product and process development (IPPD) that uses integrated product teams (IPTs). Integrated product teams are the mechanism by which various stakeholders internal to a project have been brought together to provide their perspective on the project. The use of IPTs has been focused largely on the lifecycle "ilities" associated with products, such as manufacturability, repairability, maintainability, and sustainability. The thought behind IPT's has been that firms can get a finished product to the customer faster, while increasing the total quality and marketability of the product (Cook and Graser 2001, pp.33). In fact, the perceived benefit of IPTs resulted in the DOD mandating their use in DOD programs starting in 1995 (Cook and Graser 2001, pp.34). While the perceived benefit of the IPTs has grown and is considered a key element in the lean enterprise, there is evidence that it does not immediately translate into cost savings. A contractor surveyed in the RAND study suggested that the organizational structure of IPTs is not less costly and may be more expensive than functional groups. However, they claim that the cost savings should manifest themselves in lower recurring costs due to an improved design (Cook and Graser 2001, pp.36). The report also suggests that the value of IPTs as a means for achieving a lean enterprise will manifest itself in two metrics, lowered LCC and lowered production cycle time (Cook and Graser 2001, pp.36).

Ultimately, the lean enterprise will act more like an IPT of many stakeholders at the macro level, exhibiting behavioral characteristics that aim to improve overall lifecycle value delivery. The main question to ask is whether this type of behavior can occur naturally, or must a mechanism such as IPPD be dictated?

3.2.3.2. Multi-stakeholder value exchange is not a zero sum game

There is evidence that the focus on multiple-stakeholders is not a zero-sum game when attempting to maximize enterprise value delivery. This would suggest that a pure customer focus (i.e. maximizing customer value delivery) may be a suboptimal operating point for the enterprise. Earlier in this thesis the concept of multiple enterprise stakeholders was introduced. Stakeholders are considered to be any individual, group, or entity that is impacted by the existence of the enterprise. Stakeholders can both receive value from the enterprise and contribute value to the enterprise. The list of enterprise stakeholders includes customers, suppliers, employees, shareholders, unions, end users, warfighters, system beneficiaries, system sustainers, procurement offices, society, etc. Examples of the major value categories for these stakeholders is shown in Table 13. A more extensive taxonomy of stakeholder value that builds on these categories is presented in Appendix B.

A zero sum game would imply that an increase in value delivery to one stakeholder would decrease value delivery to another, both of which would have to be of equal utility on some utility scale. Total enterprise value delivery, measured as the sum of all value delivered (on a common utility scale) would thus be a constant. If it can be shown that value delivery to one stakeholder could be increased with greater utility than it was decreased with another, then the total (net) enterprise value delivery would increase, implying a non-zero-sum game. The existence of win-win situations in the value exchange proposition would support this argument.

Enterprise Stakeholder	Value Measures
Customer	• Product/Service Quality • Cost of Ownership • Cycle Time • Relationship with Corporation
Shareholder	• Return • Risk Management • Market Position • Growth Potential • Executive Leadership • External Relations
Employees	• Compensation • Positive Work Environment • Career Management • External Factors
Unions	• Employment • Power
Suppliers	• Financial • Relationship with Corporation
Society	• Financial • Economic Attractiveness of Industry • Corporate Citizenship • Affiliated Organizations
Corporate	• Financial • Stability • Balancing Stakeholder Needs • Public

Table 13 - Major categories of stakeholder value (Mize and Hallam 2002).

According to Womack and Jones, the lean enterprise is based on maximizing customer value. Their view assumes that a lean company servicing a customer with faster lead-times, lower acquisition cost, and better product quality will automatically improve shareholder value and employee satisfaction (Womack 2001), (Womack and Jones 1996). Some form of causal value flow to other stakeholders is implicit in this assumption of the pure customer focus. However, the proof of this causal value flow has yet to be explicitly or empirically proven. In the multiple stakeholder view of LAI, it is proposed that aggregate value can be improved if one considers the value delivery function to all stakeholders, as opposed to focusing just on the customer value delivery function (Mize and Hallam 2002), (Murman et al. 2002), (Nightingale 2002b). This implies that the enterprise management team will look at the direct flow of value to the stakeholders and determine how to adjust the flows in order to attempt to optimize some enterprise-level objective function. The major distinction between the Womack and Jones view and the LAI view is that the former assumes all else works out for the best by maximizing one value stream (the customer value stream), whereas the LAI approach argues that multiple stakeholder value streams and their interactions should be considered in their totality in view of achieving a better result. Again, the explicit or empirical proof for either of these conjectures remains to be seen.

In the Womack and Jones argument, maximum enterprise value (V_{ENT}) is considered to be reached when customer value (V_{CUS}) is maximized. This would result in Equation 2 as follows

$$\text{Max}(V_{ENT}) \text{ occurs at } dV_{ENT}/dV_{CUS} = 0 \qquad \text{Equation 2}$$

In order for this relationship to hold, enterprise value would have to be purely a positive increasing function of customer value. This would mean that each stakeholder value (V_i) was also a positive increasing function of customer value as in Equation 3, or a positive increasing function of customer value and constant stakeholder values (V_j) as in Equation 4.

$$V_{ENT} = \sum V_i; \text{ where } V_i = f(V_{CUS}) \qquad \text{Equation 3}$$

$$V_{ENT} = \sum V_i + \sum V_j; \text{ where } V_i = f(V_{CUS}), V_j = \text{constant} \qquad \text{Equation 4}$$

Thus, the operating assumption of the lean enterprise under these conditions is that in order to maximize enterprise value, the delivered customer value should be maximized. While proving this argument may be difficult, one need only show the existence of non-constant stakeholder values and/or stakeholder values that are non-positively increasing in customer value to disprove the argument.

From the LAI perspective, the enterprise value is actually a function of the value proposition of each of the stakeholders, as shown in Equation 5.

$$V_{ENT} = \sum_{i=1}^{N} V_i \qquad \text{Equation 5}$$

Thus, the enterprise value is a multivariate function of N stakeholder vectors. Each stakeholder vector is composed of m elemental value metrics (v_i) as in Equation 6.

$$V_i = \sum_{k=1}^{m} \alpha_{ik} v_{ik}^{\beta_{ik}} \qquad \text{Equation 6}$$

Therefore one can see that the Womack and Jones case is only a special case of the LAI perspective as it optimizes along one stakeholder value function. It follows that unless the delivery of customer value is the cause of the delivery of all other stakeholder values, then the LAI approach will yield a better delivery of Enterprise Value.

As an example, consider the employee value function that is, in part, based on a positive work environment (see Table 13). Part of the proposed employee value taxonomy is that a positive work environment involves valuing employees' skills and ideas. Employees who feel their ideas and skills are valued will thus have a higher level of satisfaction with their job (a positive α in equation six with respect to employee value). This results in greater value delivery to the employee stakeholder, without being dependent on customer value delivery. Thus, from this simple example it would appear that the LAI perspective holds. Furthermore, employees who feel that their skills and ideas are valued will be more willing to participate and contribute to process improvement efforts which in turn can lead to even better customer value delivery (i.e. $V_{customer} = f(V_{employee})$). This implies a non-zero-sum-game since there is a potential to increase value delivery to one stakeholder without decreasing value delivery to another stakeholder. A further implication is that a multi-stakeholder focus can increase overall enterprise value delivery.

3.2.3.3. Multi-stakeholder perspective as a source of sustainability

A final consideration of the multi-stakeholder perspective of the lean aerospace enterprise is the market conditions for investors, labor, and customers. According to Donovan, most companies define value in terms of a particular dimension such as value for shareholders, customer satisfaction, or operating efficiency. By definition, this approach implies a trade-off between stakeholders that causes organizations to fall short of optimal value delivery (Donovan et al. 1998, pp.18). Donovan argues that the most successful companies create enterprise value by creating value for all of their stakeholders, customers, shareholders, employees, suppliers, the community and other entities by searching for win-win, mutually value-enhancing situations such as those discussed in the preceding section.

From a stakeholder perspective, Donovan claims that every company has three primary stakeholders, namely customers, shareholders, and employees. He argues that these stakeholders operate in an open market where they attempt to maximize their derived value from participating in an enterprise. Under competitive pressures, he argues that unless the stakeholders receive sufficient value, they will go elsewhere - customers will go to competitors, employees will look for jobs in other firms, and shareholders will sell their stock and invest elsewhere (Donovan et al. 1998).

Evidence of this type of market competition appeared during the late 1990's with the prevalence of the "new economy". While it has since passed away and has become known as a "false economy", the competitive pressures placed on enterprise stakeholders were significant in the labor and capital markets. Rebentisch, in summarizing the results of an aerospace industry roundtable on the topic, highlighted that during the "new economy" upswing, new labor was not entering the industry and existing labor was exiting the industry in favor of entering the more lucrative "dot-com" market. At the same time, investment in aerospace enterprises was diminishing as capital moved into the new economy with promises of incredibly large returns (Rebentisch 2000). While the market has since returned to its pre-dot-com position, the affect on the industry suggests that to sustain an enterprise, a multi-stakeholder perspective is necessary under the competitive pressures for labor, capital, and customers. Attempting to maximize multi-stakeholder value delivery, using win-win situations as discussed in the previous section, will help ensure that competitive pressures do not dismantle the enterprise.

3.3. Conclusions

From this chapter it appears that a Lean Aerospace Enterprise that looks beyond manufacturing can achieve greater gains than one that does not. There are systemic issues with respect to firm functions and processes, and inter-firm issues that are sources of systemic waste. Addressing these systemic issues with lean principles and practices can provide faster lead-times, lower cost and better quality. The consideration of lifecycle phases in product development and enterprise operation can lead to the creation of better enterprise lifecycle value delivery. Furthermore, the consideration of multiple-stakeholder perspectives in a lean enterprise is a source of innovation and systemic improvement. The consideration of the value exchange between stakeholders can lead to greater enterprise value delivery and the multi-stakeholder perspective will contribute to the sustainability of the enterprise.

Chapter 4 - The Strategic Value of the Lean Enterprise

The previous chapters have introduced the concept of lean, first in manufacturing, and then in the aerospace industry. The data seems to support that leaner companies are able to deliver products and services faster, better, and cheaper than their less lean competitors. This chapter explores the literature surrounding the lean enterprise as a source of a competitive advantage. An overview of strategy in the business context is provided, followed by a discussion of lean as an operational strategy that can lead to competitive advantage. The discussion leads to organizational behavior change as a major factor in creating and maintaining the competitive advantage over some finite period of time. A discussion of both short-term and long-term competitive advantage follows, along with some of the difficulties and issues associated with a lean enterprise operational strategy.

4.1. Strategy and Business

In its most generic definition, a strategy is a *"plan, method, or series of actions designed to achieve a specific goal or effect"* (Wordsmyth 2001). Rooted in military campaigns, the word "strategy" originated with the art of a commander-in-chief projecting and directing larger military movements and operations of a campaign (to achieve some goal or objective). The word "strategy" is distinguished from the word "tactics", which deals with the *"handling of forces in battle or in the immediate presence of the enemy"* (Oxford_WWW, 2001 #65). Tactics are the actions and activities employed to execute and achieve the goals of a strategy. While rooted in military history, the formal use of strategies and tactics are a major element of modern business literature and theory. Four contextual definitions of strategy are summarized by Mintzberg as follows (Mintzberg 1987, pp.11-12):

- The *basic definition* of strategy is a plan, method, or series of maneuvers or stratagems for obtaining a specific goal.
- *Military* strategy is concerned with drafting the plan of war...shaping the individual campaigns within these plans, and deciding on the individual engagements with the enemy.
- *Game theory* strategy involves a complete plan; a plan which specifies what choices (the player) will make in every possible situation.
- In *management*, strategy is a unified, comprehensive, and integrated plan designed to ensure that the basic (business) objectives of the enterprise are achieved.

This thesis is concerned with the creation of the lean aerospace enterprise, thus strategy will be discussed in a business and management context. From a business perspective, an organization's strategy begins with the desire to outperform the market (Oster 1999). A strategy, in this context, is defined as a set of concrete (well-defined) plans to help the organization accomplish this goal. Fundamentally, a strategy is a commitment to undertake one set of actions rather than another, and this commitment necessarily describes the allocation of resources (Oster 1999, pp.2). Porter argues that strategy involves the creation of a unique and valuable market position involving a different set of activities than one's competitors (Porter 1996). Porter's belief is that the fundamental reason for a strategy is that there is no one ideal position to take. If there were one ideal position, there would be no need for strategy. Equally so, if market competition was a pure game, then there would only be the set of pre-determined strategies associated with the game, and hence a defined set of tactical moves associated with the competition. In the case of businesses competing in a market system, there are such a large number of indeterminate, unpredictable (let alone controllable), and changing variables that there is a continuous need for a strategy. As such, Porter argues that strategy is based on making trade-offs in a competitive environment. His logic is that without trade-offs there would be no need for choice and thus no need for strategy. From his perspective, the essence of strategy is choosing what not to do while creating fit among a company's activities (Porter 1996).

Strategies are made in advance of the actions to which they apply, and they are developed consciously and purposefully (Mintzberg 1987, pp.11). The literature on the subject ultimately argues that a strategy is needed for a successful business for two main reasons, to make money, and to keep making money. First, if what you do is not unique in some respect, and everyone can do it, then you cannot make money at it (Oster 1999, pp.11). Second, no advantage is permanently sustainable in a competitive market because others will eventually imitate or replace what the incumbent firm does (Drucker 1964), (Clemson et al. 1996), (Wiggins and Ruefli 2002). This leads to the realization that satisfaction with the status quo is a recipe for failure as competitors will eventually find a means to capture the incumbent's market share (Hunter 2000). As a result, business strategies must always be evolving in an attempt to maintain competitive advantage.

4.1.1. Types of Strategy in a Business Environment

Even within a business context, the word strategy is used to mean different things. Hunter, in summarizing Cusumano's course notes, defines three basic types of strategy, namely *Corporate, Business, and Functional* (Hunter, 2000). *Corporate* strategy has the goal of linking multiple businesses so that their sum (in terms of performance) is greater than the individual parts performing separately (Hunter, 2000). *Business* strategy is employed at the level of actual market competition, where specific markets are served in a specific manner (Hunter, 2000). Porter contends that market competition only occurs at the business level (Porter 1987). The business strategy is intended to define how the business will compete in its specific market with specific products and/or services. Finally, Hunter describes *Functional* strategy as the plan for managing specific activities in the value chain to achieve business objectives (Hunter 2000).

The term "functional" that Hunter uses may actually be misleading, as many businesses have functions such as HR, Engineering, Sales, Finance, Legal, etc. What is perhaps more appropriate here is defining "*Operational*" (or operating) strategy - how one structures and executes sequences of activities within the organization in order to achieve business objectives. The *Operational* strategy would then be made up of both *Functional* strategies and *Process* strategies. Specific *Functional* strategies will exist within the *Operational* strategy to establish goals and objectives for functional units that provide specific expertise within the organization. *Process* strategies would establish goals and objectives for value delivery and exchange that occurs across functional and corporate boundaries. The *Operational* strategy will thus enable the strategic objectives outlined in the *Business* and *Corporate* strategies while in itself will be enabled by the *Functional* and *Process* strategies it creates.

While Hunter's definitions of the types of strategy are characterized by what level of the organization they affect, Mintzberg characterizes strategies based on their execution characteristics. In this case, Mintzberg identifies five primary classes of strategy, namely *Plan, Ploy, Pattern, Position,* and *Perspective* (Mintzberg 1987). The *Plan* strategy is defined as a consciously intended course of action or guideline(s) to deal with a situation. A *Plan* strategy deals with how leaders try to establish direction for the organization and how to set the organization on a pre-determined course of action. The *Ploy* strategy is intended to outwit or outmaneuver an opponent. The *Ploy* strategy takes us into the realm of direct competition, where threats, feints, and various other maneuvers are employed to gain advantage over competitors. The *Pattern* strategy is a consistency in behavior and focuses on action, reminding us that the value of a strategy is naught if it does not take behavior into account. The *Position* strategy is focused on locating the organization within the business environment and is aimed at creating situations for collecting economic rents and finding ways to sustain them in a competitive market. A *Position* strategy encourages us to look at organizations in context, specifically in their competitive environments, defining how they find their positions and how they protect them in order to meet, avoid, or subvert competitive pressure (this is similar to Porter's Five Forces Analysis (Porter 1979). Finally, the *Perspective* strategy suggests that strategy is a concept focused on the reflections and actions of the collectivity. Specifically this strategy focuses on how intentions diffuse through the group of people to become shared as norms and values, and how patterns of behavior become deeply ingrained in the group (Mintzberg 1987, pp.21).

4.1.2. Factors Affecting Strategy

According to Hunter, the ability to craft good strategy comes from understanding three factors: *External Factors, Internal Factors, and Strategic Positioning* (Hunter 2000b). *External Factors* include elements which are beyond the direct managerial control of the business. External factors include customer needs, competitors, and the industry structure. The latter of these is further defined by Porter's five forces as the basis for analytically establishing fit or position for the business within the market. Porter's five forces are buyer power, substitutes, supplier power, barriers to entry, and rivalry (Porter 1979). Porter also identifies other external forces such as the government, anti-trust laws, the regulatory environment, and competitive history, all of which play an important role in the aerospace industry. Porter has long-supported the view that business strategy is based on positioning and states that *"...the corporate strategist's goal is to find a position in the industry where his or her company can best defend itself against these forces and influence them in its favor"* (Porter 1979). All of these factors will affect the attractiveness of the business by ultimately influencing prices and profits.

Hunter defines the *Internal Factors* central to strategy formulation to include firm-specific unique competencies (and rigidities[3]), vision and leadership, the structure of the business organization, the existing organizational culture, and the ethics and virtues with which the organization and its employees operate (Hunter 2000b). The internal factors are the elements of the organization over which the firm can exact some control in an effort to achieve its business strategy. The lean enterprise relies on the unique development and structure of internal factors as the basis for its operational strategy.

---

[3] Core rigidities are elements of the organization that act as resistors to adaptation in the business environment. Dorothy Leonard-Barton argues that core competencies can eventually become core rigidities if firms do not evolve their competencies in line with market needs, leaving the firm with a set of practices and capabilities that are out of line with the necessary current competitive capabilities (Leonard-Barton 1992).

The *Strategic Positioning* factor addresses issues such as value, competitive advantage, the rules of competition, and sustainability (Hunter 2000b). In Hunter's view, successful strategies are those that aim to create superior value for customers, such as lower cost or more innovative products. Porter supports the same idea in saying that firms must create greater value for customers, or create equivalent value at lower cost, or both (Porter 1996). From a strategic standpoint, this is the goal of the lean enterprise; the delivery of greater value. Competitive advantage will arise from the firm's ability to deliver this greater value by means that are difficult for competitors to imitate (Porter 1996) (Oster 1999) (Hunter 2000b) (Hamel 2000). Porter states that activities are the basic unit of competitive advantage and that overall firm competitive advantage (or disadvantage) is a result of the interaction of all activities in a company (not just a select few) (Porter 1996). In his opinion, it is a holistic view of all activities as an interacting system that is needed to create real competitive advantage, and not to focus on one or two key areas without regards for the others. In this model, the competitive advantage will grow from the entire system of activities. This is indeed the goal of the lean enterprise, to look at the systemic-level sources of competitive advantage for delivering greater value than competitors.

To create competitive advantage, Hunter argues that firms must often change the rules of the game by reinventing the means by which a product or service is made, sold, or delivered (Hunter 2000b). It is important to note that this redefinition of the game is in addition to the potential innovation in the product or service itself. This supports the notion that customer value is composed both of what they get and how they get it. From the discussion that occurred in the previous two chapters, the lean enterprise would appear to change the rules of the game in favor of creating competitive advantage based on how the value is created and delivered.

However, a company can only outperform its rivals over an extended period of time if it can establish a difference that it can preserve (Porter 1996). This raises the issue of sustainable competitive advantage. Modern competitive theory clearly supports the view that a single source of competitive advantage is not sustainable in the long run due to the dynamic nature of the market place (Oster 1999) (Hunter 2000b). The difficulty of imitation of the source of competitive advantage will affect the length of its sustainability, while changing external conditions will determine whether it remains a source of competitive advantage. For long-term sustainable competitive advantage, a mix of product differentiation, operations efficiency differentiation, and flexibility in operations and strategy is needed (Hunter 2000b). While the lean enterprise will help with improving these qualities in a firm, their continual modification and recombination are necessary to maintain the difficulty of imitation, and thus sustain the competitive advantage. This implies that any successful lean enterprise transformation effort cannot be a one-time event, but rather a continuous evolution and adaptation of the operating system aimed at delivering greater value with fewer inputs.

The advantage to the lean enterprise strategy is that it is based on the interaction of all value-delivering activities within and beyond the firm, which Porter contends is more difficult for a rival to duplicate than a particular sales-force approach or single process technology (Porter 1996). Hunter argues that firms that sustain their competitive advantage over long periods of time most likely engage in a continual process of creating and destroying multiple competitive advantages and competencies over time to stay ahead of competitors (Hunter 2000b). An empirical study of 6771 firms in forty industries over twenty-five years was conducted to test whether any businesses do sustain competitive advantage over time, as measured by sustained superior economic performance (Wiggins and Ruefli 2002). It was found that only a small number of firms exhibit superior economic performance. Of those that do exhibit superior economic performance, few sustain it for an extended time period (10 years), while an even rarer few sustain it for multiple decades. Furthermore, the group that makes up the superior performers experiences little composition stability (i.e. the superior performers continuously change over time), which supports the view discussed above.

From a strategic standpoint there are numerous, if not an infinite assortment of strategies available for firms to attempt to gain sustainable competitive advantage. Ultimately, the dynamic nature of internal and external factors necessitates the continual evolution and adaptation of strategies to maintain competitive advantage, and from empirical evidence, firms will most likely experience a loss of competitive advantage after a brief period of having a competitive advantage unless they are able to create new sources of competitive advantage. The lean enterprise as an operational strategy would appear to be source of competitive advantage as it can deliver greater value with fewer inputs than non-lean enterprises. However, the lean enterprise alone is not the sole strategy an enterprise needs to consider. Koenigsaecker highlighted the fact that the company he formerly headed, Jake Brake, was a shining example of a lean producer (Koenigsaecker 2003). However, he described advents in electronically actuated engine brake technology that are on the verge of replacing Jake Brake's existing product technology. The company has made the effort to now develop capabilities in this new technology so as not to be pushed out of the market. Thus, even a lean enterprise must maintain awareness of the need for business strategy, in addition to the lean operational strategy, to sustain the enterprise. The following section will look into reasons why it may be difficult to imitate a lean operational strategy, and how this can lead to an enterprise's sustainable competitive advantage over some finite period of time.

4.2. The Lean Enterprise as an Operational Strategy

Historically, lean has been shown to improve the value delivery process in manufacturing by eliminating waste and improving value flow relative to mass or craft production techniques (Ohno 1988),(Womack et al. 1990),(Womack and Jones 1996),(Hines et al. 2000),(Murman et al. 2002). In this sense, lean manufacturing was a functional strategy, outlining the plan for how the manufacturing function would operate. As discussed in the previous chapter, the success of this functional strategy was limited by its small impact on systemic costs, quality, and time associated with the enterprise. While lean in manufacturing focuses on improving the process of building a product, the ***lean enterprise is an operational strategy*** focused on improving business operations, both within functions and across functions in enterprise processes, for delivering value to enterprise stakeholders. The improvement in business operations is an operational strategy based on the belief that the structuring and execution of functions and processes can be a source of differentiation in internal factors that will improve an enterprise's position in the market by creating better lifecycle value for its customers with equal or fewer resources than its competitors. Furthermore, the multi-stakeholder perspective of the lean enterprise also creates better value for its many stakeholders above and beyond the customer value delivery.

Creating a lean enterprise operational strategy touches on elements of plan, position, pattern, and perspective strategies as discussed by Mintzberg (Mintzberg 1987). The lean enterprise has elements of a plan strategy because it requires leadership to set the organization in a certain direction based on pre-defined needs aimed at achieving the goals associated with lean operations. Achieving successful lean enterprise transformation is a position strategy because it results in improving the current competitiveness of the enterprise in its current business environment. The lean enterprise is both a pattern and perspective strategy because it requires enterprise members to behave in a manner that is different than traditional operations with explicit value flow as the focus of the firm's employees.

From a strategic perspective, Rouse claims that there are seven basic strategic challenges that an executive must face in business, namely (Rouse 2001, pp.xv):

1) *Growth:* gaining share in saturated/declining markets
2) *Value:* enhancing relationships of processes to benefits and costs
3) *Focus:* pursuing opportunities and avoiding diversions
4) *Change:* competing creatively while maintaining continuity
5) *Future:* investing in inherently unpredictable outcomes
6) *Knowledge:* transforming information to insights to programs
7) *Time:* carefully allocating the organization's scarcest resources

The lean enterprise addresses some of these challenges. In Rouse' discussion of growth he claims that most managers come to the realization that a stable organization experiencing neither growth nor decline is difficult to achieve (if achievable at all), given the dynamic nature of the business environment in which businesses operate. Furthermore, he contends that to simply maintain current operational performance levels a company must be pursuing some form of growth strategy (Rouse 2001, pp.28). For industries in saturated or declining markets, which some have argued describes the aerospace industry (Murman et al. 2000), this becomes even more difficult as the growth has to be achieved by capturing market share from one's competitors or reconfiguring the business strategy by investing in new markets and businesses. Utterback defines a declining industry as being in its specific phase where the industry competes primarily on cost through process innovation (Utterback 1994).

The lean enterprise addresses two issues with respect to growth. First, the innovation of the operating processes leads to reduced costs, and with the addition of improved quality and lead-time, can lead to the capture of market share from competitors. Second, the lean enterprise is a potential source of freed-up scarce resources. Inventory reductions can provide additional working capital, increased productivity can provide additional intellectual capital, and reduced factory space can be made available for other uses. This gives the company an instant portfolio of strategic resources that it can choose to dispense of for short-term profitability, or reinvest in the company for breaking into new markets and improving long-term (future) performance, growth, and sustainability.

Rouse contends that value, or more specifically understanding how the enterprise provides value to the stakeholders, is a driving strategic priority (Rouse 2001, pp.61). The lean enterprise creates more stakeholder value by addressing losses due to systemic process deficiencies and attempts to maximize enterprise value by looking for win-win situations that do not result in zero-sum value exchanges between stakeholders, but rather positive sum situations that benefit multiple stakeholders.

In Rouse' opinion, focus is the ability to pursue true opportunities while avoiding diversions (Rouse 2001, pp.90). This is similar to Drucker's ideas about possessing the necessary skill and discipline to direct scarce resources at true business opportunities versus pet projects and keep-busy work that provides no return to the business (Drucker 1964). In its altruistic form, the lean enterprise is an environment that focuses on value creation and waste elimination. If, by definition, diversions are waste and opportunities are valuable, then an organization that thinks in terms of value will inherently have a better focus.

In terms of the need for change, Rouse argues that, historically, most businesses fail to change from a pre-existing style of operating to a new style, and are eventually supplanted by new entrants that almost inevitably replace the incumbents (Rouse 2001, pp.117). This issue has been presented in literature as a firm's core competencies turning into core rigidities (Leonard-Barton 1992), (Hunter 2000b). From the perspective of responsiveness to change, the lean enterprise, by definition, is a more tightly coupled system than traditional mass or craft manufacturing companies. Through better communications and interface linkages, the lean enterprise is intent on continually reinventing and improving itself in response to the need for changing stakeholder value propositions. As compared to a traditional enterprise, a lean enterprise should thus be more agile and able to adapt to change, leading to sustainability of the enterprise's competitive advantage. Rouse promotes the long-held notion that the future is a challenge because it necessarily involves investing in uncertain outcomes. This issue becomes more prominent as the time scale expands and as the probability of payoff becomes less predictable (Rouse 2001, pp.145). Creating a lean enterprise is not a guaranteed payoff, as it takes time and effort just to establish lean manufacturing (as shown in Chapter 2), so an even larger scale change may take longer and be more difficult, thus the outcome is less certain. However, the arguments in Chapter 3 do suggest that the lean enterprise has the potential for large payoffs, especially when coupled with the availability of freed-up resources.

Finally, Rouse contends that knowledge, in terms of information flow and management, is a key strategic challenge to enterprise leadership. Unlike the enterprise resource planning (ERP) objective of automating all information exchange processes with the goal of making them more efficient, the lean enterprise is aimed at making the information flow effective by focusing on its value (i.e. the right information available when needed, where needed, and of the quality and amount needed). As opposed to applying an information exchange medium on top of existing enterprise processes, as with an ERP system, the lean enterprise uses the right sized technologies to enable information exchange in the correct manner. Once all information and knowledge-based processes work effectively, then efficiency concerns can be addressed, potentially with a large-scale system like ERP. As noted in a presentation, an aerospace industry representative estimated that his company had spent approximately $225 million dollars to install an ERP system without having first created effective information exchange processes (Kessler 2001). As a result, the existing processes were automated and made efficient, but remained largely ineffectual and encumbered as they did not serve the real need of the information users. In his opinion, the company essentially threw their investment away in this effort.

It would seem that the lean enterprise as an operational strategy meets most, if not all, of the strategic needs of business executives espoused by Rouse. However, improvements in operations has been called an improvement in Operational Effectiveness by Porter (Porter 1996). Porter defines Operational Effectiveness (OE) as *"performing similar activities better than a rival."* This definition seems adequate for describing companies that compete in the market by delivering similar products or services. A more rigorous definition may be needed to account for niche market suppliers that have only one or no rivals. Porter contends that few companies have successfully competed over an extended period of time based solely on operational effectiveness, and furthermore, staying ahead of one's rivals becomes harder as time goes by. This argument is founded in Porter's belief that the rapid diffusion of best practices from leading companies to rivals will occur, giving them the same operational capability. When it comes to lean, he claims that OE is at the heart of Japanese techniques such as TQM and JIT, which aim to improve the same activities that rivals also perform. Porter contends that there is potential for rivals to easily copy OE efforts as they relate to industry "best practices" and result in the adoption of common techniques for activities across the industry, resulting in homogonization and competitive attrition (Porter 1996). This argument would lead one to question the strategic value of the lean enterprise, especially if it is not possible to compete based on an operational strategy. However, a more detailed look at this argument and the literature surrounding diffusion of knowledge appears to show the basis of why the lean enterprise is an effective operational strategy.

4.3. The Strategic Value of Knowledge and the Economics of Information

The idea of diffusion of best practices shares commonality with some of the main ideas found in the literature on the economics of investing in basic scientific research. In work concerning the economics of information, Arrow introduces the notion that invention is essentially the creation of knowledge, and that many of the properties of knowledge make it a public good (Arrow 1962). Arrow states that *"The central economic fact about the process of invention and research is that they are devoted to the production of information"* (Arrow 1962, pp.616). In summarizing the work in this field, Stephen comments on the public nature of knowledge as having specific characteristics, namely, it is not depleted when shared, and once it is made public others cannot easily be excluded from its use. Furthermore, the incremental cost of another individual gaining the knowledge is virtually zero and, unlike the case with other public goods, the stock of knowledge is not diminished by extensive use, but rather, it is often enlarged (Stephan 1996). It is interesting to note that the observation of these characteristics of knowledge have been around for quite some time, as Thomas Jefferson once wrote:

> *"If nature has made any one thing less susceptible than all others of exclusive property, it is the action of the thinking power called an idea, which an individual may exclusively possess as long as he keeps it to himself; but the moment it is divulged, it forces itself into the possession of everyone, and the receiver cannot dispossess himself of it. Its peculiar character, too, is that no one possesses the less, because no one possesses the whole of it. He who receives an idea from me, receives instruction himself without lessening mine; as he who lights his taper at mine, receives light without darkening mine"* (from Stephan 1996, pp.1201, which is quoted from The Jefferson Cyclopedia, Vol. 1, Ed.: John P. Foley, New York, Russel and Russel, pp.433 1967).

Arrow's work provided a vocabulary for describing what Jefferson observed. In particular, Arrow characterized knowledge as being indivisible, having uncertain outcomes when applied, and of being innappropriable (Arrow 1962). The creation of a quanta of knowledge necessitates a fixed expense in the form of investment in creating the knowledge. Once created, however, the marginal cost of providing the knowledge to others is essentially zero. There is no further cost of ownership associated with the knowledge, and sharing the knowledge necessitates providing the full quanta to another individual.

Uncertainty plays a role, since the economic return on owning the knowledge is unpredictable, which in turn makes it difficult to contract for the knowledge. Finally, it is difficult to allocate property rights to knowledge, especially considering that once it has been gained by another individual they cannot get rid of the knowledge they now possess. The market for knowledge is inherently imperfect because the buyer must know the information in order to value it (Rosenberg 1990). Once known, however, there is no incentive to pay for it. This leads to the inability to extract rents from the exchange of the knowledge. Porter's argument concerning operational effectiveness is mainly along the latter line of reasoning. His claim is that OE is not a source of competitive advantage because it is based on knowledge, and knowledge is readily transferred at no cost to the recipient. Thus, once the recipient has the knowledge, he/she can exploit the knowledge to his/her advantage, irrespective of the effort the knowledge developer expended on its creation.

From a knowledge creation standpoint, it thus seems that there may be a second mover advantage in knowledge diffusion situations, as the second mover can utilize the knowledge created by the first mover without having to invest in its development, and thus improve his/her OE at no cost. Thus, all else being equal, the second mover extracts the same operational improvements and benefits with no effect on the enterprise's expenses, as no cost was incurred. In fact, in studying the distribution of profits from technological innovation, Teece concludes that competitors and imitators have profited more from the innovation than the firm to first commercialize it, and furthermore, a fast second or slow third mover may outperform the innovator (Teece 1987, pp.185). In his view, imitators can often outperform innovators if they are better positioned with respect to critical complementary assets. Both Nelson and Rosenberg support this argument in saying that more diversified firms with complimentary assets will be better positioned to exploit new knowledge (Nelson 1959), (Rosenberg 1990).

Given the three issues about information, namely indivisibility, uncertainty and inappropriability, it would seem that Porter's argument holds in that there is no competitive advantage achievable with OE, since others will find out what is going on in the best firms via "best practices" and exploit the knowledge. However, while the knowledge transfer may seem free, or close to free, its exploitation is neither instantaneous nor guaranteed to be successful. As a result, there are three issues that counter the OE conclusion and support the idea of the lean enterprise as a successful operational strategy, namely:

1) Non-zero marginal cost for acquiring new knowledge
2) Absorptive capacity for understanding new knowledge
3) Organizational behavior change to exploit new knowledge

4.3.1. Non-Zero Marginal Cost of Acquiring New Knowledge

In the first issue, Dasgupta and David make the note that research or innovation findings only become a public good when they are codified in a way that others can understand. The distinction, therefore, is often drawn between knowledge, which is the product of research and innovation, and information, which is the codification of knowledge (Dasgupta and David 1994, pp.493). It appears that the marginal cost of information with respect to lean is greater than zero because users must incur the direct cost associated with codifying the knowledge. Even when the knowledge has already been codified, however, there are costs associated with purchasing and accessing sources of information, attending conferences, and/or hiring consultants as has been the case with many companies trying to become lean (Constantine 2003). Additionally, and perhaps more significantly, there is the opportunity cost of the employees time associated with learning the information (Stephan 1996, pp.1200).

This non-zero marginal cost may be insignificant for a large company, but may be very significant for a small firm that is very sensitive to any expenses. As a result, large companies might invest more readily in the acquisition of the new knowledge. However, smaller companies are known to be more flexible and adaptable than very large companies, and as a result could adopt and exploit the new knowledge more quickly, thus, increasing their potential for economic returns on the cost of the knowledge. However, if the lean enterprise requires systemic change beyond a firm's legal boundaries, the smaller firm may not be able to exert enough influence on the rest of the system to make it change, resulting in a decreasing probability of large returns on the investment in the knowledge. In this instance, the larger firm may have more power and leverage to instigate systemic change, and thus increase its potential for larger economic returns, especially if it accounts for a greater portion of the systems costs and revenues. Additionally, the larger firm may have more complimentary intellectual assets to exploit the knowledge. This brings us to the second issue concerning the strategic value of the lean enterprise, absorbing new knowledge, which is stated by Stephan in saying *"Information, of course, is only of use to those who possess the requisite intellectual framework (to exploit the knowledge)"* (Stephan 1996).

4.3.2. Absorptive Capacity for Understanding New Knowledge

Cohen and Levinthal's work promotes the argument that the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to a commercial end is critical to its innovative capabilities (Cohen and Levinthal 1990). They label this capability the firm's "absorptive capacity" (AC). Furthermore, Cohen and Levinthal suggest that absorptive capacity is largely a function of the firm's level of *a priori* knowledge in the area of interest. The development of absorptive capacity, and in turn innovative performance, is theorized to be history or path dependent, and thus the lack of investment in a specific expertise may foreclose the future development of a capability in that expertise. Furthermore, it is proposed that if the firm does not develop its AC in some initial period, then its beliefs about the availability of innovative opportunities may not change over time. This ca limit a firm's ability to adapt and change, which can threaten sustainable competitive advantage. This suggests that even with the process innovation knowledge associated with the lean enterprise transferred to the firm, it may be unable to act on it if it does not have the minimum store of intellectual capability and experience to recognize the value of the innovation and/or act on and exploit the innovation to its advantage.

Cohen and Levinthal claim that firms conducting their own research and development (R&D) are better able to use externally available information (in those fields) due to their stock of R&D knowledge (Cohen and Levinthal 1990). They claim that accumulated prior knowledge increases both the ability to put new knowledge into memory and the ability to recall and use it. This idea is in agreement with cognitive science, which considers learning to be cumulative, and furthermore, learning performance is greatest when the object of learning is related to what is already known (Bransford et al. 1999). Thus, a conclusion can be drawn that an organization's AC will depend on the individual employees' AC, which requires the provision and promotion of individual AC development. This conclusion is important because it places the success of the lean enterprise operational strategy on the shoulders of the employees, or said differently, it suggests that **a successful lean enterprise operational strategy is dependent on the abilities of the employees to understand and exploit the principles and practices of lean.**

This result leads directly to the consideration of a firm's intellectual capital as a source of differentiation and strategic importance. Stewart discusses this realization from the perspective of a knowledge-based economy, while Rebentisch summarizes the concerns from the perspective of the aerospace industry competing for intellectual resources (Stewart 1999), (Rebentisch 2000). Furthermore, this realization falls directly into the debate over the role of employees in the firm. While traditional organizations in the mass manufacturing past viewed people as a cost that needed to be monitored and controlled (called Theory X by MacGregor), the 21st century organization counters this by considering employees an asset that should be valued and developed (called Theory Y by MacGregor) (Kochan et al. 2002, pp.4). The lean enterprise as an operational strategy is rooted in the capabilities of the employees, and is clearly based on the latter of these two theories.

4.3.3. Organizational Behavior Change for Exploiting New Knowledge

The third issue that supports the lean enterprise as an operational strategy deals with organizational behavior change. The aerospace industry has been characterized as a very traditional, hierarchically managed industry using a mix of craft and mass production techniques. The lean aerospace enterprise is, by definition, a new way of operating. This means that creating the lean aerospace enterprise will require changing the types of interactions, cues, incentives, and activities that people undertake in their daily work activities. In other words, organizational behavior needs to change. The change process is difficult and the outcome is unpredictable, and as a result, those who succeed may enjoy performance advantages over rivals who do not.

Organizational behavior change takes time, is difficult, and may not achieve the intended objectives or produce the desired results (Schein 1999). The change to a lean enterprise requires the organization to function in a totally new manner compared to traditional mass or craft producers. This means that significant change in roles, duties, incentives, job definitions, skills, and personal interactions are required of the members of the enterprise, and especially of the employees in the firm leading the effort to create the lean enterprise. Transition to a lean enterprise is a form of planned change, which Robbins defines as change activities that are intentional and goal oriented (Robbins 1998, pp.629). Robbins further defines two types of planned change, namely first order change and second order change. First order change is considered a continuous, gradual, and linear change process that does not require any real change in an organization's members' assumptions about their roles and responsibilities. Second order change is considered to be multidimensional, discontinuous, and radical, requiring a major shift in the assumptions and behaviors of an organization's members. Robbins states that one of the most documented findings from behavior studies of both individuals and organizations is that they will both resist change (Robbins 1998, pp.632). Furthermore, radical or second order change will create more resistance than incremental, first order change. Individuals will resist change as a result of many factors, including habit, security, economic factors, fear of the unknown, and selective information processing (Robbins 1998, pp.633). While organizations are composed of individuals with their inherent resistance to change, the organization adds to the resistance equation via structural inertia. These organizational resistance elements include group inertia, having a limited focus for the change effort, and creating threats to expertise, threats to established resource allocation, and threats to established power relationships (Robbins 1998, pp.634). In the context of this thesis, creating the lean aerospace enterprise can be considered a second order change, and by the above definition will result in significant resistance from both the individual employees and the organization.

Schein describes culture as underlying the behavior of an organization. Culture, as he defines it, is *"the shared tacit assumptions of a group that it has learned in coping with external tasks and dealing with internal relationships. Although culture manifests itself in overt behavior, rituals, artifacts, climate, and espoused values, its essence is the shared tacit assumptions"* (Schein 1999, pp.186). Furthermore, Schein argues that people in mature organizations do not cling as tightly to the culture as do people in new or growing organizations. However, he contends that it is much more difficult to change the more mature organizations, as the culture has become imbedded in its structure and routines (Schein 1999, pp.171). The aerospace industry is a mature industry that dates back to pre-WWII aircraft manufacturers and has grown into the large corporations of today, with many diversified lines of business, expertise, and technologies. By Schein's reasoning, it will be a difficult industry to change as the culture in these organizations has become an implicit element of the *modus operandi*.

Beyond the maturity argument as an indicator of the potential resistance to change in the aerospace industry, there are characteristics of the industry that lead one to consider that any change effort will be difficult. By definition, the aerospace industry exhibits a certain amount of risk aversion, as it has a history of dealing with life-critical and mission critical systems. The practice of systems engineering as a form of program management methodology has permeated the industry since the Atlas program (Hughes 1998). In this environment, individuals have been trained to subdivide large-scale design problems into sets of smaller and smaller problems that can be handled by individuals and small teams, with little view of how their sub-element affects the system as a whole. This environment is supported by strong functional job descriptions and promotion paths based on individual performance incentives, amidst multiple layers of management hierarchy.

In addition to the working culture that has emerged in the aerospace industry, the government acquisition environment also poses a significant challenge to change efforts, as the government has and does play many roles, including customer, regulator, and enabler of technology development (Murman et al. 2002, pp.18). This is an important issue, as approximately half of the industry's revenues arise from government contracts, of which roughly two thirds (of the 50%) are related to military systems acquired by the Department of Defense (AIA 2001). If the ability to change the industry into a lean enterprise depends to any extent on changing the interactions between the government customer and the industrial supplier, then the challenge for change will become even more difficult, as the culture of the political organization of the government and the Department of Defense (DOD) is probably more entrenched and less amenable to change than any business organization that faces economic pressures to change.

The organizational structure of a lean enterprise would appear to be a flatter organization than that of a traditionally hierarchical aerospace company, as decision making is pushed closer to decision points in more of a team-based, matrix style of organization structure. In fact, the lean enterprise may be more like a distributed network of decision makers acting under the common guidance of enterprise goals and metrics, making decisions locally and only raising these decisions to the level of management necessary to provide linkages between the groups that decisions affect. This type of organization is very much different than the very hierarchical organization of the aerospace industry today, and requires new skills and attitudes for integrating the management of functions, processes, and programs in a manner that achieves some form of enterprise value maximization criteria. The lean enterprise is indeed a radical change.

It is evident that organizational behavior change is a major barrier to creating the lean aerospace enterprise. The fact that it is a barrier is then one of the strongest supporting arguments of why the lean enterprise as an operational strategy is a potential source of competitive advantage - those who achieve it will experience competitive advantage over those who do not. The change process can take a long time, as evident from manufacturing efforts where lean can take years to implement. Furthermore, of those that attempt the transformation, not all will be successful, and the levels of success will vary. Thus, the firm that achieves second order change to a lean enterprise will experience a period of internal factor differentiation from its competitors, and the inherent performance benefits associated with being a lean enterprise. This would imply that there is a first mover advantage to becoming a lean enterprise.

The tremendous difficulty associated with the change effort suggests that there is also a strong failure possibility due to resistance to change, or due to never fully affecting the total enterprise, but rather only affecting local areas of the enterprise. This would suggest that there may be second or third mover advantage if the first one or two enterprises that attempt the transformation fail, and the reasons for the failure(s) are codified in a way that allows the later movers to avoid the same pitfalls. Yet even if the lean enterprise is achieved and creates competitive advantage in operations, all of the prior arguments about continual strategic evolution hold. Failure to continue enhancing and building on the strategic value of the lean enterprise will only lead to stagnation and eventual loss of competitive advantage to others that will mimic and surpass with new strategic improvements.

4.4. Short-term versus Long-term Strategic Thinking for the Lean Enterprise

From a business perspective, the lean enterprise operational strategy has both short-term and long-term implications with respect to competitive advantage. While the short-term competitive advantage is important and beneficial to the firm, it is the position of this thesis that the absence of long-term thinking will result in lost opportunities for the firm to achieve further performance improvements from the gains achieved with a lean aerospace enterprise.

In the short-term, it would seem that a lean enterprise has the ability to outperform its rivals in terms of its cost structure, its product lead-time, and its product quality (for the reasons discussed in chapters two and three). The lean enterprise then has options for how to exploit its newfound performance. From a market perspective, the firm can exercise its improved quality and lead-time to differentiate its products and either command a higher price and increase revenues, or use the improved value of the product at constant price to capture greater market share and increase revenues. In either case, the result is greater value delivered to the customer and increased revenues for the firm.

The improved cost structure of the enterprise will result from a decrease in NVA, a reduced need for resources from increased productivity causing a reduction in need for additional capital assets, and money can be made available from the reduction of inventory and WIP. This reduced cost structure can be used to increase short-term profitability by selling off assets that are no longer needed, canceling leases on space and equipment that are no longer needed, and reducing the size of the labor force, either through layoffs, early retirements, normal labor attrition, or some form of all three. These actions will reduce the expenditures of the firm, while not having any negative effect on current revenue streams, thus short-term profitability will increase. The improved cost structure can also allow the firm to combine improved quality and lead-time with lower price, which will capture even greater market share and potentially drive competitors out of the market. The increased profitability and potential market share growth will improve shareholder satisfaction.

In the short-term, the lean enterprise can outperform its competitors, however, the tactic of reducing costs solely for boosting current financial performance does not consider any change in market conditions beyond the current product offering (i.e. this strategy does not consider changing product offerings or changing market needs). Staying with the short term-view will result in the eventual loss of competitive advantage, as competitors that do not go out of business will eventually catch up to, and perhaps surpass, the incumbent lean enterprise by creating their own lean enterprise that will compete with similar or better performance levels.

The long-term perspective views the short-term results as a means to employ competitive tactics otherwise unavailable to the enterprise. The short-term availability of freed-up resources such as facilities, space, intellectual capital, labor, equipment, and working capital, provides the enterprise with the potential to grow and evolve faster than its competitors. In the long-term strategic perspective the freed-up resources can be viewed as a source of investment in future potential. The firm would have additional people, space, equipment, and money that could be used to work on new ventures, ideas, and technologies related to the company's business and corporate strategies. While potentially increasing the scale of the firm by capturing greater market share, there is the potential to increase its scope as well, either by diversification into new markets via the creation or evolution of core capabilities, and/or attempting to vertically integrate some of the supply chain. In fact, the lean enterprise is potentially a source of job creation as the enterprise begins to compete and exploit its capabilities to grow and garner new business. This long-term view of the lean enterprise is a potential source of sustainable competitive advantage, as the enterprise will be continually exploring new ways to exploit its current capabilities as a means to create new opportunities.

4.5. Conclusions

The discussion in this chapter has introduced the idea that an operational strategy supports both business and corporate strategies, and is in turn supported by functional and process strategies. It is proposed that creating a lean aerospace enterprise is an operational strategy that is aimed at operating and structuring businesses in a way that is much different than traditional, hierarchically-managed mass or craft production companies in the aerospace industry. It is also argued that while the knowledge about lean might be freely available, the ability of a firm to capture, absorb, and act on this knowledge is not instantaneous, and furthermore, would require significant organizational behavior change. It is for these reasons that the lean enterprise is considered a source of competitive advantage, as a first mover who becomes a lean enterprise will enjoy some period of better performance over its rivals while they either exit the market or attempt the same organizational behavior change. To achieve long-term competitive advantage, the lean enterprise provides enterprise leadership with options for investing in future capabilities to increase both the scale and scope of the enterprise, while creating core capabilities on which it can build new innovations.

Chapter 5 - Hypothesis Formulation and Experimental Methods

The first few chapters of this thesis have highlighted several factors that point to the benefit and strategic advantage of being a lean aerospace enterprise. From the perspective of a customer, lean enterprises provide products and services with higher quality, lower-cost, greater functionality, and in less time than less-lean enterprises. Literature also points to the fact that a lean enterprise focuses on value delivery to multiple stakeholders. The multiple stakeholder perspective promulgates the belief that enterprise value, defined as the aggregate of value delivered to all stakeholders, can be increased by a focusing on non zero-sum-game value exchange propositions between enterprise stakeholders. This suggests that focusing solely on customer value or solely on shareholder value does not maximize enterprise value delivery. Furthermore, this thesis has argued that enterprise sustainability is a function of maximizing value delivery to all stakeholders. From a strategic perspective, the ability to create a lean enterprise is considered an operational strategy, which will result in a source of competitive advantage. This chapter explains the details of an experiment that tracks leading lean enterprise indicators as a means of measuring the extent of enterprise transformation.

5.1. Measuring the Extent of Lean Enterprise Transformation

Operating with the information presented in the previous chapters, the assumption underlying the main hypothesis of this experiment is that the leaner enterprise will outperform the less lean enterprise. The question of interest to the experiment then becomes what changes are required in internal processes and activities in the enterprise to become a leaner enterprise. This relationship can be depicted as shown in Equation 7.

$$E_{p/a} \rightarrow L_i \rightarrow P_j \qquad \text{Equation 7}$$

where

$E_{p/a}$ = some measure of enterprise processes (p) / activity (a) structure and behavior

L_i = some measure of enterprise leanness (i=1..m)

P_j = some measure of enterprise performance (j=1..n)

The question to address is if existing enterprise processes and activities are changed, modified, or executed in some appropriate fashion, will this result in improved enterprise leanness? The operating assumption of the following hypothesis formulation is that improved enterprise leanness will result in improved enterprise performance in terms of value delivery. Thus, the focus of the hypothesis formulation will be on changing activities and processes in an effort to increase enterprise leanness, the first elements of the relationship. This proposed causal relationship is depicted in Equation 8.

$$^{\Delta}E_{p/a} \rightarrow {}^{\Delta}L_i \rightarrow {}^{\Delta}P_j \qquad \text{Equation 8}$$

5.1.1. The Lean Enterprise Self-Assessment Tool (LESAT)

The experiment developed in this chapter has both the benefit and bane of the existence of a tool that was in the process of being deployed in the aerospace industry for measuring the extent of use of lean practices and activities in aerospace enterprises. This tool is called the Lean Enterprise Self-Assessment Tool (LESAT) (LAI_LESAT, 2001), (Nightingale and Mize 2002). The benefit of this tool was that the tool was in its beta test phase and it was beginning to be used in industry as a measurement device for helping direct lean improvements. The downside was that this precluded the experiment to be designed as a pure experiment with pre-test, treatment, and post-test and would thus be a form of quasi-experiment as defined by Cook and Campbell (Cook and Campbell 1976).

5.1.1.1. The LAI Decision to Create the LESAT

In early 2000, the Executive Board of the Lean Aerospace Initiative at the Massachusetts Institute of Technology chartered a team of representatives from academia, government, and industry to develop a Lean Enterprise Self-Assessment Tool (LESAT). The tool was intended to assess the leanness of the enterprise as well as its readiness for change. The effort to develop the LESAT effort was driven by the fact that the LAI had previously developed the Lean Enterprise Model (LEM) and the Transition to Lean (TTL) guide. The LEM was developed to codify the research of the LAI into a framework of lean principles and practices that should be adopted and implemented in creating a lean enterprise (LAI_LESAT, 2001). The TTL was developed to provide enterprises with a roadmap for how to organize and sequence their lean enterprise transformation activities (Nightingale et al. 2000). The LESAT was intended to complete the tool triad by providing a means to measure the state of leanness of the enterprise as a means for informing the transformation process, as depicted in Figure 15.

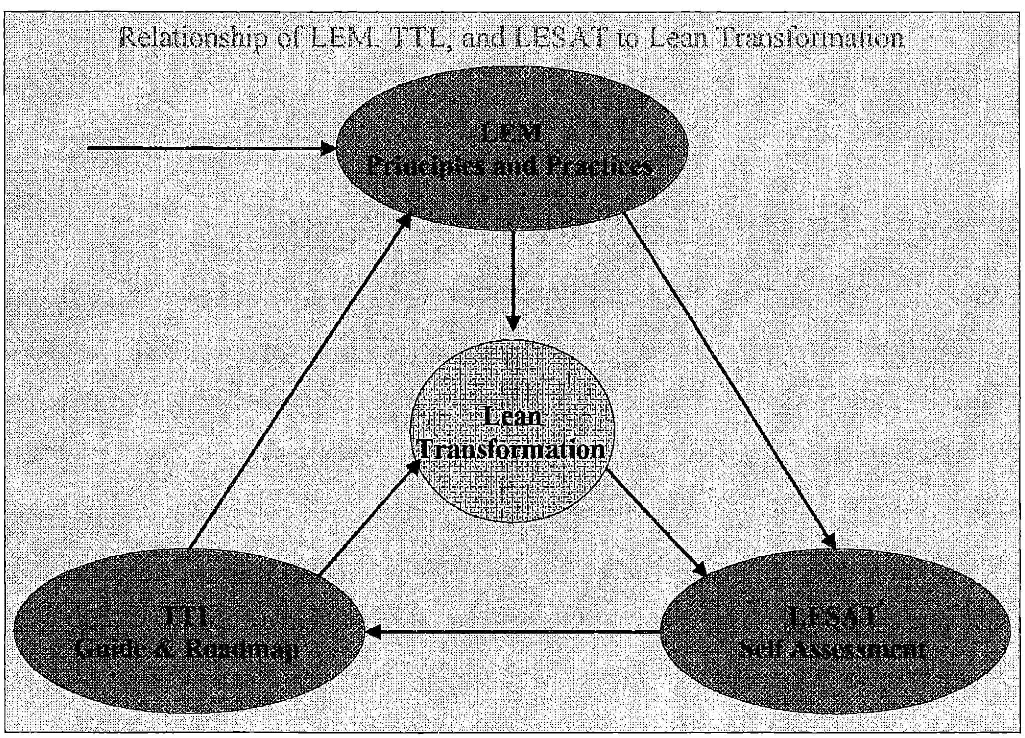


Figure 15 - LAI lean enterprise tool triad (Nightingale et al. 2001, pp.28).

The LESAT development team gathered the user requirements for the tool based on their needs relative to assessment. The consolidated set of user requirements for the tool were (Nightingale and Mize 2002):

- Must assess the degree of "leanness" for an enterprise and all of its core processes
- Must provide feedback for improvement, guidance for next steps
- Must be data driven, based on evidence that could be documented
- Should be consistent with other LAI tools like the LEM and TTL
- Should learn from existing assessment tools
- Should require minimal time and effort to create
- Should be flexible to allow assessment of varying organizational scope
- Should be understandable and easy to apply
- Should align with business planning processes
- Should accommodate various partnership arrangements for an enterprise

Three primary approaches to performance assessment were analyzed with respect to the list of user requirements, namely a Capability Maturity Matrix approach (Paulk et al. 1997), (SEI_WWW, 2002), a quality of documented process approach (Baldridge_Award_WWW 2003), (NIST 2002), and a measured performance-over-time approach (Nightingale and Mize 2002). It was determined that the Capability Maturity Matrix (CMM) approach was the best fit with the user needs. The concept behind the CMM approach requires the determination of the factors most important to an organization's performance, each of which has several levels of maturity through which the enterprise can progress. For each performance factor and each level of maturity, definitions are created that characterize the organization's maturity. Thus, an organization can assess its current state of performance as a collection of varying maturity levels in each of the factors. The organization can then decide how to improve its performance by increasing maturity in given factors, and are able to craft plans on how to get to the next level of maturity given the next level's definition as the improvement goal. Over a two year period, the LESAT went through Alpha and Beta testing, and resulted in the current version 1.0 of the tool (LAI_LESAT, 2001). The details of the tool will be discussed in the following section, as the tool forms the basis for this experiment.

5.1.1.2. Details of the LESAT Structure

The Lean Enterprise Self-Assessment Tool (LESAT) was developed as a capability maturity model that helps enterprise leaders determine the extent to which lean principles, practices, and behavior have become a part of their organization (LAI_LESAT, 2001). The LESAT is not intended as a means for comparing companies in an industry, but rather for enterprise leadership to both develop an understanding of the current state of "leanness" of their enterprise and see the potential future state that can be achieved via the as-yet unachieved higher levels in the maturity model (Nightingale and Mize 2002). The LESAT is composed of 54 practices grouped into three sections, namely:

- Section I - Lean Transformation and Leadership (28 practices)
- Section II - Life-Cycle Processes (18 practices)
- Section III - Enabling Infrastructure (8 practices)

The *Lean Transformation and Leadership* section of the LESAT focuses on the lean practices that are developed and maintained by upper-level management in the organization to guide enterprise activities, and map directly to the elements of the TTL. These practices span all enterprise entities and thus provide a snapshot of how well the tenets of lean have been adopted and applied across the enterprise, and not just within a single functional area. Enterprise Transformation and Leadership Processes are intended to

- Guide the activities of the enterprise
- Permeate all elements of the enterprise
- Provide direction for resource allocation to eliminate barriers in Life Cycle Processes
- Lead the transformation of Enabling Processes

The execution of Enterprise Leadership/Transformation Processes will establish an organization that is amenable to operating in a lean fashion. This includes having a clear definition of customer value, establishing the necessary support and incentives to create a lean transformation environment, and includes formal processes for defining, adjusting, improving, and measuring change activities within the organization to support lean operations. The 28 Enterprise Leadership/Transformation Process practices in the LESAT are shown in Table 14.

I.A Enterprise strategic planning	I.A.1. Integration of lean in strategic planning process
	I.A.2. Focus on customer value
	I.A.3. Leveraging the extended enterprise
I.B Adopt Lean Paradigm	I.B.1. Learning and education in 'lean' for enterprise leaders
	I.B.2. Senior management commitment
	I.B.3 Lean Enterprise Vision
	I.B.4. A sense of urgency
I.C Focus on the Value Stream	I.C.1. Understanding the current value stream
	I.C.2. Enterprise flow
	I.C.3. Designing the future value stream
	I.C.4. Performance measures
I.D Develop lean Structure and Behavior	I.D.1. Enterprise organizational orientation
	I.D.2. Relationships based on mutual trust
	I.D.3. Open and timely communications
	I.D.4. Employee empowerment
	I.D.5. Incentive alignment
	I.D.6. Innovation encouragement
	I.D.7. Lean change agents
I.E Create and Refine Implementation Plan	I.E.1. Enterprise level lean implementation plan
	I.E.2. Commit resources for lean improvements
	I.E.3. Provide education and training
I.F Implement Lean Initiatives	I.F.1. Development of detailed plans based on enterprise plan
	I.F.2. Tracking detailed implementation
I.G Focus on Continuous Improvement	I.G.1. Structured continuous improvement process
	I.G.2. Monitoring lean progress
	I.G.3. Nurturing the process
	I.G.4. Capturing lessons learned
	I.G.5. Impacting enterprise strategic planning

Table 14 - Twenty-eight enterprise leadership process practices in the LESAT.

The *Lean Lifecycle Process* section of the LESAT focuses on the activities that are the source of revenue for the enterprise. Life Cycle Processes are intended to:

- Be the source of value delivery to customers, and hence the source of revenue for the enterprise
- Define the product life cycle, from conception through design, production, deployment, support, and retirement/disposal (or a subset thereof depending on the needs of the customer and/or program)
- Be aligned horizontally along the customer value stream

The execution of Life Cycle Processes will form the link in the supply chain between upstream input suppliers and downstream customer demand, with some transformation function adding value between the two. The operation of lean Lifecycle Processes requires management to establish and most likely change organization design. This will also require Enabling Infrastructure Processes (LESAT Section III) to be architected with an understanding of their contribution to reducing waste and increasing value delivery within the Lifecycle Processes. The 18 Lifecycle Processes practices in the LESAT are shown in Table 15.

II.A. Business Acquisition and Program Management	II.A.1. Leverage lean capability for business growth
	II.A.2. Optimize the capability and utilization of assets
	II.A.3. Provide capability to manage risk, cost, schedule and performance
	II.A.4. Resource and empower program development efforts
II. B. Requirements Definition	II.B.1. Establish a requirements definition process to optimize lifecycle value
	II.B.2. Utilize data from the extended enterprise to optimize future requirement definitions
II.C. Develop Product and Process	II.C.1. Incorporate customer value into design of products and processes
	II.C.2. Incorporate downstream stakeholder values into products and processes
	II.C.3. Integrate product and process development
II.D. Supply Chain Management	II.D.1. Define and develop supplier network
	II.D.2. Optimize network-wide performance
	II.D.3. Foster innovation and knowledge-sharing throughout the supplier network
II.E. Produce Product	II.E.1. Utilize production knowledge and capabilities for competitive advantage
	II.E.2. Establish and maintain a lean production system
II.F. Distribute and Service Product	II.F.1. Align sales and marketing to production
	II.F.2. Distribute product in lean fashion
	II.F.3. Enhance value of delivered products and services to customers and the enterprise
	II.F.4. Provide post delivery service, support and sustainability

Table 15 -Eighteen life cycle process practices in the LESAT.

The *Enabling Infrastructure* section of the LESAT deals with practices that support the execution of the practices identified in the first two sections. In most cases, the enabling infrastructure provides supporting services to other entities within the enterprise. Since the practices in this section only enable other entities in the enterprise to deliver value to the end customer, but do not deliver the value themselves, they are often overlooked a source of waste in traditional value stream analysis (Ohno 1988), (Rother and Shook 1998). The result is that waste arising in the enabling infrastructure can negatively impact the enterprise as a whole in a manner hidden from view. Enabling Infrastructure Processes are intended to:

- Support the execution of all other processes (Leadership and Life Cycle Processes); therefore they cut across all Life Cycle processes and Leadership processes
- Provide services to internal customers in the organization (not responsible for direct customer value delivery, but may be a cause of waste in customer value delivery processes)

The direct application of lean principles and practices to existing Enabling Infrastructure Processes is only a local optimization of current activities (i.e. do the processes right, make them more efficient). A "lean enterprise" perspective of enabling infrastructure processes results in their redefinition to support the other processes becoming lean (i.e. do the right processes, a measure of process effectiveness), which can then be operated with lean principles and practices (i.e. do the right processes right, a measure of process efficiency).

The execution of Enabling Infrastructure Processes will reduce barriers to lean operations within the Lifecycle Processes. With the support and mandate of the Enterprise Leadership Processes, the Enabling Infrastructure Processes can achieve this transformation. The 8 Enabling Infrastructure Processes practices are shown in Table 16.

III.A. Lean Organizational Enablers	III.A.1. Financial system supports lean transformation
	III.A.2. Enterprise stakeholders pull required financial information
	III.A.3. Promulgate the learning organization
	III.A.4. Enable the lean enterprise with information systems and tools
	III.A.5. Integration of environmental protection, heath and safety into the business
III.B. Lean Process Enablers	III.B.1. Process standardization
	III.B.2. Common tools and systems
	III.B.3. Variation reduction

Table 16 -Eight enabling infrastructure process practices in the LESAT.

Thus, it is proposed that for the emergence of a lean enterprise, the processes in Section I set the organizational culture and structure to allow those in Sections II & III to mature, while those in Section III are also necessary to support those in Section II. These proposed process relationships, as depicted in Figure 16, form the basis for the hypothesis development and operationalization, as will be discussed later in this chapter.

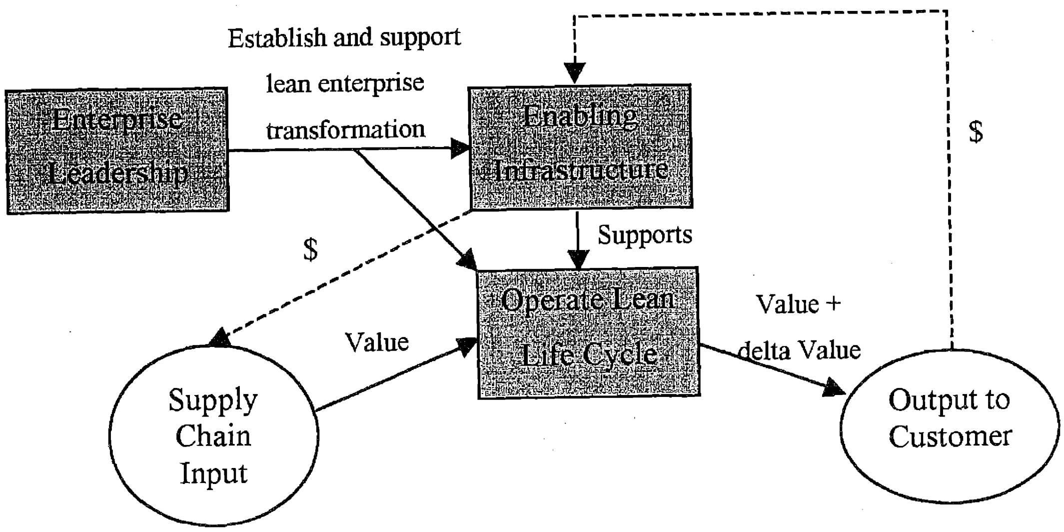


Figure 16 - Representation of interdependency of LESAT processes.

5.1.1.3. The LESAT Capability Maturity Matrix

The LESAT practices are based on the concept of the CMMI model (Nightingale and Mize 2002), (Paulk et al. 1997), (SEI_WWW, 2002). The LESAT Capability Maturity Matrix (CMM) has the 54 practices (or factors) introduced earlier in this chapter, against which the enterprise maturity is assessed. The maturity levels are based on the generic maturity level definitions shown in Table 17.

Capability Maturity	Generic Definition
Level 1	Some awareness of this practice; sporadic improvement activities may exist
Level 2	General awareness; informal approach deployed in a few areas with varying degrees of effectiveness and sustainment
Level 3	A systematic approach/methodology deployed in varying stages across most areas; facilitated with metrics; good sustainment
Level 4	On-going refinement and continuous improvement across the enterprise; improvement gains are sustained
Level 5	Exceptional, well-defined, innovative approach is fully deployed across the extended enterprise (across internal and external value streams); recognized as best practice.

Table 17 - Generic LESAT Capability Maturity Matrix level definitions.

For each of the 54 practices in the LESAT there is a specific definition tailored to every maturity level in every practice, based on the generic definitions presented above. This construction of the maturity model is intended to do three things, namely:

- Make maturity levels consistent across practices
- Make increases in maturity equal in magnitude across practices
- Make the understanding of the maturity level as clear as possible to improve the quality of the assessment data (i.e. variability in results will be due to individual's understanding of enterprise maturity, not differences in interpretation of definitions)

The creation of individual definitions for each level of each practice helps the assessor clearly identify the maturity of her/his organization, while attempting to remove some of the inherent reliability issues associated with scales measures that require interpretation of the meaning of the values on the scale. An example of this scale is presented for LESAT practice 1.B.3 - Lean Enterprise Vision. The five maturity levels for this practice are shown in Table 18. The full LESAT (V1.0) is available from the LAI web site (http:\\lean.mit.edu) and has been included in Appendix C for future reference should the LAI web site no longer exist or the model changes in future versions.

Maturity	Definition
Level 1	Senior leaders have varying vision of lean, from none to well-defined.
Level 2	Senior leaders adopt common vision of lean.
Level 3	Lean vision has been communicated and is understood by most employees.
Level 4	Common vision of lean is shared by the extended enterprise.
Level 5	Stakeholders have internalized the lean vision and are an active part of achieving it.

Table 18 - Example of lean practice maturity definitions for practice 1.B.3 - Lean Enterprise Vision (Nightingale et al. 2001).

5.1.1.4. Association of LESAT with the TTL

The LAI Transition to Lean (TTL) Roadmap and Guide were created as a proposed logical sequence of primary activities and major tasks associated with becoming a lean enterprise (Nightingale et al. 2000). The primary roadmap is shown in Figure 17. This roadmap forms the basis for the Lean Leadership/Transformation Processes in Section I of the LESAT, where each TTL block represents a sub-section of LESAT Section I.

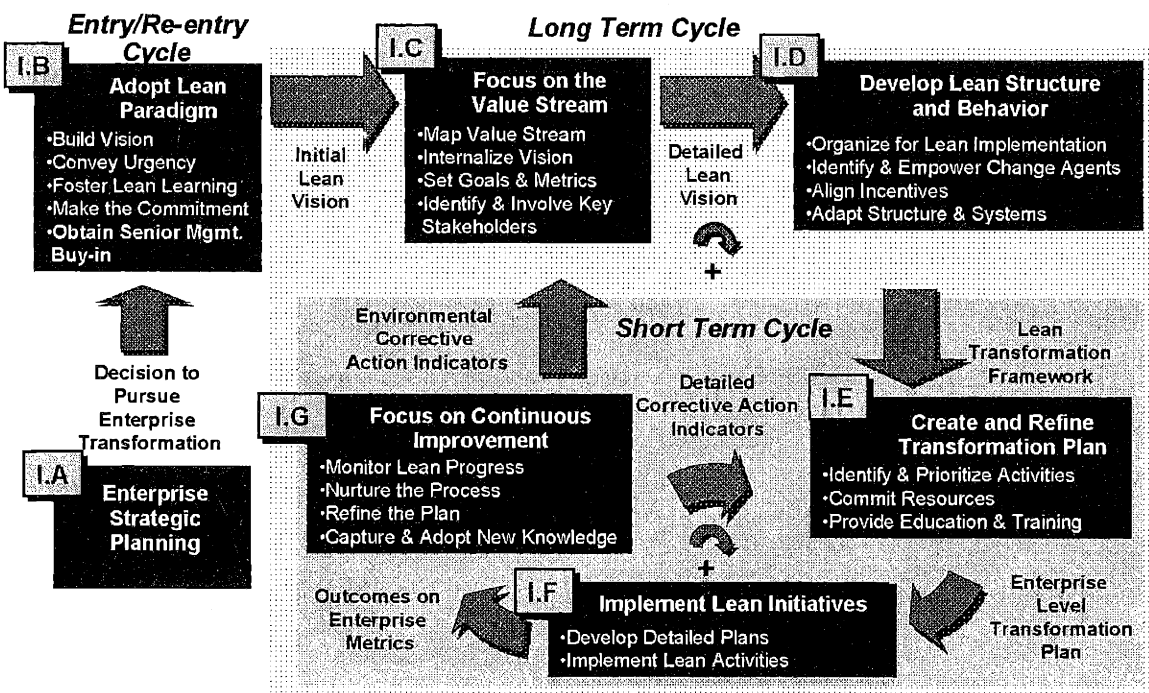


Figure 17 - Enterprise Transition to Lean (TTL) Roadmap (Nightingale et al. 2000).

The Entry/Reentry Cycle is defined as the top-level link to enterprise strategic planning and lists the actions associated with the decision to adopt the lean paradigm. It comes into effect when a significant commitment is made to pursue lean or when the enterprise's strategy is reshaped, in part, by the gains achieved from lean transformation. This is the longest duration cycle of the three as it has a time constant on the order of achieving some visible and sustained enterprise-level organizational change. The LESAT practices in this cycle are all associated with some form of leadership commitment to lean.

The Long-Term Cycle defines the actions that are needed to set the stage for lean enterprise transformation, and prepares the enterprise for beginning detailed transformation and lean implementation activities. Nightingale et al consider the return to this portion of the roadmap when there are changes in the external environment, with a time constant somewhat shorter than the Entry/Reentry Cycle (Nightingale et al. 2000, pp.46). The LESAT practices in this cycle are all associated with creating an environment that will support lean transformation.

The Short-Term Cycle defines the activities that are performed to execute the detailed lean transformation. Of the three cycles, this one has the smallest time constant, and is where the continual improvement activities take place. Much of the effort in these activities focuses around the Plan-Do-Check-Act (PDCA) cycle as described by Deming building on the work of Shewhart (Deming 1992).

It is believed that the successful navigation of the TTL roadmap can lead to a lean enterprise that will experience lean improvements in its Lifecycle and Enabling Infrastructure Processes, which will ultimately be seen as improvements in enterprise stakeholder values, the true outcome measures of success.

5.2. Operationalization and Test of Hypotheses

The hypotheses developed in this chapter will be based upon the knowledge that the LESAT will serve as the measurement instrument for the experiment. It is believed that the lean practices measured in the LESAT serve as indicators of lean enterprise maturity and behavior, and are leading indicators of enterprise performance based on the assumption proposed at the beginning of this chapter that a leaner enterprise can outperform a less lean enterprise. The hypotheses will be developed in view of identifying the means for accelerating lean enterprise transformation.

5.2.1. Leadership and Leading Indicators of Enterprise Transformation

Popular literature on the subject of leadership and organizational change espouses that radical or transformational change requires strong leadership to spearhead the change effort. For complete organizational change from the CEO on down, Nadler and Nadler claim that the CEO must be committed, willing, and personally involved in order for organizational change to be effective (Nadler and Nadler 1998). They also report that this type of leadership cannot be delegated or subcontracted, but must be part of the organizational leadership. Kotter describes the leadership role for change to include setting the change direction and vision, aligning the employees in the new direction through communication, and motivating and inspiring the employees to change by appealing to basic human needs, values, and emotions (Kotter 1999). Nanus proposes that leadership must not only lead the change effort, but must undertake multiple tasks for ensuring successful change (Nanus 1992). Nanus proposes a model of what is coined "visionary leadership" which is comprised of vision, communication, empowered employees, appropriate organizational changes, and strategic thinking (Nanus 1992, pp.156).

In the lean literature, the concept of strong leadership for change is also promoted. Henderson and Larco claim that *"lean transformation will not occur...without strong leadership because going lean turns a traditional business on its head"* (Henderson and Larco 2000, pp.96). Rother states that *"the notion that you can drive change to lean from* *the bottom is pure bunk"* (Rother 1998). In his study of lean change in US manufacturers, Liker concludes that *"all of the plants that have made significant progress were led by informed, active, and involved leadership"* (Liker 1998, pp.506). Jordan and Michel state that leadership must be a model of lean behavior in order to achieve a successful lean transformation (Jordan and Michel 2001, pp.177). In quoting Clark (1999), Jordan and Michel report that *"In the press of continual transformation, leaders cannot just set an action in motion and then expect their people to follow. They have to teach their employee's today's reality and at the same time prepare them for tomorrow"* (Jordan and Michel 2001, pp.179). The idea of the leader as a role model in lean change efforts is also supported by Constantino, who, reporting on his experiences, states *"...when people are in a process of dramatic change, they need a continuous resource whom they can trust to guide them through the change. Without this resource, there is a high likelihood that the process will either be abandoned or modified to the point that it no longer meets its original purpose"* (Constantino 1998).

Koenigsaecker, who has led companies through lean transformation, claims that change in low lean maturity organizations will face serious anti-change forces attempting to derail the effort. He states that this resistance will be a result of none of the team members having been in a lean organization yet, and as a result none will have formed a true belief in the value of the principles and practices of lean (Koenigsaecker 2001). In these situations he advocates that only strong leadership will get the organization onto the new path. In quoting an unpublished manuscript of "The Toyota Production System", Koenigsaecker reports that Taiichi Ohno firmly believed that lean change efforts necessarily had to be led by senior management, as shown in the following excerpt:

> *"I utilized my authority to the fullest extent to broaden these (lean) ideas...The top management of business must reform their consciousness and make up their mind to reverse the flow of conventional production, transfer and delivery. This faces lots of resistance and it takes courage."*

In Koenigsaecker's view, successful lean conversions are **always** led from the top, with the best lean leader being the highest level manager with a positive attitude towards change. In his mind, the executive leadership must embrace lean and create the lean vision and leadership, while the middle managers must lead the more detailed organizational change efforts, and the front line workers must experience and commit to the behavior change. He claims that the management style must continuously change as the organization changes, and full-time resources must be committed to the effort. He contends that in successful lean transformation efforts, executive leadership must be present at transformation, or Kaizen, report-out events to show they are supportive of the change, and also so that they can learn of the benefits associated with the transformation (Koenigsaecker 2001).

The literature on lean transformation is mostly centered on lean manufacturing, but has begun to span other elements of the enterprise. If one considers the importance of leadership in the transition to a lean manufacturer, as described in the previous paragraphs, then the transition to a lean enterprise, with all of its inherent additional complexities and difficulties, should require as much if not greater leadership support. This expectation of leadership support is apparent in the Transition to Lean (TTL) roadmap, where it is stated that the enterprise leader must obtain buy-in and unconstrained commitment from all senior managers and stakeholder leaders that will be encompassed in the transformation (Nightingale et al. 2000, pp.33). Murman et al summarize the current view of the LAI in saying that

> *"One thing's for sure: leadership is critical, and what leaders must do overall is clear...Senior leadership must be the champion of the change initiative, leading it personally, and must take an active role in monitoring progress, removing barriers, and motivating and providing incentives for both individual and team performance. The organizational structure must be aligned with the new vision, and change agents must be put in place to assist in making the transformation"* (Murman et al. 2002, pp.154).

From the perspective of the study of organizational change, Robbins states that along with having leaders and employees that are committed to change, the senior executive is typically looked at as the agent of change (Robbins 2001, pp.543). Robbins also proposes two views on organizational change, one being that it is an episodic activity to address disturbances and the other being that everything is continuously changing, bordering on chaos, requiring continuous change and adaptation (Robbins 2001, pp.574). From the literature on lean, it would appear that the initial transformational effort is the episodic, transformational activity, while the continuous improvement and adaptation of the lean enterprise is more in line with the second view.

Edgar Schein states that the role of the leader at the top of the organization is to translate the opportunities, demands, and constraints of the business environment into strategies, goals and targets for the organization (Schein 1980, pp.133). In a later work he expands on the leadership perspective saying that *"We tend to treat the topic of leadership in a vacuum instead of specifying what the leader's relationship to the organization is at any given point in time"* (Schein 1995c, pp.2). He contends that as the rate of technological, economic, political and socio-cultural environmental change increases, the very strengths that were institutionalized become weaknesses. This follows the argument underlying core competencies becoming core rigidities, as discussed in the previous chapter. In a high rate of change environment, he states that leaders need to think like change agents that look beyond learning and growth, but into unlearning so that the organization can shed performance-limiting cultural characteristics. Furthermore, he claims that as the rate of change itself increases, change will not refer to a one time "learn the new system" event, but rather to a continual process of learning and change (Schein 1995c, pp.11).

Schein also promotes the notion that change leaders must articulate new directions, new values, and a new vision to the employees (Schein 1999, pp.138). In his view, the vision must be articulated (and widely held) by senior management in order to succeed (Schein 1999, pp.124). The major hypotheses in this thesis will be developed around the model of leadership as a necessary and causal element in lean enterprise transformation.

5.2.2. Major Hypotheses

This research is designed around using the LESAT as the source of data characterizing the state of enterprise leanness. From the discussion of the structure of the LESAT and literature surrounding leadership and organizational change in this chapter, it is proposed that there exist non-random relations between the maturity in the enterprise-level processes measured by the LESAT. Specifically, the following three hypotheses are proposed:

H1) Enterprises that exhibit a greater value of lean enterprise Transformation and Leadership Process maturity will exhibit a greater value of lean Lifecycle Process maturity

H2) Enterprises that exhibit a greater value of lean enterprise Transformation and Leadership Process maturity will exhibit a greater value of lean Enabling Infrastructure Process maturity

H3) Enterprises that exhibit a greater value of lean Enabling Infrastructure Process maturity will exhibit a greater value of lean Lifecycle Process maturity

It is believed that the lean maturity of the processes in Section I of the LESAT set the organizational culture and structure to allow those in Sections II & III to mature, while those in Section III are also necessary to support and improve the lean maturity of those in Section II, as depicted in Figure 18. The null hypothesis in each of these three hypotheses is that non-random relations do not exist between the maturity levels of the LESAT process categories.

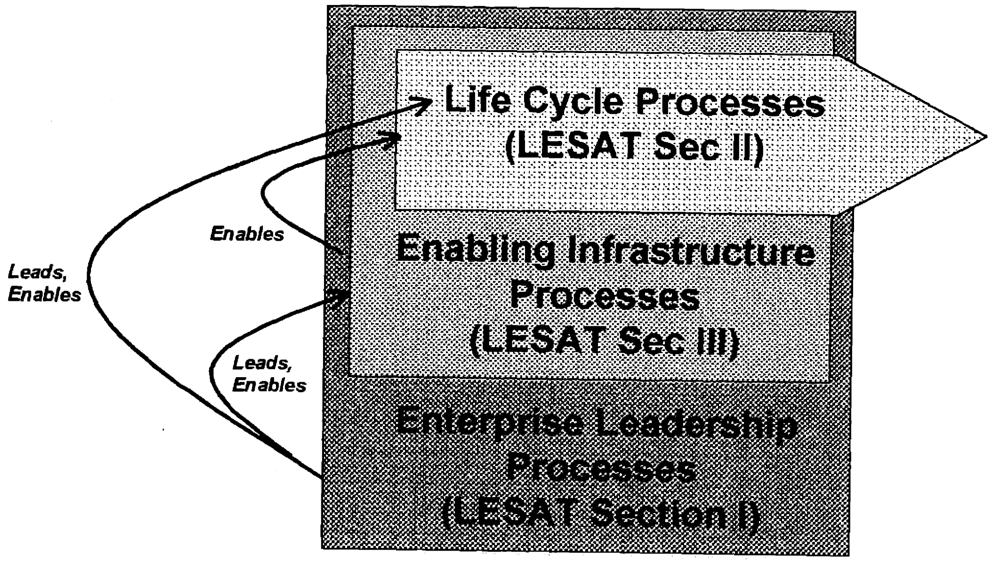


Figure 18 - Proposed relationships in enterprise process lean maturity, as measured by the LESAT.

5.2.3. Hypothesis Tests

To test the hypotheses, measures of lean maturity will be created for enterprises based on LESAT results. The LESAT (V1.0) is composed of 54 scale measures of Lean Practice Maturity (LPM's) that span most enterprise processes. The major LESAT sections, Leadership/Transformation Processes (Section I), Lifecycle Processes (Section II), and Enabling Infrastructure (Section III) form the basis for the three primary Lean Enterprise Maturity hypotheses described above.

Average LPM measures for an enterprise ($LPME_i$) are calculated as the raw average of the respondent LPM scores ($LPMR_k$) in each of the 54 LESAT LPM's, based on k participants in the assessment, as shown in Equation 9.

$$LSM_j = \frac{1}{n}\sum_{i=1}^{n} LPME_i \qquad \text{Equation 9}$$

To test the hypotheses, the LPME's are grouped in a manner consistent with the three primary section headings of the LESAT. The Lean Section Maturity (LSM_j) of an enterprise is then defined for each major LESAT section j (j=1,2,3) as the average of the raw (unweighted) values of the n LPME's in the j^{th} respective section of the LESAT. As such LSM's are calculated as

$$LSM_j = \frac{1}{n}\sum_{i=1}^{n} LPME_i \qquad \text{Equation 10}$$

By this definition, LSM_1 represents the average lean maturity of the Enterprise Leadership Process section of the LESAT, LSM_2 represents the average lean maturity of the Lifecycle Process section of the LESAT, and LSM_3 represents the average lean maturity of the Enabling Infrastructure section of the LESAT. With these three lean maturity measures for each enterprise, the hypotheses can be tested using the sample correlation coefficient r as a point estimate of the population correlation coefficient ρ of lean enterprise maturity. The correlation coefficient estimates the degree of closeness of linear relationship between two variables, in this case the LSM's.

The population correlation coefficient (ρ) between two variables x and y is defined as the covariance of two variables divided by the square root of the product of their variances, as shown in Equation 11 (Snedecor and Cochran 1980).

$$\rho_{xy} = \frac{Cov(x,y)}{\sqrt{V_x V_y}} \qquad \text{Equation 11}$$

where the covariance (Cov), variance (Var), and mean are defined as shown in equations Equation 12, Equation 13, and Equation 14 respectively (Snedecor and Cochran 1980), (Tanis 1987b).

$$Cov(x,y) = \varepsilon[(x-\bar{x})(y-\bar{y})] \qquad \text{Equation 12}$$

$$Var(x) = \varepsilon[x-\varepsilon(x)]^2 \qquad \text{Equation 13}$$

$$\bar{x} = \varepsilon(x) = \frac{1}{N}\sum_{k=1}^{N} x_k \qquad \text{Equation 14}$$

The sample correlation coefficient (r) is calculated as a point estimate of the population coefficient by using n paired observations of the data to compute r as shown in Equation 15 (Snedecor and Cochran 1980).

$$r_{xy} = \frac{\sum (x - \bar{x})(y - \bar{y})}{(n-1)S_x S_y} \qquad \text{Equation 15}$$

where S_1 and S_2 are the sample variances, as calculated in Equation 16 (Tanis 1987b).

$$S_x = \frac{\sum (x - \bar{x})^2}{(n-1)} \qquad \text{Equation 16}$$

For the correlation coefficient, if one variable can be expressed as a linear combination of the other, then the correlation coefficient will be -1 or 1. If the two variables are independent, then the magnitude of the correlation will be zero (Kim and Mueller 1989). Thus, the null hypothesis in each of the three primary hypotheses is that there is no correlation between the variables ($\rho = 0$) (Snedecor and Cochran 1980) (pp.181). To test hypotheses about ρ, when $\rho \neq 0$, requires the assumption that the pairs of data (LSM_i, LSM_j; $i \neq j$) are a random sample from a bivariate normal distribution (Snedecor and Cochran 1980). In this experiment, the pairs of data are composed from the LSM's of each of the enterprises, consistent with the hypotheses being tested. The pairs of data are extracted from the lean enterprise maturity vector (LMV) for each enterprise, as defined in Equation 17.

$$LMV = (LSM_1, LSM_2, LSM_3) \qquad \text{Equation 17}$$

The point estimate of the population correlation coefficient will thus be calculated using m pairs (for m enterprises) of LSM's enterprise by combining Equation 15 and Equation 16 as shown in Equation 18 (where $i \neq j$).

$$r_{ij} = \frac{\sum_{h=1}^{m}(LSM_{hi} - \overline{LSM}_{hi})(LSM_{hj} - \overline{LSM}_{hj})}{(\sum_{h=1}^{m}(LSM_{hi} - \overline{LSM}_{hi})^2 \cdot \sum_{h=1}^{m}(LSM_{hj} - \overline{LSM}_{hj})^2)^{0.5}}$$ Equation 18

The null hypothesis assumes that ρ is normally distributed about zero (ρ follows $N(0,\sigma)$). The hypothesis test will verify if the sample ρ as measured by r is far enough from zero at an acceptable significance level to reject the null hypothesis. Since the investigation concerns the hypotheses of increasing leanness in LSM_j associated with increasing leanness in LSM_i, a one tailed test of significance will be used since the hypothesis is assumed to be directional (i.e. the sample correlation coefficient will be positive). The three hypothesis tests can be represented as shown in Table 19.

Hypothesis	Null Hypothesis	Alternate Hypothesis
LSM_2 increases with LSM_1	H_{oa}: $r_{21} = 0$	H_{1a}: $r_{21} > 0$
LSM_3 increases with LSM_1	H_{ob}: $r_{31} = 0$	H_{1b}: $r_{31} > 0$
LSM_2 increases with LSM_3	H_{oc}: $r_{23} = 0$	H_{1c}: $r_{23} > 0$

Table 19 - Three main hypotheses defined in terms of the test statistics.

If no assumption is made about independence and/or dependence amongst the variables, then the partial correlation coefficient should be calculated (Snedecor and Cochran 1980, pp.361). The partial correlation coefficient ($\rho_{ij.k}$) in this three variable case, where the variables are LSM_1, LSM_2, and LSM_3, measures the correlation for two of the variables while holding the value of the third variable constant. The goal of this approach is to measure the correlation between the two variables (LSM_i and LSM_j) that is not a reflection of their relation with the third variable (LSM_k), as shown in Equation 19 for the sample correlation coefficient $r_{ij.k}$ (Snedecor and Cochran 1980, pp.362).

$$r_{ij.k} = \frac{r_{ij} - r_{ik}r_{jk}}{\sqrt{(1-r_{ik}^2)(1-r_{jk}^2)}}$$ Equation 19

Using Equation 19 results in an additional set of tests of the hypotheses as shown in Table 20.

Hypothesis	Null Hypothesis	Alternate Hypothesis
LSM_2 increases with LSM_1 controlling for LSM_3	H_{oa}: $r_{21.3} = 0$	H_{1a}: $r_{21.3} > 0$
LSM_3 increases with LSM_1 controlling for LSM_2	H_{ob}: $r_{31.2} = 0$	H_{1b}: $r_{31.2} > 0$
LSM_2 increases with LSM_3 controlling for LSM_1	H_{oc}: $r_{23.1} = 0$	H_{1c}: $r_{23.1} > 0$

Table 20 - Hypothesis tests using partial correlation coefficients.

5.2.3.1. Multiple time period studies to test the primary hypotheses

If enough of the participating enterprises repeat the assessment annually as part of their improvement plans, then additional tests of the hypothesis will be possible, as well as potential tests of causality. The potential for longitudinal data is expected to be for a subset of early adopters of the LESAT that have the opportunity and desire to conduct a repeated annual assessment at some time t_2 a year after the first assessment at t_1. For the set of assessments performed in period t_2, the three hypotheses can be tested using the t_2 data in the correlation coefficient test as calculated in Equation 18 and Equation 19 and shown in Table 21. Thus, there will be 2 independent tests of the hypothesis using cross sectional data in each of the two assessment periods.

Hypothesis (at time t_2)	Null Hypothesis	Alternate Hypothesis
LSM_2 increases with LSM_1	H_{oat2}: $r_{21t2} = 0$	H_{1at2}: $r_{21t2} > 0$
LSM_3 increases with LSM_1	H_{obt2}: $r_{31t2} = 0$	H_{1bt2}: $r_{31t2} > 0$
LSM_2 increases with LSM_3	H_{oct2}: $r_{23t2} = 0$	H_{1ct2}: $r_{23t2} > 0$
Partial Correlations		
LSM_2 increases with LSM_1	H_{oat2}: $r_{21.3t2} = 0$	H_{1at2}: $r_{21.3t2} > 0$
LSM_3 increases with LSM_1	H_{obt2}: $r_{31.2t2} = 0$	H_{1bt2}: $r_{31.2t2} > 0$
LSM_2 increases with LSM_3	H_{oct2}: $r_{23.1t2} = 0$	H_{1ct2}: $r_{23.1t2} > 0$

Table 21 - Hypotheses defined in terms of test statistics at time t_2.

5.2.3.2. Cross-time studies to investigate causality along the three primary hypotheses

With the availability of longitudinal data, the three primary hypotheses can be tested to a greater extent for potential causality. If it is believed that improvements in lean leadership maturity ($^{\Delta}LSM_1$) lead to improvements in enterprise process maturity ($^{\Delta}LSM_2$, $^{\Delta}LSM_3$), then Equation 18 and Equation 19 can be modified to use the correlation of change in maturity as the test statistic as shown in Equation 20 and Equation 21.

$$r_{i^{\Delta}tj^{\Delta}t} = \frac{\sum_{h=1}^{m}(^{\Delta}LSM_{hi} - ^{\Delta}\overline{LSM}_{hi})(^{\Delta}LSM_{hj} - ^{\Delta}\overline{LSM}_{hj})}{(\sum_{h=1}^{m}(^{\Delta}LSM_{hi} - ^{\Delta}\overline{LSM}_{hi})^2 \cdot \sum_{h=1}^{m}(^{\Delta}LSM_{hj} - ^{\Delta}\overline{LSM}_{hj})^2)^{0.5}} \qquad \text{Equation 20}$$

$$r_{i^{\Delta}tj^{\Delta}t.k^{\Delta}t} = \frac{r_{i^{\Delta}tj^{\Delta}t} - r_{i^{\Delta}tk^{\Delta}t}r_{j^{\Delta}tk^{\Delta}t}}{\sqrt{(1-r^2_{i^{\Delta}tk^{\Delta}t})(1-r^2_{j^{\Delta}tk^{\Delta}t})}} \qquad \text{Equation 21}$$

The hypothesis tests using changes in lean section maturity are then defined as shown in Table 22.

Hypothesis	Null Hypothesis	Alternate Hypothesis
$^{\Delta}LSM_2$ increases with $^{\Delta}LSM_1$	$H_{oa\Delta t}$: $r_{2\Delta t1\Delta t} = 0$	$H_{1a\Delta t}$: $r_{2\Delta t1\Delta t} > 0$
$^{\Delta}LSM_3$ increases with $^{\Delta}LSM_1$	$H_{ob\Delta t}$: $r_{3\Delta t1\Delta t} = 0$	$H_{1b\Delta t}$: $r_{3\Delta t1\Delta t} > 0$
$^{\Delta}LSM_2$ increases with $^{\Delta}LSM_3$	$H_{oc\Delta t}$: $r_{2\Delta t3\Delta t} = 0$	$H_{1c\Delta t}$: $r_{2\Delta t3\Delta t} > 0$
Partial Correlations		
$^{\Delta}LSM_2$ increases with $^{\Delta}LSM_1$	$H_{oa\Delta t}$: $r_{2\Delta t1\Delta t.3\Delta t} = 0$	$H_{1a\Delta t}$: $r_{2\Delta t1\Delta t.3\Delta t} > 0$
$^{\Delta}LSM_3$ increases with $^{\Delta}LSM_1$	$H_{ob\Delta t}$: $r_{3\Delta t1\Delta t.2\Delta t} = 0$	$H_{1b\Delta t}$: $r_{3\Delta t1\Delta t.2\Delta t} > 0$
$^{\Delta}LSM_2$ increases with $^{\Delta}LSM_3$	$H_{oc\Delta t}$: $r_{2\Delta t3\Delta t.1\Delta t} = 0$	$H_{1c\Delta t}$: $r_{2\Delta t3\Delta t.1\Delta t} > 0$

Table 22 - Hypotheses defined in terms of longitudinal test statistics across $^{\Delta}t$.

5.2.3.3. Cross-lagged panel correlation analysis

While the test using the statistics in Equation 20 and Equation 21 begins to explore causality, the discussion of organizational behavior change earlier in this thesis raises the issue of potential time lags associated with achieving lean organizational change. If there is a time lag between increases in lean leadership maturity and increases in lean enterprise process maturity then there may be a stronger correlation along the same three hypotheses with the leading variable at time t_1 and the lagging variable at time t_2. Thus, cross-lagged panel correlations can be used to explore the proposed causal links between leading variables and lagging variables (Cook and Campbell 1976, pp.288). Likewise, tests for proposed non-causal links can also be investigated in support of the causal hypotheses. For example, increasing lean leadership maturity at time t_2 should not correlate highly with increasing lean process maturity at time t_1. However, there could be an argument that increasing lean maturity in lifecycle processes (LSM_2) at t_1 causes leaders to accept the idea of a lean enterprise and further develop their lean leadership LSM_1 in time t_2. Figure 19 shows the potential cross-time correlations for the three sections of the LESAT.

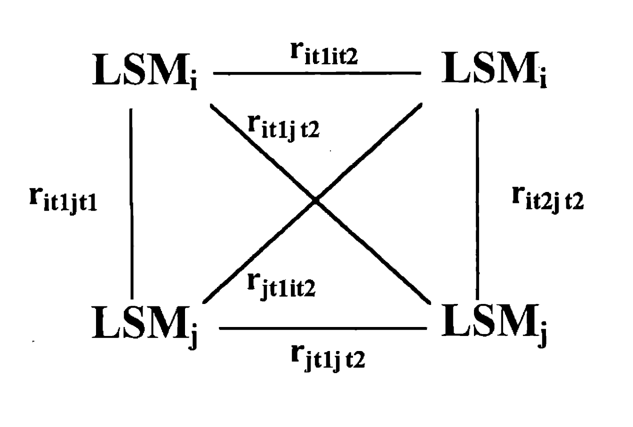


Figure 19 - Mapping of cross-time correlations in Lean Section Maturities (LSM's).

The three hypotheses in this causal analysis are then defined as shown in Table 23. The three inverse relations should not be less strongly correlated if we believe there is a causal, time-based effect in the variables.

Hypothesis	Null Hypothesis	Alternate Hypothesis
$LSM_{2(t2)}$ increases with $LSM_{1(t1)}$	H_{oa}: $r_{2(t2)1(t1)} = 0$	H_{1a}: $r_{2(t2)1(t1)} > 0$
$LSM_{3(t2)}$ increases with $LSM_{1(t1)}$	H_{ob}: $r_{3(t2)1(t1)} = 0$	H_{1b}: $r_{3(t2)1(t1)} > 0$
$LSM_{2(t2)}$ increases with $LSM_{3(t1)}$	H_{oc}: $r_{2(t2)3(t1)} = 0$	H_{1c}: $r_{2(t2)3(t1)} > 0$
Counter Hypotheses		
$LSM_{2(t1)}$ increases with $LSM_{1(t2)}$	H_{oa}: $r_{2(t1)1(t2)} = 0$	H_{1a}: $r_{2(t1)1(t2)} \neq 0$
$LSM_{3(t1)}$ increases with $LSM_{1(t2)}$	H_{ob}: $r_{3(t1)1(t2)} = 0$	H_{1b}: $r_{3(t1)1(t2)} \neq 0$
$LSM_{2(t1)}$ increases with $LSM_{3(t2)}$	H_{oc}: $r_{2(t1)3(t2)} = 0$	H_{1c}: $r_{2(t1)3(t2)} \neq 0$

Table 23 - Cross-time correlation analysis tests.

5.2.4. Exploring the Leading Lean Transformation Indicators in Greater Detail

5.2.4.1. Sub-categories of the Leadership/Transformation Measure

While the previous test looked at the LESAT sections as whole entities, a more complex model could be proposed by subdividing the Leadership/Transformation section of the LESAT (Section I) into elements that align more with the models of organizational change discussed earlier in this chapter. The proposed breakdown is by three variables derived from Section I of the LESAT, namely

1) A measure of leadership commitment to creating a lean enterprise
2) A measure of leadership creating an environment for lean enterprise change (education, resources, change agents, etc), and
3) A measure of lean enterprise transformation in practice (planning, actions, identifying and improving value streams, etc.)

These variables can be visualized as a grouping of variables that comprise the TTL Roadmap, as shown in Figure 20.

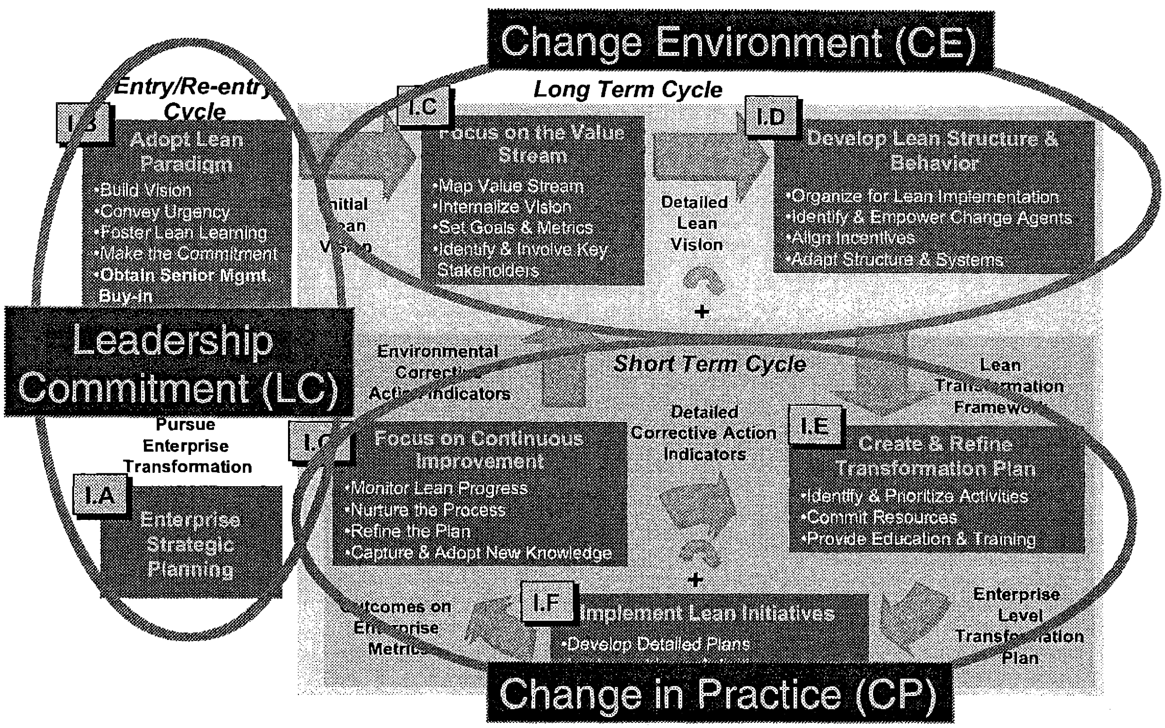


Figure 20 - Grouping of leading variables in the Enterprise Transition to Lean (TTL) Roadmap (Nightingale et al. 2000).

It is proposed that the variables follow a maturity precedence in the order they are numbered, namely increasing leadership commitment to the lean enterprise will lead to an improved environment for lean enterprise change, which will lead to increased lean enterprise transformation in practice. The outcome measures following these transformation measures would then be the maturity of the enterprise processes in Section II and Section III, as previously defined in the primary hypothesis tests. The proposed formulation of the three variables is to utilize the variables associated with the three cycles defined in the TTL, namely the entry/reentry cycle, the long-term cycle, and the short-term cycle discussed earlier in this chapter. The new variables would be composed of the j LESAT practices as shown Table 24, and calculated for each enterprise i as shown in Equation 22, Equation 23, and Equation 24.

New Variable	Composed of the following LESAT variables
LC - Leadership Commitment to a lean enterprise	Entry/Reentry Cycle - LESAT IA and IB practices
CE - lean enterprise Change Environment	Long Term Cycle - LESAT IC and ID practices
CP - lean enterprise Change in Practice	Short Term Cycle - LESAT IE, IF, and IG practices

Table 24 - Lean enteprise change variables for testing leadership.

$$LC_i = \frac{1}{7}\sum_{j=1}^{7} LPME_{ji} \qquad \text{Equation 22}$$

$$CE_i = \frac{1}{11}\sum_{j=8}^{19} LPME_{ji} \qquad \text{Equation 23}$$

$$CP_i = \frac{1}{10}\sum_{j=20}^{28} LPME_{ji} \qquad \text{Equation 24}$$

It is not a random occurrence that these measures align with the three cycles of the TTL. This was done on purpose, such that the results could be interpreted in a manner consistent with the LAI TTL Roadmap. These measures also align with the process management team structure proposed by Dimancescu, and as reported in Chapter 3, where the LC would be the realm of the senior leaders, the CE would be the realm of the process team, and the CP would be the realm of the action team. The two hypotheses associated with the variables in Table 24 are thus:

H1) Enterprises that exhibit a greater value of lean enterprise Leadership Commitment (LC) maturity will exhibit a greater value of lean enterprise Change Environment (CE) maturity

H2) Enterprises that exhibit a greater value of lean enterprise Change Environment (CE) maturity will exhibit a greater value of lean enterprise Change in Practice (CP) maturity

A correlation test statistic will be used to test the null hypothesis that no correlation exists, as shown in Table 25. A one-tailed test of significance will be used as the existence of a correlation is assumed to be directional as shown in Figure 21. The same assortment of partial correlation, cross-time, and cross-lagged panel tests applied in the previous sections could also be applied to these hypotheses as a means for exploring the inferred causality in the hypotheses.

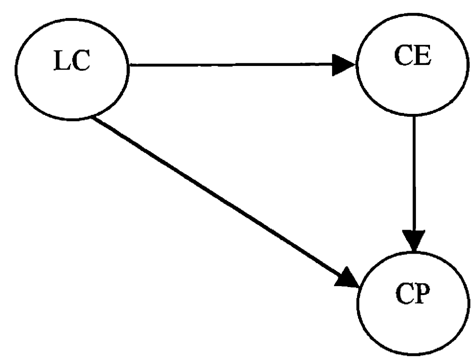


Figure 21 - Potential causal relationships between leadership/transformation sub-variables.

Hypothesis	Null Hypothesis	Alternate Hypothesis
CE increases with LC	H_{oa}: $r_{CELC} = 0$	H_{1a}: $r_{CELC} > 0$
CP increases with CE	H_{ob}: $r_{CPCE} = 0$	H_{1b}: $r_{CPCE} > 0$

Table 25 - Leadership sub-variable correlation analysis at t_1.

5.2.4.2. Exploring the Sequencing of TTL Elements

The previous section suggested some form of sequence amongst a subset of the LESAT Leadership/Transformation practices. The LAI TTL proposes a further refinement to this subdivision of LESAT Leadership/Transformation practices into seven blocks. The LESAT measures lean maturity in the seven major steps of the TTL. A test of the validity of the TTL is confirming the existence of data that supports the inference of the sequential precedence in the blocks in the roadmap. The test can be designed to verify if the lean maturity of two sequential blocks of the TTL ($TTLB_j$ and $TTLB_{j+1}$) positively correlate. The TTL block variables ($TTLB_j$) are calculated as the average of the j LPMEs in LESAT Section I subsection "k" for each of the "i" enterprises as per Equation 25.

$$TTLB_{ik} = \frac{1}{j}\sum_{q=1}^{j} LPME_{qi} \qquad \text{Equation 25}$$

If each $TTLB_i$ is labeled for its respective section of the LESAT, then the hypothesis tests are as shown in Table 26. While this hypothesis test is aimed at providing evidence in support of the sequencing of the TTL activities, further research beyond the scope of this thesis may be able to identify potential improvements in the TTL model based on empirical results.

Hypothesis	Null Hypothesis	Alternate Hypothesis
IB increases with IA	H_{oa}: $r_{IBIA} = 0$	H_{1a}: $r_{IBIA} > 0$
IC increases with IB	H_{ob}: $r_{ICIB} = 0$	H_{1b}: $r_{ICIB} > 0$
ID increases with IC	H_{oc}: $r_{IDIC} = 0$	H_{1c}: $r_{IDIC} > 0$
IE increases with ID	H_{od}: $r_{IEID} = 0$	H_{1d}: $r_{IEID} > 0$
IF increases with IE	H_{oe}: $r_{IFIE} = 0$	H_{1e}: $r_{IFIE} > 0$
IG increases with IF	H_{of}: $r_{IGIF} = 0$	H_{1f}: $r_{IGIF} > 0$

Table 26 - Test of causal inference in TTL Roadmap as measured by the LESAT at t_1.

5.2.5. Sub-Hypothesis: Variability as an Indicator of Lean Maturity

The lean enterprise, by definition, is a tightly coupled system of activities that are interconnected and highly dependent, while spanning many organizational and even legal business boundaries. A major element of the lean enterprise is promoted to be communication. The ability to create and operate a lean enterprise is thought to rest on having strong communication, common vocabulary, and a common understanding of the state of the enterprise. As such, it is proposed that less lean enterprises will have higher variability in their LESAT results, as this would indicate there is no consensus on the state of the enterprise, indicating a lack of common understanding amongst the assessors. This variable could be structured several ways, but should include a measure of response variability and a measure of enterprise leanness. Three immediate measures come to mind, including:

- Average of all of the LPME variances versus the average of the LPME scores in an enterprise (1 data point per enterprise)
- LESAT section average of LPME variances versus LSM (3 data points per enterprise)
- All LPME variances versus all LPME scores (54 data points per enterprise)

Perhaps a more focused measure of variability in leadership commitment measures versus some general lean maturity measure such as Section I variance versus section II maturity will give more insight. These measures will be explored in more detail in Chapter 6.

5.2.6. Measure of the State of the Industry

Beyond the direct hypotheses of interest, the data allows us to look at the industry as a whole. Since the tool was intended as a self-assessment, and not a benchmark, there is no intention to compare or publish the numerical results of the industry as whole. Furthermore, agreements with the enterprises providing LESAT data stated that there would be no disclosure of enterprise-specific results or industry rankings. The data does however, allow us to look at the general rank ordering of LESAT practices from lowest to highest maturity in the industry.

Each enterprise will have its LESAT practices rank ordered (Daniel 1990), (Tanis, 1987a), (Tanis 1987b). These results will then be aggregated across the industry as a sum of the rank score for each LESAT practice. These aggregate scores can then be rank ordered to develop the industry average rank ordering of the practices. This process will remove the discrepancies that may exist due to different assessment practices in each enterprise. While not divulging information about industry average scores, this rank ordering will show industry average relative practice maturity. These results can then be used to gauge which LESAT practices (or group of practices) are of low lean maturity and which are of high lean maturity in the industry. This data may provide insights to readiness of the industry as a whole for lean enterprise transformation.

5.3. Data Collection Procedures

The aerospace industry was the target source for LESAT data in this study. The primary sources of data would be the LESAT Beta test sites followed by other adopters of the tool. Since industry was involved in the request for (and creation of) the LESAT, this provided a small group of enterprises as readily available for using the tool during the Beta test phase. The target enterprises would be the business unit level or site level for which there was a major product or products and for which there was some form of P&L accountability. The assessment would be conducted by the enterprise leadership committee or its direct reports, representing all cross-functional aspects of the enterprise. Thus each enterprise would produce n sets of LESAT data from n respondents, and the raw average of the assessed maturity, as discussed earlier in this chapter, would be the enterprise maturity.

While the LESAT data was important for this research effort, the tool itself was primarily viewed as an improvement tool by the participating enterprise leadership teams. This would result in many enterprises being willing to use the LESAT (at least once). The methodology for using the tool during the Beta tests involved representatives from MIT's LAI conducting a pre-assessment introduction and overview of the tool with the enterprise leadership committee. A local enterprise facilitator would manage the distribution and facilitation of the assessment over some time period. After the data was submitted to the facilitator, it would be summarized and presented in a report-out session. The methodology is presented in the LESAT Facilitator's Guide and in the LESAT Facilitator's Course for version 1.0 of the tool (Nightingale et al. 2001), (Hallam et al. 2003). When available, copies of the data would be forwarded to the author of this thesis for confidential review and analysis.

In parallel to the U.S. enterprises involved in using LESAT, several UK enterprises also used the tool, as the development of the LESAT v1.0 was a joint effort between the UK LAI and the MIT LAI (UK_LAI_WWW 2003), (LAI_WWW 2002). The availability of LESAT data from the UK allowed the sample size to be increased. While the Beta LESAT and version 1.0 LESAT were different in some minor wording and rearrangement of the practices, the only significant difference was the addition of two lean practices in version 1.0 of the LESAT. All of the data used in the analysis was a mix of Beta results and version 1.0 results, which were converted into the version 1.0 format. As this was a new tool in the industry, all of the LESAT respondents would be first time users on their first assessment. For the Beta users and early adopters of the LESAT, longitudinal data would be collected for enterprises performing a second assessment one year after the first use of the tool.

5.3.1. Observing the Effectiveness of the LESAT

Part of this research deals with the introduction of the LESAT to the aerospace industry. The tool is new to the industry and is intended as a means for enabling and tracking lean enterprise transformation, especially in concert with the LEM and TTL as presented earlier in this chapter. This research includes tracking the perceived effectiveness and usefulness of the tool within a subset of the industry participants. This research will identify enablers and barriers to the use of the LESAT in industry, as well as looking at some of the issues with respect to improving the tool itself. This subset of the research was conducted by case study interviews with the Beta-test LESAT facilitators, as well as from less structured discussions with other LESAT users over time. Questions addressed in this part of the research include:

- Does the LESAT measure what it was intended to measure (i.e. factors for enabling lean enterprise transformation with a lean operational strategy)?
- Does the Tool not measure anything that should be added?
- How can it be integrated with other tools, such as market analysis and strategic planning tools?
- Does the LESAT do its job in helping create a common vocabulary and vision amongst enterprise leaders?
- Does enterprise action on LESAT results validate the tool?
- How could the Tool be improved to be more effective?
- How can lean enterprise transformation be accelerated based on LESAT results?
- Are enterprises utilizing the tool triad as part of their transformation efforts?

5.4. Threats to Experimental Validity

As with many experiments, there are potential threats to the internal and external validity of this study. Improving internal validity to an experiment will reduce the uncertainty of the existence of the relationship proposed in the hypothesis, while improving external validity will reduce the uncertainty that the relationship generalizes beyond the circumstances in which it was studied (Krathwohl 1998, pp.174).

In this study it does not seem feasible to set up a true experiment that would involve a pre-test, treatment, and post-test, rather a quasi-experiment will be conducted (Cook and Campbell 1976, pp.223). This study thus uses concomitant variation as an inference of causality, which Krathwohl states as being often used when it is not possible to manipulate the situation experimentally (Krathwohl 1998, pp.151). The problem with studying the lean aerospace enterprise is that enterprises are in a constant state of organizational flux from both internal and external factors. Furthermore, many aerospace companies have been using lean to some extent for years, but with varying degrees of scale and scope in application, and with varying degrees of success. Additionally, it is nearly impossible to imagine a "lean enterprise transformation" treatment that a researcher could apply and track over a short time frame while controlling for all other interacting enterprise variables. It also as difficult to imagine using a method of differences in addition to concomitant variation (Krathwohl 1998, pp.150), as this would require maintaining a control group to which no treatment was applied, and it would be near impossible to start with two identical groups of enterprises. As such, this quasi-experiment will assume that some treatment has been used and applied to varying levels and extents across the sample, and will thus look for relations amongst leading variables as "treatment" versus lagging variables as "effect" variables via the method of treatment-effect correlations (Cook and Campbell 1976, pp.293).

The confidence in the usefulness of the results of the LESAT assessments are based on two major assumptions. First, it is assumed that that the leadership committee, and/or its direct reports that participate in the assessment, will apply LESAT fairly and truthfully without attempting to manipulate or game the system. Avoiding gaming of the results was one of the reasons the LESAT was designed as a self-assessment tool, as opposed to an industry benchmarking tool (Nightingale et al. 2001), (Nightingale and Mize 2002). Second, it is assumed that the respondents all have equal weighting in the calculation of average LPME's, and furthermore, the average LPME's are a fair measure of the lean maturity of the lean enterprise practices.

There is an inherent self-selection bias in the sample used in this study, as many of the LESAT users are associated with the LAI, which would imply that they have had some exposure to lean principles and practices. Furthermore, those enterprises using the LESAT may be doing so because they too have had some exposure to lean principles and practices and wish to explore their use beyond manufacturing. This self-selection bias could lead to tightly grouped maturity data, which could lead to difficulty in drawing conclusions from the correlation analysis if there is insufficient spread in the data. The inherent difficulty with enterprise transformation and the known variability in the extent of use and application of lean principles and practices in industry would lead one to believe that there should be a spread in the data as the "lean enterprise treatment" will have been variable across even a self-selected sample. One might expect not to see data at the low end of the maturity spectrum, however, as low maturity enterprises might not have enough "lean awareness" to be undertaking a lean enterprise self-assessment. Only the collection and analysis of data can answer this question.

If it is believed that the sample of LESAT results will be spread enough to derive correlations, then the next concern is the sample size available for testing the hypotheses. The significance of a correlation coefficient test can be improved with large sample sizes (Snedecor and Cochran 1980),(Tanis 1987b). Increasing the sample size may be difficult as there is a large time investment necessary to undertake the assessment on the part of enterprise leadership. Some enterprises may not wish to make this investment, and furthermore, if the value of the beta tests are not viewed positively by the industry participants, there may be little incentive for other enterprises within the beta test companies to perform the assessment. There is also a concern about the release of LESAT data, where certain enterprises may view their results as proprietary and a source of potential liability if obtained by other competing enterprises. These issues could result in a small sample size resulting in a low number of data points and thus low reliability data. With the help of LAI, the LESAT was promoted amongst the industry members in hopes of increasing the sample size beyond 10 enterprises, and the necessary non-disclosure agreements about how the data would be presented was used to increase the willingness of enterprises to participate in the research.

Since the LESAT Beta tests were only introduced in 2001, the potential for cross-time studies are limited in this research to those companies that performed the LESAT Beta test and then repeated the assessment in 2002 or early 2003. This will result in a small sample size for t_2 data as there were a limited number of users when the tool was initially introduced.

While the LESAT offers clear definitions of each of the maturity levels of each of the lean practices, there is the potential of high variability in assessment results within enterprises. This high variability could result in less confidence in the calculated LPME's. However, as discussed earlier in this chapter, the variability itself may be a potential measure of enterprise communication, integration, and lean maturity.

External Validity is important for this research as it is attempting to create new knowledge about the necessary conditions and actions for lean enterprise transformation in the aerospace industry. The applicability to the aerospace industry in general will be affected by the size and scope of the sample enterprises. The size will help with the internal validity of the data, while the scope (the number of different types of aerospace enterprises, such as electronics producers, system integrators, airframers, etc.) will help establish the usefulness of the results to the spectrum of enterprises that comprise the aerospace industry. Furthermore, arguments may be made for the applicability of this kind of data to other highly mature and hierarchically managed industries, as the principles and practices of lean have been shown to be applicable to various industries as was discussed in Chapter 2.

5.5. Conclusions

The three primary hypotheses this thesis will test using the MIT LAI LESAT are that:

- H1) Enterprises that exhibit a greater value of lean enterprise Transformation and Leadership Process maturity will exhibit a greater value of lean Lifecycle Process maturity
- H2) Enterprises that exhibit a greater value of lean enterprise Transformation and Leadership Process maturity will exhibit a greater value of lean Enabling Infrastructure Process maturity
- H3) Enterprises that exhibit a greater value of lean Enabling Infrastructure Process maturity will exhibit a greater value of lean Lifecycle Process maturity

The experiment is a quasi-experiment using cross-sectional industry data collected via the voluntary participation of aerospace enterprises using the LESAT. The LESAT is gaining industry acceptance, which will help with data generation and collection, and should lead to a sample size consistent with performing the statistical analysis outlined in this chapter of the thesis. Longitudinal data may be too sparse for performing cross-panel correlation analysis, and may not be useful in exploring inferred causality. Interview and case study data will be gathered as necessary and available to help support the major hypotheses. The research will also help identify the value of the LESAT as a part of the LAI lean enterprise transformation tool tried, and potentially lead to recommendations for improving the tools and their use in industry.

Chapter 6 - Analysis and Results

6.1. Description of the Sample Population

The size of the sample population of aerospace enterprises involved in this research was limited by two major factors. First, enterprises had to be willing to utilize the LESAT, which requires a significant time commitment from senior enterprise leaders. Second, the enterprises that did use the LESAT had to be willing to release their data for analysis, which raised concerns of confidentiality with many of them. Both of these limitations, and the former in particular, led to a small sample size. However, the fact that the LESAT was jointly developed with industry did guarantee a minimum number of users (ten) in the Beta test phase.

The results contained in this chapter are based on a sample of thirty-one (31) enterprises that utilized the LESAT and provided their results for use in this study. Of the thirty-one (31) enterprises, twenty-four (24) were from the U.S. and seven (7) were from the United Kingdom (UK)[4]. The participating enterprises covered the full spectrum of the aerospace industry, including manufacturers and service providers in space equipment, airframes, engines, electronics, and subsystems. The enterprises had a mix of both commercial and government customers, and ranged from primes, to subcontractors, to suppliers, depending on which programs they were supplying to. The majority of enterprises assessed were at the business unit and/or site level in their respective organization, with one sample case being a program enterprise.

---

[4] Data from the UK was collected by the UK LAI. Special thanks should be given to Michael James Moore and Joseph Sammut for providing the data in a format that was useable in this thesis without compromising the confidentiality of the companies involved.

The LESAT data was made available to this study in three formats, namely in raw, average, and consensus format. In the raw format enterprises provided the data from all of the assessment participants in the enterprise (21 enterprises). In the second case, enterprises provided their average data and occasionally included the range and variance associated with each lean practice average maturity (4 enterprises). In the third case, an enterprise consensus score was provided, where the assessors, working together, reached agreement on a single maturity level for each lean practice representing the enterprise's final view of their score (6 enterprises provided data this way). For the enterprises that provided the raw data, an average of eleven participants (average of 10.8) performed the assessment. In this sample, the smallest number of participants from which an enterprise average was created was five (minimum=5) and the largest number of participants was nineteen (maximum = 19).

Of the thirty-one (31) enterprises that provided LESAT data for their first assessment, six (6) provided additional data for their second assessment, which were conducted approximately a year after the first. Of the six (6) enterprises that provided second year data, four (4) were business units within one company, one was a business site within a division in another company, and the last one was a program in a third company. The program assessment was conducted internally at the company working on the program in the first year, and expanded to include their direct supply chain customers in the second year (the prime for the system in which their program was to fit). It is not certain if this enterprise's data is useable for a cross-time study since the scope of the enterprise may have changed between the two assessments.

6.2. Hypothesis Tests

6.2.1. Primary Hypotheses

To refresh the memory, the three primary hypotheses of interest to this study were defined in Chapter 5 as follows:

H1) Enterprises that exhibit a greater value of lean enterprise Transformation and Leadership Process maturity will exhibit a greater value of lean Lifecycle Process maturity

H2) Enterprises that exhibit a greater value of lean enterprise Transformation and Leadership Process maturity will exhibit a greater value of lean Enabling Infrastructure Process maturity

H3) Enterprises that exhibit a greater value of lean Enabling Infrastructure Process maturity will exhibit a greater value of lean Lifecycle Process maturity

The data collected for the 31 enterprises was transformed into the three lean section maturity measures (LSM) per Equation 11 in Chapter 5. Each of these sets of data points represents the average LESAT lean section maturity (LSM_i, i=1..3) for each enterprise (1..31). LSM_1 is the average lean maturity of the Leadership/Transformation section of the LESAT, LSM_2 is the average lean maturity of the Lifecycle Processes of the LESAT, and LSM_3 is the average lean maturity of the Enabling Infrastructure Processes of the LESAT. Figure 22 shows the histograms for the frequency distribution of the LSM data, along with a plot of the data in three-space, where the X, Y, and Z-axes are the LSM_1, LSM_2, and LSM_3 variables respectively. The overlaid normal distributions on the histograms reveal that there is a small skew associated with the right hand tail of the distribution, but not so much as to invalidate the binomial normal distribution assumption of the correlation analysis. The first correlation analysis for testing the hypotheses will be conducted using this set of data. Further analysis will look at the same hypothesis tests with a potential outlier removed from the sample.

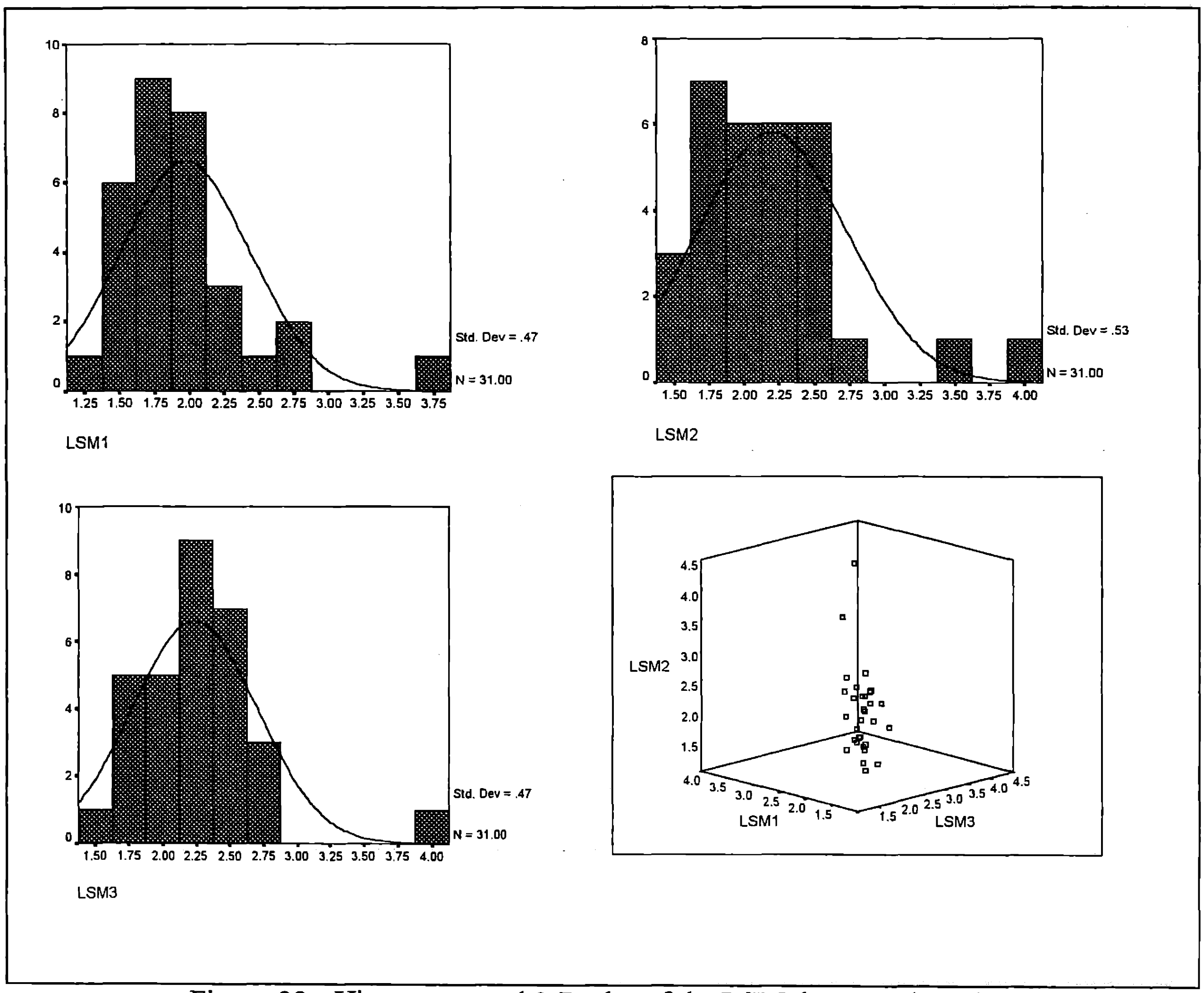


Figure 22 - Histograms and 3-D plot of the LSM data at t_1 (n=31).

6.2.1.1. Test of Primary Hypotheses at t_1 (n=31)

The data set for the first time period (t_1) includes 31 enterprises that were all first-time users of the LESAT. The test hypotheses for this data set, defined in Chapter 5, are shown in Table 27.

Figure 23, Figure 24, and Figure 25 show the graphical representation of the data for each hypothesis, with their associated linear regression lines plotted over the data. The graphical representation of the data suggests that there is a strong correlation between the measures, as the data points group fairly tightly around the trend lines. The one-tailed Pearson correlation coefficient analysis results testing these hypotheses are presented in Table 28. The results of the analyses suggest that the primary null hypotheses are disconfirmed, as the test statistics are close to one at a significance level of less than 0.001. This test suggests that the hypotheses are valid.

Hypothesis	Null Hypothesis	Alternate Hypothesis
LSM_2 increases with LSM_1	H_{oa}: $r_{21} = 0$	H_{1a}: $r_{21} > 0$
LSM_3 increases with LSM_1	H_{ob}: $r_{31} = 0$	H_{1b}: $r_{31} > 0$
LSM_2 increases with LSM_3	H_{oc}: $r_{23} = 0$	H_{1c}: $r_{23} > 0$

Table 27 - Hypotheses defined in terms of the correlation test statistics.

Correlation	**r ( )=sig.**	**r^2**	**$1-r^2$**
LSM_2LSM_1	0.873 (0.000)	0.762	0.238
LSM_3LSM_1	0.897 (0.000)	0.805	0.195
LSM_2LSM_3	0.889 (0.000)	0.790	0.210

Table 28 - Results of LSM correaltion anaylsis at t_1 (n=31).

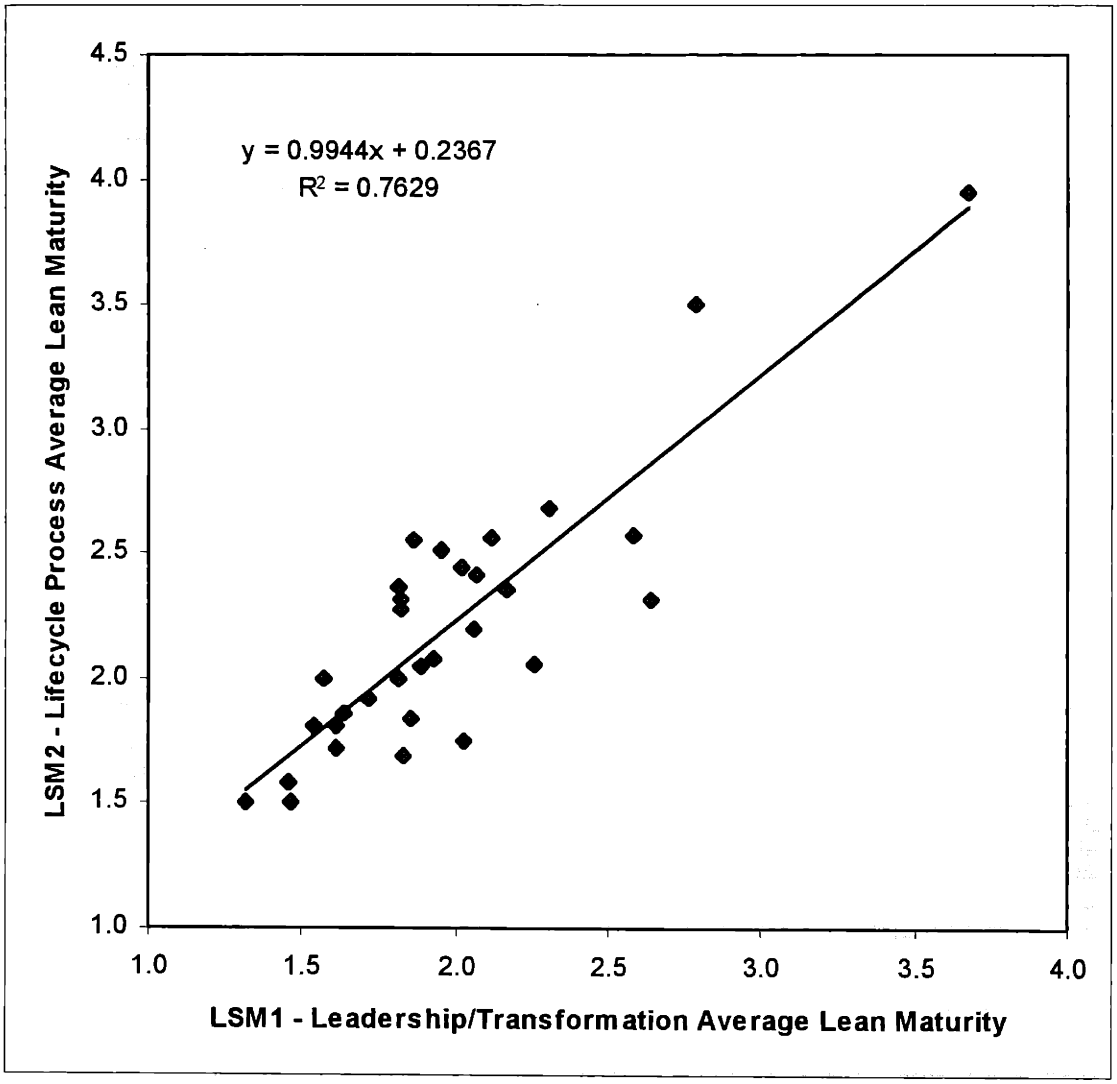


Figure 23 - Plot of data for hypothesis H1: LSM_2 increases with LSM_1 (t_1, n=31).

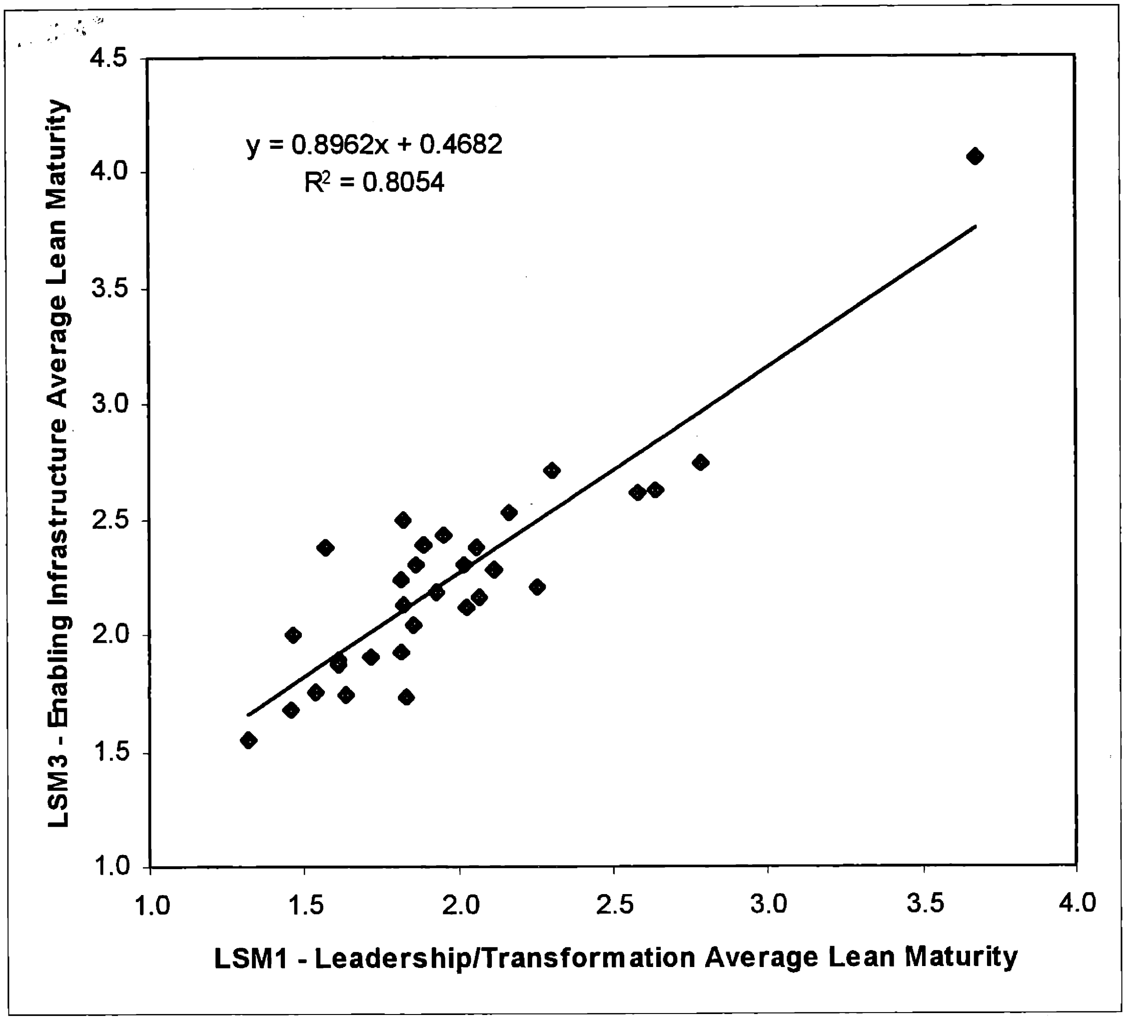


Figure 24 - Plot of data for hypothesis H2: LSM3 increases with LSM1 (t_1, n=31).

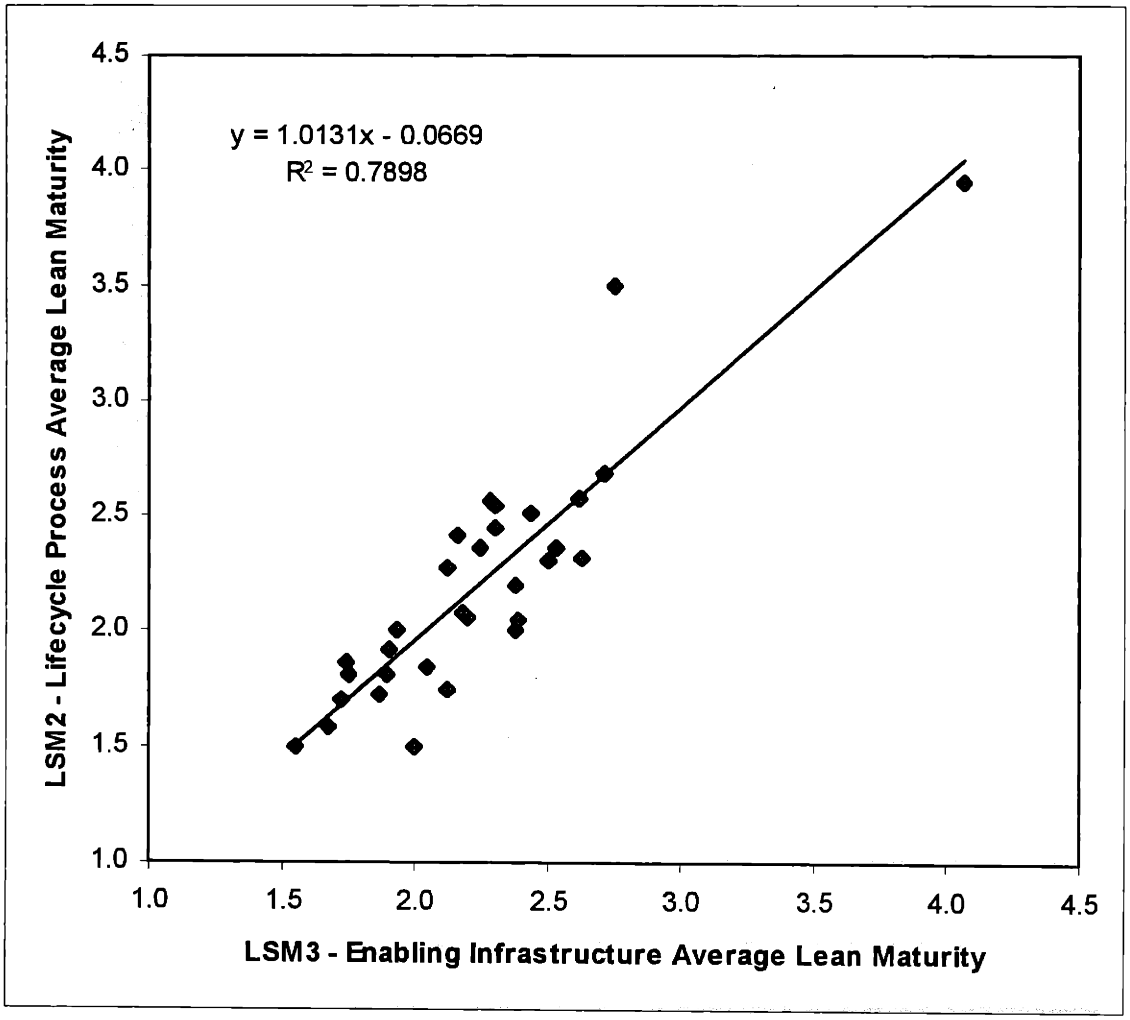


Figure 25 - Plot of data for hypothesis H3: LSM_2 increases with LSM_3 (t_1, n=31).

The three hypotheses infer path dependence between the LSM variables. The path dependence can be calculated as a means for testing the proposed causality between LSM_i and LSM_j. In this case, a test of the existence of a direct causal path between LSM_1 and LSM_2 involves verifying the magnitude of the series correlation between the LSMs and the direct path correlation. If there exists a direct causal path, then the magnitude of the series correlation should be smaller than the magnitude of the direct path correlation (Cook and Campbell 1976). For example, if the inequality in Equation 26 is satisfied, it would suggest the existence of a path dependence between LSM_1 and LSM_2.

$$r_{13} \cdot r_{32} < r_{12} \qquad \text{Equation 26}$$

For the path from LSM_1 to LSM_2 the calculation yields

$$(0.897) \cdot (0.889) = 0.797 < 0.873 \qquad \text{Equation 27}$$

This implies that the direct path does exist from LSM_1 to LSM_2. Similarly for the direct path relation from LSM_1 to LSM_3 the calculation yields

$$(0.873) \cdot (0.889) = 0.776 < 0.897 \qquad \text{Equation 28}$$

which also implies that there is a direct path dependence from LSM_1 to LSM_3. These path dependencies are supporting evidence that disconfirm the null hypotheses associated with H1 and H2. However, Snedecor and Cochran suggest a methodology for testing if r_1 and r_2 are measures of the same ρ, which can be used to verify the significance of the difference between each of the numbers in the inequalities shown in Equation 27 and Equation 28 (Snedecor and Cochran 1980). They provide a transformation (attributed to Fisher) from r to z according to Equation 29, in which z is almost normally distributed with approximate standard error according to Equation 30 (Snedecor and Cochran 1980, pp.186).

$$z_1 = (0.5)[\ln(1 + r_1) - \ln(1 - r_1)] \qquad \text{Equation 29}$$

$$\sigma_z = \frac{1}{\sqrt{n-3}}$$ Equation 30

The normal deviate is then defined as

$$\frac{D}{\sigma_D} = \frac{|z_1 - z_2|}{\sqrt{\sum \sigma_z^2}}$$ Equation 31

For the results of Equation 27, the normal deviate, calculated per Equation 31 is 0.955. This value of z in a cumulative normal frequency distribution table corresponds to a value of 0.3302 (the area under one side of the normal distribution from 0 to 0.955). Since the test is a one-tailed test, as we are looking for a direct path r value greater than the sequential path r value (implying the existence of path dependence), the total area under the normal curve is thus 0.5 (accounting for one side of the distribution) plus 0.3302, which is 0.8302. This means that the one-tailed significance for this comparison of the r values is 1 minus 0.8302 which equals approximately 0.17. Thus the difference in these r values is slightly more unusual than a chance of 1 in 5 of getting this difference from measures of the same r. As the number of enterprise increases, the denominator of the normal deviate (Equation 31) becomes smaller, and the significance level of the test becomes greater.

The partial correlation coefficients and their respective path dependencies are provided in Table 29. They demonstrate that there is still a moderate correlation when controlling for the other variables, which is evidence that further disconfirms the three null hypotheses at a relatively high significance level. It is interesting to note that the effect of LSM_1 on LSM_2 and LSM_3 appears very significant, as the correlation between LSM_2 and LSM_3 when controlling for LSM1 decreases significantly from the bivariate correlation results presented in Table 28. This is further evidence of the path dependence associated with hypotheses HI and H2.

Correlation	r ( ) = sig.	r^2	$1-r^2$
$LSM_2LSM_1.LSM_3$	0.375 (0.020)	0.141	0.859
$LSM_3LSM_1.LSM_2$	0.543 (0.001)	0.295	0.705
$LSM_2LSM_3.LSM_1$	0.488 (0.003)	0.238	0.762
Path LSM_1 to LSM_2	check r31c2.r32c1 < r21c3, (0.543)x (0.488) = 0.265< 0.375 so 1-2 exists		
Path LSM_1 to LSM_3	check r21c3.r32c1 < r31c2, (0.375)x (0.488) = 0.183 < 0.543 so 1-3 exists		

Table 29 - Results of LSM partial correaltion anaylsis at t_1.

1.1.1.1. Test of Primary Hypotheses without outlier at t1 (n=30)

While the test statistics calculated in the previous section appear very supportive of the primary hypotheses (r is close to 1 in all three cases at high significance levels), a close inspection of the graphical representation of the data shows that one of the enterprises appears to have a maturity that is significantly higher than any of the other enterprises. While this enterprise may in fact be a leading example of a lean enterprise, its effect on the correlation results appears very large. A re-plotting of the histograms of the data without the outlier yields the results shown in Figure 26. The removal of the outlier makes the distribution of the data slightly less skewed, and more closely approximates a normal distribution, which is helpful for the bivariate normal distribution assumption in the correlation calculations. This section will look at the same hypothesis tests performed in the preceding section without the outlier as a more conservative means of testing the hypotheses. The hypotheses are shown graphically in Figure 27, Figure 28, and Figure 29, with the associated trend line plotted over the data.

- This page intentionally left blank -

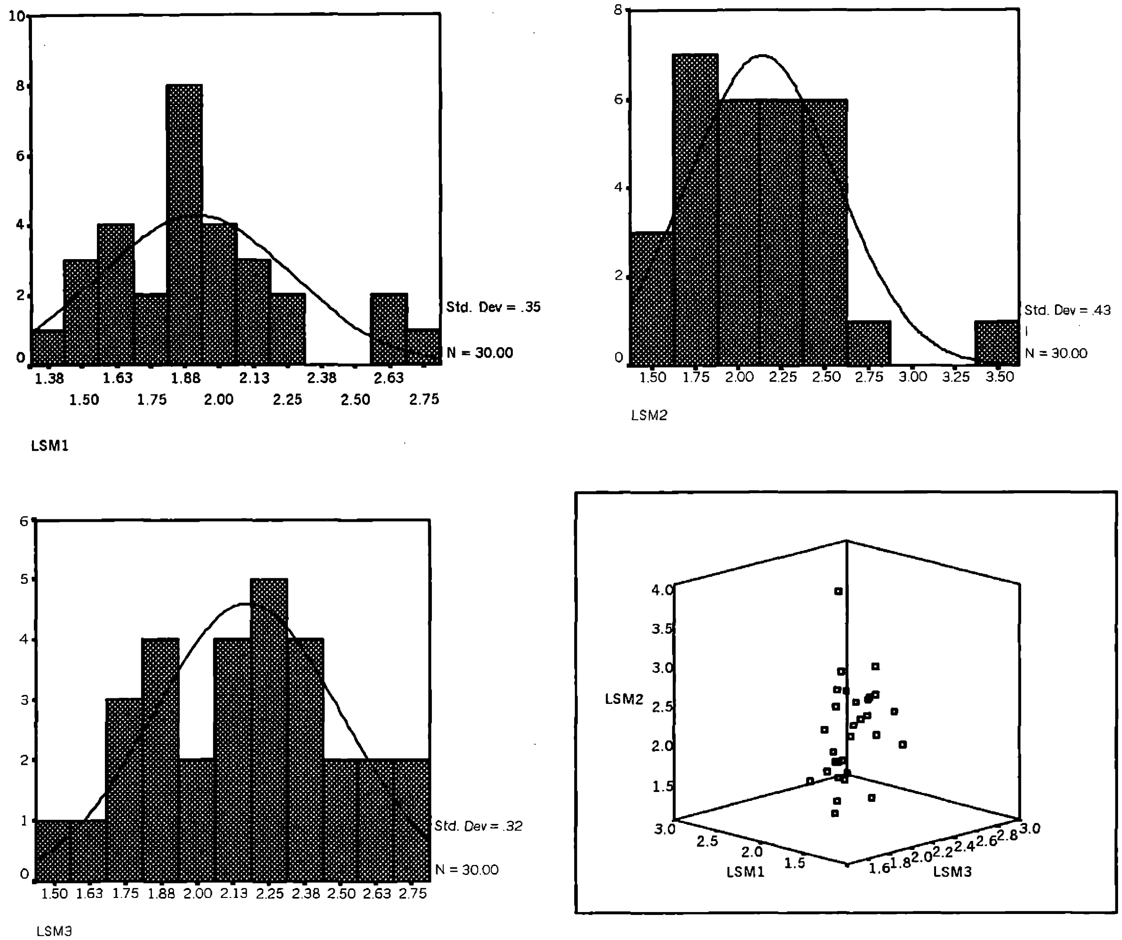


Figure 26 - Histograms and 3-D plot of the LSM data without outlier (t_1, n=30).

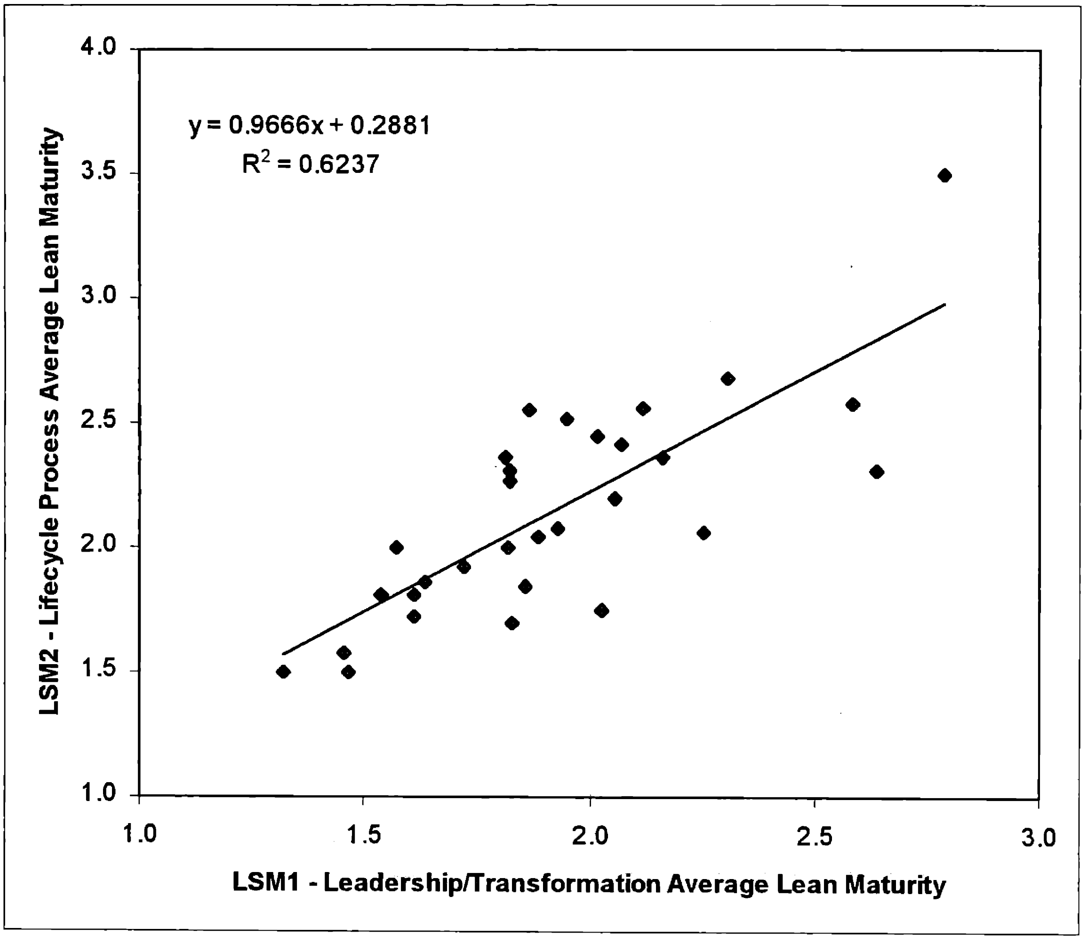


Figure 27 - Plot of data for hypothesis H1: LSM_2 increases with LSM_1 (t_1, n=30).

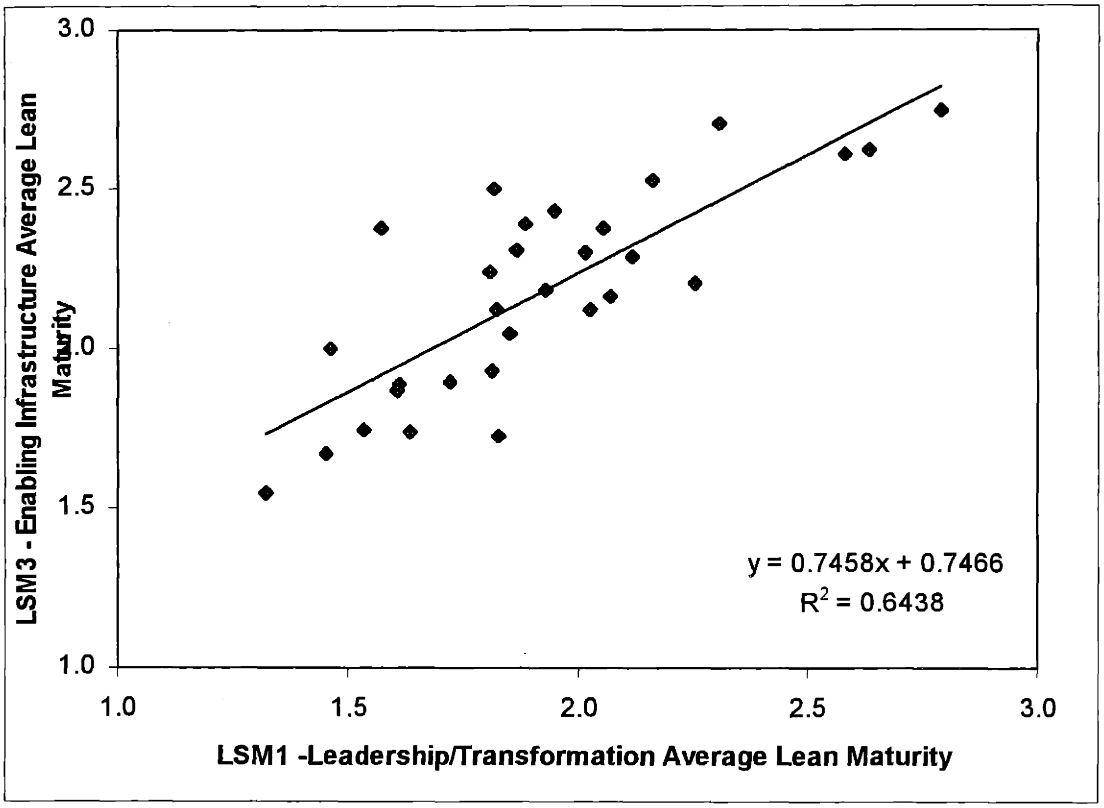


Figure 28 - Plot of data for hypothesis H2: LSM_3 increases with LSM_1 (t_1, n=30).

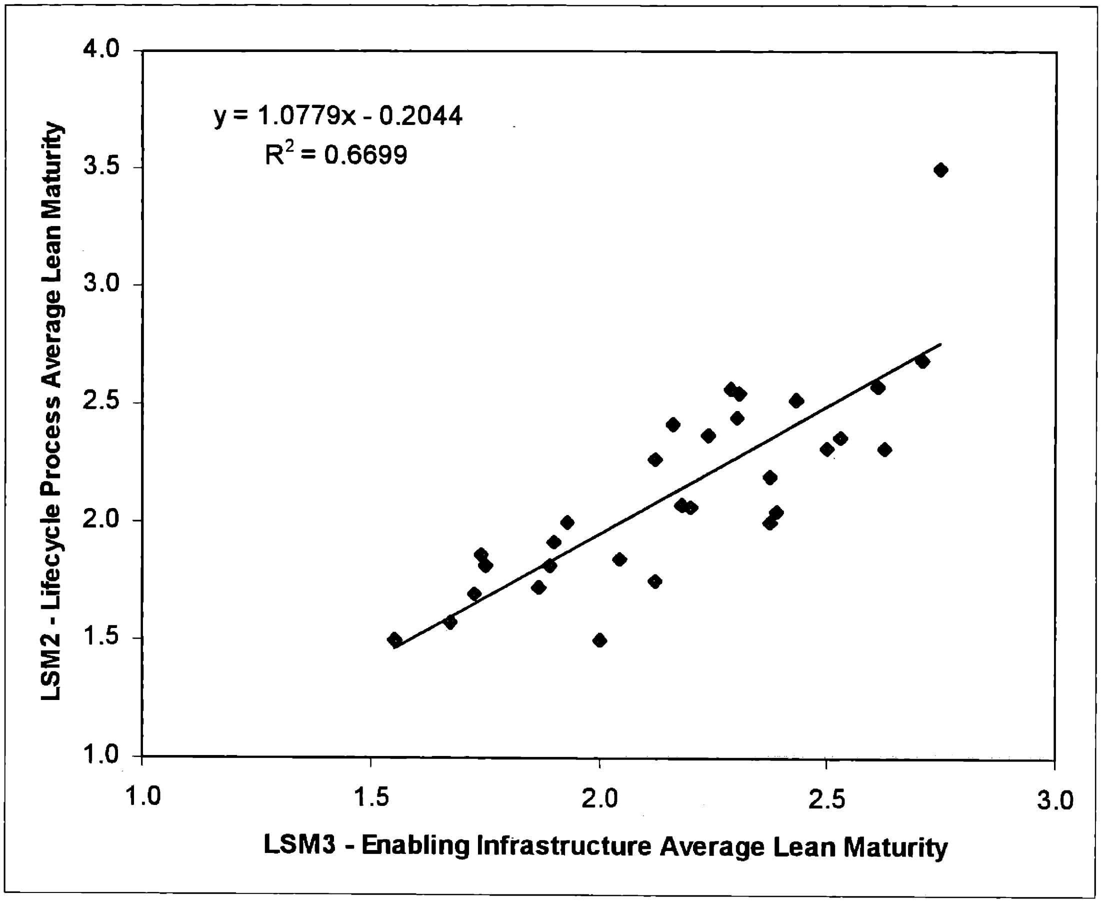


Figure 29 - Plot of data for hypothesis H3: LSM_2 increases with LSM_3 (t_1, n=30).

The graphical representation of the hypotheses without the outlier still maintains a relatively tight grouping around the trend lines. The results of a recalculation of the correlation coefficient test statistics using the new data set (n=30) are provided in Table 30. These results suggest two things. First, the outlier enterprise was having a large effect on the test statistic, as its removal resulted in a decrease of approximately 0.1 in each of the correlation coefficients. Based on the effect the outlier has on the r value, and an understanding from interactions with this enterprise that its LESAT results are probably much higher than the true maturity of the enterprise, the data from the outlier will not be included in further calculations in this thesis. This change in the data set will serve to add some conservatism to the subsequent analyses. With the outlier removed the correlation tests still show that the null hypotheses are disconfirmed with high significance level of less than 0.001.

The partial correlation coefficients support the hypotheses as they did in the previous section, and the path dependency from LSM_1 to LSM_2 and from LSM_1 to LSM_3 appear to exist using both the bivariate correlation coefficient results and the partial correlation coefficient results. Thus with a modest amount of conservatism in the analyses due to the rejection of the outlier, the three hypotheses hold under multiple tests. The path dependence results are important as they support the inferred causality between increasing the lean maturity of Leadership/Transformation LESAT practices as a means for increasing the lean maturity of the Lifecycle Processes and Enabling Infrastructure Practices associated with the LESAT. This is an important result as it could suggest that resources and effort should be applied to the Leadership/Transformation practices as a means of enabling lean enterprise transformation when the enterprise is in its lean enterprise infancy (i.e. low maturity). The fact that this is cross-sectional data would suggest that time-series data would be an important means to pursue supporting evidence of these results. This data will be covered in the following sections.

Correlation	r ()=sig.	r^2	$1-r^2$
r21	0.790 (0.000)	0.624	0.376
r31	0.802 (0.000)	0.643	0.357
r23	0.818 (0.000)	0.669	0.331
Path LSM$_1$ to LSM$_2$	check r31.r23 < r21, (0.802)x(0.818) = 0.656 < 0.790 so 1-2 exists		
Path LSM$_1$ to LSM$_3$	check r21.r23 < r31, (0.790)x(0.818) = 0.646 < 0.802 so 1-3 exists		
r21.3	0.388 (0.019)	0.151	0.849
r31.2	0.443 (0.008)	0.196	0.804
r23.1	0.505 (0.003)	0.255	0.745
Path LSM$_1$ to LSM$_2$	check r31c2.r23c1 < r21c3, (0.443)x (0.505) = 0.224 < 0.388 so 1-2 exists		
Path LSM$_1$ to LSM$_3$	check r21c3.r23c1 < r31c2, (0.388) x (0.505) = 0.196 < 0.443 so 1-3 exists		

Table 30 - Results of LSM correaltion anaylsis at t_1 (n=30).

6.2.1.3. Test of Primary Hypotheses at t_2 (n=6)

As discussed in the previous section, the three major hypotheses in this thesis infer some form of causality between the LSM variables. As such, there was a concerted effort to collect time-series data to explore the inferred causal paths in greater detail. The fact that the LESAT tool was new to the industry at the start of this research suggested that there would only be a possibility for collecting data for two time intervals. Furthermore, it was expected that the second year users would only represent a subset of the first year users, dependent primarily on how early they adopted the LESAT for its first use. As a result, there were only six (6) enterprises that provided data for two years worth of LESAT assessments at the time of the preparation of this thesis.

The graphical representation of the data in Figure 30 shows the three primary hypotheses for the data at t_2. The relations seem to be consistent with the observations at t_1, where the data appears positively correlated. However, as the test statistics data in Table 31 shows, there is a low significance level for r21, which is attributable to the low sample size and spread in the data. There are strong correlations at high significance levels (0.01 or less) in the partial correlation coefficient cases, with a negative correlation on the first hypothesis. While interesting, the low sample size and variability in the data makes the partial correlation a less reliable measure in this test compared to the t_1 data that had thirty (30) cases. The path dependence was calculated as a matter of practice in this case, but is not considered an important measure, due to the sample size issue. Thus although the data is sparse, the trend in the data and the bivariate correlations loosely support the disproof of the three null hypotheses, while the partial correlation data has too few degrees of freedom to be considered reliable.

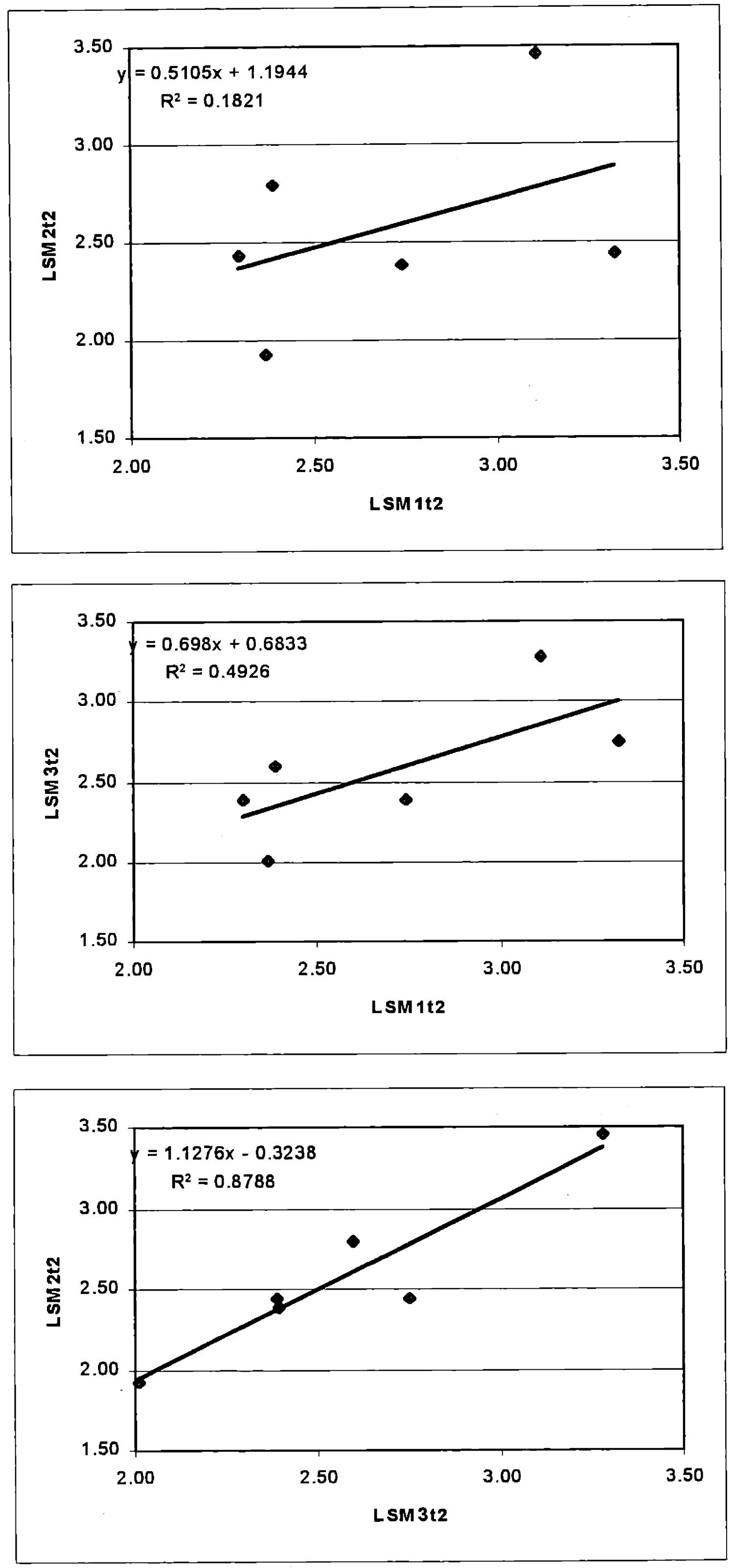


Figure 30 - Plots of LSM data according to hypotheses at t2 (n=6).

Bivariate Correlation	r ( )=sig.	r^2	$1-r^2$
r21	0.427 (0.199)	0.182	0.818
r31	0.702 (0.060)	0.493	0.507
r23	0.937 (0.003)	0.878	0.122
path 1-2	check r13.r32 < r12, (0.702)x(0.937) = 0.658 > 0.427 so 1-2 does not exist		
path 1-3	check r12.r32 < r13, (0.427)x(0.937) = 0.400 < 0.702 so 1-3 exists		
r21.3	-0.932 (0.011)	0.869	0.131
r31.2	0.958 (0.005)	0.919	0.081
r23.1	0.990 (0.001)	0.980	0.020

Table 31 - Results of LSM correaltion anaylsis at t_2 (n=6).

6.2.1.4. Cross-Time Differential Test of Primary Hypotheses (n=6)

An extension of the test of the inferred underlying causality between the sections of the LESAT is to consider changes in the LSM's over time. For the six (6) enterprises that reported two years of data, the difference in LSM_i between t_1 and t_2 was calculated ($dLSM_i$), and results in the data presented in Table 32. The plots in Figure 31 show the dLSM relationships according to the structure of the three primary hypotheses. The relations seem to be consistent with t_1 data in that the relations appear positively correlated. However, as the data in Table 33 shows, there is a low to moderate correlation with low significance for rd21 and rd31, and the correlation for rd32 does appear high with a good significance of less than 0.05. From a hypothesis test standpoint, the first two null hypotheses are not disproved by this data. The trend in the data may align with the three hypotheses but is not significant enough to be considered conclusive or supportive of the three hypotheses.

A second point of interest in this data is the apparent decrease in average section maturity in some instances, as shown by negative dLSM values in Table 32. This may be the result of a learning effect, where the second assessment is conducted by individuals who are now more familiar with the vocabulary and meaning of the LESAT maturity measures and lean in general. In these cases the enterprises might actually rate themselves lower in the second assessment, as their first assessment may have been too optimistic or uncertain in their choice of maturity level. Unfortunately, there is not enough data to investigate the variability in lean practice maturity (LPM) across the two time intervals as only 3 of the enterprises provided the raw data for both assessments.

	LESAT Section Maturity Average		
Enterprise Number	**$dLSM_1$**	**$dLSM_2$**	**$dLSM_3$**
5	0.107	0.0678	-0.230
6	0.369	0.350	0.292
7	0.832	0.115	0.263
8	0.739	-0.131	0.138
9	0.321	0.347	0.531
11	-0.0089	-0.243	-0.319

Table 32 - Differential LSM data for enterprises reporting second set of LESAT data at t_2 (n=6).

Bivariate Correlation at t2	**r ( )=sig.**	**r^2**	**$1-r^2$**
rd21	0.123 (0.408)	0.0152	0.985
rd31	0.569 (0.119)	0.324	0.676
rd23	0.766 (0.038)	0.587	0.413

Table 33 - Results of dLSM correaltion anaylsis (n=6).

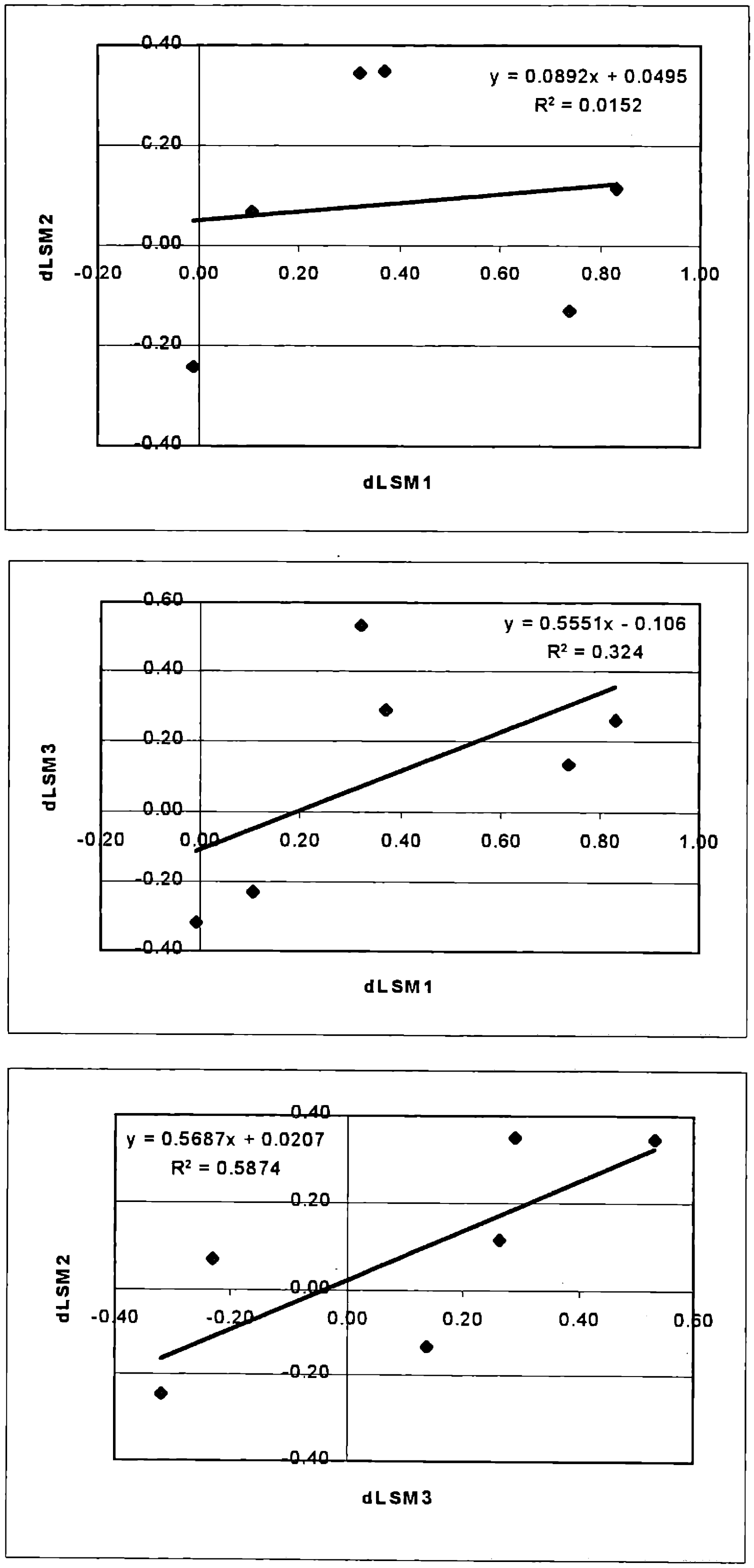


Figure 31 - Plots of cross-time differential LSM data (dLSM) according to primary hypotheses (n=6).

6.2.1.5. Cross-Lagged Panel Correlation Analysis (n=6)

The cross-lagged panel correlations are intended to explore the inferred causality in greater detail by looking at how an inferred causal LSM at time t_1 is correlated with the inferred outcome LSM at time t_2. This analysis consists of only using the 6 enterprises that provided two years of LESAT data, and suffers from the same sparseness issues found in previous sections utilizing data from t_2. The primary hypotheses are represented by the plots in Figure 32 where the inferred causal LSM variable taken at t_1 is on the x-axis and the inferred outcome LSM variable taken at t_2 in on the y-axis.

The results of this anlysis, as shown in Table 34, indicate that there are moderate to strong correlations in support of the primary hypohteses, but with significance levels only in the 0.1 and better range. The counter hypotheses are aimed at testing the inverse of the proposed causal path, such as LSM_{2t1} leads to increases in LSM_{1t2}. The results of these analyses are shown in Table 35. The results indicate that the first two counter hypothesis correlation coefficients are not as large nor as significant as the first two primary hypotheses correlations. This would suggest that the first two hypotheses hold. The third counter hypothesis suggests that the causal path from $LSM_{3(t1)}$ to $LSM_{2(t2)}$ may actually be stronger in the $LSM_{2(t1)}$ to $LSM_{3(t2)}$ direction, which could suggest that the Lifecycle Process maturity leads the enabling infrastructure process maturity. The full set of cross-panel correlations and their significance levels are shown in Figure 33.

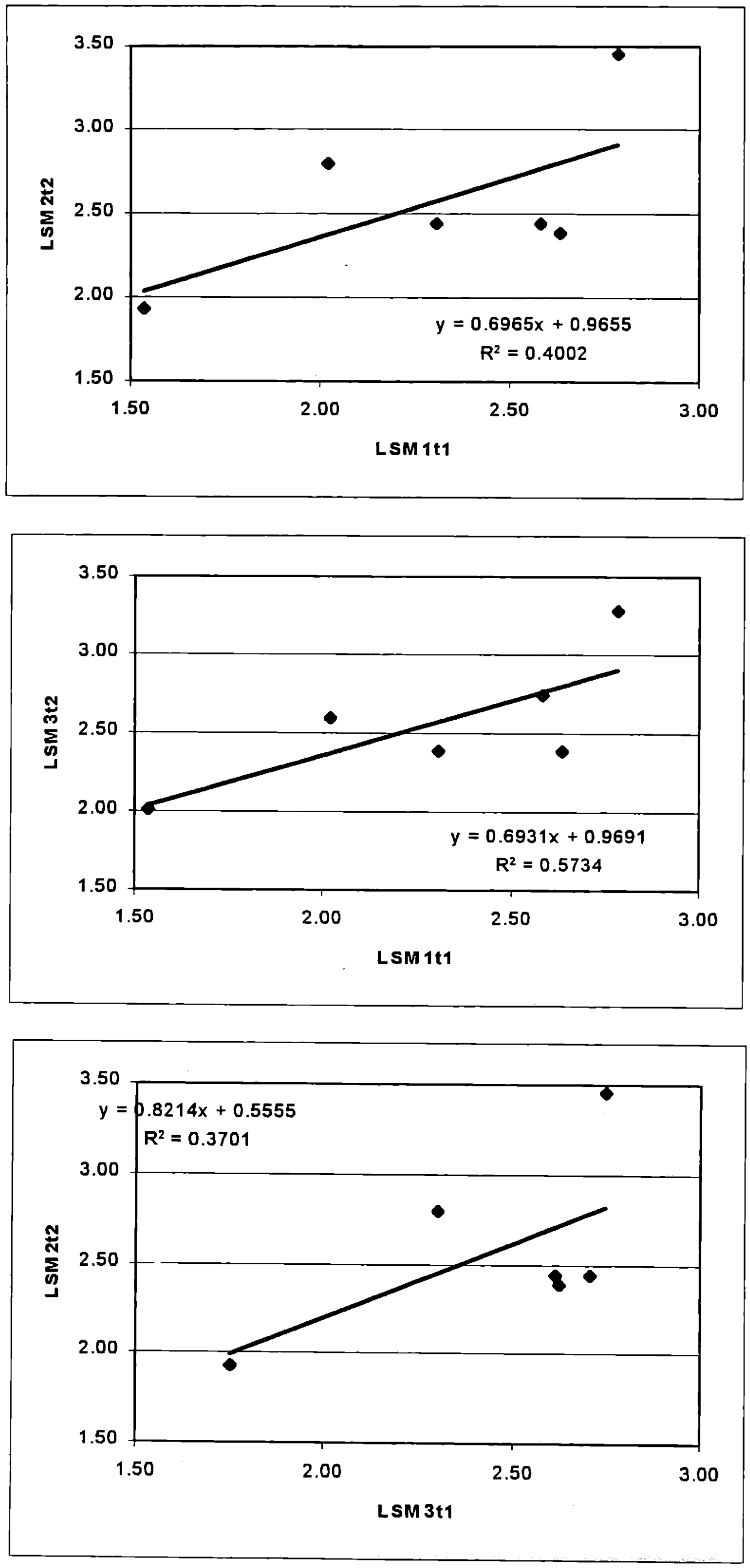


Figure 32 - Cross-panel LSM data representing the three primary hypotheses (n=6).

Hypothesis	r ( ) = sig.	r^2	$1-r^2$
$LSM_{2(t2)}$ increases with $LSM_{1(t1)}$	0.633 (0.089)	0.401	0.599
$LSM_{3(t2)}$ increases with $LSM_{1(t1)}$	0.757 (0.041)	0.573	0.427
$LSM_{2(t2)}$ increases with $LSM_{3(t1)}$	0.608 (0.100)	0.370	0.630

Table 34 - Cross-panel correlation results (n=6).

Counter Hypotheses	r ( ) = sig.	r^2	$1-r^2$
$LSM_{2(t1)}$ increases with $LSM_{1(t2)}$	0.499 (0.157)	0.249	0.751
$LSM_{3(t1)}$ increases with $LSM_{1(t2)}$	0.494 (0.159)	0.244	0.756
$LSM_{2(t1)}$ increases with $LSM_{3(t2)}$	0.905 (0.007)	0.819	0.181

Table 35 - Counter hypotheses in cross-panel analysis (n=6).

While these correlations appear supportive of the primary two hypotheses, and in fact indicate evidence of inferred causality, the analyses should be continued while controlling for other variables that could be influencing the calculations. For example, in testing the hypothesis that $LSM_{2(t2)}$ increases with $LSM_{1(t1)}$ while holding $LSM_{1(t2)}$ constant the correlation coefficient drops to 0.519 at a significance level of 0.185. Controlling for $LSM_{2(t2)}$ instead leads to an r of -0.2495 at a significance level of 0.343. Controlling for both $LSM_{1(t2)}$ and $LSM_{2(t2)}$, r is -0.2916 with a significance level of 0.354. The data set appears too small and with large enough variation to make the cross-lagged panel analyses that control for variables inconclusive. The analysis methods that control for variables proposed in this section could become more useful as the data set grows over time. However, the general bivariate correlation test using the cross-lagged panel results does provide an indication that the inferred causality may exist, even with the current small sample size.

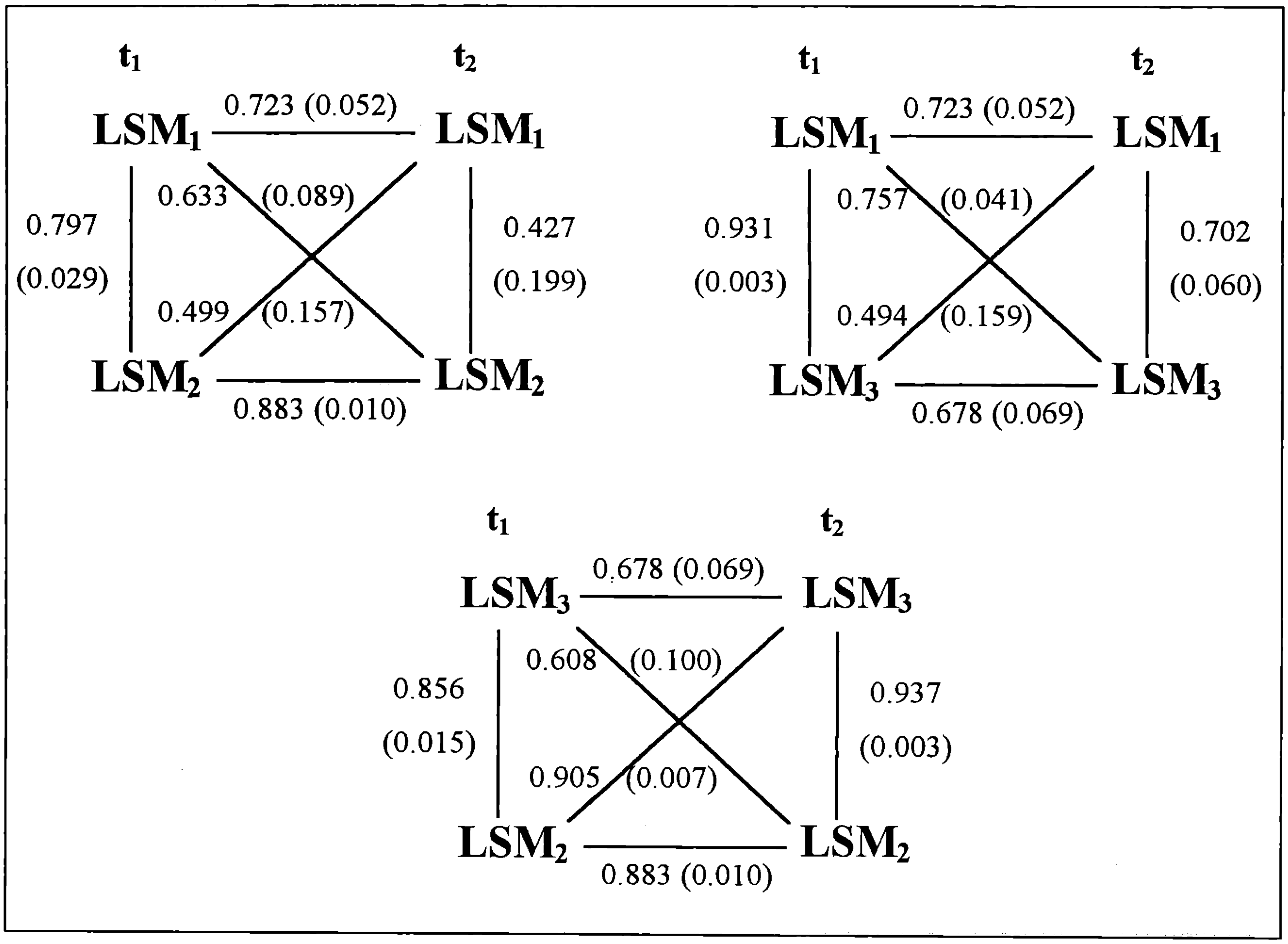


Figure 33 - Cross-panel correlations for six enterprises reporting LESAT data at t_1 and t_2.

6.3. Extension of the Lean Transformation Hypotheses

6.3.1. Sub-Categories of Leadership/transformation Transformation Measure

As described in Chapter 5, there is interest in understanding the leadership influence associated with lean enterprise transformation. It was thus proposed that the LSM_1 variable which covered the Leadership/Transformation LESAT practices, and appears to correlate significantly with Lifecycle Process and Enabling Infrastructure LESAT practices, be subdivided into more discrete variables. These variables were proposed to represent a measure of lean enterprise Leadership Commitment (LC), a measure of creating a lean enterprise Change Environment (CE), and a measure of lean enterprise

Change in Practice (CP). Table 36 shows how these variables were constructed from the LESAT data, and Table 37 shows the statistical tests associated with the null hypotheses. Figure 34 and Figure 35 provide a graphical representation of these two hypotheses using t_1 data with an n of 30. These figures show a tight grouping of the measures around the positive sloped trend lines, which appears to be in agreement with the hypotheses.

New Variable	Composed of the following LESAT variables
LC - Leadership Commitment to a lean enterprise	Entry/Reentry Cycle - LESAT Practices in Sections IA and IB
CE - lean enterprise Change Environment	Long Term Cycle - LESAT Practices in Sections IC and ID
CP - lean enterprise Change in Practice	Short Term Cycle - LESAT Practices in Sections IE, IF, and IG

Table 36 - Definition of leadership/transformation sub-variables.

Hypothesis	Null Hypothesis	Alternate Hypothesis
CE increases with LC	H_{oa}: $r_{CELC} = 0$	H_{1a}: $r_{CELC} > 0$
CP increases with CE	H_{ob}: $r_{CPCE} = 0$	H_{1b}: $r_{CPCE} > 0$

Table 37 - Leadership sub-variable correlation analysis test statistics.

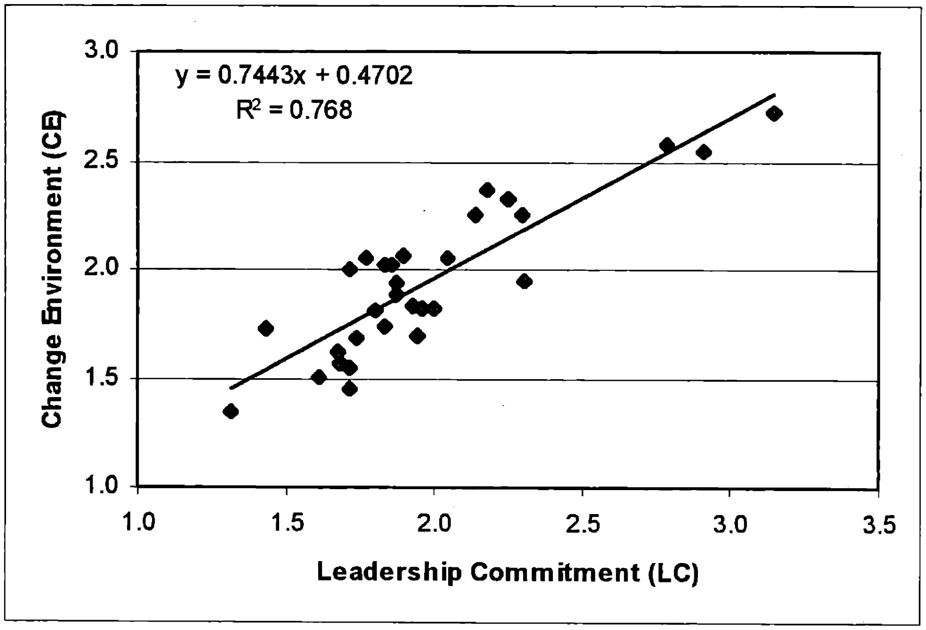


Figure 34 - Lean change environment (CE) as a function of leadership commitment (LC) measured at t_1 (n=30).

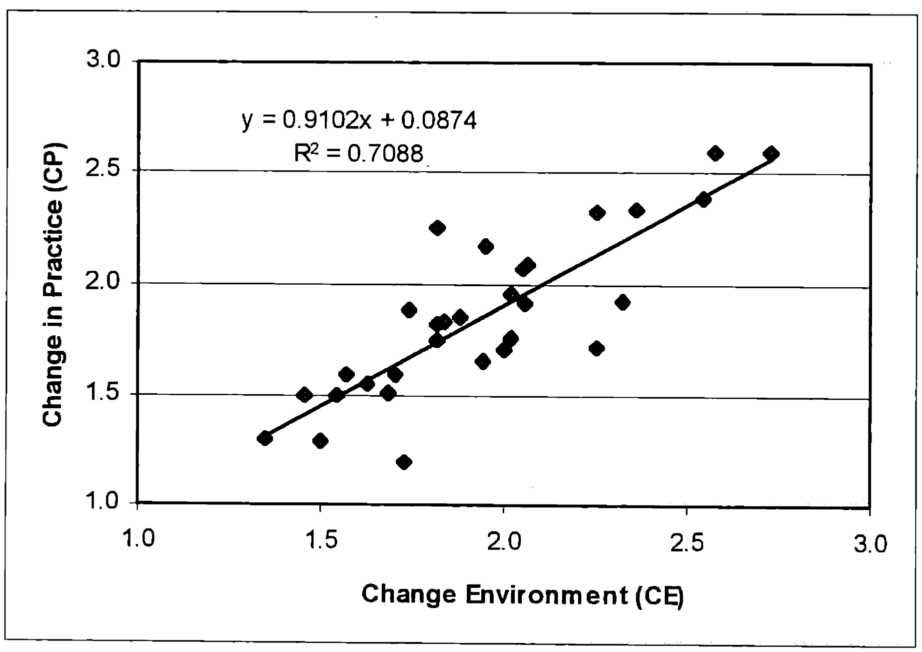


Figure 35 - Lean change in practice (CP) as a function of lean change environment (CE) measured at t_1 (n=30).

As the bivariate correlation test data in Table 38 shows, there is a strong correlation of these measures at high one-tailed significance, which disconfirms the null hypotheses in Table 37. The data also suggests that there could be a path-dependence from lean enterprise leadership commitment (LC) to lean enterprise change in practice (CP) as shown in Figure 36. When controlling for CP, the partial correlation coefficient from LC to CE remains high at a significance level of greater than 0.001. This strongly supports the hypothesis that lean enterprise leadership commitment is a key factor in achieving lean enterprise transformation, as exhibited through lean maturity in CE and CP.

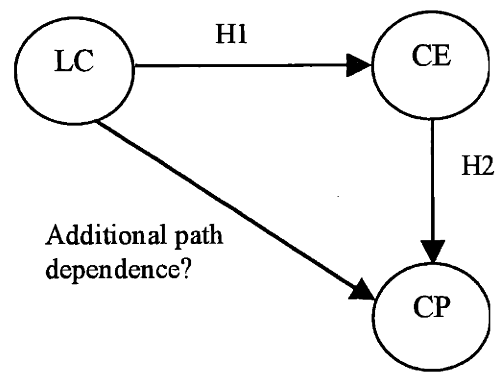


Figure 36 - Proposed causal relationship between leadership/transformation sub variables.

Correlation	r ( )=sig.	r^2	$1-r^2$
r_{CELC}	0.876 (0.000)	0.767	0.233
r_{CPCE}	0.842 (0.000)	0.709	0.291
r_{CPLC}	0.842 (0.000)	0.709	0.291
path LC-CE	check $r_{CPCE} \times r_{CPLC} < r_{CELC}$; (0.842)(0.842) = 0.709 < 0.876		
path CE-CP	check $r_{CELC} \times r_{CPLC} < r_{CPCE}$; (0.876)(0.842) = 0.738 < 0.842		
$r_{CELC.CP}$	0.575 (0.001)	0.331	0.669
$r_{CPCE.LC}$	0.399 (0.016)	0.159	0.841
$r_{CPLC.CE}$	0.403 (0.015)	0.162	0.838
path LC-CE	(0.399)(0.403) = 0.161 < 0.575		
path CE-CP	(0.575)(0.403) = 0.232 < 0.399		

Table 38 - Leadership/transformation sub-variable correlation analysis at t_1 (n=30).

The data in Table 39 utilizes the results from the year 2 LESAT users. Within reason of the low sample size of the year 2 data set, the hypotheses tested at t_2 (with n=6) yields extremely high correlations at high significance levels (less than 0.01). These results also serve to disconfirm the null hypotheses. While the partial correlation coefficients might be unreliable due to the low degrees of freedom of the test, it is interesting to see that the strong relationship between LC and CE at a significance level of better than 0.05 when controlling for CP. These results are also present in the differential data that correlates the change in measures from t_1 to t_2 (i.e. dLC, etc.), as shown in Table 40.

Correlation at t2	r ( )=sig.	r^2	$1-r^2$
r_{CELC}	0.971 (0.000)	0.943	0.057
r_{CPCE}	0.939 (0.003)	0.882	0.118
r_{CPLC}	0.901 (0.007)	0.812	0.188
partials			
$r_{CELC.CP}$	0.8362 (0.039)	0.699	0.301
$r_{CPCE.LC}$	0.6187 (0.133)	0.383	0.617
$r_{CPLC.CE}$	-0.1291 (0.418)	0.017	0.983

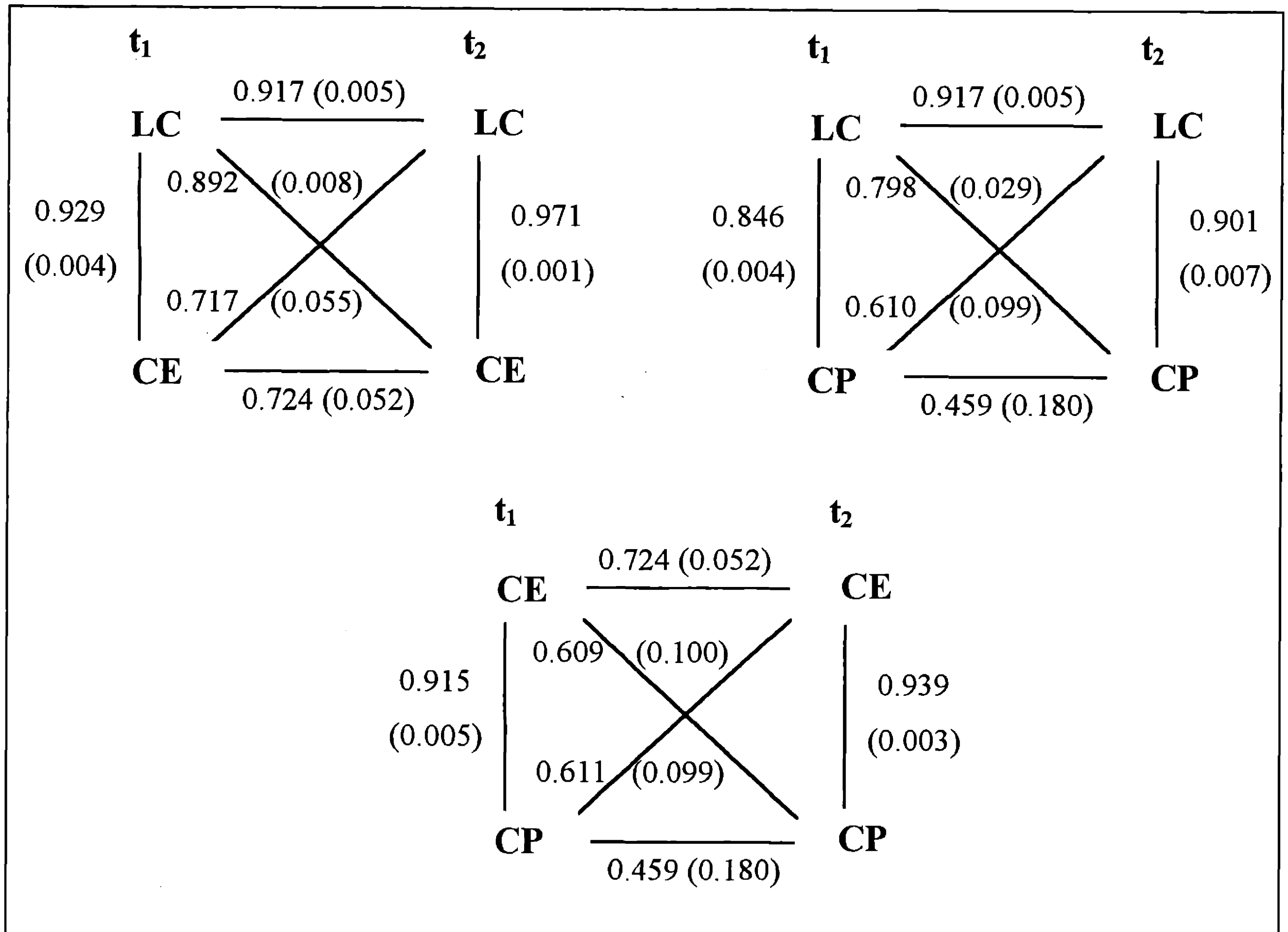
Table 39 - Leadership/transformation sub-variable correlation analysis at t_2 (n=6).

Correlation	r ( )=sig.	r^2	$1-r^2$
rd_{CELC}	0.856 (0.015)	0.733	0.267
rd_{CPCE}	0.758 (0.040)	0.575	0.425
rd_{CPLC}	0.495 (0.159)	0.245	0.755
partials			
$rd_{CELC.CP}$	0.8496 (0.034)	0.722	0.278
$rd_{CPCE.LC}$	0.7461 (0.074)	0.557	0.443
$rd_{CPLC.CE}$	-0.4601 (0.218)	0.212	0.788

Table 40 - Leadership/transformation sub-variable differential correlation analysis (n=6).

The cross-lagged panel correlations shown in

Figure 37 explore the inferred causality between the variables by using the data from the six enterprises in a similar fashion to the cross-lagged panel analysis done previously in this chapter. The hypotheses are tested using the proposed causal variable at t_1 correlated to the proposed outcome variable at t_2. Conversely, the opposite correlations are tested to verify that the outcome variable at t_1 does not have as high a correlation with the causal variable at t_2, which could suggest that the inference is proposed in the wrong direction. It appears that H1 holds as the correlation in the inferred causal direction is higher and more significant than in the converse direction. The same holds true for the causal inference from LC to CP. What is interesting is that there is little difference between the two cross-time paths associated with CE and CP. While they have high correlations in constant time periods, their cross time correlations are lower, but approximately equal in magnitude and significance. This could imply that the two variables are more closely related in time than suggested by this model test using a time difference of 1 year. This specific result could be interesting to pursue as a greater amount of time-series data is



made available for future study.

Figure 37 - Cross-panel correlation analysis of leadership/transformation sub-variables across two time periods (n=6).

The data presented in this section supports the hypotheses proposing that enterprises exhibiting high maturity LC would exhibit high maturity in CE, and enterprises exhibiting high maturity in CE would exhibit high maturity in CP. Furthermore, it also appears that there is a path-dependence between LC and CP. These results suggest that creating maturity in LC could have a positive impact on both CE and CP, and that lean enterprise transformation efforts may be more likely to succeed in creating higher enterprise lean maturity as LC maturity is increased.

6.3.2. Exploring the Sequencing of TTL Elements

The test of the TTL sequencing is aimed at looking for correlations of significance between the TTL blocks, as defined in Figure 38 by their LESAT section number (i.e. I.A, I.B, etc…). The existence of correlations between the major blocks would disconfirm the null hypothesis that there is not some form of causal sequencing in the model. The data in Table 41 shows a strong correlation between each of the sequential blocks, as proposed in the TTL. The data in Table 43 also shows strong correlations between the blocks at t_2, which would seem to support the t_1 findings.

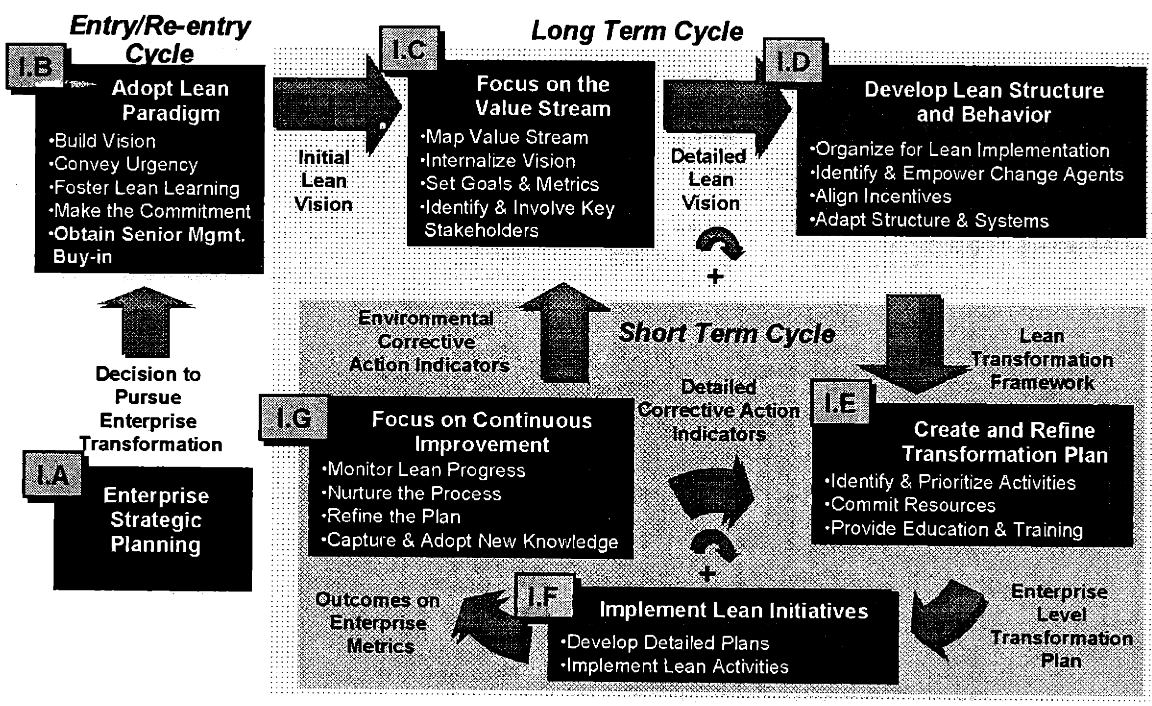


Figure 38 - Enterprise Transition to Lean (TTL) Roadmap (Nightingale et al. 2000).

The complete bivariate partial correlation results for t_1 and t_2 data are shown in Table 42 and Table 44 respectively. This data supports the sequencing of lean enterprise transformation activities outlined in the TTL. Further analysis might reveal a better sequencing for the activities, especially in the presence of stronger correlations between TTL blocks out of sequence, but this is not a primary focus of this thesis. It suffices for the purpose of this thesis that the data supports the belief that the sequence of the TTL is acceptable for lean enterprise transformation and could be a good guide for enterprises that have not outlined the steps of a formal lean enterprise transformation plan.

Correlation	r ( )=sig.	r^2	$1-r^2$
r_{IBIA}	0.607 (0.000)	0.368	0.632
r_{ICIB}	0.723 (0.000)	0.523	0.477
r_{IDIC}	0.776 (0.000)	0.602	0.398
r_{IEID}	0.730 (0.000)	0.533	0.467
r_{IFIE}	0.821 (0.000)	0.674	0.326
r_{IGIF}	0.916 (0.000)	0.839	0.161

Table 41 - TTL block correlation analysis at t1 (n=30).

Correlations

		IA	IB	IC	ID	IE	IF	IG
IA	Pearson Correlation	1	.607**	.690**	.781**	.613**	.630**	.715**
	Sig. (1-tailed)	.	.000	.000	.000	.000	.000	.000
	N	30	30	30	30	30	30	30
IB	Pearson Correlation	.607**	1	.723**	.751**	.761**	.760**	.779**
	Sig. (1-tailed)	.000	.	.000	.000	.000	.000	.000
	N	30	30	30	30	30	30	30
IC	Pearson Correlation	.690**	.723**	1	.776**	.694**	.841**	.738**
	Sig. (1-tailed)	.000	.000	.	.000	.000	.000	.000
	N	30	30	30	30	30	30	30
ID	Pearson Correlation	.781**	.751**	.776**	1	.730**	.729**	.806**
	Sig. (1-tailed)	.000	.000	.000	.	.000	.000	.000
	N	30	30	30	30	30	30	30
IE	Pearson Correlation	.613**	.761**	.694**	.730**	1	.821**	.830**
	Sig. (1-tailed)	.000	.000	.000	.000	.	.000	.000
	N	30	30	30	30	30	30	30
IF	Pearson Correlation	.630**	.760**	.841**	.729**	.821**	1	.916**
	Sig. (1-tailed)	.000	.000	.000	.000	.000	.	.000
	N	30	30	30	30	30	30	30
IG	Pearson Correlation	.715**	.779**	.738**	.806**	.830**	.916**	1
	Sig. (1-tailed)	.000	.000	.000	.000	.000	.000	.
	N	30	30	30	30	30	30	30

**. Correlation is significant at the 0.01 level (1-tailed).

Table 42 - Bivariate correlations amongst LESAT leadership/transformation variables aggregated at the LESAT X.X level (aka TTL block level, t_1, n=30).

Correlation at t2	r ( )=sig.	r^2	$1-r^2$
r_{IBIA}	0.872 (0.012)	0.361	0.639
r_{ICIB}	0.981 (0.000)	0.539	0.461
r_{IDIC}	0.929 (0.004)	0.605	0.395
r_{IEID}	0.848 (0.017)	0.546	0.454
r_{IFIE}	0.882 (0.010)	0.676	0.324
r_{IGIF}	0.957 (0.001)	0.845	0.155

Table 43 - TTL block correlation analysis at t2 (n=6).

Correlations

		S1A	S1B	S1C	S1D	S1E	S1F	S1G
S1A	Pearson Correlation	1	.872*	.897**	.828*	.896**	.745*	.785*
	Sig. (1-tailed)	.	.012	.008	.021	.008	.045	.032
	N	6	6	6	6	6	6	6
S1B	Pearson Correlation	.872*	1	.981**	.982**	.813*	.857*	.932**
	Sig. (1-tailed)	.012	.	.000	.000	.025	.015	.003
	N	6	6	6	6	6	6	6
S1C	Pearson Correlation	.897**	.981**	1	.929**	.762*	.754*	.852*
	Sig. (1-tailed)	.008	.000	.	.004	.039	.042	.016
	N	6	6	6	6	6	6	6
S1D	Pearson Correlation	.828*	.982**	.929**	1	.848*	.932**	.978**
	Sig. (1-tailed)	.021	.000	.004	.	.017	.003	.000
	N	6	6	6	6	6	6	6
S1E	Pearson Correlation	.896**	.813*	.762*	.848*	1	.882*	.893**
	Sig. (1-tailed)	.008	.025	.039	.017	.	.010	.008
	N	6	6	6	6	6	6	6
S1F	Pearson Correlation	.745*	.857*	.754*	.932**	.882*	1	.957**
	Sig. (1-tailed)	.045	.015	.042	.003	.010	.	.001
	N	6	6	6	6	6	6	6
S1G	Pearson Correlation	.785*	.932**	.852*	.978**	.893**	.957**	1
	Sig. (1-tailed)	.032	.003	.016	.000	.008	.001	.
	N	6	6	6	6	6	6	6

*. Correlation is significant at the 0.05 level (1-tailed).

**. Correlation is significant at the 0.01 level (1-tailed).

Table 44 - Bivariate correlations amongst LESAT leadership/transformation variables aggregated at the LESAT X.X level (aka TTL block level, t_2, n=6).

6.4. Variability in Assessment Results as an Indicator of Enterprise Maturity

The hypothesis that leaner enterprises will exhibit less variability in assessed maturity was tested three ways using the t_1 data set (n=28). The first test involved the comparison of all average lean practice maturities against the variance in the scores for each lean practice. This data is shown in Figure 39. The test was also conducted using the section maturity versus the average of the lean variances in the particular LSM, as shown in Figure 40. The overall average enterprise maturity was plotted against the average of the variances in each of the lean practices, as shown in Figure 41. An attempt was also made to see if a correlation existed between the variance in the Leadership/Transformation LESAT practices and the maturity of the Lifecycle Process and Enabling Infrastructure practices as shown in Figure 42. The correlation results from these analyses are shown in Table 45.

The graphical representations of the hypothesis and the table of test statistics show that there is a low to moderate correlation at high significance levels in each of the tests. The interesting result here is that the correlation is in the opposite direction of what was anticipated. It was felt that there should be a negative correlation between variability in assessed maturity and enterprise maturity as it was thought that higher maturity requires higher levels of communication and integration amongst members of the enterprise leadership committee. While this hypothesis may in fact be true, the use of this data set in the proposed manner is actually a flawed test, as the only way to have high variability is to have a spread in the data. Thus a low maturity enterprise (say a level 1) can only have high variability if it has scores that are higher than 1. This results in the overall average maturity increasing, and thus there is an exhibited trend of increasing maturity with increasing variability. As the scale increases further, the variability must begin to decrease, as averaging a 5 on the scale requires that all respondents score a 5, resulting in zero variability. Thus the results of this test as structured are inconclusive. However, the measure of variability in assessed lean practice maturity may still be an indicator of how well the enterprise leadership team understands the lean maturity of the enterprise. A corrected scale could plot the variance normalized by the maximum variance that would result in the same average maturity for the given number of respondents. This transformation would correct for the scale issues associated with this hypothesis.

Test Variable	N	r ( ) = sig	r^2	$1-r^2$
$LPME_i$ vs. variance in $LPME_I$	1008	0.3457 (0.000)	0.1195	0.8805
LSM_i vs. average variance in LPME's in section i	57	0.3764 (0.002)	0.1417	0.8583
Average enterprise LM vs. average variance in all LPME's	19	0.5158 (0.012)	0.2661	0.7339
Average maturity for all of section II&II vs. average variance in Section I LPME's	19	0.560 (006)	0.3135	0.6865

Table 45 - Results of correlation analysis between in lean maturity and variance in lean maturity scores.

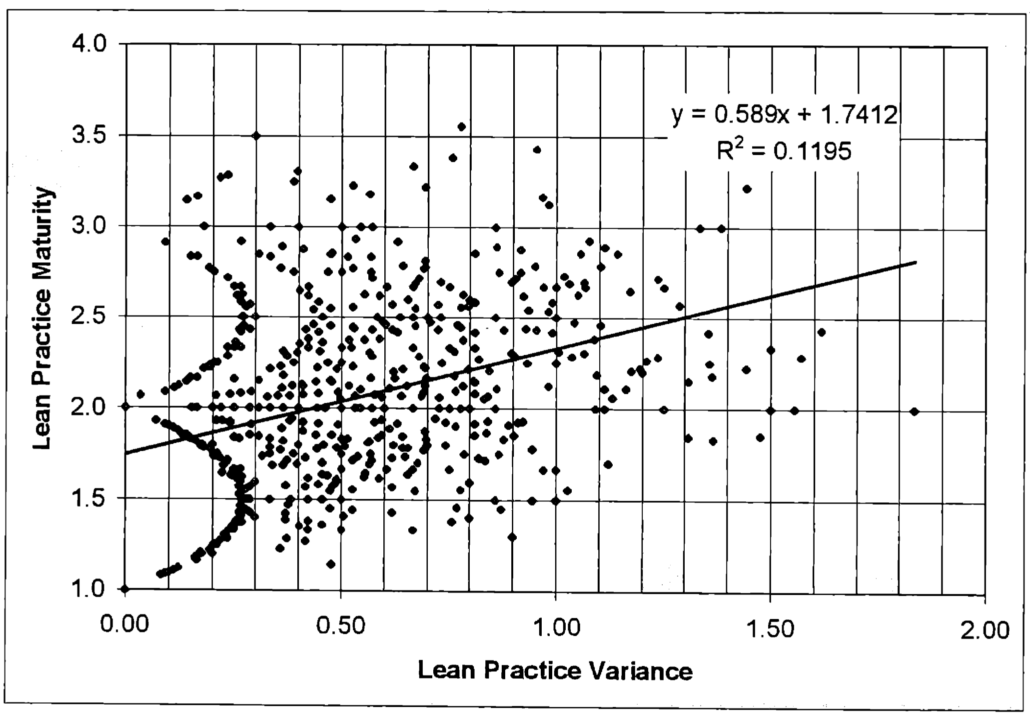


Figure 39 - Average lean practice maturity versus assessment variance (n=1008).

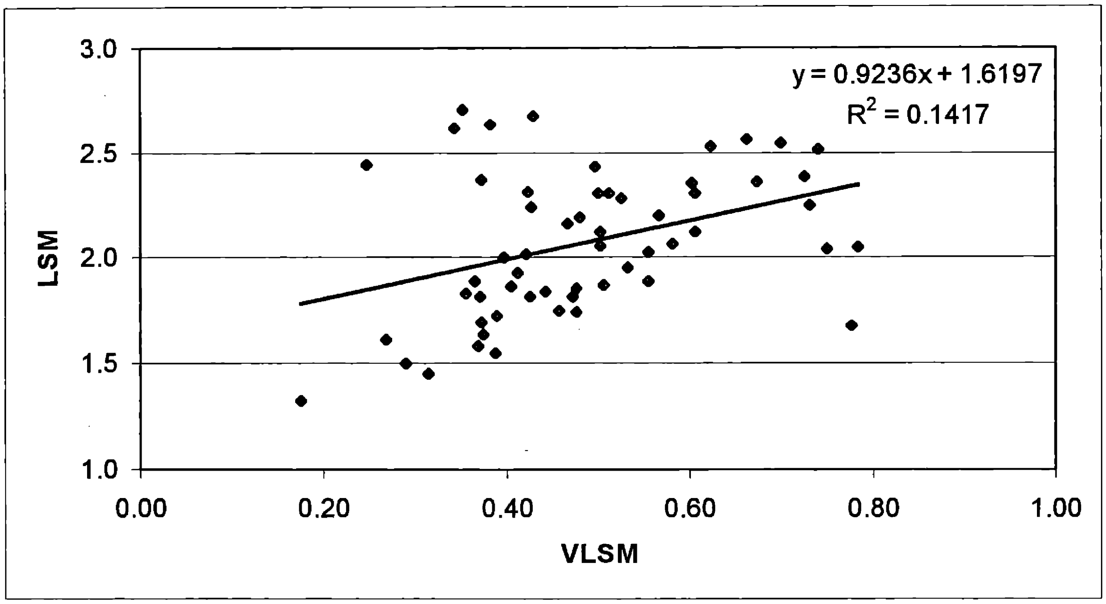


Figure 40 - Average lean section maturity versus average variance of lean practice scores in the section (n=57).

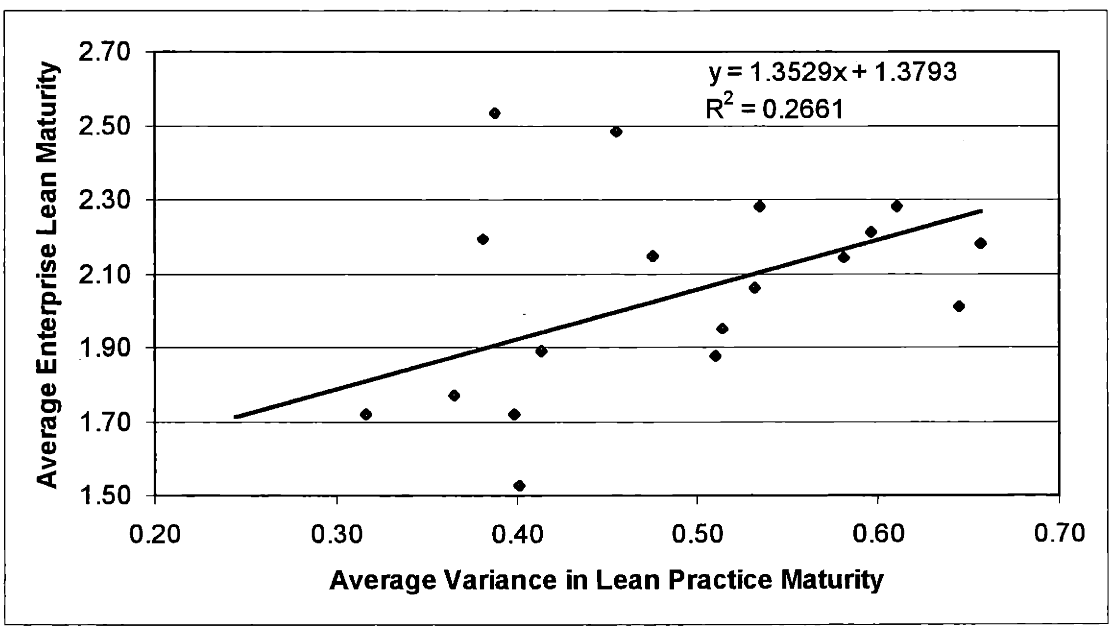


Figure 41 - Average enterprise maturity versus average of lean practice maturity variances.

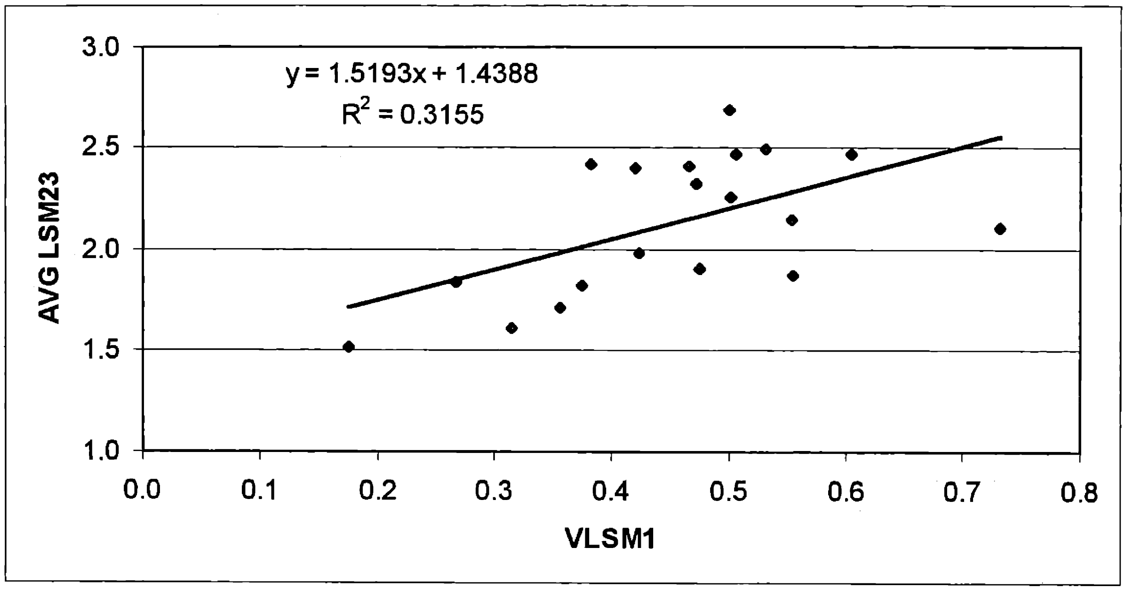


Figure 42 - Average of lifecycle process and enabling infrastructure practice maturity versus average variance in leadership/transformation practices.

6.5. Industry Average Data

Since the LESAT was not intended as a benchmarking tool, data will be reported about average industry scores or comparisons amongst the maturity of each enterprise. However, the rank order of the overall industry results provides some insight into the current state of lean enterprise transformation in the Aerospace Industry. The data presented in Table 46 shows the average rank order of LESAT practices across the industry. Some insights about lean enterprise transformation in this industry can be gained by looking at both the highest ranked practices and lowest ranked practices.

LESAT Practice (Rank: lowest = 1, highest = 54)	Average Rank Order
I.C.3. Designing the future value stream	1
I.F.1. Development of detailed plans based on enterprise plan	2
I.B.3 Lean Enterprise Vision	3
I.E.1. Enterprise level lean implementation plan	4
I.C.1. Understanding the current value stream	5
I.B.4. A sense of urgency	6
II.A.1. Leverage lean capability for business growth	7
II.B.2. Utilize data from the extended enterprise to optimize future requirement definitions	7
I.E.3. Provide education and training	9
I.C.2. Enterprise flow	10
I.D.7. Lean change agents	11
III.A.1. Financial system supports lean transformation	12
I.F.2. Tracking detailed implementation	13
I.G.5. Impacting enterprise strategic planning	13
I.D.6. Innovation encouragement	15
I.D.5. Incentive alignment	16
I.G.2. Monitoring lean progress	17
III.A.2. Enterprise stakeholders pull required financial information	17
III.B.3. Variation reduction	19
II.B.1. Establish a requirements definition process to optimize lifecycle value	20
I.B.2. Senior management commitment	21
II.A.2. Optimize the capability and utilization of assets	22
II.D.1. Define and develop supplier network	23
I.C.4. Performance measures	24
III.A.3. Promulgate the learning organization	25
I.G.4. Capturing lessons learned	26
I.A.3. Leveraging the extended enterprise	27
II.F.3. Enhance value of delivered products and services to customers and the enterprise	28

LESAT Practice (Rank: lowest = 1, highest = 54)	Average Rank Order
II.F.2. Distribute product in lean fashion	29
I.D.2. Relationships based on mutual trust	30
I.B.1. Learning and education in 'lean' for enterprise leaders	31
I.G.1. Structured continuous improvement process	32
I.G.3. Nurturing the process	33
II.C.3. Integrate product and process development	34
I.A.2. Focus on customer value	35
II.D.3. Foster innovation and knowledge-sharing throughout the supplier network	36
I.E.2. Commit resources for lean improvements	37
II.E.1. Utilize production knowledge and capabilities for competitive advantage	38
II.D.2. Optimize network-wide performance	39
II.F.4. Provide post delivery service, support and sustainability	40
II.F.1. Align sales and marketing to production	41
III.A.4. Enable the lean enterprise with information systems and tools	42
I.D.4. Employee empowerment	43
II.A.4. Resource and empower program development efforts	43
II.E.2. Establish and maintain a lean production system	45
I.A.1. Integration of lean in strategic planning process	46
II.C.1. Incorporate customer value into design of products and processes	47
I.D.1. Enterprise organizational orientation	48
III.B.1. Process standardization	49
I.D.3. Open and timely communications	50
II.C.2. Incorporate downstream stakeholder values into products and processes	51
II.A.3. Provide capability to manage risk, cost, schedule and performance	52
III.B.2. Common tools and systems	53
III.A.5. Integration of environmental protection, heath and safety into the business	54

Table 46 - Average rank order of LESAT practices in the aerospace industry.

6.5.1. Highest Ranking Industry Practices

The highest ranking practices (numbers 45 through 54 in Table 46) are not all necessarily the result of lean transformation efforts. While the development of the LESAT identified them as important to the lean enterprise, they are also associated with other management efforts that may explain why they ranked as some the highest maturity practices. For instance, practice III.A.5 (Integration of Environmental Protection, Health and Safety into the Business) can be largely attributed to requirements set forth in the Occupational Safety and Health Act (OSHAct) of 1970 (Ashford and Caldart 1996), and in some cases union rules that establish guidelines above and beyond what is enforced under the OSHAct.

Modern systems engineering, especially as it is instituted in the aerospace industry, reinforces the concepts of managing risk, cost, and schedule, and performance in most if not all major programs (Hughes 1998), (Browning 1998), (McNutt 1998). Additionally, the field of systems engineering deals heavily with requirements management and tracking. For complex systems this includes the creation and tracking of sub-requirements down to the detailed component level and back up through system integration, verification, and validation (Boppe 1996), (Maier and Rechtin 2000), (Grady 1994). Related efforts in concurrent engineering utilize Integrated Product and Process Development (IPPD) that is executed by Integrated Product Teams (IPT's) to ensure that downstream stakeholder values (the "ilities" such as manufacturability, repairability, reliability, etc.) are considered during the upstream design and development processes (SOCE 2003), (Boppe 1996), (Ulrich and Eppinger 2000). The fact that these practices have been in use in the aerospace industry for some time are probably a good reason why practices II.C.2 (Incorporate downstream stakeholder values into products and processes), II.A.3 (Provide capability to manage risk, cost, schedule and performance), and II.C.1 (Incorporate customer value into design of products and processes) all ranked highly on the maturity matrix.

Practices III.B.1 (Process Standardization) and III.B.2. (Common Tools and Systems) ranking highly could be the result of many past actions. DOD oversight and management procedures could have led to some level of maturity as they required or dictated the use of certain processes, tools, and/or systems. Furthermore, a myriad of improvement efforts have permeated the industry for several decades, including Total Quality Management (TQM), Six Sigma (6σ) statistical process control, and Business Process Reengineering (BPR) to name a few, all of which have elements of creating some form of standard process and system commonality.

It may not surprise some to see practices I.D.1 (Enterprise Organizational Orientation) and I.D.3 (Open and Timely Communications) ranking high in maturity. Again, maturity in these practices is not necessarily a result of lean transformation efforts, even though they are considered an integral part of the lean enterprise. The wording of practice I.D.1 at level 3 maturity essentially represents the beginning of a matrix style organization of some kind. For the most part, enterprises participating in this study operate in corporations that have strong functional capabilities as well as strong program focus, which is a form of matrix organization. To operate in such a matrix environment requires good communications, as there is an inherent tension between functional goals and program goals (Allen 1997), (Ulrich and Eppinger 2000). As a result it might be expected that I.D.3 ranks comparably with I.D.1, as there is an implied connection between the two maturities. Perhaps it would be interesting to study if the increase in communications maturity is associated with a change in enterprise management hierarchy from a very top-down command and control structure to a flatter, more distributed decision making environment (the latter of which could be associated more with a lean enterprise).

One of the more interesting results in the top ranking practices is the presence of practice I.A.1 (Integration of Lean in Strategic Planning Process). This is interesting for two reasons. First, it suggests that the sample (while largely biased towards enterprises that are thinking about lean and/or have deployed lean to some extent), is starting to include lean in their strategic planning efforts, a result that would not have been expected a decade ago when LAI began. This would suggest that lean, to some extent, is becoming an element of management's thinking in the industry. This is further supported by the fact that the next highest ranked practice, II.E.2 (Establish and Maintain a Lean Production System) suggests that lean is gaining a foothold in the industry as a formal means of operations in manufacturing. However, the second reason that I.A.1 ranking so highly is interesting is the fact that 1.G.5 (Impacting Enterprise Strategic Planning) ranked so low (13th lowest out of 54 practices). This fact suggests that the ideas of lean may be surfacing in strategic planning efforts, but the actual results and lessons learned from the improvement efforts are largely not feeding back into the strategic planning. There appears to be an "open-loop" effect occurring where the knowledge about what lean has done (and can do) within the enterprise is not informing or helping shape the strategic direction of the enterprise.

6.5.2. Lowest Ranking Industry Practices

The lowest ranking LESAT practices, on average for the industry are primarily associated with the Leadership/Transformation section of the LESAT (Section I). Of the ten (10) lowest-ranking practices, eight (8) are in the Leadership/Transformation section of the LESAT. This represents 80% of the lowest 10 practices while the Section I practices only account for 51% of the total number of practices in the LESAT.

What is noticeable right away from the list is that I.B.3 (Lean Enterprise Vision) is on average one of the lowest maturity practices in the industry. This fits with our presupposition of the aerospace industry only beginning to consider lean enterprise transformation. A low "lean enterprise vision" maturity can be considered the major explanation why I.E.1 (Enterprise-Level Lean Implementation Plan) and 1.F.1 (Development of Detailed Plans Based on Enterprise Plan) also ranked so low. The logic behind this conclusion is that lean enterprise implementation plans do not manifest themselves with little or no imperative and guidance from enterprise leadership. It follows that the lack of a mature lean enterprise vision results in low maturity in implementation plans, which in turn, results in low maturity in detailed plans, as the former is required to create the latter. The argument that the detailed plans could be mature without a lean vision would suggest that the two were independent. Data from the cross-sectional industry study shows this not to be the case (there is a correlation of 0.741 with a significance of less than 0.001 between the two variables).

The lowest ranked LESAT practice for the industry average maturity was I.C.3 (Designing the Future Value Stream). This low maturity derives from several factors, including the low maturity of the lean enterprise vision, and also the low maturity of I.C.1 (Understanding the Current Value Stream). While the work of process improvement initiatives such as business process reengineering (BPR) does not advocate the requirement of a detailed "current state" process map (Uzair 2001), (Malhotra 1998), a minimum level of understanding of how business is currently done is required to create a future state, even if informal. However, understanding the current value stream in the context of the LESAT involves establishing an understanding of the needs and desires of current enterprise stakeholders. Thus it follows that a lack of maturity in this practice can lead to an inability to increase the maturity of I.C.3. In fact, the rank order of these results supports this proposition, in that I.C.1 is slightly more mature than I.C.3 on average for the industry (the two variables also have a correlation coefficient of 0.750 at a significance level of less than 0.001). The low maturity of 1.C.2 (Enterprise Flow) is also a consequence of the low maturity of the previous elements, as creating flow at an enterprise level requires understanding value streams and developing lean implementation plans to drive the creation of flow.

The low maturity of II.A.1 (Leverage Lean Capability for Business Growth) is also linked to the low maturity in lean enterprise vision, since there needs to be some sort of view of how to exploit the gains achieved with a lean system. A lack of this vision could lead to no action, and hence low maturity, in capitalizing on the strategic gains achieved with a lean production system and/or enterprise. This could also be a result of the apparent "open-loop" issue identified between I.A.1 and I.G.5 discussed earlier. A lack of feeding back to management knowledge of the production system capabilities may lead to its oversight when crafting growth strategies.

A significant finding of research into organizational behavior is the fact that there needs to be some form of anxiety required for people to change (Schein 1983), (Schein 1999). The LESAT provides a measure of this anxiety in practice I.B.4 (a Sense of Urgency). It seems plausible that without a sense of urgency about becoming lean, or no anxiety that leads leadership to conclude that lean enterprise transformation is necessary, then there will probably be little effort to create a lean enterprise vision, hence I.B.3 will be low. It follows that with no sense of urgency to go lean, there will be little to no effort to mature practice I.E.3 (Providing Education and Training in Lean), and thus I.D.7 (Lean Change Agents) will not mature as there will be no imperative to commit resources to lean enterprise issues. This explanation seems to fit the rank ordering of the results fairly well. A factor that could cause the maturity of lean change agents to be higher is that there have been lean change agents in the manufacturing functions of many of these enterprises for some period of time. However, the low maturity in I.B.3 could prevent the addition of lean enterprise change agents to the mix.

The only LESAT practice in the lowest maturity category yet to be discussed is II.B.2. (Utilize Data from the Extended Enterprise to Optimize Future Requirement Definitions). This is not a tool or tactic original to lean in its traditional sense. This issue has arisen in the aerospace industry in areas such as reducing wasted effort in repair and overhaul of aircraft by utilizing in-service performance and past repair trend data to guide repair and overhaul efforts so that they are less exploratory and more directed. The extension of thoughts on this type of intelligent repair service is to tie the data into the development of new products and services in the industry. This requires better enterprise and extended enterprise information integration, as there are communication issues and large temporal delays associated with currently fielded systems and the design and development of new systems. As such, the complexity of this issue across functional, corporate, and temporal horizons may be an explanation as to why the maturity in this practice ranked low.

6.6. Observing the LESAT in Use

6.6.1. LESAT Beta Test Case Studies

During the winter and spring of 2001, ten US aerospace companies participated in the Beta Test of the LESAT. The Beta test was used as a means to improve the tool and its associated documentation, which resulted in the release of Version 1.0 of the tool. Follow-up interviews were conducted with the appropriate point of contact in each of the companies in the fall of 2001. These interviews were conducted to develop an understanding of how enterprises were utilizing their LESAT assessment results. What emerged from these interviews was a broad spectrum of responses, ranging from no action after the assessment, to annual operating plans (AOP's) developed with improvement targets based on the assessment results.

While the LESAT was not intended for single functions to use, it was found by several of the participating companies that Section I of the LESAT was valuable for understanding the maturity of lean transformation efforts in specific support functions, while much of Section 2 and 3 were found not to be applicable as they did not consider their function as delivering a physical product to a customer. This raises a question for future consideration - can the LESAT be used by a function when it considers other functions as suppliers and customers? While this might work, it would be interesting to explore if this would lead to the same types of localized optimizations that result in enterprise level waste discussed in Chapter 3.

The interview process was structured around a set of questions aimed at understanding the connection between the assessment results and the eventual choice of improvement actions. The interviews were typically held with the LESAT facilitator(s) who coordinated the assessment sessions for the enterprises. Interviews were not rigid in only focussing on the pre-set questions, but rather were allowed to flow into areas of interest that arose as the dialogues matured. The goal was to extract as much information as possible from each of the cases. The following questions served as the basis for the interviews:

Q1. What have your enterprise leaders done with the results of the LESAT assessment?
Q2. Has the use of LESAT impacted the degree of understanding of "lean" at the enterprise level? Please explain.
Q3. Have you used or plan to use LESAT in another part of your organization? What is the status of this use?
Q4. Are the LESAT results being viewed as a means for establishing actions by your enterprise leaders? If yes, how are these actions being established and prioritized?
Q5. Do you have plans to repeat the assessment, and if so, when?
Q6. Do you anticipate LESAT becoming a part of your management, assessment, and improvement process?
Q7. Does enterprise leadership expect certain changes in the LESAT results by the next assessment? If yes, what are these changes and how are they to be achieved?
Q8. What has the LESAT been most useful for in helping you become a lean enterprise?
Q9. What would be the most significant improvement you would recommend for creating lean enterprise transformation and evaluation tools?

From the interviews it was found that the majority of participants in the Beta test of the LESAT felt that the assessment process itself was as valuable as the results. The introduction and report-out sessions were found to increase the amount of lean enterprise communication amongst executives, as they covered many of the cross-functional issues within their enterprises. Some executives even pursued individual education to become more versed in the tenets of lean as a result of the use of the LESAT. Additionally, the assessment participants felt they began to establish a common vocabulary for discussing issues related to creating a lean enterprise, which resulted in fewer interpretation problems as participants discussed post-assessment actions. The enterprises reported that the results of the LESAT assessment provided a clear picture of how their enterprise was performing relative to lean principles and practices and the tool was said to provide an obvious improvement path as the next levels of maturity were well defined for each of the practices.

The fact that the LESAT is aimed at executive management and enterprise leadership teams raised concerns about the time cost of participating in the assessment. On average, it takes approximately 4-6 hours to complete the LESAT introduction session, the individual maturity ratings, and the final report out. This does not include the time for an individual tasked with managing the assessment to collect, analyze, and summarize the results, nor the time to develop action plans. Given this issue, the enterprises reported both pros and cons with using the LESAT as part of their suite of management tools. From a logistics perspective, the problem of coordinating the schedules of multiple executives from across the enterprise does prove to be an issue, as does the need to educate and train an in-house LESAT facilitator to manage the assessment process. In view of creating a real-time assessment capability, there have been numerous requests that a web-enabled, automated version of the LESAT be developed. The biggest problem people found with the tool is that while an improvement path is apparent with the LESAT, the question of "How" to achieve the next level of maturity is not. In some enterprises the question of "Where" to start the improvement efforts also arose. This may indicate the potential for further areas of research

6.6.2. Models of how Enterprises Act on their LESAT Results

The interviews with the ten LESAT beta test enterprises and discussions with some of the LESAT v1.0 users provided evidence that the use of the LESAT falls into 3 categories, namely:

1. Open Loop Control
2. Dissociated Closed-Loop Control
3. Integrated Closed-Loop Control

The Open-Loop Control category was characterized by companies investing the time and effort to perform the LESAT but not utilizing the results for influencing any sort of improvement action, as depicted in Figure 43 (note the addition of resources as a limiting function). The first question to ask is why would anyone perform this assessment, investing numerous hours of executive management and facilitator time, and then not utilize the results? One answer is that the Beta tests of the tool were intended as a means to field-test and improve the tool for release across the aerospace industry, and was thus not necessarily viewed as a means to drive lean enterprise transformation during the tool's development phase. This development involved MIT working with its LAI consortium members to develop consensus on the wording and format of the tool to ensure its usefulness to enterprise leaders in the aerospace industry. This said, there were numerous enterprises that intended to act on the results of their assessments even as the tool was being perfected. However, the enterprises in the open-loop control category each had slightly different reasons for not acting on their assessment results.

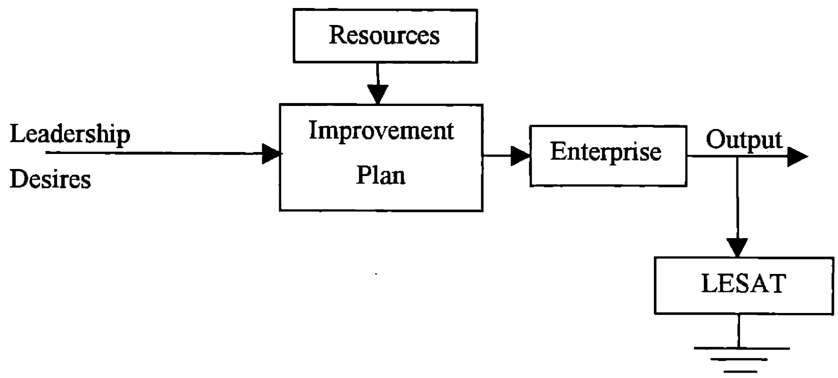


Figure 43 - Open loop control.

In one case, a corporate merger took place shortly after the assessment, resulting in a reorganization of the enterprise and its management team. Ultimately, this enterprise plans to perform another assessment and act upon the results as it deems appropriate at some future time. Another user of the LESAT is attempting to reconcile the existence of multiple lean assessment tools into a standard toolbox for use across the enterprise, with tools specified for each level of management and/or type of function. This enterprise plans on formally incorporating the LESAT into its toolbox, but has opted not to use the Beta test results for any formative change plans. Another enterprise that participated in the Beta testing of the LESAT also failed to act on any of their assessment results as it operated under a corporate-wide continuous improvement (CI) initiative that does not include the LESAT nor currently have plans to include a tool such as the LESAT. In this case the tool was viewed as "more work" and not as a potential for gaining insight into the organization's lean enterprise behavior.

The second category of enterprises, the Dissociated Closed-Loop Control category, was found to be the first level of closed-loop thinkers using the LESAT. These enterprises were characterized by a desire and effort to utilize their assessment results for affecting some form of change in view of becoming a leaner enterprise, as shown in Figure 44. The distinguishing factor in this category is that the improvement plans were LESAT-centric and not tied to other enterprise improvement plans. This results in multiple improvement efforts competing for a finite set of resources to accomplish multiple, and not necessarily mutually exclusive or mutually reinforcing tasks.

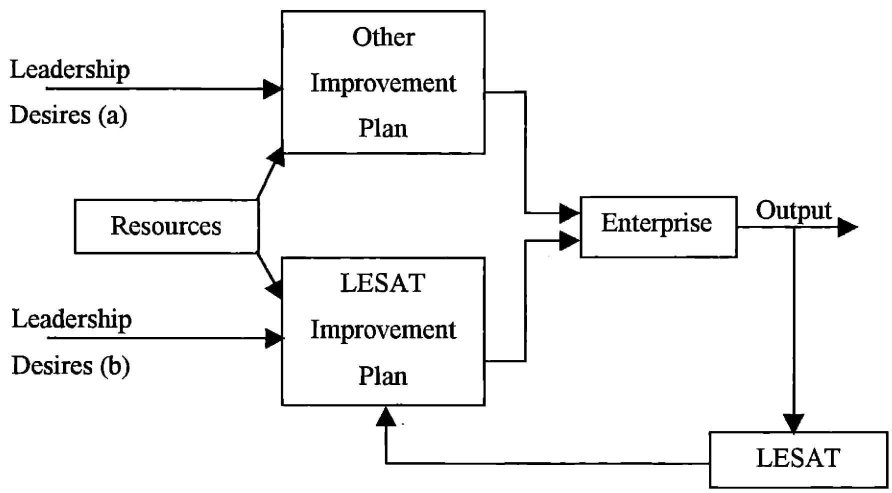


Figure 44 - Dissociated closed-loop control.

In most instances, the Category 2 assessors were focussed on improving the least mature practices in the LESAT assessment, as identified by the lowest maturity levels. In some cases, practices that appeared to have a large variance in responses from the assessors (i.e. from 1 to 4 in the same practice) were addressed as potential areas for education, as there appeared to be disagreement amongst the enterprise leaders about the maturity of the specific practice. In one instance, an assessment team noted that although there were low maturity practices in all three of the LESAT sections, their efforts would be better spent working on the two or three that appeared in Section I (Lean Transformation/ Leadership) as they felt there would be causal effects that would lead to improving some of the other practices in the enterprise. Finally, there were instances where executive leadership requested across-the-board improvements by the following assessment period, usually 1 level (or point) in all practices within 1 year.

The third category of enterprise, the Integrated Closed-Loop Control category, was characterized by the coupling of the LESAT assessment results with other enterprise strategic issues to develop an integrated and coherent continuous improvement (CI) plan, as shown in Figure 45. This approach offers the advantage that improvement efforts can be prioritized based on the knowledge of where the enterprise wishes to strategically position itself and allows the planning to consider the limited resources available for improvement efforts (remember that category 2 enterprises did this CI planning devoid of the other CI projects).

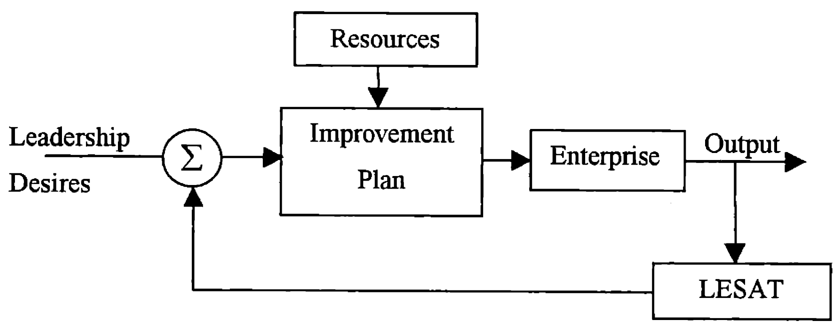


Figure 45 - Integrated closed-loop control.

In this category of enterprise the assessors realized that their improvement plans needed to be aligned with their strategic business direction. The means of creating CI plans was to first follow the same method as for category 2 enterprises, and create a listing of the least mature LESAT practices. Next, the category 3 enterprises attempted to cross-reference these low maturity practices to those that were most important for the business direction of the enterprise. Thus the LESAT practices most important for CI are a combination of lowest maturity and highest strategic value. In one instance, the enterprise leaders were given ownership of the assessment results, and based on the prioritization scheme, were tasked with developing Annual Operating Plans (AOP) that were to provide the tactics for addressing and improving maturity in individual LESAT practices. It was found that specific numerical improvement targets were not dictated in these enterprises, rather the goal of the CI plans was to work in a manner that would shift the enterprise further up the maturity scale over time.

While the interviews highlighted the existence of these three categories of enterprises, it was difficult to develop a clear interpretation of which category each enterprise fell into. There were often differences between intended actions with the LESAT results versus actual actions, in some cases due to external circumstances. An objective measure was needed to help categorize the enterprises. One of the measures in the LESAT, I.G.5 (Impacting Enterprise Strategic Planning) provided a measure of the existence of lean enterprise information feedback to enterprise strategic planning. The first three maturity levels of this measure are defined in the LESAT as:

- Level 1 - Results of lean implementation are not fed back to strategic planning process.
- Level 2 - Benefits of lean implementation are beginning to influence the strategic planning process.
- Level 3 - Executive management considers potential impact of performance improvement initiatives in its assessment of new business opportunities.

For categorization purposes, the three levels of I.G.5 map approximately to the three observed management categories described in this section. If one considers that an average maturity value between two levels indicates that some of the assessors believe the enterprise is at the higher maturity level, then it proposed that the division between the categories could be made at the half level as follows:

Category	Range of I.G.5 Values
A - Open Loop	I.G.5 < 1.51
B - Dissociated Closed-Loop	1.5 < I.G.5 < 2.51
C - Integrated Closed-Loop	2.5 < I.G.5

Table 47 - Numerical measure associated with categorization of observed enteprise management control style.

Using this categorizing variable a plot of the Lifecycle Process variable against the Leadership/Transformation variable shows that the higher maturity enterprises are also the ones exhibiting characteristics associated with the better management information feedback models as shown in Figure 46.

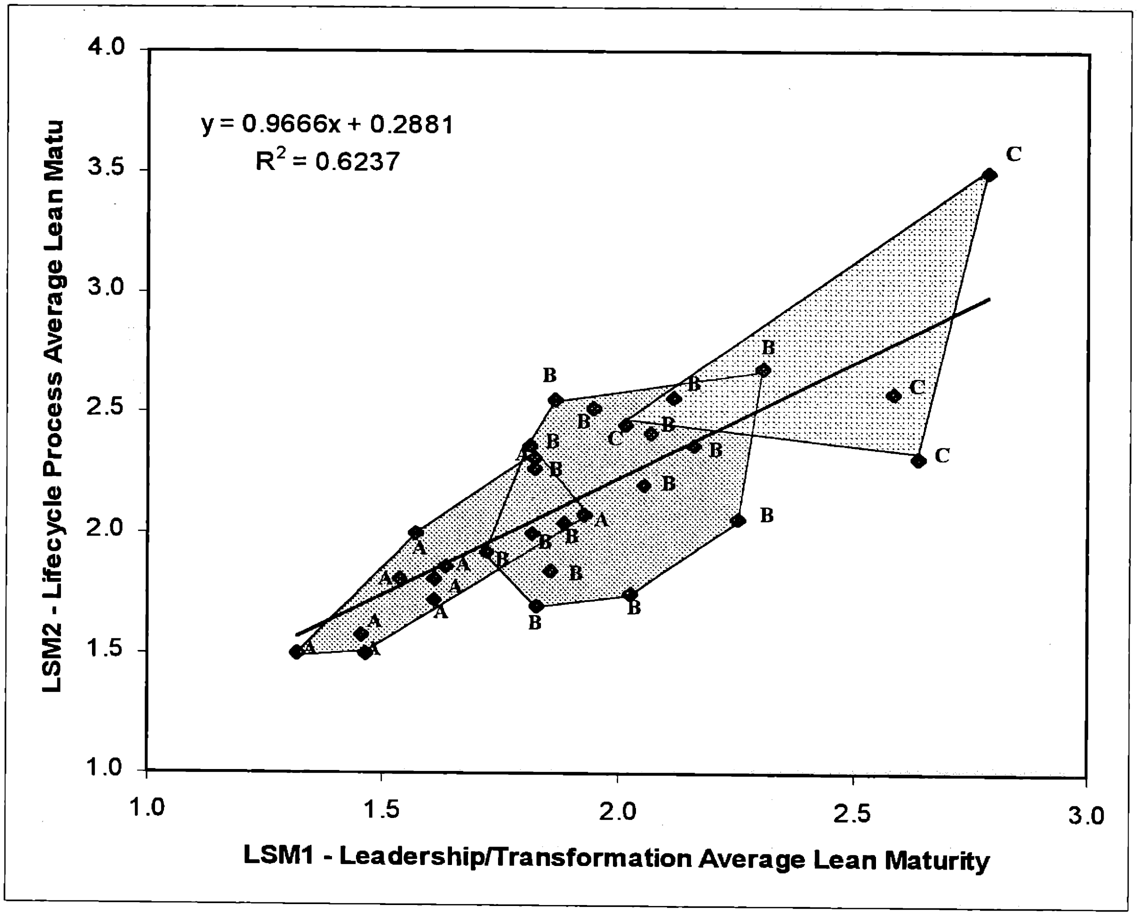


Figure 46 - Categorization of enterprises based on management information feedback.

Only time will tell if any of these control schemes will dominate lean enterprise transformation efforts. However if enterprises can figure out how to deal with the complexities of Integrated Closed-Loop Control, they may well transform more quickly than either of the other two categories of enterprise due to less wasted effort and internal conflict, and a focus on strategically valued improvement efforts.

6.7. Conclusions

This research was able to collect cross-sectional data from 31 aerospace enterprises in the U.S. and UK using the LAI Lean Enterprise Self-Assessment Tool (LESAT). An outlier was observed in the data, and so all analyses were conducted using data from 30 of the enterprises at t_1. The null hypothesis was rejected for each of the primary hypotheses H1, H2, and H3 and the path dependency calculations further supported hypotheses H1 and H2. Time-series data suggested the three hypotheses held, but were too sparse for effective statistical treatment (having only an n of 6 at t_2).

Further analysis of the data revealed that lean enterprise leadership commitment (LC) correlated strongly with creating a lean enterprise change environment (CE), both of which correlated strongly with lean enterprise change in practice (CP). The cross-time data was supportive of these findings and leads to the conclusion that LC (as defined by the LESAT practices in this study) is a strong leading variable for enabling lean enterprise transformation.

The Transition to Lean (TTL) Roadmap appears to be a logical and empirically validated plan for directing lean enterprise transformation. In its current sequencing, it would suggest that focusing on maturing lean enterprise practices early in the roadmap helps lead to maturity in lean enterprise practices later in the roadmap. It follows from the structure of the LESAT (the Leadership/Transformation Section represents the TTL in its entirety), and the validation of the three primary hypotheses, that the increasing maturity of the practices in the TTL will help mature the enterprise's Lifecycle processes and Enabling Infrastructure practices.

Finally, the industry as a whole is in its relative infancy when it comes to lean enterprise transformation. Data suggests that a focus on the early practices in the TTL, such as creating a lean enterprise vision, could help start the transformation process. Thinking of the transformation as a continuous feedback process between assessing lean maturity and capabilities, and informing strategic decision making may serve as a means to achieve and accelerate a successful lean enterprise transformation process.

Chapter 7 - Conclusions and Discussion

This chapter provides a summary of the conclusions derived from this research effort. The conclusions are divided into two sections, those derived from the literature and theoretical work, and those derived from the empirical results of the study. Each of the conclusions is followed by a brief discussion of the supporting evidence, a discussion of the implications of the conclusion for industry, and a select few potential research issues associated with the conclusion.

7.1. Conclusions from Literature and Theoretical Work

Conclusion #1 - A firm with a lean production system has the potential to outperform a firm with a less-lean production system (i.e. mass or craft) as it can deliver greater customer value with equal or fewer resources.

Evidence

The discussion in Chapter 2 presented an introduction to the concepts of lean manufacturing. Empirical evidence was presented from literature that showed that significant gains are achievable with lean manufacturing in terms of better productivity, quality, lead-time, and cost compared to mass or craft manufacturing techniques. These improvements can lead to both higher customer satisfaction and better financial performance. While originating in the automotive industry, cases showing lean transformation in other industries support the notion that the principles and practices of lean manufacturing are generalizable and applicable to other industries, including the aerospace industry.

A review of lean change efforts in the aerospace industry demonstrated that the successful application of lean in manufacturing has created similar performance gains as in other industries. The timescale of successful change efforts tends to vary from industry to industry and from product to product, and has been shown to take several years to achieve substantial improvements in the aerospace industry. No real "failures" to go lean were discussed in the literature, as it is largely a biased sample of self-selecting cases reporting successful transformation efforts. An important finding from the aerospace industry studies is that many of the lean changes done in local manufacturing functions are "islands of success" as they have minimal impact on overall program costs and schedules.

Implications for Lean Aerospace Enterprise Transformation

The creation of a lean production system can be an easy place to start the lean transformation process as the waste in manufacturing is often very visible and quantifiable (i.e. scrap, rework, inventory, etc.). It is also easy to see the improvement gains associated with implementing lean principles and practices in manufacturing, especially as the waste disappears. These lean improvements can free-up working capital and resources from the system, which can then be used to perform other lean improvement activities. Furthermore, the physical nature of lean manufacturing provides a tangible example of the improvement processes that can be used for training others in the principles and practices of lean, building on Piaget's concept of concrete operational learners (Bransford et al. 1999).

While lean improvements in manufacturing can reduce the requirement for direct labor, the strategic value of the improvements is that they provide the firm with an additional capacity with no increase in labor costs. If there is no immediate need to increase capacity, then the available resources can be re-tasked or used to develop and grow internal competencies. If lean improvements are viewed merely as a cost reduction effort aimed at reducing labor, there will be tremendous resistance to change from the workforce. Natural attrition via retirements and people leaving the company for their own reasons are preferred mechanisms for reducing the labor force after lean improvements, without causing undue anxiety in the workers' minds that their improvement efforts are going to be the cause of layoffs.

The creation of a lean manufacturing environment must not be viewed as a one-time event, but rather it must become the way of life in the function and the firm. Operating in a lean fashion is a new way of doing business as it establishes a flow system with strong interdependencies amongst production system elements. As one area becomes lean, the next bottleneck or problem in the system will become apparent, and will become the next place in the system to fix. In fact, going lean becomes a continuous process of identification and correction of waste-creating activities in the production system. These improvements will continuously provide returns to the firm. However, lean manufacturers must also realize that improvements in the lean manufacturing system will be limited by the restrictions placed on the manufacturing function by other enterprise functions and processes.

Implications for Further Research

The creation of a lean manufacturing system results in the elimination of many production system elements that previously acted as buffers to flow. While this is good from a waste-removal perspective, it also makes the production system activities more tightly coupled. The result is that any disturbance to the system will propagate quickly. While disturbances internal to the firm can often be managed and used to identify necessary improvement areas, disturbances external to the firm can result in serious production disruptions. An interesting area to explore is the idea of modeling inter-firm supply buffers as options that attempt to minimize production system waste and cost, while maximizing supply coverage in case of inter-firm systemic disruptions. The cost of the option is the increased buffer size, which is characterized by many factors including materials, storage, handling, tracking, labor, increased lead-time, potential for delays in finding defects, etc. The value of the option is the value of avoiding delivery delays when upstream disruptions occur, as measured by maintaining operations, customer satisfaction and revenue flow. This may be a poignant issue considering the effects experienced on American supply chains as a results of terrorist activities in 2001 (Sheffi 2001), or during west coast dock worker strikes in 2002 (Kioa 2002).

Another area of interest is the study of lean manufacturing transformation failures and/or the lack of lean transformation in some industries. The literature is full of examples of lean transformation successes, but equally important would be the documentation of why such efforts have failed or have not been attempted in certain industries. The lack of this information is primarily a result of the self-selection bias associated with the literature on lean.

Finally, the contracting and acquisition environment for the aerospace industry is an interesting area of study, as many of the gains associated with lean manufacturing improvements assume that there is a future potential for product sales and increased market share via cost competitiveness. In an acquisition environment that focuses on yearly budget cycles, and has a long-tradition of cost-plus contracting for systems that may be cancelled or ordered in small quantities, the incentives for becoming a lean manufacturer are unclear. Will the aerospace companies be driven by commercial program incentives, by fear that competitors are going lean, or by government-imposed lean requirements? This is a difficult and complex problem involving multiple stakeholders and decision-makers that is ripe for investigation.

Conclusion #2 - A lean enterprise has the potential to outperform a firm with only a lean manufacturing function, as it can deliver greater lifecycle value to more enterprise stakeholders with equal or fewer resources.

Evidence

The discussion in Chapter 3 introduced the concept of the "lean enterprise". The definition promulgated by LAI and accepted by this author is *"a lean enterprise is an integrated entity that efficiently creates value for its multiple stakeholders by employing* *lean principles and practices"* (Murman et al. 2002). The literature shows two important issues with respect to the lean enterprise - the existence of systemic waste in enterprises and the amount of cost and time associated with activities outside of manufacturing. First, much of the reason for "islands of success" in lean manufacturing is that the improvement efforts reach a control limit as the scope of the improvement effort reaches beyond the authority of the manager(s) responsible for the lean improvement. Once the effort requires changes in other enterprise functions, processes, or even beyond corporate boundaries, the local production managers responsible for the improvement can no longer drive the improvement effort. Further improvements require individuals who are given authority to look beyond functional improvements and address the systemic improvement initiatives. It appears that many enterprise systemic wastes exist due to the local optimization of performance measures in functions and processes, disconnected from the enterprise-level performance measures. The lean enterprise attempts to remove these wastes, thus creating more value than a lean manufacturer.

The second major reason for looking beyond manufacturing is that for many aerospace companies, a significant portion of schedule time and cost is associated with activities outside of manufacturing. For example, a major portion of system production cost is actually acquired from supply chains. The successful integration of suppliers is shown to improve cycle time, cost, and quality, to the benefit of the prime, the supplier, and the customer. Furthermore, in the aerospace industry, a greater amount of schedule cost, and overall lifecycle value is associated with activities other than direct manufacturing at the prime contractor, including design, development, test, evaluation, support, sustainment, and disposal. Approximately two-thirds (2/3) of lifecycle costs occur in the operations and support (O&S) phase of an aerospace product's life, while most of this cost potential has been locked in by the end of design and development. The lean enterprise operates with the intention of maximizing lifecycle value by managing the processes and their interactions in these areas outside of manufacturing. This will create much greater lifecycle value with equal or fewer resources than an enterprise that focuses only on lean manufacturing.

Implications for Lean Aerospace Enterprise Transformation

From a lean enterprise transformation perspective, a company could look at existing lean manufacturing elements of the production system as a source of education and resource availability. The supply chain should then be integrated into the lean enterprise, as should efforts to create a lean customer that can both enable and benefit from the lean enterprise via its contracting and requirements development procedures. The largest contributors to cost and schedule should be considered candidates for lean improvement based on their potential impact on lifecycle value, and not just acquisition cost. The enterprise will have many systemic wastes that have emerged due to the interaction (or lack thereof) between enterprise elements, whether functions, processes, or other companies. The lean enterprise must be structured to seek out and eliminate these systemic wastes.

A possible solution is the development of Enterprise-level metrics that are flowed-down to all enterprise elements, replacing local metrics that have traditionally led to local optimization at the expense of enterprise value. All activities should be undertaken and their performance measured with respect to some form of enterprise-value-maximizing function. This may require establishing new incentive systems that promote the enterprise-value-maximizing behavior, as opposed to the traditional local optimization behavior.

Implications for Further Research

While the concept of systemic wastes in the enterprise has specific examples, as discussed in Chapter 3, a concerted effort could be made to codify and classify categories of enterprise waste and their associated cause. Research could then investigate the existence of local optimization behavior that causes the wastes and attempt to propose enterprise-level optimization schemes that eliminate the systemic waste. If successful, this work could have an impact on how firms are managed and how managers are trained by creating a rigorous management methodology that results in greater enterprise value delivery. The actual method for changing to a new model of managing the enterprise would rest on the work done by other experts in psychology and organizational change.

However, the study of incentives aligned with enterprise-level value metrics as a means for lean enterprise transformation could be an interesting area of study.

Conclusion #3 - The multi-stakeholder focus of the lean enterprise, versus a pure customer focus, is a source of improved enterprise value delivery.

Evidence

The lean enterprise, by definition, focuses on the value exchange that occurs amongst multiple enterprise stakeholders, as defined in Chapter 3. There are three primary reasons that this multi-stakeholder value focus is important from an enterprise value delivery perspective, namely, collective capabilities, increased enterprise value delivery, and enterprise sustainability. The consideration of multiple stakeholders as part of a single entity, the enterprise, is a means for stakeholders to share in enterprise goals and to formalize the value exchange mechanisms. Literature on the subject points to performance gains achieved by utilizing and sharing the collective intelligence of multiple stakeholders, such as suppliers and customers, to create greater value via better products and processes. Furthermore, the extension of conclusion number 2 to multiple stakeholders can identify further systemic wastes that permeate the operation of the enterprise. There is evidence that arms-length relationships with stakeholders exhibited in many industries results in less value delivery than a lean enterprise that incorporates all of the stakeholders into the value proposition process.

The theoretical work in Chapter 3 suggests that a multi-stakeholder focus can improve overall enterprise value delivery instead of a pure customer focus. This result is based on the fact that there are activities or processes that do not involve customer value, but do involve value delivery to other stakeholders. This implies that an enterprise can create more value by focusing on all stakeholders. Furthermore, there appear to be value exchanges that are beneficial to some stakeholders while not reducing the value delivered to others. This suggests that there is a non-zero sum game associated with total enterprise value delivery, and the identification and exploitation of these win-win situations can increase overall enterprise value delivery. Finally, the competitive nature of business leads to the belief that a lean enterprise that delivers greater value to stakeholders will have a higher likelihood of sustainability than a non-lean enterprise. Simply stated, if all enterprise stakeholders are receiving greater value with the use of equal or fewer resources than a non-lean enterprise, then the lean enterprise will be the more favorable option for stakeholder involvement.

Implications for Lean Aerospace Enterprise Transformation

The transition to a lean enterprise should include the creation of a list of enterprise stakeholders. Management needs to understand what value the stakeholders currently contribute to the enterprise and what value the stakeholders currently derive from the enterprise. Extending this list to include what values *could* be contributed and derived from the enterprise is a potential means for identifying capabilities within the enterprise partnership that could be further developed and exploited. Asking how the value is currently delivered and how it might be increased will help identify systemic circumstances that cause waste. Improving these value delivery processes could increase overall enterprise value delivery. Furthermore, the enterprise managers need to seek out and emphasize value delivery propositions that increase value to multiple stakeholders, the "win-win" situation.

Implications for Further Research

This conclusion raises questions about the formality of value-exchange analysis in the business world. It appears that the investigation and creation of a formal stakeholder value exchange framework that allows lean enterprise members to quickly and easily track the trade-offs and potential gains associated with a multi-stakeholder perspective could be an interesting and valuable area of study. Beyond simple value exchange propositions, utility modeling may be a means for creating predictive value exchange models. From the stakeholder perspective, a methodical study of the stakeholder value-exchange could identify the existence of general, non-zero-sum game stakeholder scenarios as a means for generating greater enterprise value delivery, irrespective of industry. Coupled with system dynamics, outcomes-based models, this could be a powerful means for structuring enterprises for maximum value delivery.

The temporal effects of stakeholder value considerations could also be an area of research interest. From the work performed in LAI, there appears to be a need to balance between short-term demands, such as improved shareholder returns, and long-term needs, such as sustained employment in the community. Understanding how the value exchange occurs over time may give insight into strategic decisions about how to prioritize and sequence enterprise activities and value allocation to balance the tension between short-term and long-term enterprise goals.

Conclusion #4 - The lean enterprise is an operational strategy that can lead to competitive advantage.

Evidence

This thesis promulgates that a lean enterprise is an operational strategy, a strategy based on how one structures and executes sequences of activities in order to achieve the objectives established in the business and corporate strategies. Some of the literature on business strategy discussed in Chapter 4 calls this operational effectiveness (OE). The lean enterprise is promulgated as an operational strategy because it provides competitive advantage in the form of an ability to deliver greater stakeholder value than competitors with equal or fewer resources. The competitive advantage of the lean enterprise is rooted in three issues that make it difficult for competitors to easily copy, namely the non-zero marginal cost of lean knowledge, the enterprise's absorptive capacity, and the need for organizational behavior change to become a lean enterprise.

While the non-zero marginal cost of lean knowledge and information appears to be a minor point for large firms such as those in the aerospace industry, as discussed in Chapter 4, the absorptive capacity and organizational behavior change both appear important and interrelated issues. It is evident from case studies on the subject that companies do not instantaneously become lean. All cases point to a tremendous effort needed to get people to change their belief systems and work habits in order to operate in a lean manner. This is most difficult in mature industries where the behavior has become institutionalized and internalized by the workforce. It also appears that companies that have successfully incorporated lean manufacturing have used effective transformations in local areas as a means to increase their understanding and acceptance of how lean works before applying it successfully on a larger scale. This would imply that the workforce gaining some threshold amount of stock of information and understanding in lean helps promote and accelerate the transformation. All of these factors make the transition a difficult and uncertain process, especially at the enterprise level. Thus, the enterprise that successfully completes the transformation will experience a period of competitive advantage while others attempt, and potentially fail, to achieve the same transformation.

It would appear that there is a first mover advantage to becoming a lean enterprise. However, the improvement process cannot be seen as a single effort or the first mover may be surpassed by a successful second mover after some time period. Furthermore, the fact that business and corporate strategies change will require continual adjustments to the operational strategy.

From a resource utilization perspective, a pure cost-cutting vision of the lean enterprise could result in the elimination of valuable intellectual resources that could have detrimental long-term effects to the enterprise. The lean enterprise may offer strategic advantages in terms of making resources and intellectual capital available for use in other initiatives that lead to increases in market share, program extensions, and the development of new core competencies and new markets as a means for growth and sustainability of the enterprise.

Implications for Lean Aerospace Enterprise Transformation

Industry must first recognize that the transition to lean is a lengthy and continuous process aimed at changing how the enterprise operates. Many in the aerospace industry have pockets of experience with lean improvement programs (even though they may come under other CI umbrellas such as Six Sigma or LM21). This existing knowledge needs to be nurtured as a means to extend the transformation efforts throughout the enterprise.

Senior leaders must also accept the fact that their competitive advantage from becoming a lean enterprise will be based on outperforming their rivals, and will be sustained for some finite period of time due to the difficulty others will have in making similar lean organizational behavior changes. Recognizing that the change will be hard is important and attempting to reduce the barriers to change must be pursued. While it is important to establish the anxiety for the need to change in the workforce, minimizing the anxiety associated with the change process itself will help accelerate the transformation. This transformation can build on the idea of incentive-alignment as discussed in conclusion number two, and eliminate incentives that work to retain the non-lean enterprise structure and behavior. It is important to recognize that there will be those that do not wish to change. These employees must be removed from their positions so as not to derail the change efforts. Finally, leadership must recognize that while the lean enterprise creates greater value than its non-lean competitors, the sustained competitive advantage will rely on utilizing and reinvesting some of the available resources and intellectual capital to help make the enterprise leaner, and to attack other strategic initiatives of importance to the enterprise such as new market development, new product development, and research and development (R&D).

Implications for Further Research

It is apparent that the lean enterprise is more than the rearrangement of an organization chart. However, it is not apparent what structural form a lean enterprise takes. There are interesting management questions about how to structure functions, processes, and programs, as well as how to manage and coordinate them so as to enable lean enterprise behavior. Furthermore, understanding the time associated with lean transformation is an important variable that is currently unknown. There are numerous research ideas that can be derived from these questions and lead to valuable insights. Equally interesting is the development of a clear understanding of where the weaknesses are in the lean enterprise and how these could be exploited by rivals in a competitive environment. The development of this understanding could serve to create defensive positions aimed at guarding against the exploitation of the weaknesses.

7.2. Conclusions from Empirical Results

Conclusion #5 - The aerospace industry has yet to create a lean enterprise.

Empirical Evidence

The rank-ordering of LESAT Practice maturity results averaged across the industry shows that aerospace enterprises participating in this study rank themselves least mature in areas covering lean enterprise vision, planning, and implementation. Table 48 shows the ten lowest ranking LESAT practices across the industry sample. Chapter 6 discussed the meaning of the specific practices in this ranking in more detail, however, it is noteworthy to consider that the sample was largely a self-selected sample of enterprises that consider themselves lean or are attempting to create lean enterprises. Thus, even with a sample that should be largely biased towards the adoption and implementation of lean, the results still showed very low maturity in lean enterprise practices.

Rank 1 = lowest 54 = highest	**LESAT Practice**
1	I.C.3. Designing the future value stream
2	I.F.1. Development of detailed plans based on enterprise plan
3	I.B.3 Lean Enterprise Vision
4	I.E.1. Enterprise level lean implementation plan
5	I.C.1. Understanding the current value stream
6	II.A.1. Leverage lean capability for business growth
7	I.B.4. A sense of urgency
7	I.E.3. Provide education and training
9	II.B.2. Utilize data from the extended enterprise to optimize future requirement definitions
10	I.D.7. Lean change agents

Table 48 - Ten lowest-ranking LESAT practices in the industry.

Further evidence in support of this conclusion is that no enterprise in the study, even including second year assessments, was able to achieve a level 3 on all LESAT practices. Returning to the generic maturity level definitions presented in Chapter 5, a level 3 would be an enterprise that has a *"Systematic approach/methodology deployed in varying stages across most areas, facilitated with metrics, and is being sustained."* With no enterprise in the sample achieving this level of maturity in all of the LESAT practices, there is little evidence that a lean enterprise exists in the aerospace industry. Furthermore, if a truly lean enterprise is expected to exhibit even higher maturity, such as a level 4 on average, then the industry has even more room for improvement.

During site visits and participation in LESAT assessments, other evidence surfaced that support conclusion number five. In many of the low maturity enterprises, interpretation issues arose with the vocabulary in the tool, where the assessment participants asked many questions about the meaning of certain lean terminology. In these enterprises there was a range of lean knowledge amongst the leadership teams, from little or no knowledge to some exposure to lean principles and practices. In the more mature enterprises there was less discussion about the terminology and more heated debate about the actual maturity level of the enterprise. However, even in these enterprises it was often observed that the leadership team members had great insight into their own functional areas of expertise, but often had moderate to poor knowledge of the lean maturity of other functions, or cross-functional processes. In some instances, it was found that leadership team members were, in some instances, were unaware of the roles their peers currently had in the enterprise. In all cases, there was no indication that the enterprises had been structured or improved to optimize value delivery to multiple stakeholders or that the lean gains in production were influencing strategic planning efforts.

Implications for Lean Aerospace Enterprise Transformation

From an industry standpoint, it is evident that the lean aerospace enterprise is in its infancy. There are very few examples to follow for determining how to increase enterprise lean maturity in specific LESAT practices, let alone completely transforming to a lean enterprise in all practices. In most cases, enterprises are trying to address low maturity and high variability LESAT practices as a means for prioritizing improvement activities.

The infancy of the lean aerospace enterprise may be a boon for a select few enterprises that are able to achieve the lean transformation and gain competitive advantage. There may be a first-mover advantage to those that achieve the transformation as they will be able to deliver greater total enterprise value with equal or fewer resources, thus outperforming their competitors. The sustainability of the competitive advantage remains a question, as the first movers may cause competitors to exit the industry, or there may be a second mover advantage. The second mover may be able to utilize the results of the first mover's transformation efforts as a means to avoid the same errors and achieve the transformation more effectively than the first mover (i.e. reach a higher level of maturity faster than the first mover).

Implications for Further Research

The aerospace industry has many examples of lean in practice over the last decade, but the principles and practices beyond production have been slow to change. This raises questions about why the industry has not been changing its organizational behavior beyond production to think and operate like a lean enterprise. There has been research into lean product development, lean supply-chains, and lean sustainment, yet many of these efforts have been conducted independently. Integration of these improvement initiatives could be an interesting area to explore as a means for accelerating lean enterprise transformation.

Another question to consider is how the mindset that programs reign supreme in the aerospace industry contributes or detracts from lean enterprise transformation. The existence of strong programs should lead to an ability to clearly identify value streams around which the lean enterprise could operate. Yet doing so is a form of local sub-optimization, as most enterprises have multiple programs. The study of cross-program value stream management might lead to the discovery of enterprise level wastes that could be removed from the system. Research into cross-program lean transformation might identify new policy and acquisition practices that the government could implement to achieve better value delivery, while also identifying potential requirements for how to structure and organize enterprise management.

Conclusion #6 - Observed maturity in some lean enterprise practices can be attributed to other business initiatives familiar to the Aerospace Industry.

Empirical Evidence

The rank-ordering of LESAT practice maturity results averaged across the industry shows that aerospace enterprises participating in this study rank themselves most mature in areas that are not only a part of the lean enterprise, but are parts of other industry efforts as well. Table 49 shows the ten highest ranking LESAT practices across the industry sample. Chapter 6 discussed the meaning of the specific practices in this ranking in more detail. Much of the systems engineering culture that has been the hallmark of the aerospace industry can be associated with the high degree of maturity in these practices, along with improvement efforts such as TQM, IPPD, IPT's, and Six Sigma.

Rank 1 = lowest 54 = highest	**LESAT Practice**
45	II.E.2. Establish and maintain a lean production system
46	I.A.1. Integration of lean in strategic planning process
47	II.C.1. Incorporate customer value into design of products and processes
48	II.A.3. Provide capability to manage risk, cost, schedule and performance
49	I.D.3. Open and timely communications
50	I.D.1. Enterprise organizational orientation
51	III.B.1. Process standardization
52	III.B.2. Common tools and systems
53	II.C.2. Incorporate downstream stakeholder values into products and processes
54	III.A.5. Integration of environmental protection, heath and safety into the business

Table 49 - Ten highest-ranking LESAT practices in the industry.

It is interesting to note that lean production ranked very high (45th out of 54). This is a good indicator that the efforts to implement lean production in the industry are recognized by senior enterprise leadership, granted this is a biased sample of enterprises that have been attempting lean production in some form or other for a number of years. However, this data also reveals that even amidst years of lean production improvement, there has been little extension of the ideas to the enterprise level as observed in conclusion number 5. The presence of "Integration of Lean in Strategic Planning" (I.A.1) in the top ten also supports the view of lean becoming a part of the industry practices (i.e. behavior) in the sample. However, the low ranking of "Impacting Enterprise Strategic Planning" (I.G.5) suggests there may be an open-loop management issue arising here. This would suggest that while the strategic planners are considering lean in their planning, the actual gains, experience, and capabilities from lean efforts are not being fed back and utilized as part of the planning efforts. Without this feedback the transformation efforts will not be sustainable.

Implications for Lean Aerospace Enterprise Transformation

From an industry standpoint, enterprise leaders should understand where they currently rank high in maturity. These capabilities may not require the allocation of improvement resources, and may allow resources currently allocated to be redistributed to low maturity areas. Furthermore, these mature areas, especially in lean production, can serve as examples of success on which to build maturity in other areas.

Lean enterprise transformers also need to be aware that other improvement efforts exist within the aerospace culture of their organizations, and this may have led to high maturity in some practices. Successful lean enterprise transformation must attempt to create improvement efforts that either build on the past efforts or create new ones that do not create conflicts with the existing efforts. When it is apparent that an existing improvement effort is in conflict with lean transformation efforts, action needs to be taken to rationalize how to proceed. The options are to either abandon one and follow the other, or find a means to combine the efforts where there are mutually reinforcing and beneficial relationships.

Conclusion # 7 - The transformation to a lean aerospace enterprise can be accelerated by first maturing lean Leadership/Transformation practices. Increasing maturity in lean Leadership/Transformation practices will enable the improvement in lean maturity in Lifecycle Processes and Enabling Infrastructure.

Empirical Evidence

The LESAT data from 31 aerospace enterprises showed strong correlations at high significance levels for each of the three primary hypotheses of the LESAT study, namely:

H1) Enterprises that exhibit a greater value of Enterprise Transformation and Leadership Process maturity will exhibit a greater value of Lifecycle Process maturity

H2) Enterprises that exhibit a greater value of Enterprise Transformation and Leadership Process maturity will exhibit a greater value of Enabling Infrastructure Process maturity

H3) Enterprises that exhibit a greater value of Enabling Infrastructure Process maturity will exhibit a greater value of Lifecycle Process maturity

The three hypotheses were not disconfirmed by the bivariate correlation tests and partial correlation tests controlling for the third variable. Furthermore, the path dependence calculations supported the inferred causality of hypotheses H1 and H2. The longitudinal data, while only covering two time periods and sparsely populated with six enterprises, also supported the inferred causality of the hypotheses. The hypotheses were tested via the bivariate and partial correlation tests at t_2, the differential bivariate and partial correlation tests, and the cross-lagged panel correlation tests. The low number of data points at t_2 made it difficult to control for variables, as it reduced the number of degrees of freedom in the statistical tests.

Site visits and discussions with industry participants in the LESAT study provided additional evidence in support of conclusion number six. Enterprises that had low maturity in their Leadership/Transformation practices were experiencing difficulties in extending lean beyond manufacturing practices and were encountering barriers to lean enterprise transformation. In some instances, the apparent lean "islands of success" were viewed favorably as long as they did not encroach upon the management authority of other functions. Conversely, enterprises with high maturity in their Leadership/Transformation practices showed a willingness to work towards a lean enterprise that was evident in a reduction in barriers to transformation (i.e. resources available, senior management commitment to support the effort, eagerness to see the change happen, etc.). Furthermore, there appeared to be a willingness of functional leaders to look for ways to improve cross-functional processes and reduce systemic wastes.

Implications for Lean Aerospace Enterprise Transformation

This conclusion suggests that efforts aimed at creating a lean aerospace enterprise need to increase lean maturity in the Leadership/Transformation section of the LESAT, because it will help establish the environment, the plans, and the direction required to increase the maturity of the Lifecycle Processes and Enabling Infrastructure. Furthermore, an inability to improve the lean maturity of the practices in the Leadership/Transformation section of the LESAT will probably result in stagnation of any lean enterprise transformation efforts, as they will be ad hoc rather than strategically directed. The best outcomes of ad hoc efforts will be the creation islands of success, while the worst outcome is an adverse impact on the enterprise while expending scarce resources. The existence of pockets of lean within the enterprise could serve as starting points for gaining hands-on experience with lean and for extending lean transformation across functions and processes.

Industry should also note that the time delays between increases in lean maturity of practices in the Leadership/Transformation section of the LESAT and increases in lean maturity of the practices in the Lifecycle Processes and Enabling Infrastructure sections of the LESAT are unknown, at least from the perspective of this research. As with many improvement programs, there may even be a time of decreased performance as processes are reorganized. However, as long as the Leadership/Transformation practices are kept mature, it is anticipated that the maturity of the other practices will follow, even if there is a brief period of reduced performance during the disruption and reorganization of the system. The time lag issue will also be important when it comes to tracking enterprise value delivery. While improving the enterprise lean maturity, as measured by the LESAT, is intended to lead to greater stakeholder value delivery, the value delivery will lag the improvements in maturity in Lifecycle Processes and Enabling Infrastructure practices. Enterprise leadership must be warned not to expect instantaneous increases in value delivery. They should rather expect that over time, with continued efforts at increasing enterprise maturity in the LESAT practices, their enterprise will perform better on outcome metrics such as customer satisfaction, shareholder satisfaction, employee satisfaction, and supplier satisfaction.

Implications for Further Research

The development of a formal understanding of the time lags associated with improvement efforts would help industry in planning lean transformations. From a research perspective, this could lead to the systems dynamics modeling of the lean enterprise transformation process. By understanding the time lags and causal connections between improving various elements of the lean enterprise, policy decisions for prioritizing resource allocation and improvements efforts could be made. The ability to tie this systems dynamics model to an enterprise's financial model, and eventually stakeholder value exchange model, could help create a simulation tool for testing management and policy decisions aimed at increasing value delivery.

Conclusion # 8 - Of the lean Leadership/Transformation practices, Leadership Commitment (LC) is necessary for creating a successful lean Change Environment (CE). The creation of a successful lean Change Environment (CE) is then necessary to allow lean Change in Practice (CP) to permeate the enterprise.

Empirical Evidence

As discussed in Chapter 5, there was an attempt to subdivide the data in the Leadership/Transformation section of the LESAT into three variables that explained some of the causal relationship in the lean transformation process. Three variables were proposed, namely a Leadership Commitment to lean variable (LC), a creating a lean Change Environment variable (CE), and a lean Change in Practice variable (CP). The primary hypotheses tested using these variables were

H1) Enterprises that exhibit a greater value of lean enterprise Leadership Commitment (LC) maturity will exhibit a greater value of lean enterprise Change Environment (CE) maturity

H2) Enterprises that exhibit a greater value of lean Change Environment (CE) maturity will exhibit a greater value of lean enterprise Change in Practice (CP) maturity

The bivariate and partial correlation tests, using cross-sectional industry data, did not disconfirm these hypotheses. Likewise, longitudinal tests of the data supported the hypotheses and did not disconfirm the inferred causality.

From the site visits, it was found that enterprises with high leadership commitment (LC) appeared to have an operating environment that was amenable to lean change (CE). In these cases, the lean change environment (CE) was highly supportive of lean enterprise change activities in practice (CP). Some enterprises demonstrated that they had good lean change activities in manufacturing, but did not have a mature lean enterprise change environment nor a mature lean enterprise leadership commitment. These latter enterprises were having difficulty with lean enterprise efforts, and often asked questions such as *"how do we convince them (senior leaders) that we need to do this?"* This was quite different from the types of questions encountered in enterprises exhibiting high LC and CE lean maturity. In these latter cases, the concerns of the lean change agents were focused on how to create transformation plans and prioritize the activities that would meet the senior leadership goals for lean enterprise transformation.

Implications for Lean Aerospace Enterprise Transformation

From an industry perspective, successful lean enterprise transformation requires senior leadership commitment to lean. In most cases this means that senior management must have a compelling reason for buying-in to the lean transformation. The reason may be past, successful experiences the senior leaders had with lean, or a sense of urgency that they need to adopt lean principles and practices, otherwise they might be surpassed by competitors. Either way, there is little evidence to suggest that senior leaders will commit to lean enterprise transformation unless they understand lean and are convinced of its potential benefits, especially as it applies to their careers and to their enterprise.

The establishment of a lean change environment requires a belief from leadership that process improvements are achievable and will lead to the elimination of systemic wastes. Furthermore, there needs to be a belief that a multi-stakeholder focus can lead to greater enterprise lifecycle value delivery. The more mature lean enterprise transformers will view this type of change environment creation as a strategic investment of resources that will lead to future gains. Some enterprises view the people doing the lean enterprise change activities as a pure cost. In these cases there is a lack of vision in the strategic value of the lean enterprise and this may derail any improvement efforts under their management by destroying the lean change environment (i.e. the maturity of CE decreases).

The lean change in practice can operate at a local level, as has been seen in lean improvements in manufacturing cells and functions, with little or no real need for enterprise LC or CE. However, as the improvement efforts cross functional, process, and even corporate boundaries, there will be a need to increase maturity in enterprise lean LC and CE in order to affect the appropriate enterprise-level change.

Implications for Further Research

An interesting next step would be to study/interview enterprises in the industry that have different levels of leadership commitment (LC). This information could shed light on why some enterprises are considering the lean enterprise an important objective while others are not. This information could also help identify some of the barriers to lean enterprise transformation, as well as some of the enablers. It might be useful to test the enterprise leaders to see if they agree with conclusions one through four in this thesis, and furthermore if any of these conclusions formed part of their rational for becoming a lean enterprise.

If the model supported in this conclusion is valid, then it would be informative to look for relations between the level of LC and CE maturity needed as the scope of lean change efforts change. For example, at what level of maturity can local lean change occur within a function, such as manufacturing. As the scope of lean change increases to include cross-functional, cross-process, and multi-corporate activities one would expect to see associated increases in the maturity of the LC and CE measures. Knowing these relations could lead to an ability to identify necessary maturity improvements in the LESAT Leadership/Transformation section practices in order to support lean transformations of a specific scope.

Conclusion # 9 - The TTL roadmap in its current logical sequencing is a practical and effective means for organizing and prioritizing the lean enterprise transformation process.

Empirical Evidence

The data analysis at t_1 showed that there was a strong correlation at high significance level between the major TTL roadmap blocks in their current sequencing. This disconfirmed the null hypotheses that there was no relation amongst the variables in their current order. Strong correlations with high significance were also seen with the t_2 data. This data suggests that the progression of the TTL Roadmap, in its current sequence, is an appropriate sequencing of lean enterprise improvement steps.

In site visits and interviews, enterprises that were using the using the TTL, even if only as a reference tool, pointed out that they found many of the TTL elements necessary to create an effective lean enterprise transformation plan. To them, the ordering seemed logical, and there were only minor variations in ordering certain of the practices. This reordering was a consequence of parallel efforts in multiple blocks of the roadmap and of micro-iterations amongst some of the practices. For example, the development of detailed planning in some cases identified new enterprise issues that influenced a review of the enterprise plan, which resulted in a change in scope of the detailed plan.

Of those enterprises using the TTL to some degree, it was found that they were having an easier time visualizing, creating, and executing the lean enterprise transformation plans. Their most common response to questions about the TTL was that the roadmap seemed reasonable. The enterprises not using the TTL to any extent were often unsure of their transformation plans and had difficulty establishing a set of activities (either sequential or parallel) that would enable improvement in lean enterprise maturity.

Implications for Lean Aerospace Enterprise Transformation

From an industry perspective, this conclusion would suggest that enterprises attempting to transition to lean should, as a minimum, consider the TTL as a starting point for understanding the types of activities involved in the transformation effort. The suggested sequencing of the TTL activities represents a proposed methodology for conducting the lean enterprise transformation, and enterprises should attempt to map their current activities to the TTL activities. This would help identify missing activities, and identify where low maturity practices may need to be improved in sequence in order to mature downstream activities. The TTL should also be considered a recommended roadmap, but should be evolved and modified as best suited to specific enterprises. Many improvement activities will occur in parallel and with frequent feedback loops to previous activities in an attempt to improve overall enterprise Leadership/Transformation maturity. An important issue to consider is the feedback of improvement efforts and results to enterprise leadership such that the strategic planning process is not an open-loop practice, but a closed-loop improvement process that builds on the gains achieved in previous efforts.

The prioritization of improvement activities associated with the LESAT practices in the TTL should consider the current maturity of the practices in combination with their sequential location in the roadmap. For example, an enterprise with moderate maturity in the short-term cycle elements, but low maturity in the long-term cycle elements should focus its efforts on improving the long-term cycle practices. In cases when the maturity is approximately equivalent across all practices, it is proposed that the focus should return to improving their maturity at the start of the TTL elements, as this is purported to help increase the downstream practices (i.e. if all the practices have a maturity level of 2, then go to the first block 1.A and try to increase its maturity and work through the TTL loops). The integrative nature of the TTL roadmap, and the existence of parallel improvement activities, may actually result in small maturity improvements throughout the roadmap, as the iterative feedback loops continually build on each other. Instead of needing a maturity of 3 in 1.A and 1.B before 1.C can move beyond a 2, the leading TTL blocks may only need to increase a partial maturity level before effects are seen in other maturity areas, suggesting the time delays in maturing these practices may be smaller than those associated with maturing Lifecycle Process and Enabling Infrastructure maturity.

Implications for Further Research

A formal study of lean enterprise change efforts could be conducted by comparing enterprises that are using the TTL to those that are not. One would expect the users of the TTL to progress more quickly than those that have to figure out how to orchestrate the transformation (i.e. develop their own TTL). Case studies about these change efforts could help validate the value of the tool, or provide evidence of other more effective methods of transformation. The studies could also help identify if there is a better ordering of the activities other than as presented in the TTL roadmap. Furthermore, the identification of elements missing from the TTL or needing to be removed from the TTL could help establish the tool as a standard methodology for lean enterprise transformation. Tests of the tool in industries other than aerospace could verify its generalizability as a standard methodology.

Conclusion #10 - The LESAT can be an important part of lean enterprise transformation and management.

Empirical Evidence

From a tool standpoint, the LESAT itself provided enterprise leadership committees with an enterprise-level lean assessment tool. This was new to all of the enterprises, as other lean tools had focused on factory floor improvements, or supplier improvements using many of the same metrics as the factory floor tools (i.e. lead-time, takt time, inventory turns, frequency of shipments, number of defects, etc.). In almost all cases, the users of the LESAT claimed that the tool created a common lean enterprise vocabulary that many of them had not previously developed. This common vocabulary also led to the raising of many enterprise-level issues, such as cross-functional flow problems that had not surfaced in a manner that would lend themselves to further analysis and improvement. This was often quoted as an "ah-ha" instance of enlightenment when the issue became apparent to the assessors. For these two reasons alone, the LESAT was accepted by many users as an important addition to their management toolkit.

The use of the LESAT helped identify disconnects amongst leadership team members, where it was often observed that many assumed what the other was doing, but rarely talked openly about it or discussed the implications of their activities on each others' activities. Along these lines, the use of the LESAT gave the opportunity for a truthful assessment (as observed by the low scores in many cases) at two levels. First, it allowed the assessors to divulge their perception of the lean maturity of the enterprise in an objective manner. This may not have been possible in leadership meetings where strong members of the leadership team may have dominated and/or strongly influenced decisions. Second, the average maturity scores for each LESAT practice, assuming individual truthfulness in the assessment, could be considered an accurate indication of the perception of the leadership team as a whole of the enterprise's current state of lean enterprise maturity. This provided the leadership team with a measure that is devoid of team member cross-influence and is hopefully an honest picture of the state of the enterprise. The senior leader then has the option to keep her/his assessment separate from the average results to see if her/his vision and understanding of the enterprise is consistent with the leadership committee's. In some instances this was found not to be the case as the senior leader's assessment was measurably higher than the rest of the leadership committee's. This can indicate a need for better communication and interaction amongst the enterprise's leadership team.

The case studies demonstrated that the LESAT provides a means for management feedback control, where the LESAT acts as the sensor that informs the enterprise improvement decision-making process. Without the tool, many of the enterprises resort to outcome-measure management based on lagging financial indicators. From an improvement perspective, the tool gives enterprise leadership an ability to see where they are strong and weak in terms of lean practice maturity as a leading indicator of performance. Users also see where there is large variability amongst leadership committee member perceptions of the lean maturity of the enterprise. This data, if properly fed back into the enterprise management process can provide insight on where to focus education and improvement efforts given limited resources, versus an ad hoc approach that improves for the sake of improvement, with no strategic direction. However, as discussed in conclusion number six, while many of the enterprises were incorporating the idea of lean into strategic planning, the actual lean improvements were not themselves informing the strategic planning process, indicating that the management control loop had not been formally closed.

Implications for Lean Aerospace Enterprise Transformation

For enterprises intending to attempt lean enterprise transformation, an annual LESAT assessment should be considered as part of the transformation program. Making the assessment part of an annual operating plan (AOP) is a good way to institute the use of the tool and help establish common lean language amongst the leadership team. This will ensure there is continuity in the assessment process, and hopefully avoid the LESAT being perceived as a "flavor of the month" tool. There may be training and support needed to initially get the assessors up to speed on the language and use of the tool, but this should lessen as the tool gets more use. Establishing a feeling of safety for the assessors will be important to ensure that they will answer truthfully, as any game playing with the numbers will only lead to a misperception of the current lean state of the enterprise and misdirection of any LESAT-driven improvement efforts.

From an improvement activity standpoint, setting the "Desired" state maturity should be done based on the goals of the 5-year plan, with the improvement targets set for the next 1-2 years. This will keep the strategic vision in mind while establishing achievable short-term improvement targets. Targets such as "a one point improvements across the board in the next year" are not realistic, nor are they well crafted. A combination of the weaknesses in the current state lean maturity, the strategic direction of the enterprise, and the maturity of the TTL elements of the LESAT need to be considered as a whole when crafting improvement plans with a goal of increasing maturity in specific practices. Change leaders should not dictate numerical improvement goals, but rather provide the direction to improve maturity over some time period. As the goals and direction of the enterprise change, the specific improvement efforts may change accordingly.

Implications for Further Research

From an objectivity standpoint, the LESAT could be improved by developing metrics associated with each LESAT practice and each practice maturity level. While the definitions based on the capability maturity model are fairly specific, they still leave room for interpretation, and thus variability in scores due to the instrument rather than the assessors understanding of the lean maturity of the enterprise. The ability to equate each level of maturity in each practice with quantifiable (and readily available) measures from the enterprise would serve to reduce the variability associated with the tool.

The LESAT tool itself offers a host of data that can be of interest to researchers. The growth of a data set with additional longitudinal data will allow the hypotheses in this thesis to be further tested, along with numerous other hypotheses. Coupled with case study information, the development of a knowledge base of "how" enterprises improved their lean maturity could provide the details many enterprises are seeking to help guide their transformation efforts. Tracking outcome measures such as customer satisfaction, financial performance, employee satisfaction, and supplier satisfaction over time along with the LESAT data could lead to a rich database for testing potential causal inferences between leading lean practice maturity and lagging performance indicators. The availability of this data could help establish a decision support model for use in prioritizing and allocating resources in lean enterprise transformation efforts that are intended to achieve specific outcomes. Work could also focus on integrating the LESAT with other management instruments to give a complete picture of the enterprise.

Chapter 8 - Recommendations and Future Research

This thesis has highlighted many of the issues associated with the lean enterprise and lean enterprise transformation. Furthermore, evidence has been presented that suggests there exists a means to formally and logically accelerate lean enterprise transformation by creating leadership commitment and following the TTL, rather than following a random-path improvement process. This chapter will present a recommended integrative information feedback model for lean enterprise transformation that builds on the TTL and the work contained in this thesis.

While this model is derived from research conducted in the aerospace industry, the methodology is considered generic enough to apply to most industries that deliver a product and/or service. The recommended methodology is expected to align well with enterprises that show similar characteristics to aerospace enterprises, in terms of organizational hierarchy, industry maturity, product complexity, scale, and cost to name a few. There are few industries that exhibit many of the same kind of characteristics as the aerospace industry, other than perhaps shipbuilding (especially for the military). However, there is no overwhelming argument to believe that this methodology would not apply to industries with very different characteristics such as less complex products and acquisition processes. In fact, this methodology might have greater impact outside of the aerospace industry, since financial returns on the transformation efforts may be realized faster because there are more market incentives to drive the change and the timescale for impacting product/service development and delivery is much shorter. These do remain assumptions however, and can only be validated with further study.

This chapter concludes with proposed research topics based on the integrative lean enterprise transformation model. These research questions are above and beyond the research questions of interest previously identified in Chapter 7.

8.1. An Integrative Model for Lean Enterprise Transformation

A model for lean enterprise transformation is proposed based on integrating the knowledge learned in this thesis with existing LAI lean enterprise tools. This model will identify how the tools interact to enable lean enterprise transformation, and more importantly, where formal information feedback loops need to be developed and managed to enable and accelerate the transformation. The model also shows how enterprise strategy can both impact and be impacted by lean enterprise transformation efforts. The model will be built up in stages through the discussion in this chapter. This chapter represents the culmination of this thesis and what the author feels is the next level of thinking in lean enterprise transformation.

8.1.1. Step 1 - Creating Leadership Commitment (LC)

The first step to creating a lean enterprise requires establishing leadership commitment to lean enterprise transformation. Both literature and the research in this study support this requirement. Without the leadership's commitment to change there will be no significant lean enterprise transformation. While local lean improvements may occur without senior leadership commitment under the purview of a manager who believes in going lean, the cross-functional and cross-process nature of the lean enterprise by definition requires senior management commitment and support as it necessitates coordination across existing management boundaries. From
Figure 47 it is proposed that this commitment stems from some form of anxiety or desire to become a lean enterprise. This anxiety or desire can arise either from external pressures, internal pressures, or a combination of both.

External pressure for the lean enterprise can arise from a need to catch up to competitors, surpass competitors, or stay ahead of competitors that are believed to be adopting lean principles and practices as part of their operating procedures. For this external pressure to cause anxiety about becoming a lean enterprise, there has to be a belief that the external pressure can be overcome via the use of lean principles and practices. This belief may arise from industry publications and conferences, benchmarking, literature, word-of-mouth, etc. that promulgate the improvements achievable by going lean. Koenigsaecker claims that few manufacturing CEO search out lean as a potential operational strategy, and for the most part only do so when their operations are faced with dire economic and/or competitive circumstances (Koenigsaecker 2003b).

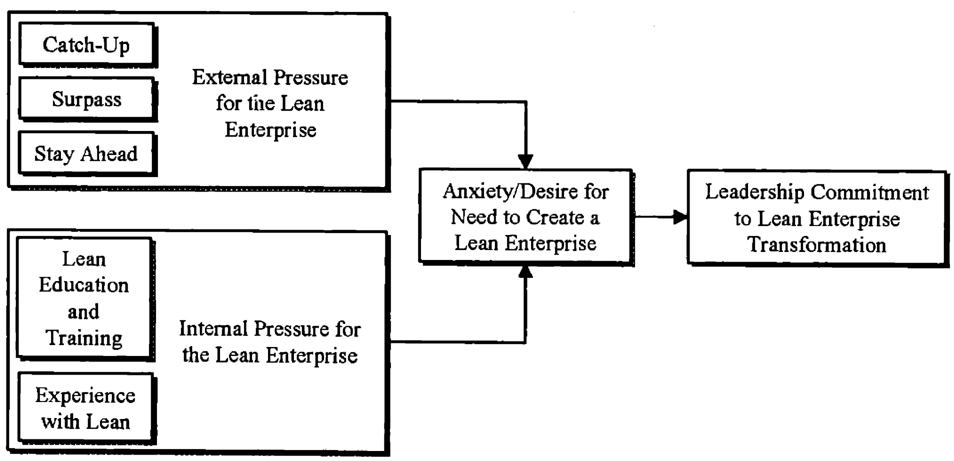


Figure 47 - Development of leadership commitment (LC) in the lean enterprise transformation information feedback model.

Internal pressure for lean enterprise transformation is based on the creation of beliefs in the value of lean principles and to the enterprise leader. Past positive experience with lean is one source of these internal beliefs. The prior exposure and involvement with successful lean efforts will have created an understanding of the potential achievable with lean enterprise transformation. However, previous experiences with lean that have failed can serve to reduce the pressure, or even create a desire not to change. The other source of internal pressure is education and training in lean which aims to infuse the leader with an understanding of what lean is and what it can do. Beyond simply giving the leader a lecture on lean, the establishment of local lean efforts can serve to demonstrate the performance gains achievable with lean. The combination of information and example serves to create a sense of the value of the lean enterprise in the leader, and leads to an increased anxiety/desire for a need to undertake lean enterprise transformation.

This portion of the model also suggests that a change in enterprise leadership is a potential threat to lean enterprise transformation. If new management has low anxiety or desire for creating a lean enterprise, then it follows that their commitment to lean enterprise transformation will be low. In fact, new leadership that does not support lean may view it as a waste of resources and move to instill her/his ideals on the enterprise and stop any pre-existing lean enterprise transformation efforts. If one does not believe this, then one must ask how often is new leadership is willing to adopt the practices of previous leadership if they themselves are not versed in those practices? In this type of environment efforts from within the enterprise are needed to build external and internal pressure to change the leader's level of anxiety/desire for creating a lean enterprise. Determining who does this and how is not a set procedure, but must be determined based on the enterprise's current lean maturity. The political environment in which current lean efforts operate and are supported/fought by the existing senior leadership team and lean implementing-employees needs to be considered. The senior lean leader in the enterprise should be prepared to make the case for continued lean improvements if there is a change of leadership unversed in lean principles and practices.

The evidence of leadership commitment (LC) will show up in behaviors of both the leader and of the enterprise as a whole. Reflecting on the LAI Transition to Lean (TTL) Roadmap in Figure 48, the signs of leadership commitment will be seen in practices associated with adopting the lean paradigm and enterprise strategic planning, otherwise labeled as the Entry/Re-Entry cycle of the TTL. The maturation of lean enterprise behavior in these practices will set the stage for enterprise transformation activities.

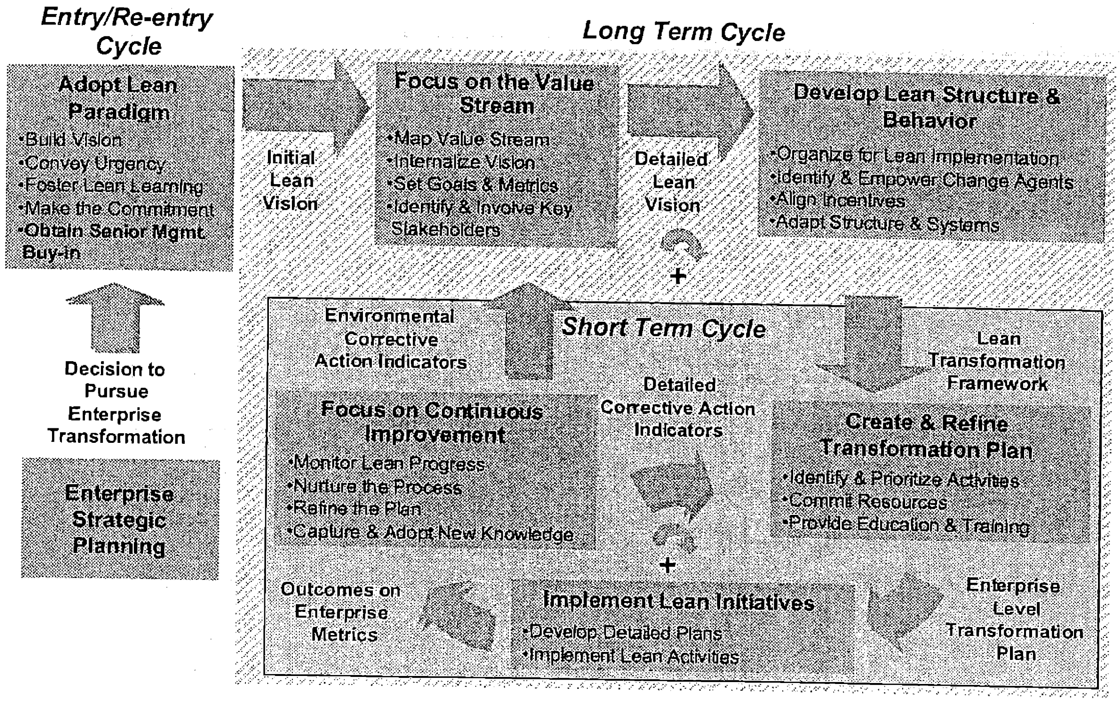


Figure 48 - LAI Transition-to-Lean (TTL) Roadmap (Nightingale et al. 2000).

8.1.2. Step 2 - Following the TTL to Establish CE and CP

As the leader's anxiety/desire about lean enterprise transformation increases, and leadership commitment (LC) to the lean enterprise matures, there are two effect paths that become stronger, as shown in Figure 49. First, the enterprise strategic planning process will need to include a focus on the lean enterprise transformation effort. Creating this lean focus is part of the leadership commitment portion of the TTL. For the purposes of this model, the strategic planning block is shown outside of the TTL activities, as there are other influences to strategic planning beyond those addressed by lean enterprise transformation, such as external factors, business strategy, corporate strategy, and R&D strategy to name a few.

Since the lean enterprise is a different operational and structural business model for most enterprises, there must be formal consideration of the new lean enterprise model in conjunction with the strategic needs of the enterprise. Recognition must be given to the requirements for creating a lean enterprise, such as new roles for management, and the effects the new model is expected to have on stakeholders and on the enterprise's performance.

The second effect path that becomes stronger with increasing leadership anxiety or desire for transforming to a lean enterprise is the path associated with the TTL activities. The increasing leadership commitment to the lean enterprise will enable the creation of a lean enterprise change environment (CE), which means the maturation of activities associated with the Long-Term Cycle of the TTL. This will then enable lean enterprise change in practice (CP), which is associated with the maturation of the Short-Term Cycle activities in the TTL. The Short-Term Cycle focuses on the prioritization, deployment, execution, and monitoring of detailed lean enterprise change activities, which is the level at which the lean behavior changes are affected at the employee level.

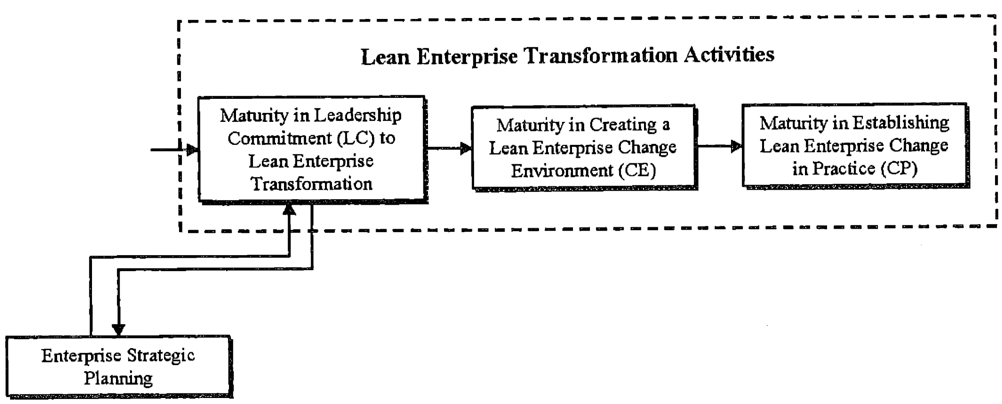


Figure 49 - Leadership commitment (LC) as the starting point of lean enterprise transformation activities.

8.1.3. Step 3 - Improving Lean Maturity In Enterprise Processes

The lean enterprise change in practice (CP) efforts described in the previous section focus on the activities aimed at improving the lean maturity of the enterprise. These activities are focussed on improving lean maturity in enterprise lifecycle processes and enabling infrastructure as shown in Figure 50. The improvement of lean maturity in enabling infrastructure practices is intended to reduce waste in the enabling infrastructure as well as support the operation of lifecycle processes in a leaner manner. The operation of lifecycle processes in a leaner manner will reduce waste in these processes, which is good for the P&L statement of the enterprise. It will also focus on creating more value for enterprise stakeholders, which is good for enterprise sustainability and thus long-term P&L. These stakeholders include customers, shareholders, employees, and suppliers amongst others, as discussed in Chapter 4. This step in the lean enterprise transformation model covers activities up to and including improvements in the value creation and resource utilization processes that comprise the enterprise. The TTL provides a clear set of activities aimed at organizing and structuring the detailed lean transformation efforts, and includes feedback for monitoring the detailed lean improvement activities.

While creating leadership commitment is aimed at the senior leader(s) of the enterprise, the development, implementation, and tracking of detailed lean enterprise transformation plans requires that there be a lean transformation leader and lean implementation team that operates with the support and commitment of the enterprise leader and her/his leadership team. This support and commitment from the leadership team is essential, as the improvement efforts will cross functional, process, and thus management boundaries. There is little change of successful transformation if the lean office is considered an independent activity and group that does not interact with the functional, process, and program managers.

Furthermore, the lean change team must be composed of individuals that are versed in lean and understand the multitude of processes and functions that span the enterprise. This team will be responsible for creating lean enterprise change plans and then providing the education and training to specific areas of the enterprise that will be required to develop detailed implementation plans for executing the transformation. While there is an internal feedback loop for tracking the detailed lean implementation efforts, the model at this point is largely an open-loop model based on leadership desires and enterprise strategic needs flowing down to drive detailed implementation activities.

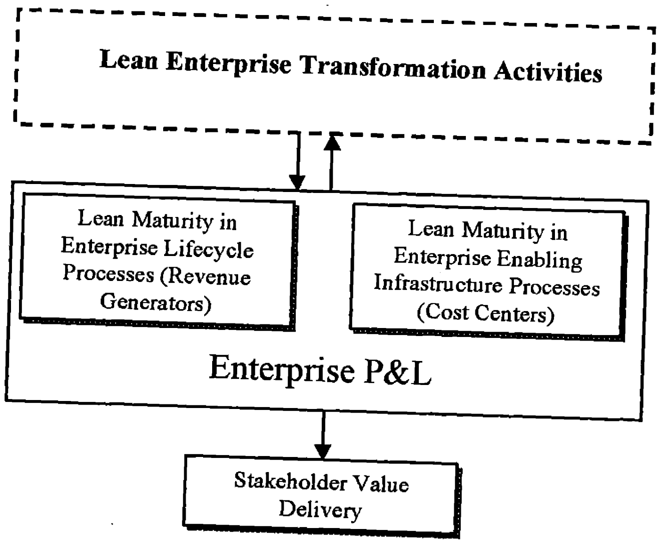


Figure 50 - infrastructure processes.

8.1.4 Step 4 - Closing the Transformation Management Loop

The value of the lean enterprise transformation model proposed in this Chapter arises as the information loops are closed by feeding back into the lean enterprise planning and transformation process. The full lean enterprise transformation process feedback model is shown in Figure 51. The purpose and benefit of each of the feedback connections, labeled "A" though "I" in Figure 51 will be discussed in greater detail as they offer new knowledge in this domain.

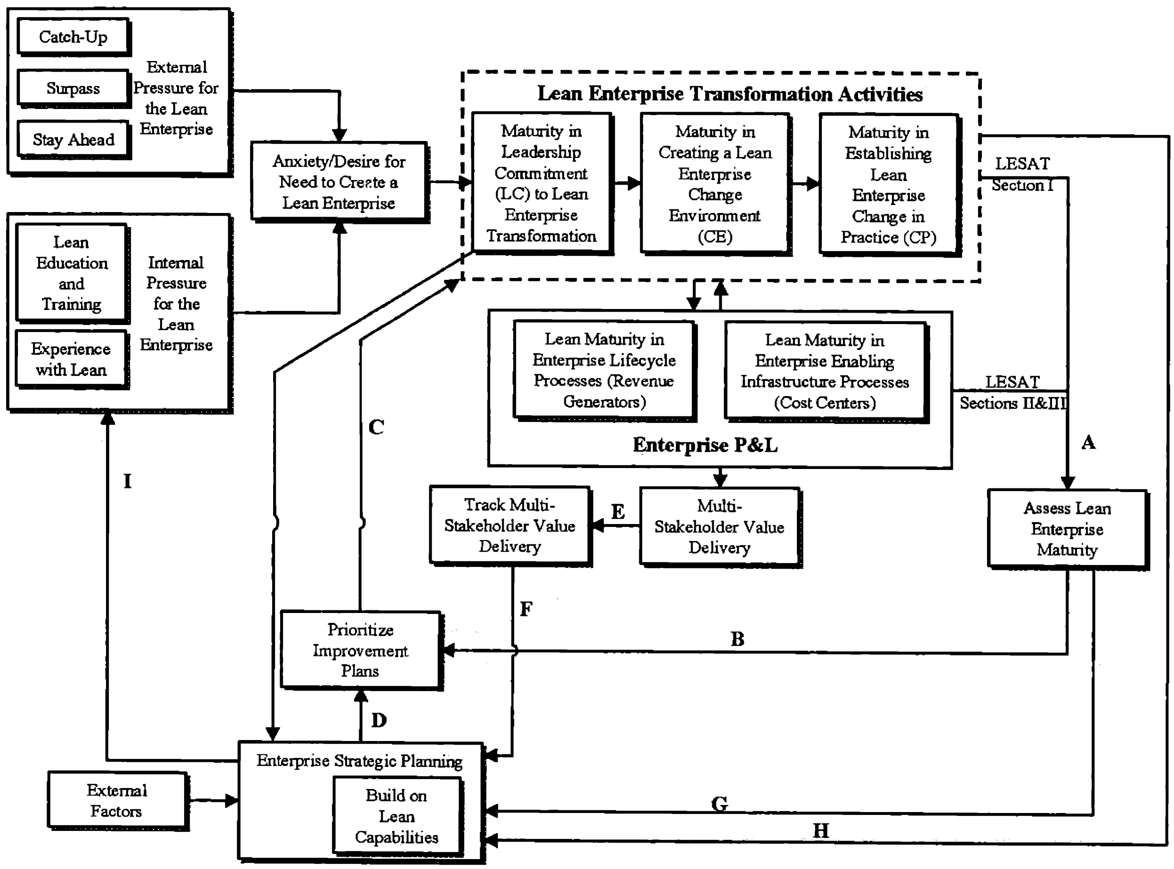


Figure 51 - Fully integrated closed-loop lean enterprise information feedback transformation model.

8.1.4.1. Information Flow ABC - Understanding Lean Enterprise Maturity

The first set of information feedback linkages in the lean enterprise transformation model are shown by the connectors A, B, and C. The ABC information path constitutes a Lean Enterprise Assessment feedback loop. This loop serves to inform future lean enterprise transformation plans based on the current state of the enterprise. Connector A involves using the LESAT to measure the current lean enterprise maturity. Connector B delivers these results to a decision block where areas for improvement are prioritized. Connector C feeds these prioritized improvement areas into the detailed transformation planning and implementation blocks of the TTL.

The prioritization of improvement areas should be the responsibility of the lean change leader and her/his team. The areas may be prioritized based on low maturity, high variability, or a combination of both, especially when present in the TTL elements. These prioritized areas for improvement are then fed back into the TTL practices via connector C, and resources need to be allocated (which may initially constitute the whole lean change team if it is small) for improving the priority areas. In some instances, the high variability in assessed maturity in specific practices may be addressed by education to create common understanding of the terminology or by creating a medium for discussion such that there is common understanding amongst the assessors. Creating this formal feedback mechanism is an improvement over open-loop control as it leads to the allocation of resources to the areas needing the greatest amount of lean improvement. This is the first step at formalizing closed-loop lean enterprise transformation and management.

8.1.4.2. Information Flow D - Strategically-Driven Lean Improvement Plans

The addition of connector D is intended to integrate the lean enterprise improvement plans with the strategic needs of the enterprise. Connector D is established to enable the improvement plan prioritization process to consider LESAT areas for improvement when they are both low in maturity and important to the enterprise's strategic objectives, as shown in Figure 52. This might seem like a simple and obvious step, yet it was observed that the majority of LESAT users in industry had failed to create this linkage. The lack of this linkage means that assessment-based lean enterprise improvements relying only on the ABC connectors are devoid of enterprise strategic influence and are thus somewhat ad hoc with respect to the strategic direction the enterprise is attempting to take. The lack of connector D may preclude improvement in areas most needing lean improvement from a strategic perspective, and may negatively interact with other improvement efforts that are strategically driven. Connector D can be established by making the lean change leader a formal part of the strategic planning process so that she/he is fully aware of the strategic needs of the enterprise. Another option is that the strategic plans are codified in a manner that allows the lean change team to easily parse out the main strategic need in order of importance to the enterprise.

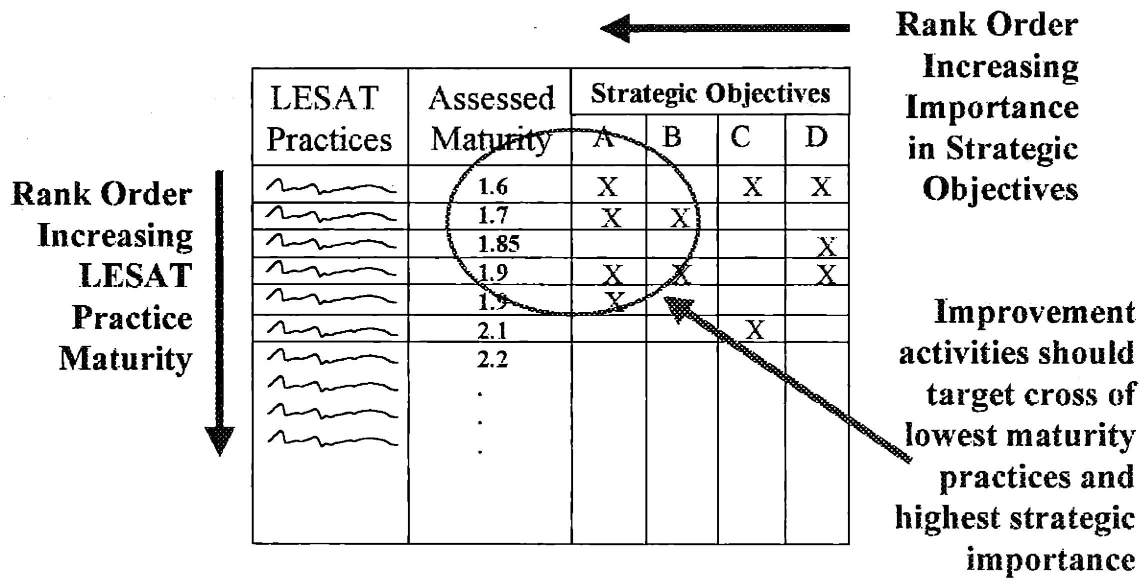


Figure 52 - Prioritization of lean enterprise improvement areas based on lean maturity and strategic value.

The creation of a formal information connector D will focus improvement efforts and resource allocation on strategically important areas. This connector will strengthen arguments for allocating resources to specific improvement efforts, since they will be directed at strategically important areas of the enterprise. Furthermore, it may help leadership identify where there is a need to move resources from less-strategically important areas to more strategically important areas.

8.1.4.3. Information Flow E & F - Monitoring Multi-Stakeholder Outcomes

The creation of connectors E and F are intended to bring formal recognition of the multi-stakeholder focus of the lean enterprise into the strategic planning process. Connector E implies that a means will be devised for measuring and tracking multi-stakeholder value delivery using some defined set of metrics. Connector E also includes the tracking of

Enterprise P&L information. Connector F then implies that these results are codified in a manner that supports strategic decision-making. The lean enterprise team should be responsible for determining the appropriate stakeholder metrics to track, identifying who and how they should be tracked, and then working with other enterprise employees to implement the tracking system. In doing so, they should also be looking for the elimination of existing metrics (and their tracking systems) that do not provide value to the enterprise decision making process. The lean leader should work with the strategic planning and enterprise leadership groups to understand what stakeholder information they can act on and what stakeholder information they may be missing in their decision-making processes.

The formal tracking of multiple stakeholder outcomes will identify where there are strategic issues with respect to the enterprise's stakeholder constituents. Furthermore, this formal multi-stakeholder value tracking process may identify new areas to address that were not previously considered when decisions were made with only financial and/or customer-centric metrics. This feedback will result in modifications to new strategic plans and subsequently lead to modified prioritization requirements for improvement activities (i.e. focus on developing key suppliers based on their expertise in areas X, Y, and Z, and then work to bring their core competencies into the product development efforts). The creation of these formal information connections now leads to an integrated enterprise that considers multi-stakeholder value, external factors, and internal lean enterprise maturity as a means for prioritizing improvement plans.

8.1.4.4. Information flow G & H - Strategically Leveraging Lean Enterprise Maturity

While all of the previous information connectors lead to the integration of strategic needs and the acceleration of lean enterprise transformation by focusing on improvement areas, there is still an information feedback shortfall with this model that can be addressed by the addition of information connectors G and H. The improvements without these connectors will lead to a leaner enterprise, but do not necessarily result in the strategic leveraging of the lean capabilities for growth. Even with "consideration" for lean in strategic planning, a lack of feedback of lean-derived capabilities means that the lean efforts are only aimed at improving current efficiencies. This is good for cost cutting measures, but misses out on the additional benefit of the lean enterprise, the potential for growth. By creating connectors G and H, the strategic planning process is informed of the lean maturity of the enterprise, and of the gains achieved and potentially achievable with further lean enterprise transformation. This requires the lean change team to report on the state of enterprise leanness, as well as provide hard metrics including capabilities, performance, and resource availability that can be used for strategic planning efforts.

Growth from the lean enterprise can occur via two methods, either via increased market share in current markets or by entering new markets. From a market share perspective, the enterprise has the ability to make strategic decisions about how to capitalize on its ability to deliver greater value at lower cost as it becomes leaner. In a purely competitive market environment this translates into three potential strategic moves. First, the enterprise would have an ability to extract higher profits from current product offerings at current prices, thus leading to increased shareholder satisfaction with no decrease in customer satisfaction. Second, the enterprise could decrease the product price and thus increase sales as current customers may be willing to purchase more of the product, and new customers may enter the market at the lower price. This second move would both increase customer satisfaction by delivering an equal product at a lower price, and increase shareholder satisfaction (and supplier satisfaction as well) due to the increased sales and revenue, and thus increased profits. The third option for the enterprise is to offer greater product value at current prices, which under conditions of perfect competition would cause buyers of competitors' products to switch to the higher value product. This option leads to greater customer value delivery, as they would receive more value at an equal price, and lead to increased market share leading to the same increase in shareholder and supplier satisfaction as was just discussed.

From the perspective of entering new markets, the lean enterprise leaders must first realize that the lean transformation will make resources available, including people, cash, equipment, and facilities. They can use these resources for continuing lean transformation efforts and they can also consider strategies of vertical integration and horizontal diversification for growth. As the value stream becomes a central part of the lean enterprise, management can consider bringing more of the supply chain "in-house" by using the available resources to tackle more of the value stream activities. This leads to the enterprise capturing a greater portion of the value stream revenue with equal (or slightly increased for unique equipment) use of resources, albeit at the loss of supplier satisfaction. Vertical integration may also lead to the creation of new core competencies in the newly integrated supply chain activities that allow the enterprise to compete in those product/service lines in other markets. Thus, the vertical integration scheme leads to higher profitability and the potential for diversification into new markets associated with supply chain products. There is also the potential to focus on pure horizontal diversification by using the newly available resources to develop new competencies and products/services. Diversification can be accomplished by either extending or modifying existing products for new markets, or by building wholly new products based on existing or modified core capabilities. The result of this strategy can also lead to greater sales, profitability, growth, and potentially sustainment of the enterprise as it will have the ability to adapt and focus its resource utilization as external market factors change.

Connector G is intended to formally establish an understanding of where the enterprise currently has strengths and weaknesses with respect to lean enterprise practices in the strategic planning group. The establishment of this understanding can be achieved by having members of the strategic planning group participate in the LESAT assessment and report out sessions, as well as provide their group with a summarized set of results showing where the current lean enterprise strengths and weaknesses lie in the organization. The goal is to help the strategic planners understand the near-term implications of the lean enterprise maturity, as many of the lifecycle process and enabling infrastructure maturities will only increase in the long run. As such, the strategic planning group can consider the mature practices as areas that can potentially be exploited for near term strategic needs, while less emphasis should be placed on the weaker practices. There are also two specific LESAT practices of importance in this information connector, namely 1.G.2 (Monitoring Lean Progress) and 1.G.5 (Impacting Enterprise Strategic Planning). Both of these practices, to some degree, measure the maturity of information connector H. Thus, by understanding the current maturity of 1.G.2 and 1.G.5, the strategic planning group can consider how to increase the quality of the information feedback connectors by increasing their maturity in these two practices.

Information connector H is intended to provide the enterprise strategic planning group with the knowledge necessary for establishing lean-based growth objectives. The first requirement this places on the lean improvement group is that the TTL element focused on monitoring lean improvement progress should standardize and codify the types of improvement results associated with detailed improvement efforts. The standard performance results, such as lead-time, cost, quality, productivity, and capacity need to be summarized in a manner that allows the strategic planning group to quickly review and understand the current performance capabilities of the enterprise. This understanding could then influence decisions for increasing future sales and market share based on the improved performance, as discussed in the preceding paragraphs.

These results can also be categorized based on where they have been achieved (i.e. in the supply chain, engineering, manufacturing, specific value streams, and/or specific processes). This categorization can provide the strategic planning group with a clear indication of what the current capabilities are in certain aspects of the enterprise, along with the potential future capabilities that could be achieved with further lean improvements. In the aerospace industry, this can give the strategic planning group an indication of what type and number of contracts could be bid in the coming year(s) based on the understanding of the categories of improving enterprise capabilities.

Finally, the lean office needs to formally track resource availability in terms of people, cash, equipment, and facilities associated with the lean improvements. The resources, and potentially forecasted resource availability, should be summarized and presented to the strategic planning group such that they can consider how to capitalize on and deploy some of the resources. A pure cost-cutting focus will try to divest of all unused resources, while a pure growth focus will attempt to fully re-allocate the resources within the enterprise for future growth projects. The lean office resource report can also include the retention of a certain number of resources for other lean improvement activities, such that the lean efforts become self-sustaining without utilizing scarce resources from other elements of the enterprise. Having a formal knowledge of resource availability may provide the strategic planning group with a wider set of options to consider when crafting strategic decisions for the enterprise, especially in the context of growth strategies.

Information connectors G and H in the lean enterprise transformation model are the most important information flows that have largely been neglected in the sample studied in this thesis, perhaps due in part to the relative infancy of lean enterprise transformation in the aerospace industry. Ultimately, successful lean enterprise transformation will force leadership to make a resource allocation choice of strategic importance to the enterprise. The lean enterprise transformation will make resources available, which leadership must then decide how to use. There is a strategic choice to be made between short-term cost cutting efforts and long-term reinvestment of scarce resources for enterprise growth. The pure-cost cutting focus of the lean enterprise will lead to no long-term advantage, as new technologies and products will eventually supplant the existing products in a lean company. Likewise, a pure long-term focus may not help the enterprise maintain operations in the short-term if there are burdensome financial pressures. The actual choice of enterprise leadership will most likely lie somewhere in the spectrum between the two extremes, undertaking some cost cutting for current needs and reinvesting some scarce resources for business growth.

8.1.4.5. Information Flow I - Reinforcing Leadership Belief in the Lean Enterprise

The creation of information connector I is aimed at informing the enterprise leader of the changes in enterprise outcome measures associated with the lean enterprise transformation. While this connector need not come from the strategic planning group, it essentially represents the combination and summary of all lean transformation inputs that are fed into the strategic planning function. The tracking of lean enterprise maturity, capability, and outcome metrics associated with multiple stakeholders will increase the leader's understanding of the impact the lean enterprise can have. This is a reinforcing loop that will help build leadership commitment to the lean enterprise by building the leader's experience with lean in the "Internal Pressure for the Lean Enterprise" block in Figure 51. This information flow requires tracking of specific outcomes associated with specific changes in enterprise processes and activities in order to show the causal connection between the lean enterprise transformation and the outcome. One reason for tracking results of improvement changes is that the other variables that affect enterprise performance, such as a potentially unstable investment market, or a decline in overall industry spending, may still lead to poor enterprise performance. In this type of environment, the goal is to show that the lean enterprise improvements have resulted in better performance over how the enterprise would have performed without the improvements. Thus, even while overall industry performance may be on the downswing, the lean enterprise improvements will show better performance than had they not changed, and thus reinforce leadership belief in the lean enterprise.

Accomplishing this kind of feedback suggests that there is a need to develop and track multi-stakeholder metrics that are shown to link to enterprise processes. Furthermore, multiple period data is needed to show the improvement gains associated with lean change (i.e. productivity at t_2 is much higher than at t_1 after some set of improvement activities that resulted in reconfiguring a process). This feedback may also lead to the development of enterprise-level optimization models for improving overall stakeholder value delivery, versus a collection of many locally-optimized, functionally-focused models that do not necessarily lead to higher enterprise value delivery (as discussed in Chapter 3).

The lean enterprise transformation information feedback model suggests the need for formal communications channels and a group responsible for managing the information flow. As suggested in the Transition to Lean (TTL) Guide and this thesis, and as seen in industry, lean enterprise transformation requires a senior enterprise leader to be responsible for the lean change activities. More generally, this should be the leader responsible for the continuous improvement/change efforts of the enterprise, of which lean may be a part, to ensure the integration, and not the competition, of improvement efforts. The lean enterprise transformation efforts will then be focused under the guidance of the change office, and should be staffed by full-time employees versed in lean principles and practices.

The lean office cannot be viewed as an added cost to the enterprise, because this will be a potential source of cost reductions if the firm faces financial difficulty. The lean change office must be seen and supported as a source of increased competitive advantage, which can both reduce current costs and improve future performance. The enterprise leader and the senior leadership team must view the lean office as an integral part of enterprise operations, just as finance, engineering, and manufacturing are integral parts of enterprise operations. If the lean office is viewed as "another improvement effort", the change efforts will face significant resistance as they cross management boundaries. There must be a willingness of senior leadership to support the lean office and participate in the improvement activities as routine activities, not as one-time events to please a senior leader. If this can occur, then lean will begin to permeate the organization as the modus operandi and result in changed organizational behavior. The temporal alignment of lean improvement monitoring, LESAT assessment, strategic planning, and the creation of annual operating plans (informed by the improvement plans) will be critical to maintaining the information flows identified in the transformation model.

It is the belief of this author, supported by literature and empirical evidence from this study, that the creation of information connectors A through I in Figure 51, as discussed in the preceding pages, will serve to accelerate lean enterprise transformation. The lack of these feedback mechanisms will lead to open loop management that will produce marginal, ad-hoc improvements at best, and adverse changes at worst.

8.2. Potential for Further Research

From the perspective of the proposed integrative lean enterprise transformation information feedback model, there are many questions associated with the structuring, staffing, and enabling of the identified information flows. While the preceding discussion presented a methodology for organizing and managing the information flows, these propositions remain to be tested. In fact, there are a myriad of questions associated with the model that could be explored, including:

- How are the information connections established?
- Does someone need to manage the connection, and if so, who?
- What format does the information take when flowing between blocks in the lean enterprise transformation model?
- Who is the recipient of information and how are they supposed to use it?
- What existing tools support the information flows?
- What new tools are needed to enable the flows?
- What is not shown in the model that would help the information flow?
- What could disrupt the connection and how could one mitigate against these disruptions?

Beyond questions about structuring and managing the information feedback mechanisms, there are important questions about accelerating lean enterprise transformation that are associated with this model. The major proposition associated with the model is that it will lead to accelerated lean enterprise transformation, suggesting that enterprises that do not follow the model will have greater difficulty or require a longer time to achieve a similar transformation. While evidence that supports this proposition has been provided in this thesis, it remains to be formally tested. An experiment could be devised to track the lean transformation of a company or companies over time as they attempt to use this model. A control group for the study could be comprised of enterprises that are electing not to use this model in their transformation efforts. However, this may not be a real control group due to the many differences in existing lean maturity in the participating enterprises. As such, the development of an experiment that attempts to measure transformation time, scope, and effectiveness using differences between a control group not using the model and a group using the model does not seem likely.

The model proposed in this chapter may be more readily studied using case methodologies that follow enterprises that are willing to adopt the model as part of their transformation efforts and then tracking the improvements that the tool is reported to have enabled. Using some form of pre-transformation lean enterprise maturity measure (i.e. the LESAT) could help establish the starting point of the efforts and allow the categorization of participating enterprises based on their initial state (i.e. low maturity, medium maturity, etc.). Understanding which improvements would not have been possible without the model might be achievable in the study, and thus show the value of the model. An interesting element of the study would be the discovery of variations to the model that emerge as beneficial to the transformation efforts, thus providing recommended improvements to the model. Enterprises that ignore parts of the model, or place little emphasis on parts of the model, would serve as a test of the value of the model by measuring the extent to which they do or do not have difficulty in their transformation efforts. A strong correlation between the absence of information connectors and certain transformation problems, along with the strong correlation between the lack of similar transformation problems when the connectors exist would help validate the model.

The LAI member community may be a good place to attempt to introduce and track the model for further research, as they are already active LESAT users. Further testing of the model could be achieved by testing it in other industries, which would thus test the generalizability of the theories that are implicit to the model. Beyond studying the generalizability of the model, studying these cases might identify industry-specific variations to the model that could improve their transformation process.

Appendix A - Some of the Mathematics Describing the Gains Achievable with Lean Production

A.1 - The Mathematical Basis for Understanding the Performance of Lean Manufacturers

The results of lean transformation in manufacturing are definitely positive in terms of productivity, cost and quality. A major source of these improvements can be attributed to the removal of waste in the manufacturing system, and more specifically, the removal of activities that do not add value to the end product.

The literature on lean suggests that all activities can be defined as either value-added (VA) or non-value-added (NVA) (Rother and Shook 1998), (Womack and Jones 1996), (Murman, Allen et al. 2002). Value added activities are defined as activities that transform a product for which customers are willing to pay. Non-value-added activities are those activities for which the customer would not be willing to pay. A subset of Non-value added activities are those that are necessary, called non-value-added-but-necessary (NVAN). These activities, while of no value to the customer, provide value to some other entity such as data collection for process quality monitoring. The customer does not value this activity, however the process can only be improved with this data and thus while non-value added in the eyes of the customer, it is necessary to make the process function more effectively.

The lean literature promotes the removal of all NVA activities from manufacturing processes in view of improving process performance. To see the effects of the removal of NVA activities, a simplistic systems dynamics model of a hypothetical manufacturing company has been created in Figure 49 to show the relationship between NVA activities and process performance measures such as time, productivity, and cost.

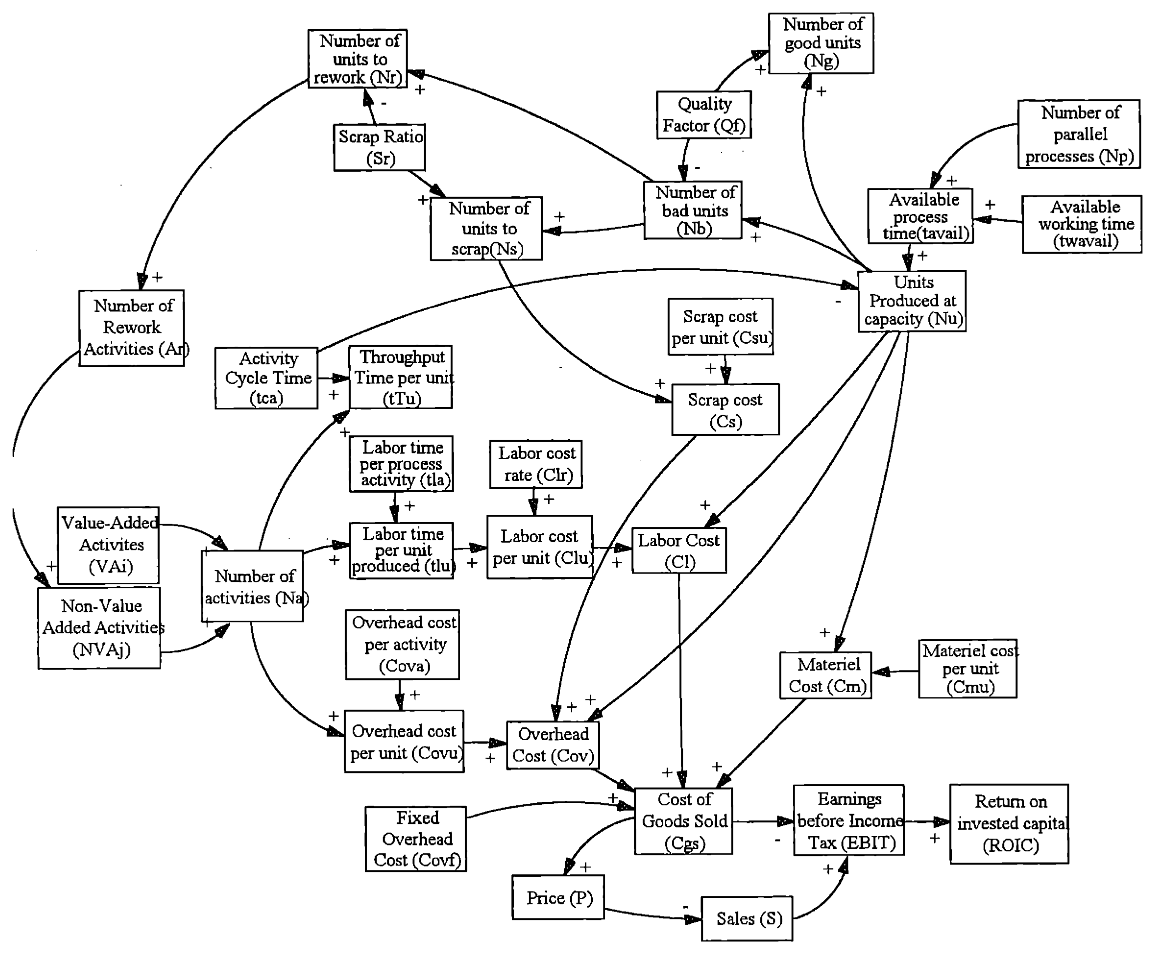


Figure 53 - Theoretical model of a manufacturing system's impact on firm performance measures.

Using this model we can look at the interaction of process activities, time, productivity, cost, and quality. The throughput time (t_T) is defined as the product of the number of activities (N_a) in the process and the average cycle time per activity (t_{ca}), resulting in Equation 32.

$$t_T = (t_{ca})(N_a)$$ Equation 32

$$(N_a) = (VA + NVA)$$ Equation 33

Knowing that the activities are comprised of a number of value adding activities (VA) and a number of non-value adding activities (NVA) as shown in
Equation 33, we can see through simple substitution that the throughput time is a function of both value adding and non value adding activities, as shown in Equation 34.

$$t_T = (t_{ca})(VA + NVA)$$ Equation 34

This equation is easily transformed into a discrete event case (Equation 35), by considering the m value-adding activities and the n non-value adding activities as each having individual activity cycle times.

$$t_T = \sum_{i=1}^{m} t_{cai} \cdot VA_i + \sum_{j=1}^{n} t_{caj} \cdot NVA_j$$ Equation 35

As the waste is removed from the process at initial time t_i, NVA activities disappear from the equation resulting in a leaner process at a future time t_f. Substituting values for t_i and t_f into Equation 34, and dividing the final result by the initial result, we obtain

$$\frac{t_{Tf}}{t_{Ti}} = \frac{(t_{caf})(VA_f + NVA_f)}{(t_{cai})(VA_i + NVA_i)}$$ Equation 36

and knowing that

$$t_{caf} = t_{cai}, VA_f = VA_i, NVA_f < NVA_i$$ Equation 37

yields

Equation 38

$$\frac{t_{Tf}}{t_{Ti}} < 1$$

We see from Equation 38 that the throughput time in the leaner final state at t_f is less than the initial throughput time at t_i. This result impacts both the lead-time (t_L) for the product and the productivity (P) of the process.

A.1.1 - Lead-time

The lead-time is the time required to fulfill an order, and is a performance measure of importance to the customer. The lead-time is a function of the throughput time, the activity cycle time, and the total number of units waiting to be produced. The total number of units can be further subdivided into those units in queue to enter production (N_q) and those that have been ordered and are going to enter the queue (N_o). The lead-time is thus defined in Equation 39 as

$$t_L = t_T + t_{ca} \cdot (N_q + N_o)$$ Equation 39

This representation of the lead-time assumes there is no inventory waiting to be sold off, which would have zero lead time from a production perspective. With products in the queue (i.e. previous orders that have already been logged), the production system is fully populated. In this instance, the lead-time for the order will include the time it takes to get the queue backlog into the production system, and then the time to get the order through the system. If there are no products in the queue, then the production system is under-utilized, which means there is no waiting time required before the order enters production. As the number of non-value added activities are reduced in making the system leaner, the throughput time reduces, while all else remains the same. Thus from Equation 38 it follows that the lead-time will also decrease, resulting in the inequality of Equation 40. Thus from a customer satisfaction perspective any removal of non-value added activities (waste) from the production system will result in better product lead time, and therefore increase their satisfaction with the company.

$$\frac{t_{Lf}}{t_{Li}} < 1$$

Equation 40

A.1.2 - Productivity

Productivity (P) is an important measure of the efficiency of the production system, or how well the resources are functioning to create sellable output. Any increase in productivity can be translated into increased profitability, since it means that more output can be sold without a change in resource utilization, other than an increase in bill of materials (BOM) expenses associated with ordering more of the consumables utilized in each of the additional units produced. Productivity is a measure of the number of units produced (N_u) in a given period of time (t_u), as shown in Equation 41.

$$P = \frac{N_u}{t_u}$$

Equation 41

On a per unit basis, the productivity is defined in terms of the time to create 1 unit, which is in fact the throughput time. Thus on a per unit basis, the calculation for productivity can be defined as shown in Equation 42.

$$P = \frac{1}{t_T}$$

Equation 42

Since the productivity is inversely proportional to the throughput time, it follows that any lean improvement that decreases the number of non-value-added activities, and thus decreases the throughput time, will result in higher productivity. Using the inequality in Equation 38, we have the relationship showing the increase in productivity from an initial productivity (P_i) before the change, to a final productivity (P_f) after the change as shown in Equation 43.

$$\frac{P_f}{P_i} = \frac{t_{Ti}}{t_{Tf}} > 1$$

Equation 43

An increase in productivity means sell more (with same L and slight marginal cost increase equal to the BOM and consumables) to make more profit, or sell the same but remove resources (L and overhead) to cut costs and make more profit.

A.1.3 - Cost

The costs of goods sold (C_{gs}) are comprised of labor costs (C_l), overhead costs (C_{ov}), and Material costs (C_m). If these costs are calculated based on an average cost per unit (C_{lu}, C_{ovu}, C_{mu}), then the cost of goods sold can be expressed as the product of the per unit costs and the total number of units produced, plus the fixed overhead costs that are not attributable to unit production (C_{ovf}) as shown in Equation 44.

$$C_{gs} = C_{ov} + C_l + C_m = (C_{ovu} + C_{lu} + C_{mu}) \cdot N_u + C_{ovf}$$ Equation 44

The overhead cost per unit (C_{ovu}) can be represented as the product of the overhead cost per activity (C_{ova}) and the total number of activities in the process. The labor cost per unit (C_{lu}) can be represented as the product of the labor rate (Lr), the labor time per activity (t_{la}), and the number of activities in the process. Equation 44 can thus be expanded to create Equation 45.

$$C_{gs} = ((C_{ova} + t_{la} \cdot Lr) \cdot (VA + NVA) + C_{mu}) \cdot N_u + C_{ovf}$$ Equation 45

Grouping the terms that both depend on the number of activities and expanding the equation to show value-added and non-value added activities we have Equation 46.

$$C_{gs} = ((C_{ova} + t_{la} \cdot Lr) \cdot (VA + NVA) + C_{mu}) \cdot N_u + C_{ovf}$$ Equation 46

The creation of a lean manufacturing process, by reducing the non-value added activities, will result in a reduction of the unit overhead cost and the unit labor cost associated with producing the goods, which will result in a reduction in the cost of goods sold. All else being equal this will increase in the return on invested capital (ROIC). The material costs will not be reduced, as there is no reduction in the amount of invoiced material for the units produced (i.e. production remains constant). Equally so, the removal of non-value added activities does not have a direct impact on the fixed overhead costs. The reduction in fixed overhead costs from the removal of non-value-added activities requires additional action. For example, a real reduction in warehouse costs due to the removal of inventory from the production system requires the company to actually do something with the warehouse. It can be sold or leased to another party, have its lease terminated if it is rented, or be used for other purposes such as new production. In the first two cases it would actually lower the fixed overhead, whereas the latter case would not, but does provide a new resource available for other uses. Any action that reduces the fixed overhead costs or creates new revenue from the use of freed-up resources will result in increased ROIC.

From a lean perspective, the removal of non-value-added activities, or waste from the production system positively impacts productivity, lead-time, the cost of goods sold, and ultimately ROIC. These results lead to improved customer satisfaction and improved financial performance. Now let us look at the impact of quality on the production system. For simplicity of argument, all of the mathematical relations presented herein are for steady-state conditions and do not attempt to model the transient associated with the change in quality over time. Considering the quality loop in Figure 3, we can look at the effect of quality on the same performance measures as above, namely time, productivity, and cost.

A.1.4 - Lead-Time and Quality

Any real production system will have the potential to introduce defects or errors into its production process. A measure of the quality of the system is the ratio of the number of defect-free units produced (# of good units = N_g) to the total number of units produced. In the following discussion, this ratio will be called the quality factor (Q_f), a number between zero (no good units produced) and one (no defects produced). The number of bad units produced (N_b) will thus be defined as

$$N_b = N_u \cdot (1 - Q_f)$$ Equation 47

Of the bad units produced, a certain number will be repairable (N_r) to meet specification, and a certain number will be unrepairable and will have to be scrapped (N_s). The scrap ratio (S_r), a number between 0 and 1, defines the percentage of bad units that cannot be repaired. So the total number of units to rework is thus defined as

$$N_r = N_u \cdot (1 - Q_f) \cdot (1 - S_r)$$ Equation 48

The number of rework activities (A_r) will rise in proportion (constant = α) to the number of units that can be reworked. Since rework only exists because the product was not built right the first time, it is all non-value added. So the total number of non-value added activities in the production system (NVA) will be the sum of the existing non-value added activities (NVA_e) and the rework activities as follows

$$NVA = NVA_e + A_r$$ Equation 49

The expansion of Equation 49 by substituting Equation 48 yields

$$NVA = NVA_e + \alpha \cdot N_u \cdot (1 - Q_f) \cdot (1 - S_r)$$ Equation 50

The result of Equation 50 is that any increase in quality will cause the quality factor to rise, thus reducing the number of non-value added steps in the process. Following the lead-time argument based on the removal of non-value added steps in the previous section, it holds that if the quality factor can improve, then the lead-time will decrease.

$$\text{if } \frac{Q_{ff}}{Q_{fi}} > 1 \text{ then } \frac{t_{Lf}}{t_{Li}} < 1$$ Equation 51

A.1.5 - Productivity and Quality

From a productivity standpoint it is necessary to distinguish between line productivity (P_L) and effective productivity (P_{eff}). The line productivity is associated with the total number of units produced in the production system over the production time (t_P), irrespective of defective units. The effective productivity uses the actual number of good units produced in its calculation.

$$P_{eff} = \frac{Q_f \cdot N_u}{t_P} = Q_f \cdot P_L \qquad \text{Equation 52}$$

Substituting Equation 42 for the line productivity, Equation 34 for the throughput time, and Equation 50 for the number of non-value added activities, the following relation is defined for the effective productivity.

$$P_{eff} = \frac{Q_f}{(t_{ca})(VA + NVA_e + \alpha \cdot N_u \cdot (1 - Q_f) \cdot (1 - S_r))} \qquad \text{Equation 53}$$

From Equation 53 we see that an increase in quality will cause the numerator to increase proportionally to the quality increase. Additionally, the denominator will decrease as quality increases. Thus it holds that an increase in quality will increase the effective productivity of the production system. Thus it holds that

$$\text{if } \frac{Q_{ff}}{Q_{fi}} > 1 \text{ then } \frac{P_{efff}}{P_{effi}} > 1 \qquad \text{Equation 54}$$

A.1.6 - Cost and Quality

The cost of goods associated with improved quality is a slightly more complex relation. First, Equation 46 must be modified to include the cost of scrap material (C_{ovs}), which is a part of the total overhead cost.

$$C_{gs} = ((C_{ova} + t_{la} \cdot Lr) \cdot (VA + NVA) + C_{mu}) \cdot N_u + C_{ovf} + C_{ovs} \qquad \text{Equation 55}$$

The scrap cost is defined as

$$C_{ovs} = N_u \cdot (1 - Q_f) \cdot S_r$$

Equation 56

The total number of units produced can be defined in terms of the quality factor and the number of good units as

$$N_u = \frac{N_g}{Q_f}$$

Equation 57

Substituting Equation 50, Equation 56, and Equation 57, into Equation 55 provides the cost equation in terms of the quality factor as shown in Equation 58.

$$C_{gs} = ((C_{ova} + t_{la} \cdot Lr) \cdot (VA + NVA_e + \alpha \cdot \frac{N_g}{Q_f} \cdot (1 - Q_f) \cdot (1 - S_r)) + C_{mu}) \cdot \frac{N_g}{Q_f} +$$

$$C_{ovf} + \frac{N_g}{Q_f} \cdot (1 - Q_f) \cdot S_r$$

Equation 58

What is immediately apparent from Equation 58 is that improved quality only has a positive effect on the cost of goods sold. The number of units to produce goes down as the quality increases, resulting in less material throughput in the system. The increased quality also reduced the amount of rework and the amount of scrap. Thus labor costs go down, material costs go down, and overhead costs (per unit overhead costs and scrap overhead costs). The resulting cost savings can either go directly to ROIC, or be used to try and capture more market share with lower pricing. The overhead cost associated with rework equipment, space, warehousing, and tracking can be eliminated if the rework equipment is sold and the space is utilized to reduce expenses or increase revenue, as discussed earlier.

Appendix B - Stakeholder Value Taxonomy

The stakeholder value taxonomy presented in this appendix was developed as part of the Enterprise Value Stream Mapping and Analysis (EVSMA) work conducted by academic and industry members of the LAI during 2002. The taxonomy represents the latest draft prepared by Mize and Hallam, but is by no means presented as an exhaustive representation of the topic (Mize and Hallam 2002). The major enterprise stakeholders are each represented in this appendix, including customers, suppliers, unions, shareholders, employees, society, and the corporation. The taxonomy builds from the left-hand side of the page from proposed elemental value measures into the final satisfaction value measure at the right-hand side of the page. No weightings, orderings, or interactions amongst the value measures are explored in this proposed taxonomy, but may be of interest for future research.

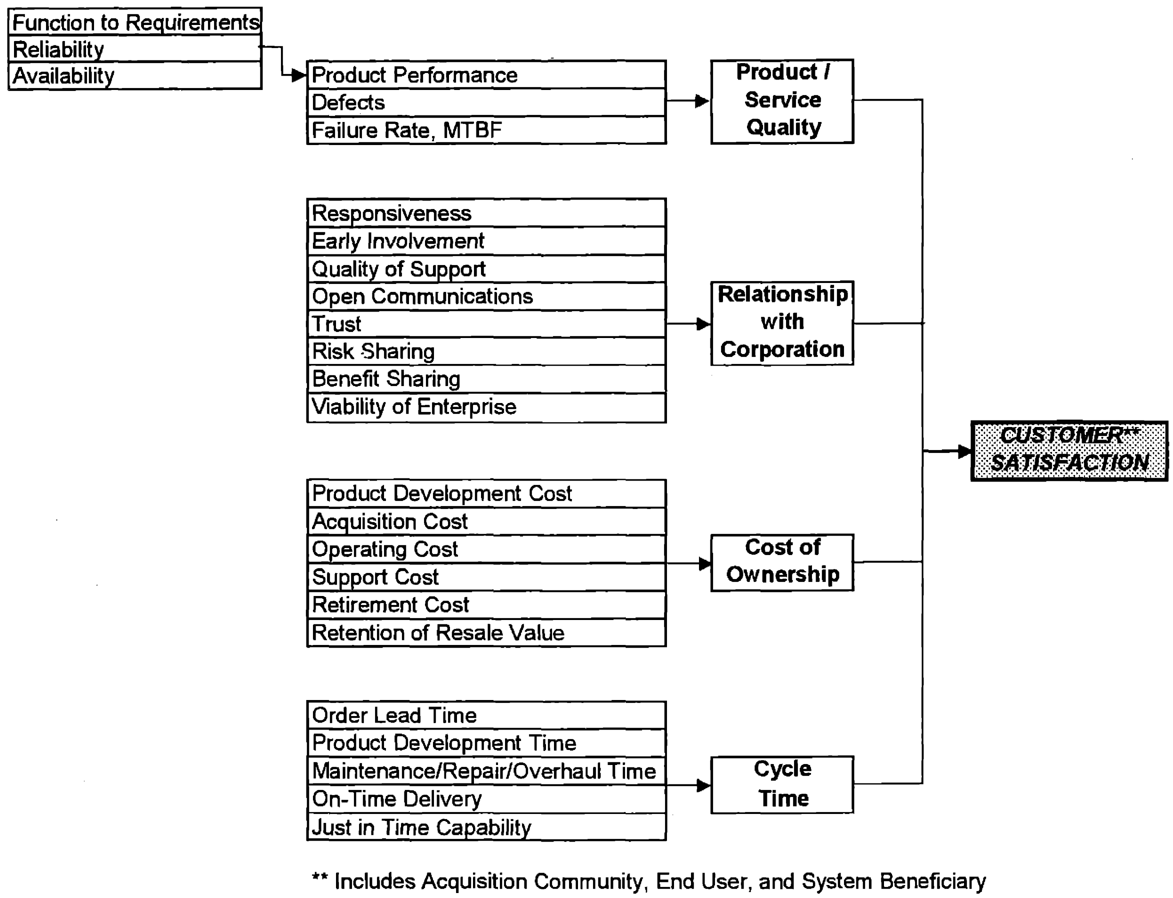


Figure B.1 - Customer satisfaction value taxonomy.

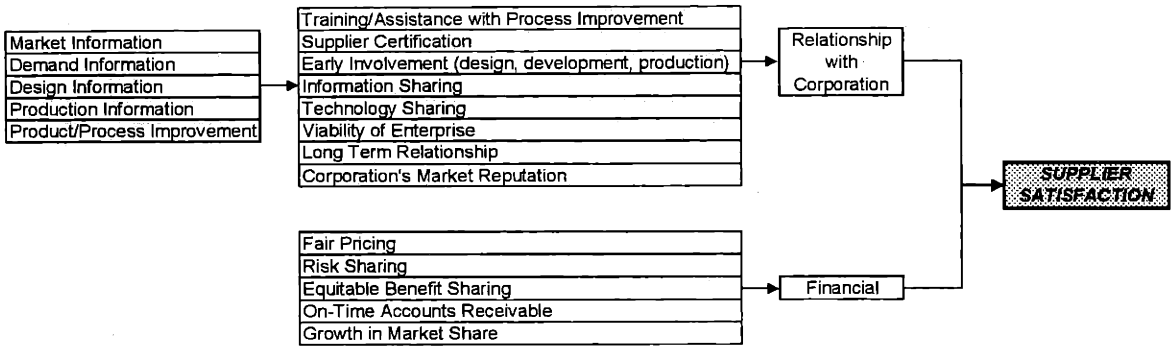


Figure B.2 - Supplier satisfaction value taxonomy.

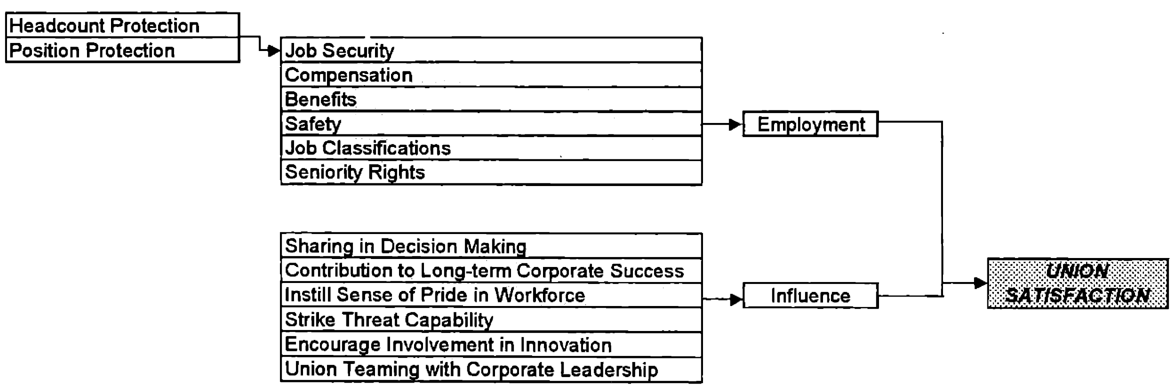


Figure B.3 - Union satisfaction value taxonomy.

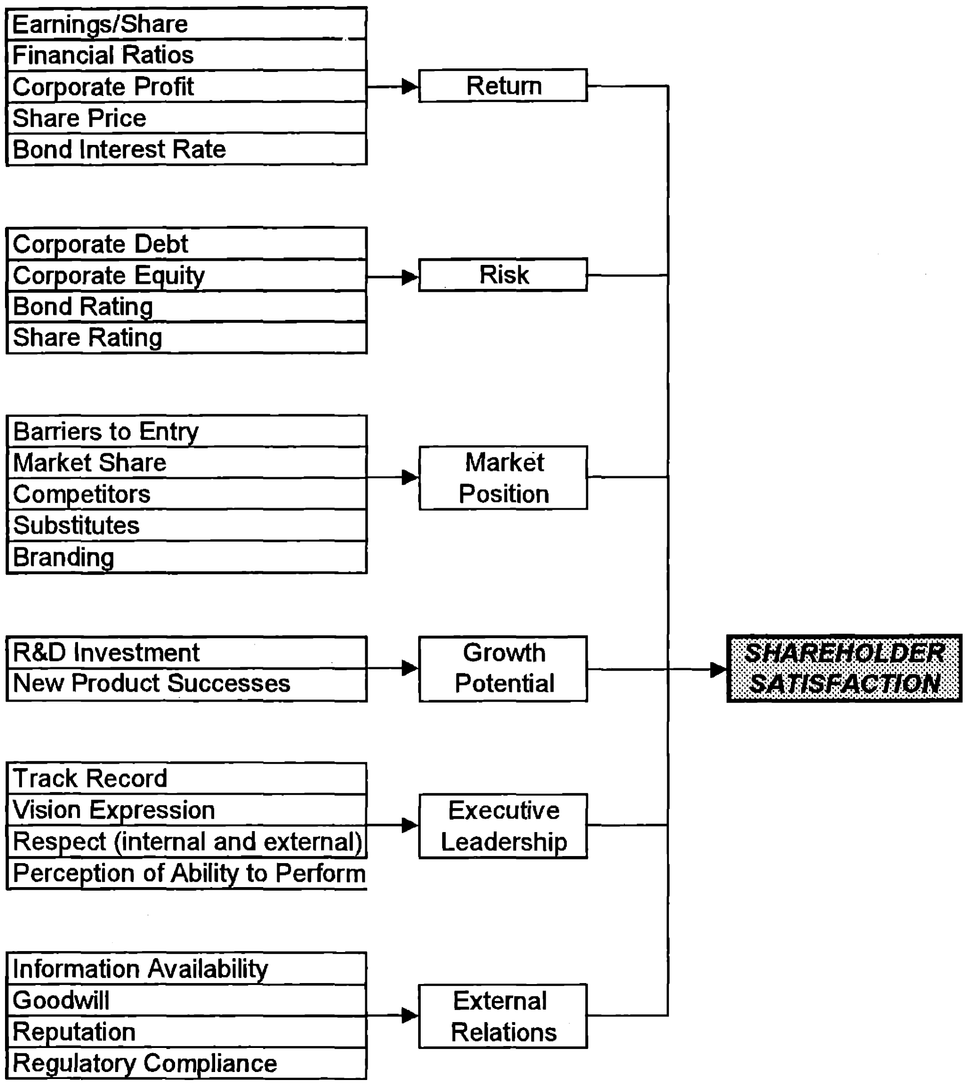


Figure B.4 - Shareholder satisfaction value taxonomy.

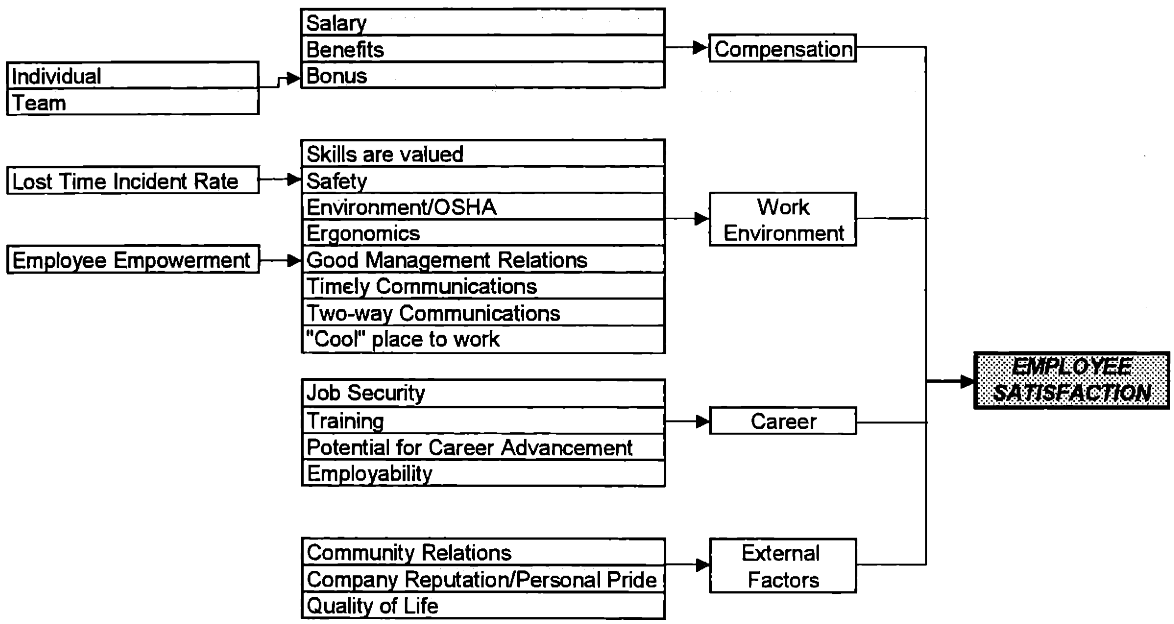


Figure B.6 - Employee satisfaction value taxonomy.

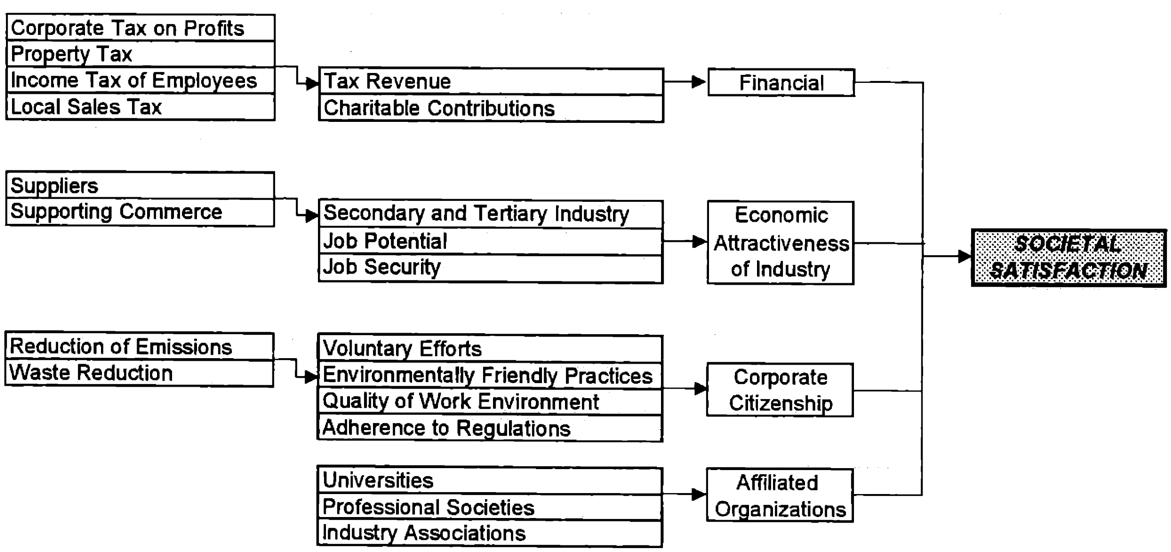


Figure B.7 - Societal satisfaction value taxonomy.

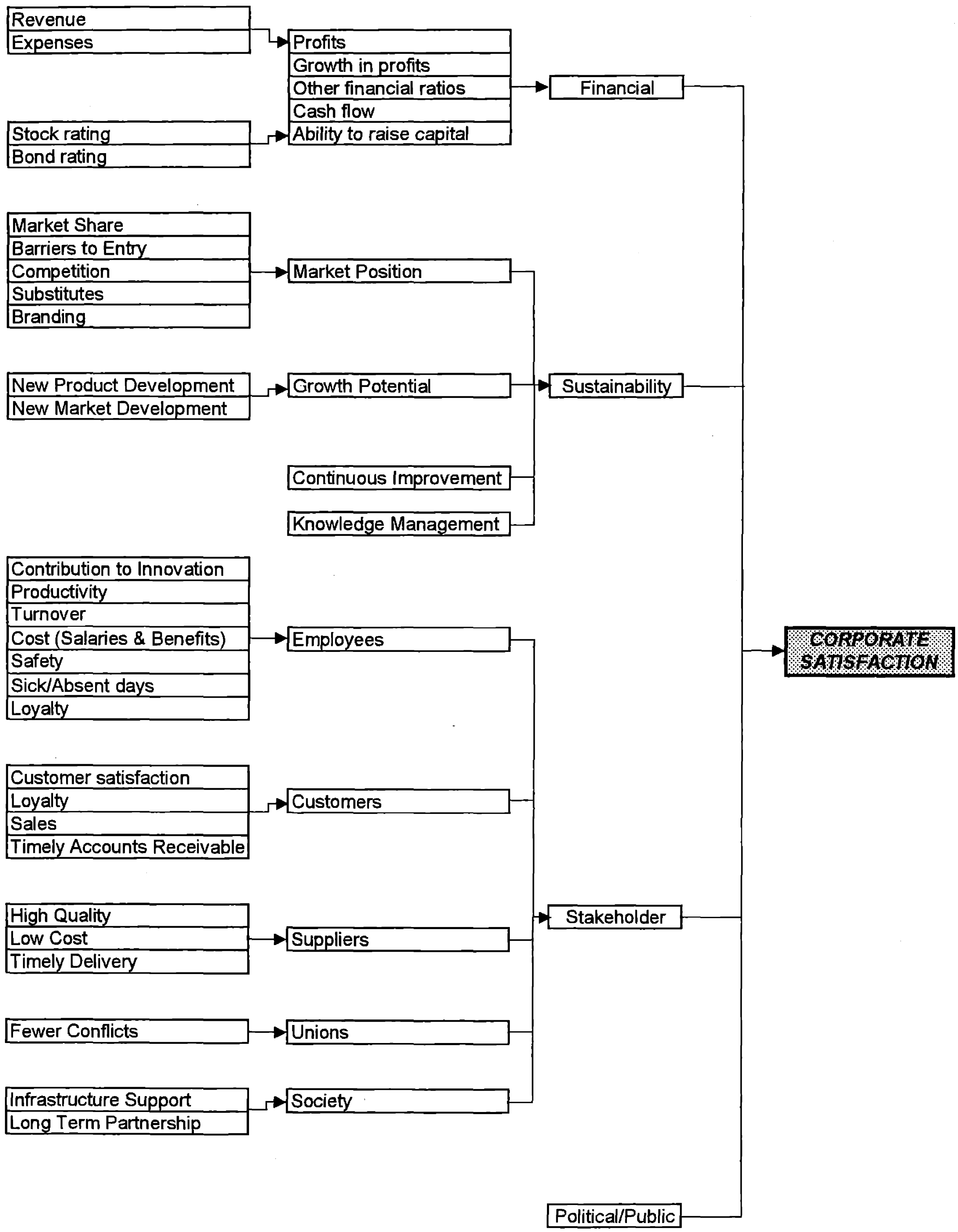


Figure B.8 - Corporate satisfaction value taxonomy.

Appendix C - Lean Enterprise Self-Assessment Tool (LESAT)

The following pages contain copies of the actual LESAT assessment sheets used by the enterprises involved in the research discussed in this thesis. These are provided for reference to researchers who may not have access to the same version of the LESAT at some point in the future.

- This page intentionally left blank -

SECTION I: LEAN TRANSFORMATION/LEADERSHIP

Definition: Develop, deploy, and manage lean implementation plans throughout the enterprise, leading to: (1)- long-term sustainability, (2)- acquiring competitive advantage, and (3)- satisfaction of stakeholders; along with a continuous improvement in all three parameters.

I.A. Enterprise Strategic Planning - the decision to pursue a lean transformation is strategic in nature. Its impact throughout the enterprise is profound and pervasive, affecting all business practices and processes. The lean enterprise will behave in a fundamentally new manner, significantly eliminating waste and enhancing relationships with all stakeholders.

Diagnostic Questions

- **Are enterprise leaders familiar with the dramatic increases in competitiveness that many companies have realized as a result of transitioning to lean?**
- **Are enterprise leaders fully aware of the potential opportunities (i.e. greater growth, profitability and market penetration) that can be realized within their own organization as a result of transitioning to lean?**
- **Has a suitable strategy for growth been identified to utilize resources freed up by improvements?**
- **Does "customer value" strongly influence the strategic direction?**
- **Has full leverage of the extended enterprise stakeholders been incorporated into the strategic plan?**

LP #	Lean Practices	Capability Levels: *Level 1*	*Level 2*	*Level 3*	*Level 4*	*Level 5*
I.A.1.	**Integration of Lean in Strategic Planning Process** *Lean impacts growth, profitability and market penetration*	Concepts and benefits of lean principles and practices are not evident in culture or business plans. C D	Lean is recognized, but relegated to lower levels of the enterprise and application is fragmented. C D	The growth implications of lean are understood and lean implementation plans are formulated, but not integrated into the strategic plan. C D	Transitioning to lean is adopted as a key enterprise strategy and included in the strategic plan. C D	Strategic plans leverage the results of lean implementation to achieve growth, profitability and market position. C D
	Lean Indicators (Examples)	• Lean implementation is included explicitly in the enterprise strategic plan. • Strategic planning makes allowance for anticipated gains from lean improvements.				
	Evidence					
	Opportunities					
I.A.2.	**Focus on Customer Value** *Customers pull value from enterprise value stream*	Means of defining value to customer(s) is informal and unstructured. C D	Structured process for defining value is applied to selected customers. C D	How the enterprise can best contribute to customer's success is well defined and incorporated into most projects/programs. C D	Customer definition of value strongly influences the strategic direction. C D	Competitiveness is enhanced, as customer value becomes the predominant driving force throughout the extended enterprise. C D
	Lean Indicators (Examples)	• Enterprise employs a formal process for determining customer value. • The enterprise understands what constitutes success for its customers. • A formal process exists to measure and assess customer satisfaction. • Customer value strongly influences policies, practices and behavior.				
	Evidence					
	Opportunities					

LP #	Lean Practices	Capability Levels				
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Level 5*
I.A.3.	**Leveraging the Extended Enterprise** *Value stream extends from customer through the enterprise to suppliers*	Relations with customers and suppliers reflect a "We-They" mentality. C | D	Initial opportunities identified for establishing extended enterprise linkages. C | D	Strategic planning process explicitly includes consideration of key stakeholders in value streams. C | D	Integration and balancing of stakeholder values are achieved via collaborative supplier relations and strategic partnering. C | D	Integration of the extended enterprise contributes to innovation, growth, increased profitability and market position. C | D
	Lean Indicators (Examples)	• Strategic planning is strongly influenced by stakeholder and customer value. • Strategic planning encompasses the total enterprise, including customer, alliances/partners, employees and suppliers. • Risk and responsibilities are apportioned when leveraging the extended enterprise suppliers and partners.				
	Evidence					
	Opportunities					

I.B. Adopt Lean Paradigm - Transitioning to lean requires a significant modification to the business model of the enterprise. It is imperative that the enterprise leadership understands and buys into the lean paradigm since they will be required to create a vision for doing business, behaving and seeing value in fundamentally different ways.

Diagnostic Questions

- **Do enterprise leaders and senior managers understand the lean paradigm at the enterprise level?**
- **Do all senior leaders and management enthusiastically support a transformation to lean?**
- **Has a common vision of lean been communicated throughout the enterprise and within the extended enterprise?**
- **Has a compelling case been developed for the Lean transformation?**

LP #	Lean PRACTICES	Capability Levels: *Level 1*	*Level 2*	*Level 3*	*Level 4*	*Level 5*
I.B.1.	**Learning and Education in "Lean" for Enterprise Leadership** *"Unlearning" the old, learning the new*	Little interest in learning lean principles is evident among enterprise leadership. C D	Leaders are actively seeking opportunities to learn about lean. There is an initial grasp of the extent of the paradigm shift for the enterprise. C D	The leaders are adopting lean learning and continuously applying lean principles across the enterprise. C D	Leaders contribute to the development / refinement of the body of knowledge about lean. C D	Lessons learned in implementing lean are actively shared across the organization and within the extended enterprise. C D
	Lean Indicators (Examples)	• A formal lean education process for senior leaders has been established. • Majority of enterprise leaders have received significant exposure and education in lean principles, practices and behavior. • Leaders regularly apply and use lessons learned in "lean".				
	Evidence					
	Opportunities					
I.B.2.	**Senior Management Commitment** *Senior management leading it personally*	Level of commitment among senior leaders and management is variable – some endorse while others may actively resist. C D	Senior management buys into group commitment; senior leaders / managers who cannot or will not adapt are replaced. C D	"Lean" is integral to enterprise-wide meetings, senior staff meetings, etc.; senior managers personally and visibly lead lean transition. C D	Senior leaders are championing the transformation to lean within the enterprise. C D	Senior leaders and management mentor and foster lean champions internally and through the extended enterprise. C D
	Lean Indicators (Examples)	• There is a consensus commitment supporting a transformation to lean. • Management provides support and recognition for positive actions • Senior management are champions in transforming the enterprise.				
	Evidence					
	Opportunities					

LP #	Lean Practices	Capability Levels				
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Level 5*
I.B.3.	**Lean Enterprise Vision** *New mental model of the enterprise*	Senior leaders have varying visions of lean, from none to well-defined. C | D	Senior leaders adopt common vision of lean. C | D	Lean vision has been communicated and is understood by most employees. C | D	Common vision of lean is shared by the extended enterprise. C | D	Stakeholders have internalized the lean vision and are an active part of achieving it. C | D
	Lean Indicators (Examples)	• The role that lean plays in achieving the vision is clearly defined. • The vision has been communicated to all levels and has extensive buy-in by most employees. • The vision incorporates a new mental model of how the company would act and behave according to lean principles and practices.				
	Evidence					
	Opportunities					
I.B.4.	**A Sense of Urgency** *The primary driving force for Lean*	Scan of environment identifies competitive threats and need for action. C | D	Enterprise senior leaders develop an urgent and compelling case for the lean transformation. C | D	Urgent and compelling case for lean transformation has been communicated and the organization rallies behind it. C | D	Urgent and compelling case for lean is expanded to and accepted by key suppliers. C | D	Urgent and compelling case for lean is expanded to and accepted throughout the extended enterprise. C | D
	Lean Indicators (Examples)	• A compelling business case for lean has been developed and communicated. • The implications and time scales of the vision have been translated for each area of the enterprise. • Lean transformation progress is integral to leadership discussions and events.				
	Evidence					
	Opportunities					

I.C. Focus on the Value Stream - Value creation with minimal waste becomes the primary driving force of the enterprise. The current means of delivering customer value are documented, followed by improving the value stream by minimizing waste. Lean metrics are specified and stakeholder involvement clarified.

Diagnostic Questions

- **Is a formal process utilized to explicitly determine "value to the customer"?**
- **Have the value streams of all stakeholders been mapped, integrated and balanced?**
- **Does the enterprise understand how material and information flow throughout the various elements of the enterprise?**
- **Are enabling infrastructure processes being aligned to value stream flow?**
- **Does the enterprise understand clearly how it currently delivers value to customers?**
- **Has a system of balanced performance measures been established that reflect progress towards strategic business objectives?**

LP #	Lean Practices	Capability Levels: *Level 1*	*Level 2*	*Level 3*	*Level 4*	*Level 5*
I.C.1.	**Understanding the Current Value Stream** *How we now deliver value to customers*	The documented process flow differs from the actual flow. There is an initial understanding of the need for formal mapping and analysis. C / D	Key stakeholders and what they value are identified. Present processes are mapped and initial analysis is underway. C / D	Principal current value stream(s) are defined, allowing the identification of critical interactions. Significant opportunities for eliminating waste and creating value are identified and aligned with the strategic objectives. C / D	Depth and breadth of knowledge of value stream elements and supporting processes exposes interdependencies across the enterprise. C / D	Updated value streams and their independencies are evaluated across the extended enterprise. C / D
	Lean Indicators (Examples)	• A formal process has been established for identifying customer and stakeholder value. • The practice and language of value stream mapping is recognized as an important part of an iterative improvement process. • Current value streams of major customers/product lines have been mapped, and hand off points and interfaces clearly defined.				
	Evidence					
	Opportunities					
I.C.2.	**Enterprise Flow** *"Single piece flow" of materials and information*	Material and information flows are disjointed and "optimized" process by process. "Push" mentality prevails. C / D	Some primary flow paths have been overhauled to overcome significant barriers to flow. C / D	Primary flow paths are simplified and aligned to the value stream(s), which allows information and material to flow as required. C / D	Material and information flow seamlessly throughout the enterprise. C / D	Material and information flow seamlessly and responsively throughout the extended enterprise. C / D
	Lean Indicators (Examples)	• Information flows have been rationalized to assure interoperability among enterprise elements. • Material flow paths have been simplified and shortened to enhance flow. • Information and material flows are responsive to stakeholder needs.				
	Evidence					
	Opportunities					

LP #	Lean Practices	Capability Levels				
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Level 5*
I.C.3.	**Designing the Future Value Stream** *Value stream to meet the enterprise vision*	Management understands that the present processes do not meet the future lean enterprise objectives. C D	A concept for future value stream(s) design has been created based on balanced stakeholder requirements. C D	Future value stream(s) are developed, which encompass future enterprise goals and satisfy stakeholder requirements. C D	Future value stream(s) are refined to accommodate a changing environment. C D	Future value stream(s) are refined to dynamically accommodate a changing environment across the extended enterprise. C D
	Lean Indicators (Examples)	• A formal process has been established to identify how the enterprise can best deliver value to customers and stakeholders. • The future value stream(s) reflects new and improved ways to realize value and minimize non-value adding activities. • Future value stream(s) designs have been generated for the primary value stream(s) and their supporting processes.				
	Evidence					
	Opportunities					
I.C.4.	**Performance Measures** *Performance measures drive enterprise behavior*	Performance measures are ad hoc, inconsistent and focused on functional areas rather than value streams. C D	Baseline performance measures are established to stimulate progress towards the lean future state and are visible throughout the enterprise. C D	Performance measurement system uses a minimal and balanced set of measures based on strategic objectives and aligning local with enterprise metrics. C D	Measurement systems and target setting pulls performance improvement throughout the enterprise. C D	A common target setting and measurement process pulls performance improvement across the extended enterprise. C D
	Lean Indicators (Examples)	• A balanced and minimal set of performance measures are used to track lean implementation progress towards the strategic direction. • Performance measures used assure that local and enterprise measures are aligned.				
	Evidence					
	Opportunities					

I.D. Develop Lean Structure and Behavior - Organization infrastructure must be assessed and modified prior to launching a lean initiative as well as throughout the transformation. Organizational structure, incentives, policies, business systems and processes must be aligned and coordinated to elicit the behavior required for successful implementation of lean principles and practices.

Diagnostic Questions

- **Has an organizational structure been implemented that focuses on core processes along the customer value stream?**
- **Is organizational structure designed for flexibility and responsiveness to changes in the external environment?**
- **Are relationships with stakeholders based on mutual respect and trust?**
- **Have policies and procedures been revised to promote and encourage lean behavior?**
- **Have incentives been developed which are consistent with the behavior desired?**
- **Has decision-making been delegated to the lowest practical level?**
- **Is prudent risk taking encouraged?**
- **Are lean change agents positioned and empowered to provide guidance and leadership for the lean transformation?**

LP #	Lean Practices	Capability Levels: *Level 1*	*Level 2*	*Level 3*	*Level 4*	*Level 5*
I.D.1.	**Enterprise Organizational Orientation** *Organize to support value delivery*	The enterprise operates as functional silos. C | D	Initial efforts are underway to identify functional barriers and understand their full implications. C | D	Partially deployed cross-functional organizational processes are aligned with enterprise value stream(s). C | D	Extensive cross-functional processes are implemented across the enterprise. Functional units now serve as knowledge centers for skill retention. C | D	Cross-functional, process-based orientation is aligned across the extended enterprise. C | D
	Lean Indicators (Examples)	• Functional barriers have been minimized. • There is extensive use of cross-functional processes across the enterprise. • Career progression potential exists across both processes and functions.				
	Evidence					
	Opportunities					
I.D.2.	**Relationships Based on Mutual Trust** *"Win-win" vs. "we-they"*	Relationships tend to be determined by organizational role, resulting in a "we-they" perspective. C | D	Selective application of enterprise perspective results in breaking down of organizational barriers and developing mutual trust. C | D	Stable and cooperative relationships exist across the enterprise; cooperative relations are established with some enterprise partners. C | D	Mutual respect and trust exists across the extended enterprise with equitable sharing of benefits from continuous improvement initiatives. C | D	Stakeholders modify behavior so as to enhance extended enterprise performance (win-win). C | D
	Lean Indicators (Examples)	• Communication barriers based upon organizational position have been significantly reduced. • Stable and cooperative relationships exist among most enterprise stakeholders.				
	Evidence					
	Opportunities					

LP #	Lean Practices	Capability Levels				
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Level 5*
I.D.3.	**Open and Timely Communications** *Information exchanged when required*	Communication is largely top-down, limited and lagging. C / D	Basic communication mechanisms are employed but are not uniform; communication strategy is under development. C / D	Enterprise leaders are accessible and visible, developing two-way communications in open, concise and timely form. C / D	Communication processes are undergoing continuous refinement and information is exchanged or can be pulled as required. C / D	Comprehensive system of two-way communication is employed throughout the extended enterprise. C / D
	Lean Indicators (Examples)	• Open and timely communications exist among stakeholders, i.e. regular meetings with employees, newsletters, etc. • Technology has been leveraged to speed communications flow and accessibility, while filtering unnecessary communications. • Employee input is valued and plays a key part in decision-making.				
	Evidence					
	Opportunities					
I.D.4.	**Employee Empowerment** *Decision-making at lowest possible level*	Centralized decision-making occurs in a hierarchical structure with limited delegation of authority. C / D	Appropriate structure and training is being put in place to enable empowerment. C / D	Organizational environment and management system supports limited decision-making at point of application and need. C / D	Decision processes are continually refined to promote increased accountability and ownership at point of use. C / D	Decision-making across the extended enterprise is delegated to the point of application. C / D
	Lean Indicators (Examples)	• Managers and supervisors serve as mentors and educators, promoting lower level decision-making. • The extent and types of empowerment are tailored to match the environment and people empowered. • Empowerment enables swift and effective decision-making closest to the point of use.				
	Evidence					
	Opportunities					
I.D.5.	**Incentive Alignment** *Reward the behavior you want*	There is sporadic use of incentives and an awareness that some incentives discourage lean behavior. C / D	Incentives that reward and encourage lean behavior are deployed in some areas. C / D	Executive compensation and employee incentives are linked directly to attainment of lean objectives. C / D	Incentive systems successfully contribute to achievement and sustainability of lean objectives. C / D	Lean incentives are deployed, with measurable success across the extended enterprise. C / D
	Lean Indicators (Examples)	• Incentives include a balance of money and non-monetary rewards / recognition to encourage lean activity. • Incentives are based on performance measures that encourage lean activity. • Incentives encourage local improvements that will benefit multiple processes or value steam performance.				
	Evidence					
	Opportunities					

LP #	Lean Practices	Capability Levels				
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Level 5*
I.D.6.	**Innovation Encouragement** *From risk aversion to risk rewarding*	Innovation initiatives are sporadic and ad hoc; security, stability and risk aversion drive most decision-making. C D	Initial efforts are underway to develop systems, processes and procedures for fostering innovations. C D	Innovation initiatives are underway in selected areas; measures for assessing impact are in use. C D	Innovation initiatives are flourishing across the enterprise; prudent risk taking is encouraged and rewarded. C D	Comprehensive innovation program is implemented and positive results recognized across the extended enterprise. C D
	Lean Indicators (Examples)	• The review process for suggestions has been streamlined and gives clear visibility of the progress of each suggestion. • Suggestion programs have been properly incentivized to give recognition to originators of innovative ideas.				
	Evidence					
	Opportunities					
I.D.7.	**Lean Change Agents** *The inspiration and drivers of change*	Change agents are sporadically distributed, but without change authority. C D	There is formal identification of change agents, along with role definition, authority delegation and program of education and training for change agents. C D	Appropriately skilled change agents are assigned to key areas with the authority to effect changes. C D	Change becomes self-generating, initiated by employees as well as change agents. C D	Change agents are providing a critical resource of lean knowledge, skill and experience in transforming the extended enterprise. C D
	Lean Indicators (Examples)	• Lean change agents have been designated and empowered. • Lean change agents operate throughout all areas and cross-transfer lean implementation experience. • Process for developing "lean masters" and other change agents has been established.				
	Evidence					
	Opportunities					

I.E. Create and Refine Transformation Plan - Identify, prioritize and sequence a comprehensive set of lean initiatives that collectively constitute the plan for achieving the desired transformation.

Diagnostic Questions

- **Is the enterprise level lean transformation plan prioritized and aligned with strategic business objectives?**
- **Have adequate resources been provided to facilitate lean transformation?**
- **Does the current education and training program adequately support the strategic direction(s) and lean transformation?**
- **Have lessons learned and best practice been effectively incorporated within lean transformation planning?**

LP #	Lean Practices	Capability Levels: *Level 1*	*Level 2*	*Level 3*	*Level 4*	*Level 5*
I.E.1.	**Enterprise-Level Lean Transformation Plan** *Charting the course across the extended enterprise*	Individual planning efforts are mostly bottom up initiatives with little priority or coordination established at enterprise level. **C D**	Enterprise-level view identifies lean implementation projects, which are prioritized to meet long and short-term strategic objectives. **C D**	Enterprise improvement plans are coordinated and prioritized across enterprise value stream(s), with a timeline for expected measurable results. **C D**	Lean transformation plan is continuously refined through learning from implementation results and changing strategic requirements. **C D**	Lean transformation plan balances mutual benefits of stakeholders across the extended enterprise. **C D**
	Lean Indicators (Examples)	• A process is in place to incorporate lessons learned into the enterprise-level lean transformation plan. • The milestone targets of the lean transformation plan are broken-down by section and deployed across the enterprise. • Plans balance long-term and short-term stakeholder objectives for the best overall solution.				
	Evidence					
	Opportunities					
I.E.2.	**Commit Resources for Lean Improvements** *Resource provision for lean*	Little or no resources are provided for process improvement or waste elimination. **C D**	Limited enterprise-level resources are committed and often applied to the symptom rather than the root cause. **C D**	Resources are allocated as required for execution of the lean transformation plan and prioritized across the value stream. **C D**	A pool of earmarked resources is provided for lean initiatives with minimal justification required. **C D**	A pool of earmarked resources is provided for lean initiatives across the extended enterprise. **C D**
	Lean Indicators (Examples)	• Resources are committed to support the level and speed of lean transformation required. • Time to build on improvements by personal contribution is given at all levels. • The procedure to apply for improvement resources has been simplified, and gives priority to improvements that benefit multiple areas.				
	Evidence					
	Opportunities					

LP #	Lean Practices	Capability Levels				
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Level 5*
I.E.3.	**Provide Education and Training** *Just-in-time learning*	There is little coordination of education and training programs to facilitate change. C D	Education and training covers a set of skills required to support the lean transformation projects. C D	Education and training program is comprised of a balanced and sequenced set of elements to support the coordinated transformation plan. C D	Education and training at all levels is periodically reviewed to check alignment and suitability to the lean transformation plan. C D	Education and training program supports the upcoming needs of the extended enterprise transformation plan. C D
	Lean Indicators (Examples)	• Education and training programs, including refreshers, are provided on a just-in-time basis. • Education and training has a balanced and sequenced set of elements to support the lean transformation plan. • The application of lean principles learned in training and education is formally appraised.				
	Evidence					
	Opportunities					

I.F. Implement Lean Initiatives - Flow down the enterprise-level plan into specific actions, programs and projects that are executed within each process organizational area and determine how they are integrated at the enterprise level.

Diagnostic Questions

- **Has the enterprise level lean transformation plan been translated into detailed execution projects?**
- **Has a uniform system been established to track the progress of lean initiatives with respect to the overall plan?**
- **Do lean initiative plans contain a feedback mechanism for revision and to share lessons learned?**

LP #	Lean Practices	Capability Levels				
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Level 5*
I.F.1.	**Development of Detailed Plans Based on Enterprise Plan** *Coordinating lean improvements*	Improvements are generally optimized for individual areas and employees cannot clearly see the links between localized and enterprise goals. C D	Key goals of the enterprise lean transformation plan are understood by most employees. Process owners are involved in developing detailed plans linked to the goals/strategic objectives of the enterprise plan. C D	Detailed lean implementation plans supporting the enterprise level plan are developed and coordinated across processes. C D	Detailed lean implementation plans accounting for any interdependencies are refined and integrated across the enterprise. Best practices are shared. C D	Implementation plans from extended enterprise are coordinated with and support the lean transformation plan. C D
	Lean Indicators (Examples)	• Detailed implementation plans are aligned to milestone targets of the enterprise-level plan. • A process is in place to incorporate lessons learned in detailed implementation plans. • Detailed improvement plans are coordinated throughout the enterprise where shared implications exist.				
	Evidence					
	Opportunities					
I.F.2.	**Tracking Detailed Implementation** *Assessing actual outcomes against goals*	Results of process improvement initiatives are observed but not quantified. C D	Process is under development to permit tracking and quantification of progress of the detailed lean implementation. Data from some projects is being reviewed. C D	There is a project management process implemented to track progress of detailed lean projects against milestones, with feedback provided to enterprise level. Appropriate corrective action is initiated within individual projects. C D	The project management process can readily assess detailed plans and can accommodate revisions mandated by changes to the enterprise level lean transformation plan. C D	The project management process is deployed across the extended enterprise to enable real-time tracking. C D
	Lean Indicators (Examples)	• Lean initiatives are coordinated and tracked, with the individual results "rolled up" and assessed against enterprise level milestones and targets. • The responsibility and accountability for improvement success is assigned locally to enable fast corrective action on deviations from the plan. • Changes to processes / value stream map(s) are documented and updated regularly.				
	Evidence					
	Opportunities					

I.G. Focus on Continuous Improvement - Successful execution of lean implementation plan forms the basis for further improvement. The improvement process is monitored and nurtured, lessons learned are captured, and improved performance becomes a strong driving force for future strategic planning by enterprise executives.

Diagnostic Questions

- **Are guidelines for continuous improvement sufficiently developed for effective facilitation of enterprise-wide transformation plans?**
- **Are enterprise participants being challenged to build-on and sustain existing improvements?**
- **Are senior managers actively involved in monitoring progress of lean implementation at all levels?**
- **Is appropriate support and encouragement being provided to all participants in lean implementation?**
- **Are lessons learned being captured in a consistent, systematic manner?**
- **Are lean implementation results impacting strategic planning?**

LP #	Lean Practices	Capability Levels: *Level 1*	*Level 2*	*Level 3*	*Level 4*	*Level 5*
I.G.1.	**Structured Continuous Improvement Processes** *Uniformity in how we get better*	Improvement initiatives are ad hoc and not data driven. C / D	An improvement process for the enterprise is broadly defined and being selectively applied. C / D	Systematic, structured methodology for continuous improvement and value creation is developed and deployed across many areas. C / D	Structured continuous improvement process is deployed at all levels across the enterprise, using value analysis to target improvements. C / D	Structured continuous improvement process is fully ingrained throughout the extended enterprise. C / D
	Lean Indicators (Examples)	• A consistent improvement/transformation approach is implemented, sustaining improvements gained. • The continuous improvement process challenges people to tackle the root cause, rather than the symptom. • Lean principles are being applied to most enterprise systems and processes, utilizing lessons learned.				
	Evidence					
	Opportunities					
I.G.2.	**Monitoring Lean Progress** *Assessing progress toward achieving enterprise objectives*	Enterprise leaders are not actively involved in the review of overall lean implementation plan progress. C / D	Implementation plan progress is reviewed against enterprise level milestones and success criteria, for some projects. C / D	A formal methodology is used by enterprise leaders to analyze the overall progress across all lean implementation projects. Current plans are adjusted based on learning from lean implementations. C / D	Results of implementation projects are aggregated to permit reallocation of resources and to ensure on-going alignment with strategic objectives. C / D	Senior managers monitor lean progress throughout the extended enterprise. Results are impacting future enterprise strategic planning. C / D
	Lean Indicators (Examples)	• Lean transformation progress is judged by the aggregate benefits, not individual or localized improvements. • Leaders actively participate in monitoring implementation progress and addressing deficiencies within the transformation plan. • Lean progress reviews are documented in a common format and disseminated.				
	Evidence					
	Opportunities					

LP #	Lean Practices	Capability Levels				
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Level 5*
I.G.3.	**Nurturing the Process** *Assure executive level involvement*	There is growing awareness that successful lean implementation is highly dependent upon senior management support and encouragement. C D	Some senior managers are providing encouragement, support and recognition, which is not consistent across the enterprise. C D	Managers seek to identify and remove barriers to lean implementation. Teams and individuals who successfully implement lean practices are recognized and rewarded. C D	Senior managers across the entire enterprise are highly visible in their involvement, support and encouragement of the lean initiative. An enthusiastic atmosphere is evident. C D	Senior executives and managers champion and nurture a culture of continuous improvement in the extended enterprise. C D
	Lean Indicators (Examples)	• Management actively supports and is involved in ensuring the success of improvements. • Positive actions and the effort taken are recognized and rewarded, even if improvements are not fully successful.				
	Evidence					
	Opportunities					
I.G.4.	**Capturing Lessons Learned** *Ensuring that successes lead to more successes*	Lessons learned from improvement activities are not documented, residing only in the memories of participants. C D	Lessons learned in some areas are documented and maintained in paper files, design rulebooks, etc. C D	A formal process for readily capturing and communicating lessons learned is being applied. Employee contributions are actively sought. C D	Lessons learned are consistently captured, communicated and regularly used in a structured manner. An enterprise knowledge base is created. C D	A formal knowledge management process is adopted. Lessons learned are routinely and explicitly incorporated into the formulation of new lean initiatives. C D
	Lean Indicators (Examples)	• "Best" practice, suggestions and lessons learned are maintained in a concise and clear standard format. • A formal process has been established throughout the enterprise for capturing and reusing lessons learned. • Lessons learned are periodically reviewed to maintain relevance of information kept.				
	Evidence					
	Opportunities					
I.G.5.	**Impacting Enterprise Strategic Planning** *Results lead to strategic opportunities*	Results of lean implementation are not fed back to strategic planning process. C D	Benefits of lean implementation are beginning to influence the strategic planning process. C D	Executive management considers potential impact of performance improvement initiatives in its assessment of new business opportunities. C D	Forecasted improvements from lean implementation are incorporated into enterprise planning and budgeting decisions. C D	Executive management integrates forecasted future results of lean implementation in its assessment of new business opportunities and potential market impact. C D
	Lean Indicators (Examples)	• Business results reflect improvements resulting from lean implementation. • Strategic planning makes allowance for anticipated gains from lean improvements. • Gains realized from lean implementation are leveraged to achieve growth, profitability, market position and employment stability.				
	Evidence					
	Opportunities					

SECTION II – LIFE-CYCLE PROCESSES

Definition: Implement lean practices across life-cycle processes for defining customer requirements, designing products and processes, managing supply chains, producing the product, distributing product and services, and providing post delivery support.

II.A. Business Acquisition and Program Management – To be successful in the globally competitive environment of the twenty-first century, enterprises must develop and manage partnerships with their customers and be able to dynamically re-configure and align core competencies among suppliers, the enterprise and its partners in order to deliver best life cycle value to customers.

Diagnostic Questions

- **Are new business opportunities arising from lean enabled capabilities being fully exploited?**
- **Does customer feedback and usage data drive new business process development?**
- **Are assets allocated across the value stream in a consistent and balanced manner?**
- **Are program risks and resource requirements balanced to assure optimal flow throughout the product life cycle?**
- **Are skills and resources drawn from across the extended enterprise to enhance program development efforts?**

LP #	Lean Practices	Capability Levels: *Level 1*	*Level 2*	*Level 3*	*Level 4*	*Level 5*
II.A.1	**Leverage Lean Capability for Business Growth** *Exploiting new business opportunities arising from lean enabled capabilities*	Business improvement initiatives are ad hoc and are focused on operational efficiency. C D	Improvement gains provide resources to facilitate future improvements. Potential business opportunities from applying lean thinking across core competences are recognized and plans have been developed. C D	Benefits sustained from applying lean thinking within the enterprise are used to retain current business and/or win new business. C D	There is full use of the enhanced capabilities and customer knowledge throughout the enterprise to leverage opportunities for competitive advantage. C D	The strategic plan dynamically incorporates extended enterprise capabilities and stakeholder interests to identify and leverage opportunities. C D
	Lean Indicators (Examples)	• Reduced cost, increased quality and faster response times from waste eliminated are used to maintain or win new business. • The ability to improve and refine processes quickly is used extensively to respond to changing customer requirements. • A process is used to scan the competitive environment to exploit opportunities arising from the enhanced capabilities of the lean enterprise.				
	Evidence					
	Opportunities					
II.A.2.	**Optimize the Capability and Utilization of Assets (People, equipment, facilities, etc.)** *Lean enables business growth through the redeployment of assets*	Utilization of people and material assets is optimized within functional units. C D	There is evidence of ad hoc cooperation between functional units to eliminate waste and share resources. C D	An enterprise approach provides consistent and balanced asset allocation across the value stream. C D	As a result of the application of lean concepts and techniques, assets are freed up to be applied across the enterprise to support current or growth activities. C D	The ability exists to easily and quickly shift or divest resources to new opportunities. C D
	Lean Indicators (Examples)	• Assets freed up from lean implementation are readily redeployed. • Workforce and its knowledge is nurtured, reallocated and maintained where possible. • Available assets and resources are coordinated throughout the enterprise to leverage resources to the maximum.				
	Evidence					
	Opportunities					

LP #	Lean Practices	Capability Levels				
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Level 5*
II.A.3.	**Provide Capability to Manage Risk, Cost, Schedule and Performance** *Success follows effective risk management*	Programs are managed and staffed as independent entities. C | D	There is a management system to monitor and control program performance and staffing. Regular reviews focus on cost, schedule and performance of individual programs. C | D	Program reviews assess risk within individual programs and staffing is adjusted as necessary to mitigate risk. C | D	The programs are reviewed assessing the risk across the portfolio of programs with appropriate reallocation of resources. C | D	Risk abatement processes are used to optimize performance of the portfolio of programs. C | D
	Lean Indicators (Examples)	• Programs and process reviews have a portfolio approach to achieve enterprise balance. • A risk management process is fully integrated across the enterprise.				
	Evidence					
	Opportunities					
II.A.4	**Allocate Resources for Program Development Efforts** *Teaming for success*	Program development efforts rely on functional units for allocation of the required skills. C | D	Some but not all skills / resources necessary are dedicated and assigned to program development. Skilled resources are narrowly guarded within programs. C | D	Some of the skilled resources are routinely shared across programs. Formal methods are being developed for determining team makeup and assignment of necessary skills. C | D	Resources and skills are routinely balanced and shared across the portfolio of programs. C | D	"Virtual organizations" are created as needed from the extended enterprise and provided with the skills and resources necessary to execute the development effort(s). C | D
	Lean Indicators (Examples)	• A process is defined and used to ensure that cross-disciplinary skills are represented on teams. • Resources and skills are easily and quickly shifted or divested to balance requirements across all program development efforts.				
	Evidence					
	Opportunities					

II.B. Requirements Definition – Customer needs and values must be assessed continuously and translated into requirement statements that form the basis for product and process design.

Diagnostic Questions

- **Are the customer's needs continually evaluated in determining product and process requirements?**
- **Is a data collection and customer feedback process defined and deployed?**
- **Is product life-cycle data used in determining requirements and subsequent specifications?**
- **Are product and process capability data matched to design criteria?**

LP #	Lean Practices	Capability Levels: *Level 1*	*Level 2*	*Level 3*	*Level 4*	*Level 5*
II.B.1	**Establish a Requirement Definition Process to Optimize Lifecycle Value** *Stakeholder pull vs. technology/product push*	Requirements are defined internally based on past experience, rather than on a formal requirements definition process. C / D	Requirements definition process, which balances cost, schedule and performance, is partially developed, deployed and documented. C / D	Requirements definition process leverages value chain capabilities and focuses on overall life cycle implications. C / D	An iterative requirements definition process spans the value chain resulting in a minimal set of requirements that balances cost and performance. C / D	The requirements process is a strategic advantage for the extended enterprise contributing to increased responsiveness and new business opportunities. C / D
	Lean Indicators (Examples)	• There is a process in place to determine clear and concise product and life cycle requirements, with acceptable ranges. • The process ensures a balanced representation from all disciplines across the value chain. • Structured methods are used to elicit and gather needs from the different stakeholders/customers.				
	Evidence					
	Opportunities					
II.B.2	**Utilize Data from the Extended Enterprise to Optimize Future Requirement Definitions** *Closed loop processes are in place to capture operational performance data*	Warranty claims and deficiency reports represent the primary source of data that is collected and analyzed for impacts to present requirements. C / D	A proactive process is being developed to collect product usage data as the basis for future requirements. C / D	Data are collected on usage, maintenance, disposal and future needs from across the present value chain and fed into future design solutions and requirement definitions. C / D	Process allows real-time access, collection and dissemination of data from across the extended enterprise for analysis by stakeholders for future use. C / D	The process is established across the extended enterprise to actively seek data on needs, usage and process capability to populate a data repository that can be mined for future requirements. C / D
	Lean Indicators (Examples)	• Customer feedback is actively sought and provided as input to the requirements definition process. • A database of usage, maintenance and disposal data is maintained and extensively used to establish future requirements definitions. • Enhanced knowledge of customer and stakeholder requirements and desires is used to leverage future requirements.				
	Evidence					
	Opportunities					

II.C. Develop Product and Process – Product and process design decisions must be based upon value quantifications and tradeoffs that incorporate inputs from affected stakeholders.

Diagnostic Questions

- **Is the product development process formalized and understood?**
- **Are customers and other lifecycle stakeholders regularly involved in product and process development?**
- **Are downstream stakeholder issues in design and development considered and incorporated as early as possible in the process?**
- **Have most of the unnecessary iterations in the development cycle been removed?**
- **Has the development cycle been simplified and aligned to the critical path?**
- **Are products and processes being developed concurrently?**

LP #	Lean Practices	Capability Levels				
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Level 5*
II.C.1.	**Incorporate *Customer Value* into Design of Products and Processes** *Understanding customer value allows continuous improvement of product and process*	Customer inputs are captured only at the beginning of the development. C | D	Customer inputs are considered qualitatively through top-level liaison and occasional reviews. C | D	The customer(s) are formally represented on Integrated Product Teams (IPT) and feedback mechanisms exist to facilitate timely design iterations. C | D	The customer(s) are actively involved with the IPT at multiple levels to jointly improve the effectiveness and quality of the product and process design. C | D	The customer(s) are routinely involved with IPT with effective, continuous communication. Sharing of benefits is well established; value quantification and tradeoffs are a continuous and automatic part of the process. C | D
	Lean Indicators (Examples)	• Customer inputs are sought and used actively throughout the development process. • Designs satisfy customer value requirements, without unnecessary functionality.				
	Evidence					
	Opportunities					
II.C.2	**Incorporate Downstream *Stakeholder Values* (Manufacturing, Support, etc.) into Products and Processes** *Understanding downstream stakeholders allows value to flow seamlessly to customer*	Manufacturing issues are considered late in design. C | D	Manufacturing and assembly issues are considered earlier in projects, but in an ad hoc manner. Supplier and cost considerations are limited. C | D	Multi-functional teams include some downstream disciplines and key suppliers. C | D	Priorities of downstream stakeholders are quantified as early as possible in design, and used for process evaluation and improvement. C | D	Downstream stakeholders' values in the extended enterprise are quantified, and balanced via tradeoffs, as a continuous part of the process. C | D
	Lean Indicators (Examples)	• There is early consideration and incorporation of downstream stakeholders issues throughout design development. • The scope of considerations integrated into designs has been extended to include manufacturing, assembly, serviceability and cost implications. • Products are easier to produce and have lower life-cycle costs.				
	Evidence					
	Opportunities					

LP #	Lean Practices	Capability Levels				
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Level 5*
II.C.3.	**Integrate Product and Process Development** *Breaking down of functional silos enables seamless communication and value flow*	Development is performed in functional organizations. C D	Multidisciplinary development is used to a limited extent. C D	Multidisciplinary development is used extensively; metrics are established for process evaluation. C D	Multidisciplinary techniques are deployed for most programs/product development efforts; metrics are used for process evaluation and improvement. C D	Product and process definition is seamlessly integrated both internally and with the upstream and downstream stakeholders. C D
	Lean Indicators (Examples)	• Resources and skills are balanced across projects and programs, to aid maximum re-use and sharing of knowledge. • Suitability and timing of design information released, is matched to the requirements of subsequent processes.				
	Evidence					
	Opportunities					

II.D. Manage Supply Chain – Internal enterprise core competencies are aligned with those of suppliers such that the customer value chain is optimized throughout the extended enterprise.

Diagnostic Questions

- **Have the number of suppliers been reduced to a level that can be effectively managed?**
- **Do contractual arrangements enable supplier flexibility and adaptation to both expected and unexpected changes?**
- **Are in-house capabilities balanced with supplier capabilities to optimize network-wide performance?**
- **Have opportunities for supply chain development been fully exploited?**
- **Are constraints and bottlenecks throughout the extended enterprise identified and rapidly resolved to ensure continuous flow?**
- **Are supplier partnerships and strategic alliances established to strengthen dynamic competitive advantage?**

LP #	Lean Practices	Level 1	Level 2	Level 3	Level 4	Level 5
II.D.1	**Define and Develop Supplier Network** *Core competencies aligned across supplier network*	Large number of direct suppliers in an hierarchical structure. There is little evidence of a defined supplier strategy and limited knowledge of the relationships within the supplier network. C D	The supplier base has been rationalized to focus on key suppliers with high impact on strategic objectives. C D	Supplier network is defined based on strategic analysis of value creation processes internally and across suppliers. C D	Strategic outsourcing and make-buy decisions focus on achieving an optimal combination of core competencies both within the enterprise and across the supplier network. C D	Supplier network is defined, developed and integrated to ensure efficient creation of value for enterprise stakeholders over the entire product lifecycle. C D
	Lean Indicators (Examples)	• The supplier network is defined and developed in line with the strategic plan to ensure efficient creation of value for all enterprise stakeholders. • Supplier expertise and capabilities complement enterprise core competencies; unnecessary overlap and duplication has been removed. • Supplier network is flexible and can quickly adapt to changing requirements and unanticipated disruptions.				
	Evidence					
	Opportunities					
II.D.2.	**Optimize Network-Wide Performance** *Partnering with key suppliers and optimizing processes to achieve customer value*	Supplier relationships are at arm's length and adversarial. Purchasing department manages a large number of short-term, lowest-bid contracts. C D	Formal processes are in place for supplier assessment and approval. Long-term purchase agreements focus on cost reduction. Limited visibility into supplier business processes. C D	Common objectives, roles and responsibilities are established and communicated, with a few supplier partnerships or strategic alliances in place. Early involvement of key suppliers in design and development. C D	Strategic alliances with key suppliers emphasize a high degree of information-sharing, risk-sharing & benefit sharing. For others a differentiated set of strategies and practices are in place. Production and delivery are synchronized across the supplier network. C D	Supplier capabilities are dynamically optimized to ensure efficient value creation and building durable competitive advantage, creating flexibility and responsiveness to shifts in the marketplace. C D
	Lean Indicators (Examples)	• Formal processes are in place for supplier assessment and approval. • Roles and responsibilities are clearly defined in contractual relationships, and risk and reward shares agreed upon. • Production and delivery are synchronized throughout the supplier base to ensure continuous flow, with minimal waste.				
	Evidence					
	Opportunities					

LP #	Lean Practices	Capability Levels				
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Level 5*
II.D.3.	**Foster Innovation and Knowledge-Sharing Throughout the Supplier Network** *Incentivizing innovation & technology transfer*	Primary focus on internal capabilities, with little cognizance of tacit (experience-based) or explicit (formal) knowledge across suppliers. C D	Internal organizational structures and processes are established to leverage supplier-based knowledge and innovation. C D	Technology roadmaps include suppliers in pursuance of common strategic vision. Shared metrics for continuous improvement are utilized. C D	Knowledge transfer mechanism is created for open and rapid access throughout the supplier network. C D	Mutually-beneficial arrangements are established to foster innovation across suppliers. A process for on-going communication of needed changes in vision, strategy, metrics and implementation is in place. C D
	Lean Indicators (Examples)	• Long-term collaborative relationships are established and maintained where possible. • Processes to facilitate sharing and transfer of innovation, knowledge and technology are deployed. • A mutually beneficial continuous improvement process is established throughout the supplier network over the entire product lifecycle.				
	Evidence					
	Opportunities					

II.E. Produce Product – The production system must be designed and managed according to the principles and practices of the lean production paradigm.

Diagnostic Questions

- **Is production knowledge and capability regarded as a strategic competitive advantage?**
- **Has enterprise strategy been aligned with manufacturing capability?**
- **Are products pulled in accordance with customer demand in real-time?**
- **Have the production processes been ordered and adapted for flow?**
- **Are inventories maintained at minimal levels throughout the production process?**

LP #	Lean Practices	Capability Levels: Level 1	Level 2	Level 3	Level 4	Level 5
II.E.1	**Utilize Production Knowledge and Capabilities for Competitive Advantage** *Strategic leveraging of manufacturing capability*	Production capability is not understood outside the manufacturing organization. C D	Production knowledge and capabilities are captured and used to influence manufacturing strategy including make/buy decisions. C D	Production capabilities are understood and utilized across the enterprise. Enterprise strategy and manufacturing capabilities are aligned. C D	Manufacturing system design is integrated with strategic make/buy decisions across the enterprise and aligned with enterprise strategy to create competitive advantage. C D	Production knowledge is leveraged across the extended enterprise to generate strategic opportunities for value creation. C D
	Lean Indicators (Examples)	• Production capability constitutes a major consideration in enterprise level long-range, strategic planning. • Knowledge of production capabilities are maintained and shared throughout the extended enterprise.				
	Evidence					
	Opportunities					
II.E.2.	**Establish and Maintain a Lean Production System** *Defect free production pulled by the customer*	Production system operates on a batch and queue schedule with high in-process inventory, with quality based on inspection rather than prevention. C D	Production system operates with a batch and queue schedule with limited cellular or in-line layouts to improve flow. C D	Product flow paths are identified and key elements of the layout have been reordered enhancing flow and reducing in-process inventory, with some suppliers delivering to point of use where appropriate. C D	Selected products are produced using a flow system pulled directly by customer demand (takt time), which includes key suppliers. C D	Work is segmented and organized along the value stream flows to achieve defect free production upon demand through the implementation of pull from customer through material suppliers. C D
	Lean Indicators (Examples)	• Conversion to lean has freed up floor space, equipment, human resources and capital for re-deployment. • Inventory levels have been reduced in line with gains made to process stability and variation reductions. • Work is performed only when "pulled" from subsequent "customers" in the value chain.				
	Evidence					
	Opportunities					

II.F. Distribute and Service Product – On-time deliveries of defect free products are complemented by superior post delivery service, support and sustainability.

Diagnostic Questions		• **Are production schedules and capacity considered prior to making a sales/contract commitment?** • **Are product delivery data flowed throughout the value chain?** • **Does the organization satisfy customer maintenance requirements effectively?** • **Are in-service usage data deployed to appropriate personnel?** • **Are customer rejects/returns treated as opportunities?**				
LP #	**Lean Practices**	**Capability Levels**				
		Level 1	***Level 2***	***Level 3***	***Level 4***	***Level 5***
II.F.1.	**Align Sales and Marketing to Production** *Matching demand and capabilities*	Marketing pushes product sales/bids with little consideration of current production capacity. **C D**	Marketing provides production with partial visibility to current and future potential order base. Order base not aligned to production capacity. **C D**	Products are supplied in smaller more frequent batches, balancing orders to current production capacity. Most running orders are fully visible to production. **C D**	Matching real-time customer demand and delivery requirements with production capabilities, using extensive knowledge base of customer preferences. **C D**	Actual and future prospective orders are matched in real-time with production capabilities throughout the extended enterprise. **C D**
	Lean Indicators (Examples)	• Sales / bids are aligned to current and future production capacity and capabilities. • There is constant feedback and input between sales/marketing and production elements across the enterprise. • Sales / bids commit product delivery to real-time customer demand, without the use of buffer stocks.				
	Evidence					
	Opportunities					
II.F.2.	**Distribute Product in Lean Fashion** *Right product, right quantity at the right time*	Distribute from inventories by batch; customer inspects products upon receipt. **C D**	Distribute in smaller batch sizes more frequently in line with increased reliability. There are programs in place to reduce customer receipt inspection. **C D**	Product distribution from low stock levels is triggered by an internal pull system; some products are delivered directly to point of use with limited inspection. **C D**	Defect free items are produced and delivered without receipt inspection to real-time customer usage; customers are given access to databases for order status visibility. **C D**	Defect free distribution on demand is achieved via the implementation of customer pull from end customer through material suppliers. **C D**
	Lean Indicators (Examples)	• Point of use delivery to customers with minimal receipt inspection has become standard practice. • Deliveries are synchronized to minimize goods in transit and transportation requirements. • Delivery cycle is shorter and more reliable.				
	Evidence					
	Opportunities					

LP #	Lean Practices	Capability Levels				
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Level 5*
II.F.3	**Enhance Value of Delivered Products and Services to Customers and the Enterprise** *Responding to the voice of the customer*	Product support system reacts to customer needs, usually on-time and from inventory. C | D	Support system delivers products / services on time, but with disruptions to production flow and associated resources. C | D	Support system flow paths are identified and are beginning to be integrated with lean product development and production flows. C | D	Standardized customer and product support processes provide responsive information and product flow fully integrated with development and production flows. C | D	Customer needs for post-delivery products / services are anticipated in enterprise plans and fulfilled by adaptation and extension of capabilities already provided. C | D
	Lean Indicators (Examples)	• Solutions to product / service issues are coordinated throughout the extended enterprise to find fast, cost effective solutions. • Customer and product support processes have been standardized and are regularly reviewed against customer feedback. • Disruptions to design and production flow from support services has been minimized.				
	Evidence					
	Opportunities					
II.F.4.	**Provide Post Delivery Service, Support and Sustainability** *Providing customer solutions*	High level of spares necessary because of unknown failure rates and long lead times for spare replenishment. C | D	Collection of data on failure trends permits both determination of service interval points for preventative maintenance and a reduction of spare part levels. C | D	The enterprise is increasingly involved in addressing customer maintenance solutions. Spare levels are reduced through common platforms; root cause analyses are fed back into product design. C | D	The enterprise is part of the customer's maintenance solution by ensuring availability through replacement of critical components before failure. C | D	The enterprise has become part of customer's business solution via warranting of product performance. C | D
	Lean Indicators (Examples)	• Customer feedback is proactively maintained and used to predict any emerging service issues and enhance future designs. • Spares levels are reduced in line with short predicable lead times for replacement spares.				
	Evidence					
	Opportunities					

SECTION III - ENABLING INFRASTRUCTURE

Definition: To achieve a successful lean transformation, the enterprise infrastructure must support the implementation of lean principles, practices and behavior.

III.A. Lean Organizational Enablers – The support units of an enterprise must themselves become lean in executing their assigned function, but they must also redefine what they do such that they support lean implementation within the life cycle processes and the lean transformation/leadership processes.

Diagnostic Questions

- **Do the finance and accounting measures support the implementation of lean?**
- **How well have the financial and accounting systems been integrated with non-financial measures of value creation?**
- **Can stakeholders retrieve financial information as required?**
- **Are human resource practices reviewed to assure that intellectual capital matches process needs?**
- **Are the information technology systems compatible with stakeholder communications and analysis needs?**
- **Do processes create the least amount of environmental hazards practical?**

LP #	Lean Practices	Capability Levels: *Level 1*	*Level 2*	*Level 3*	*Level 4*	*Level 5*
III.A.1.	**Financial System Supports Lean Transformation** *Lean requires appropriate financial data*	Finance system provides basic balance sheet and cost accounting data; there is little awareness and exploration of broader support roles for finance. C D	Initial efforts are underway to adapt or modify systems to compensate for the inadequacies of the formal financial system. C D	Finance system is overhauled to provide data and financial information to support and enable a lean transformation at any level. C D	Financial system scope is expanded to integrate with non-traditional measures of value creation (e.g., intellectual capital, balanced scorecard, etc.). C D	Financial systems provide seamless information exchange across the extended enterprise, with emphasis on value creation for all stakeholders. C D
	Lean Indicators (Examples)	• Financial measures that conflict with lean activity are no longer used to measure progress and performance. • The financial system handles a balanced set of financial and non-financial measures to assist decision-making. • The financial system has been overhauled to ensure fast and efficient processing of information as required.				
	Evidence					
	Opportunities					
III.A.2.	**Enterprise Stakeholders Pull Required Financial Information** *Data on demand*	Lagging financial information is reported through regularly scheduled standardized reports. Specific requests for measures require extraordinary effort. C D	Finance actively provides traditional financial information to assist users in planning and programming activities. C D	Users are able to directly access and use financial information to make trade-off decisions. C D	Users are able to pull financial and other value creation information to support decision analysis in the format desired. C D	Users across the extended enterprise generate and share timely financial and performance data. Data reflects extended enterprise results. C D
	Lean Indicators (Examples)	• Financial and performance measurement data can be accessed as needed in user-defined format. • Financial information can be extrapolated to forecast outcomes. • System provides up to date information on request and rationalizes information no longer used.				
	Evidence					
	Opportunities					

LP #	Lean Practices	Capability Levels				
		Level 1	*Level 2*	*Level 3*	*Level 4*	*Level 5*
III.A.3.	**Promulgate the Learning Organization** *Learning Organizations create a flexible workforce*	The human resources processes concentrate on recruiting, placement and benefits. Personnel training is ad hoc and not aligned to organizational needs. C | D	A well-defined personnel development process, aligned with organizational needs, is applied for selected employees. C | D	Personnel development process is extended to all employees and incorporates the anticipated future needs of the lean enterprise. Resources and facilities are dedicated for learning. C | D	A learning climate is promoted within the enterprise through ready access to information and input to strategy/ policy making. Opportunities for extending learning experiences are provided. C | D	A learning climate is promoted throughout the extended enterprise by the sharing of capabilities, knowledge, skills and best practice. C | D
	Lean Indicators (Examples)	• Intellectual capital is regarded as a corporate asset. • Employees have individual training plans, which are aligned to the current and projected skill base requirements. • Employees actively capture and incorporate lessons learned into future training and practices.				
	Evidence					
	Opportunities					
III.A.4.	**Enable the Lean Enterprise with Information Systems and Tools** *Facilitate the flow of information and knowledge*	The information infrastructure consists mainly of stand-alone systems. The need for systems integration is recognized but no improvement plan exists. C | D	Elements of a common information infrastructure have been determined, and an implementation plan is under development. Maintenance of legacy systems consume most IT resources. C | D	The information infrastructure has been formalized and is in use in selected locations. Legacy systems are rationalized and aligned across the value stream. C | D	An information infrastructure is deployed that supports seamless information exchange across the enterprise. C | D	Information systems are fully interoperable and the pertinent information is easily accessible and usable across the extended enterprise. C | D
	Lean Indicators (Examples)	• Compatible information systems and tools exist across the extended enterprise. • Information systems facilitate fast and effective transfer and retrieval of information required. • Information systems and tools complement lean processes and practices and are easily adapted to accommodate change.				
	Evidence					
	Opportunities					
III.A.5.	**Integration of Environmental Protection, Health and Safety into the Business** *"Cleaner, healthier, safer"*	The enterprise complies with all known legal and regulatory requirements and reacts if issues are identified. C | D	Consideration is given to means of mitigating conditions that cause environmental, health and safety issues. C | D	A process is in place to proactively identify Environmental protection, Health and Safety (EHS) risks and manage them appropriately, with a preference for source prevention. C | D	Forward thinking solutions to potential life cycle EHS risks are implemented early in product (service) design and throughout the value stream. C | D	EHS risk prevention and mitigation is part of the natural way business is conducted across the extended enterprise, creating a sustainable environment and creating a competitive advantage. C | D
	Lean Indicators (Examples)	• Health and safety issues are routinely addressed in employee driven improvement activities. • Processes and designs are proactively adapted to minimize environmental, health and safety issues at source. • Designs meet current environmental regulations and are capable of easy adaptation to meet projected changes over the life cycle of the product.				
	Evidence					
	Opportunities					

III.B. Lean Process Enablers – A number of enablers can facilitate lean implementation via consistent application throughout the enterprise.

Diagnostic Questions

- **Have the full benefits from process standardization been realized across the enterprise?**
- **Has process standardization and reuse been imbedded in enterprise policies and procedures?**
- **Are common tools and systems used throughout the enterprise?**
- **Is process variation continually reviewed and reduced in all processes throughout the enterprise?**

LP #	Lean Practices	Level 1	Level 2	Level 3	Level 4	Level 5
III.B.1.	**Process Standardization** *Strive for consistency and re-use*	Processes vary by program or product line. [C] [D]	Key processes in the organization have been identified that could benefit from standardization, with initial efforts underway. [C] [D]	Selected processes are standardized across the enterprise. [C] [D]	Process standardization and reuse is consistently employed across the enterprise. [C] [D]	Extended enterprise interface processes have been standardized. [C] [D]
	Lean Indicators (Examples)	• The workforce plays a significant role in devising standard processes and practices, which are adhered to and periodically updated. • Process improvements are documented in a concise and easy to use standard format and transferred. • Processes are standardized where applicable throughout the extended enterprise.				
	Evidence					
	Opportunities					
III.B.2.	**Common Tools and Systems** *Assuring compatibility, reducing costs*	Tools and systems vary by program or work center. [C] [D]	Have identified high leverage opportunities for common tools and systems; initial deployment in a few areas. [C] [D]	Plans are in place for achieving common tools and systems and have been implemented to varying degrees across the enterprise. [C] [D]	Common tools and systems have been implemented throughout the enterprise. [C] [D]	Compatibility of tools and systems with those of enterprise partners in the extended enterprise. [C] [D]
	Lean Indicators (Examples)	• Policies have been established and deployed that require the use of common tools and systems throughout the enterprise. • Common tools and systems provide easy access and reuse of knowledge across the product life cycle. • Enterprise-wide use of common tools and systems provides enhanced compatibility between processes and aids employee transfer.				
	Evidence					
	Opportunities					
III.B.3.	**Variation Reduction** *Reduce uncertainty by reducing variation*	There is limited use of variation reduction tools and methods. There is some evidence of variation understanding in parts of the organization. [C] [D]	There is evidence that sources of variation are being identified and analyzed. Initial efforts are underway to reduce variability. [C] [D]	A formal approach that balances customer value and variation reduction is implemented in many parts of the enterprise. [C] [D]	Considerable benefits are realized from reduced variation in processes and practices across the enterprise. [C] [D]	Benefits of reduced variation are realized across the extended enterprise. [C] [D]
	Lean Indicators (Examples)	• Process ownership and visual displays of process variation enable quick and easy identification of adverse trends. • High levels of process stability are maintained by utilizing mistake proofing and root cause identification techniques to the fullest. • Variation reductions achieved enable short predicable lead times for information and material flow.				
	Evidence					
	Opportunities					

References

1. Abair, R. 2000. 'Lean Checklist Self-Assessment' . Northboro, MA: Robert Abair Associates.
2. Abernathy, F.H. and Dunlop, J.T. 2000. 'Control Your Inventory In a World of Lean Retailing'. *Harvard Business Review* Reprint #R00601: 1-8.
3. Adamson, S. 2002. 'Discussion of Defense System Total Ownership Cost' : Naval Center for Cost Analysis via the Air Force Cost Analysis Agency.
4. AHD_WWW 1996. *'The American Heritage® Dictionary of the English Language, Third Edition'* : Houghton Mifflin Company.
5. Ahmadjian, C.L. and Lincoln, J.R. 2001. 'Keiretsu, Governance, and Learning: Case Studies in Change from the Japanese Automotive Industry'. *Journal of Organization Science* 12: 683-701.
6. AIA 2001. *Aerospace Facts and Figures 2001/2002.* Washington D.C.: Aerospace Industries Association of America (AIA).
7. AIA_WWW 2002. 'Aerospace Industries Association Overview' .
8. AIN_WWW 2000. 'Toyota Donates Type G Automatic Loom to Britain's Science Museum' : Automotive Intelligence News.
9. Allen, T.J. 1997. 'Organizational Structure for Product Development (MIT Sloan School of Management Report 166-97)' . Cambridge, MA: Massachusetts Institute of Technology.
10. Al-Sudairi, A.A., Diekmann, J.E., Songer, A.D. and Brown, H.M. 1999. 'Simulation of Construction Processes: Traditional Practices Versus Lean Principles' *IGLC-7.* University of California, Berkeley.
11. Andersin, H.E., Reinikka, M. and Wickstrom, L.A. 1992. 'Measuring the Degree of Enterprise Integration' . Helsinki, Finland: Helsinki University of Technology.
12. Anderson, D.D.L. and Lee, D.H. 2000. 'Synchronized Supply Chains: The New Frontier' : Andersen Consulting.
13. Anderson, P. 1999. 'Complexity Theory and Organizational Science'. *Organizational Science* 10: 216-232.
14. Anonymous 1997. 'Lean Manufacturing Systems Have Big Payoff'. *Journal of Purchasing* 123: 221-227.
15. APQC 1996. 'APQC Process Classification Framework' . Houston: APQC International Benchmarking Clearinghouse.

16. Arjmand, D.M. and Roach, S. 2000. 'Creating Greater Customer Value by Synchronizing the Supply Chain' : Anderson Consulting.

17. Arrow, K.J. 1962. 'Economic Welfare and the Allocation of Resources for Invention' in Nelson, R.R. (ed.) *The Rate and Direction of Inventive Activity: Economic and Social Factors*. Princeton, NJ: National Bureau of Economic Research, Princeton University Press.

18. Ashford, N.A. and Caldart, C.C. 1996. *Technology, Law, and the Working Environment*: Island Press.

19. ATA_WWW 2002. 'Air Transport Association Home Page' : Air Transport Association.

20. AW&ST 2002. 'Report Card Unmasks Best, Worst in Shareholder Value Creation' *Aviation Week and Space technology*.

21. AW&ST 2002b. 'Methodology for Determining Top Performers' *Aviation Week and Space technology*.

22. Baldridge_Award_WWW 2003. 'Malcolm Baldridge Quality Award' : National Institute of Standards and Technology.

23. Barlas, S., Curatola, A., Randall, R. and Williams, K. 1999. 'Cost Management of Supply Chains' *Strategic Finance*.

24. Baudin, M. 1999. 'Lean Production: The End of Management Whack-A-Mole' . http://www.mmt-mst.com: Manufacturing Management and Technology Institute.

25. Bensoussan, A., Jr., E.G.H. and Naslund, B. 1974. *Management Applications of Modern Control Theory*. New York: American Elsevier Publishing Company.

26. Bentley, G., Nightingale, D. and Taneja, A. 2000. 'Lean Enterprise Model (LEM)' . Cambridge.

27. Bernstein, J.I. 2001. 'Multidisciplinary Design Problem Solving on Product Development Teams' *Technology, Management, and Policy Program*. Cambridge: Massachusetts Institute of Technology.

28. Berry, W.D. and Feldman, S. 1990. *Multiple Regression in Practice*. London: SAGE Publications.

29. Blake, D.A. 2002. 'Lean Effects on Aerospace Programs - Boeing 737 Fuselage Comments and Insights' *LAI Plenary Conference: Enterprise Value - The New Lean Horizon*. Century City, CA: MIT LAI.

30. BLD 1999. *Black's Law Dictionary*.

31. Boeing_WWW 2003. 'Boeing 777 Program Background' : Boeing Company.

32. Boppe, C. 1996. '16.870 Aerospace Product Design (Course Notes)' . Cambridge: Massachusetts Institute of Technology.

33. Bozdogan, K. 2002. 'Basics of Lean Supply Chain Management' *Lean Enterprise Value: An Executive Short Course*. Cambridge, MA: MIT LAI.

34. Bozdogan, K., Deyst, J., Hoult, D. and Lucas, M. 1998. 'Architectual Innovation in Product Development through Early Supplier Integration'. *R&D Management* 28: 163-173.

35. Bransford, J.D., Brown, A.L. and Cooking, R.R. 1999. 'How People Learn: Brain, Mind, Experience, and School' . Washington, DC: National Academy Press.

36. Bresnahan, T.F. and Trajtenberg, M. 1995. 'General Purpose Technologies: Engines of Growth?'. *Journal of Econometrics* 65: 83-108.

37. Brown, A. 2000. 'Learning to Think Lean: Delphi Lean Engineering Initiatives'. *Automotive Manufacturing and Production* 112: 76-77.

38. Brown, M.G. 1996. *Keeping Score: Using the Right Metrics to Drive World-Class Performance*. New York: Quality Resources.

39. Brown, S.L. and Eisenhardt, K.M. 1998. *Competing on the Edge: Strategy as Structured Chaos*. Boston, MA: Harvard Business School.

40. Browning, T.R. 1998. 'Modeling and Analyzing Cost, Schedule, and Performance in Complex System Product Development' *Technology Management and Policy, Lean Aerospace Initiative*. Cambridge: Massachusetts Institute of Technology.

41. Cantrell, J., Nightingale, D., Kenworthy, E.J. and Kosmal, B. 1999. 'Evidence of Lean Site Visits Interim Report' . Cambridge, MA: Massachusetts Institute of Technology Lean Aerospace Initiative.

42. Carlile, P.R. 2002. 'A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development'. *Organization Science* 13.

43. Carlile, P.R. 2002b. 'Transferring, Translating and Transforming: An Integrative Framework for Managing Knowledge Across Boundaries' . Cambridge, MA.: Massachusetts Institute of Technology, Sloan School of Management.

44. Christensen, C.M. 1997. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Boston: Harvard Business School Press.

45. Clemson, E.K., Croson, D.C. and Weber, B.W. 1996. 'Market Dominance as a Precursor of a Firm's Failure: Emerging Technologies and the Competitive Advantage of New Entrants.'. *Journal of Management Information Systems* 13: 59-75.

46. Cochran, D.S., Kim, Y.-S. and Kim, J. 2000. 'The Alignment of Performance Measurement with the Manufacturing System Design' *First International Conference on Axiomatic Design*. Massachusetts Institute of Technology.

47. Cohen, M.A. 2000. 'Saturn's Supply Chain Innovation: High Value in After-Sales Service'. *Sloan Management Review* Summer 2000.

48. Cohen, W.M. and Levinthal, D.A. 1990. 'Absorptive Capacity: A New Perspective on Learning and Innovation'. *Administrative Science Quarterly* 35: 128-152.

49. Constantine, E. 2003. 'Introduction to Simpler Business Systems: Lean Implementation and Consulting in the US' . Ottumwa, IA: Simpler Consulting Inc.

50. Constantino, B. 1998. 'Cedar Works: Making the Transition to Lean' in Liker, J.K. (ed.) *Becoming Lean: Inside Stories of US Manufacturers*: Productivity Press.

51. Cook, C.R. and Graser, J.C. 2001. *Military Airframe Acquisition Costs: The Effects of Lean Manufacturing*: RAND.

52. Cook, T.D. and Campbell, D.T. 1976. 'The Design and Conduct of Quasi-Experiments and true Experiments in Field Settings' in Dunnette, M.D. (ed.) *Handbook of Organizational and Industrial Psychology*. Chicago: Rand McNally College Publishing Company.

53. Cool, C. 2001. 'Journey to A Lean Enterprise' : Northrop Grumman Integrated Systems.

54. Cooper, R. 1995. *When Lean Enterprises Collide*. Boston, MA: Harvard Business School Press.

55. Cooper, R. 1996. 'Look Out Management Accountants'. *Journal of Management Accounting* 77.

56. Cooper, R. and Slagmulder, R. 1999. 'Supply Chain Management for Lean Enterprises: Interorganizational Cost Management'. *Strategic Finance* 80: 15-16.

57. Cooper, R. and Slagmulder, R. 1999b. 'Develop Profitable New Products With Target Costing'. *Sloan Management Review*: 23-33.

58. Cox, D.R. and Wermuth, N. 1996. *Multivariate Dependencies: Models, Analysis and Interpretation*: Chapman and Hall/CRC.

59. Crute, V. and Graves, A. 2001b. 'Managing the Change to Lean Performance' . Bath, England: University of Bath School of Management as part of the UK Leean Aerospace Initiative for the Society of British Aerospace Companies (SBAC).

60. Crute, V., Ward, Y. and Graves, A. 2001. ''High' Success and 'Low' Success in Performance Improvement Activities - What Made the difference?' . Bath, England: University of Bath School of Management as part of the UK Lean Aerospace Initiative for the Society of British Aerospace Companies (SBAC).

61. Cusumano, M.A. 1994. 'The Limits of "Lean"'. *Sloan Management Review*: 27-32.

62. Cusumano, M.A. and Nobeoka, K. 1998. *Thinking Beyond Lean: How Multi-Project Management is Transforming Product Development at Toyota and Other Companies*: The free Press.

63. Cutcher-Gershenfeld, J. 2001. 'Genuine Learning: Aerospace Workforce Case Studies' *Racing Towards Knowledge: Get on Track with Lean"*. Charlotte, NC: MIT LAI.

64. Cutcher-Gershenfeld, J., Barrett, B., Rebentisch, E., Kochan, T. and Scott, R. 2001b. 'Developing a 21st Century Workforce' *for submission to the Human Capital Task Force, the U.S. Commission on the Future of the Aerospace Industry*. Cambridge: MIT.

65. Czarnecki, H. 2001. 'Lean Transformation' *LEI/University of Michigan 7th Annual Lean Manufacturing Conference*. Dearborn: Lean Enterprise Institute.

66. Daft, R.L. 'Fundamentals of Organization Structure' *Essentials of Organization Theory and Design*: South-Western College Publishing.

67. Daniel, W.W. 1990. *Applied Non-Parametric Statistics*: PWS-Kent.

68. Darlington, J. 1999a. 'Chasing Muda'. *Journal of Management Accounting* 77: 26-30.

69. Darlington, J. 1999b. 'Lean Thinking and Mass Customization: The Relationship Between Production and Costs'. *Management Accounting* 77: 18-21.

70. Dasgupta, P. and David, P.A. 1994. 'Toward a New Economics of Science'. *Journal of Research Policy* 23: 487-521.

71. Dausch, B. 2002. 'Managing the Enterprise Centered on Value-Based Processes' : Aerojet/Northrop Grumman.

72. Davidz, H., Nightingale, D.H. 2002. 'Lean Effects on Aerospace Programs (LEAP) Project: AMRAAM Case Study Report' . Cambridge: Massachusetts Institute of Technology Lean Aerospace Initiative.

73. Davidz, H. 2002b. 'Lean Effects on Aerospace Programs - Raytheon AMRAAM Case Study' *LAI Plenary Conference: Enterprise Value - The New Lean Horizon*. Century City, CA: MIT LAI.

74. Deming, W.E. 1992. *Out of the Crisis*. Cambridge: Massachusetts Institute of Technology Center for Advanced Educational Study.

75. Dhillon, B.S. 1989. *Life Cycle Costing*.

76. Dimancescu, D., Hines, P. and Rich, N. 1997. *The Lean Enterprise: Designing and Managing Strategic Processes for Customer Winning Performance*: American Management Association.

77. Donald, C.G., Lyons, T.S. and Tribbey, R.C. 'The Next Stage in Employee Involvement: Partnerships for Strategic Planning and Management.' . Louisville: University of Louisville.

78. Donovan, J., Tully, R. and Wortman, B. 1998. *The Value Enterprise: Strategies for Building a Value-Based Organization*: McGraw-Hill Ryerson.

79. Drucker, P.F. 1964. *Managing for Results: Economic Tasks and Risk-Taking Decisions*: Harper & Row.

80. Drucker, P.F. 1998. 'The Information Executives Truly Need' *Harvard Business Review on Measuring Corporate Performance*. Boston: Harvard Business Review.

81. Eccles, R.G. 1998. 'The Performance Measurement Manifesto' *Harvard Business Review on Measuring Corporate Performance*. Boston: Harvard Business Review.

82. Emiliani, M.L.B. 2001. 'A Mathematical Logic Approach to the Shareholder vs. Stakeholder Debate'. *Management Decision* 39: 618-622.

83. Emilinai, M.L.B. 2001b. 'CLBM Director's Message: Do Companies Exist to Maximize Shareholder Value' .

84. EQFM 2003. 'European Forum for Quality Management (EQFM) Model of Excellence' : European Forum for Quality Management (EQFM).

85. EWM_WWW 2002. 'Biography of Eli Whitney' : Eli Whitney Museum.

86. Fabrycky, W. 1991. *Life Cycle Cost and Economics*: Prentice-Hall.

87. Feld, W.M. 2001. *Lean Manufacturing: Tools, Techniques, and How to Use Them*: The St. Lucie Press / APICS Series on Resource Management.

88. Ferdowsi, B. 2002. 'Lean Effects on Aerospace Programs - Boeing 737 Fuselage' *LAI Plenary Conference: Enterprise Value - The New Lean Horizon*. Century City, CA: MIT LAI.

89. Fine, C.H. 2000. 'Clockspeed-Based Strategies for Supply Chain Design'. *Production and Operations Management* 9.

90. Fleming, Q.W. and Koppelman, J.M. 2000. *Earned-Value Project Management*: Project Management Institute.

91. Ford_WWW 2002. 'History of Ford' .

92. Franklin, G.F., Powell, J.D. and Emami-Naeini, A. 1991. *Feedback Control of Dynamic Systems*: Addison Wesley Publishing Company.

93. Freidman, R.E. and Pollack, J.S. 2002. *Standard and Poor's Industry Survey: Aerospace and Defense*: McGraw-Hill.

94. Gannaway, J.N. 2002. 'F-16 Lean Journey 1992-2001: A decade of Continual Improvement' *LAI Plenary Conference: Enterprise Value - The New Lean Horizon*. Century City, CA: MIT LAI.

95. Gass, M.C. 2002. 'Atlas Launch Vehicles: Enterprise Value through Operating Excellence' *LAI Plenary Conference: Enterprise Value - The New Lean Horizon*. Century City, CA: MIT LAI.

96. George, M.L. 2002. 'Lean Six Sigma: The power to Drive Rapid and Sustained Value Creation' . Cambridge: The George Group.

97. Glad, E. and Becker, H. 1995. *Activity-Based Costing and Management*: John Wiley and Sons.

98. Glasser, W. 1994. *The Control Theory Manager*: Harper Business.

99. GME 1997. 'Grolier's Interactive Encyclopedia' : Grolier Interactive Inc.

100. Gonzales, J.F. and Sarama, T.J. 1999. 'Lean Methods Above the Manufacturing Floor in an Aerospace Military Program' *Alfred P. Sloan School on Management*. Cambridge: Massachusetts Institute of Technology.

101. Good, P.I. 1999. *Resampling Methods: A Practical Guide to Data Analysis*: Birkhauser.

102. Grady, J.O. 1994. *System Integration*: CRC Press.

103. Grant, R.M. 1995. 'The Concept of Strategy' *Contemporary Strategy Analysis*: Basil Blackwell Ltd.

104. Haggerty, A. 2002b. 'Life Cycle Costs (personal communication)' .

105. Haggerty, A.C. 2002. 'Lean Engineering Has Finally Come of Age (Or, Why We Can't Ignore 80% of a Product's Cost Anymore). Massachusetts Institute of Technology 2002 Minta Martin Lecture.' . Cambridge: Massachusetts Institute of Technology.

106. Hallam, C., Sheilds, T. and Mize, J. 2003. 'LESAT Facilitator's Workshop' . Cambridge: MIT LAI.

107. Hallam, C.R.A., Nightingale, D. and Mize, J. 2001. 'Enterprise Value Stream Mapping White Paper' . Cambridge: Massachusetts Institute of Technology.

108. Hamel, G. 2000. *Leading the Revolution*. Boston, MA: Harvard Business School Press.

109. Hamel, G. 2000b. 'Business Concept Innovation' *Leading the Revolution*. Boston, MA: Harvard Business School Press.

110. Hammer, M. 2002. 'Process Management and the Future of Six Sigma'. *MIT Sloan Management Review* 43: 26-32.

111. Handell, D. 2002. 'F-22 War on cost Update' *LAI Plenary Conference: Enterprise Value - The New Lean Horizon*. Century City, CA: MIT LAI.

112. Harris, R. 2002. 'The Right Automation Level for Lean' : Society of Automotive Engineers.

113. Harris, R. and Rother, M. 2001. 'Creating Continuous Flow' *LEI/University of Michigan 7th Annual Lean Manufacturing Conference*. Dearborn: Lean Enterprise Institute.

114.Harrison, B. 1994. *Lean and Mean: The Changing Landscape of Corporate Power in the Age of Flexibility*: Basic Books.

115.Harry, M. and Schroeder, r. 2000. *Six Sigma: The Breakthrough Management Strategy Revolutionizing the World's Top Corporations*: Currency-Doubleday.

116.Hauser, J.R. 2000. 'Metrics Thermostat' . Cambridge: MIT.

117.Hayes, R.H. and Pisano, G.P. 1994. 'Beyond World Class: The New Manufacturing Strategy.'. *Harvard Business Review*: 77-86.

118.Henderson, B.A. and Larco, J.L. 2000. *Lean Transformation: How to Change Your Business into a Lean Enterprise*: The Oaklea Press.

119.Hesselbein, F., Goldsmith, M. and Beckhard, R. 1996. 'The Drucker Foundation: The Leader of the Future: New Visions, Strategies, and Practices for the Next Era' : Jossey-Bass.

120.Hines, P., Lamming, R., Jones, D., Cousins, P. and Rich, N. 2000. *Value Stream Management: Strategy and Excellence in the Supply Chain*: Prentice Hall.

121.Hines, P. and Taylor, D. 2000b. *Going Lean: A Guide to Implementation*: Lean Enterprise Research Center, Cardiff Business School.

122.Hitchings, S. 2002. 'Lean Effects on Aerospace Programs - Atlas Case Study' *LAI Plenary Conference: Enterprise Value - The New Lean Horizon*. Century City, CA: MIT LAI.

123.Hout, T.M. and Carter, J.C. 1995. 'Getting it Done: New Roles for Senior Executives'. *Harvard Business Review* 73: 133-145.

124.Hughes, T.P. 1998. *Rescuing Prometheus: Four Monumental Projects that Changed the World*. New York: Vintage Books.

125.Hunter, S. 2000. '15.370 Strategic Management: Summary Thoughts (based on Notes from Prof. M. Cusumano)' . Cambridge, MA: Massachusetts Institute of Technology.

126.Hunter, S. 2000b. '15.370 Some thoughts about "What is Strategy"' . Cambridge, MA: Massachusetts Institute of Technology.

127.Imai, M. 1997. *Gemba Kaizen: A Commonsense, Low-Cost Approach to Management*: McGraw-Hill.

128.ISO_WWW 2003. 'ISO Standards' : International Standards Organization (ISO).

129.James, D. 2002. 'Rockwell Collins Enterprise Value Stream Review' .

130.Jarris, R. 2002. 'The Right Automation Level for Lean' : Society of Manufacturing Engineering.

131.Jenner, R. 1998. 'Dissipative Enterprises, Chaos, and the Principles of Lean Organizations'. *Omega International Journal of Management Science* 26: 397-407.

132.Jones, D. 2001. 'Seeing the Whole: Mapping the Extended Value Stream' *LEI/University of Michigan 7th Annual Lean Manufacturing Conference*. Dearborn: Lean Enterprise Institute.

133.Jordan, J.A. and Michel, F.J. 2001. *The Lean Company: Making the Right Choices*. Dearborn, MI: Society of Manufacturing Engineering.

134.Kaplan, K. 1998. 'Design Departure' *LA Times*. Los Angeles.

135.Kaplan, R.S. and Norton, D.P. 1996. *The Balanced Scorecard: Translating Strategy Into Action*. Boston, Massachusetts: Harvard Business School Press.

136.Kaplan, R.S. and Norton, D.P. 1998b. 'The Balanced Scorecard - Measures that Drive Performance' *Harvard Business Review on Measuring Corporate Performance*. Boston: Harvard Business Review.

137.Kaplan, R.S. and Norton, D.P. 2000. 'Having Trouble With Your Strategy? Then Map It.'. *Harvard Business Review*.

138.Kessler, W. 2001. 'From Lean Production to Lean Enterprise: A Key to Operating Performance (Guest Lecture/Presentation in Integrating the Lean Enterprise, MIT 16.852)' : Lockheed Martin Aeronautics Company.

139.Kim, J.-O. and Mueller, C.W. 1989. *Introduction to Factor Analysis: What it is and How to Do It*. London: SAGE Publications.

140.Kioa, K. 2002. 'How did the West Coast Dock Strike Affect the Nation's Supply Chains?' : Institute for Supply Management.

141.Klassen, R.D. 2000. 'Just-in-Time Manufacturing and Pollution Prevention Generate Mutual Benefits in the Furniture Industry'. *Interfaces* 30: 95-106.

142.Knuf, J. 2001. 'Deep Pattern Change: A dialectic of Behavioral and Organizational Paradigms in Lean Transformations' . Cambridge: Joachim Knuf, University of Kentucky.

143.Kochan, T., Orlikowski, W. and Cutcher-Gershenfeld, J. 2002. 'Beyond McGregor's Theory Y: Human Capital and knowledge-Based Work in the 21st Century (Revised Draft) prepared for the Sloan School 50th Anniversary Session on October 11, 2002.' . Cambridge: Massachusetts Institute of Technology.

144.Koenigsaecker, G. 2001. 'Senior Management's Role in Leading Lean Change: Creating Change Dynamics and Organizational Alignment' *LEI/University of Michigan 7th Annual Lean Manufacturing Conference*. Dearborn: Lean Enterprise Institute.

145.Koenigsaecker, G. 2003. 'Lessons Learned from Leading Conversion Efforts as Either the President or a Group President with Company Presidents' *LAI Plenary Conference: Transformation Across Enterprise Boundaries*. Dayton, Ohio: Lean Aerospace Initiative.

146.Koenigsaecker, G. 2003b. 'Telephone Conversation about "Why Lean Fails"' .

147.Kotter, J.P. 1999. *John P. Kotter on What Leaders Really Do*: Harvard Business Review.

148.Krafcik, J.F. 1988. 'Comparative Analysis of Performance Indicators at World Auto Assembly Plants' *Sloan School of Management*. Cambridge: Massachusetts Institute of Technology.

149.Krathwohl, D.R. 1998. *Methods of Educational and Social Science Research: An Integrated Approach*: Addison-Wesley.

150.LAI 2002. 'Roadmap for Creating Program Value' . Cambridge: Massachusetts Institute of Technology Lean Aerospace Initiative.

151.LAI_LEM 2001. 'Lean Enterprise Model (LEM)' : Massachusetts Institute of Technology Lean Aerospace Initiative.

152.LAI_LESAT 2001. *Lean Enterprise Self-Assessment Tool*. Cambridge: Massachusetts Institute of Technology, Lean Aerospace Initiative.

153.LAI_WWW 2002. 'Lean Aerospace Initiative Home Page' : MIT LAI.

154.Leach, T. 2001. 'Lean Enterprise Assessment and Planning Process' : Northrop Grumman.

155.Leonard-Barton, D. 1992. 'Core Capabilities and Core Rigidities: A Paradox in Managing New Product Development'. *Strategic Management Journal* 13: 111-125.

156.Liker, J.K. 1998. 'Becoming Lean: Inside Stories of US Manufacturers' : Productivity Press.

157.Lipsey, R.G., Purvis, D.D. and Steiner, P.O. 1991. *Economics*: Harper Collins.

158.LMCO, L.M.C. 2002. 'Lean Scorecard and Self-Assessment Tool' : Lockheed Martin.

159.LMCO_WWW 2002. 'Supplier Lean Deployment Web Site' : Lockheed Martin.

160.Lucero, A. 2002. 'Lean Aerospace Initiative Enterprise Value Stream Mapping Workshop - An Industry Example' : Lockheed Martin Missiles and Space.

161.Magretta, J. 1998. 'The Power of Virtual Integration: An Interview with Dell Computer's Michael Dell'. *Harvard Business Review* Reprint 98208: 73-84.

162.Mahoue, F. 2000. 'e-Lean' . Cambridge: MIT LAI.

163.Maier, M.W. and Rechtin, E. 2000. *The Art of System Architecting*: CRC Press.

164.Malhotra, Y. 1996. 'Organizational Learning and Learning Organizations: An Overview (www document)' .

165.Malhotra, Y. 1998. 'Business Process Redesign: An Overview' : BRINT Institute.

166.Markish, J. 2002. 'Valuation Techniques for Commercial Aircraft Program Design' *Aeronautics and Astronautics*. Cambridge: Massachusetts Institute of Technology.

167.Maskell, B. 2001. 'How to Calculate the Financial Benefits of Lean Manufacturing' *LEI/University of Michigan 7th Annual Lean Manufacturing Conference*. Dearborn: Lean Enterprise Institute.

168.Maskell, B.H. and Baggaley, B.L. 'Lean Management Accounting for Lean Manufacturing' . Cherry Hill: Brian Maskell Associates, Inc.

169.McDougal, W.A. 1997. *The Heavens and the Earth: A Political History of the Space Age*. Baltimore, MD.: The Johns Hopkins University Press.

170.McLaughlin, M. and Keyte, B. 2001. 'Value Stream Mapping Beyond the Plant Floor' *LEI/University of Michigan 7th Annual Lean Manufacturing Conference*. Dearborn: Lean Enterprise Institute.

171.McNutt, R. 1998. 'Reducing DOD Product Development Time: The Role of the Schedule Development Process' *Aeronautics and Astronautics*. Cambridge: Massachusetts Institute of Technology.

172.McQuirter, P.D. and Woodfolk, A.K. 2001. 'Lean Logistics: Transformation to Lean' *LEI/University of Michigan 7th Annual Lean Manufacturing Conference*. Dearborn: Lean Enterprise Institute.

173.Mecham, M. 2002. 'Digital Bloodlines Make JSF a Different Breed' *Aviation Week and Space Technology*.

174.Mel Eisman, D.G. 1997. 'Life Cycle Cost Assessment for Military Transatmoshperic Vehicles.' : RAND.

175.Merriam-Webster 2001. 'Dictionary Definition of Strategy' : Merriam-Webster.

176.Meyer, C. 1998. 'How the Right Measures Help Teams Excel' *Harvard Business Review on Measuring Corporate Performance*. Boston: Harvard Business Review.

177.Mintzberg, H. 1987. 'Strategy Concept I: Five P's for Strategy'. *California Management Review* 30: 11-24.

178.Mintzberg, H. and Lampel, J. 1999. 'Reflecting on Strategy Process'. *Sloan Management Review*: 21-30.

179.Mize, J. and Hallam, C. 2002. 'LAI Enterprise Value Stream Mapping and Analysis Working Group: Stakeholder Value Taxonomy' . Cambridge: Massachusetts Institute of Technology.

180.Mize, J.H. 2002. 'Value Stream Mapping: Multiple Stakeholder Perspective' *Enterprise Value Stream Mapping Workshop*. Seal Beach, CA.: Massachusetts Institute of Technology Lean Aerospace Initiative.

181.Morrison, D.F. 1990. *Multivariate Statistical Methods*: McGraw-Hill.

182.Murman, E. 2000b. 'Enhancing Enterprise Value: An LAI Plenary Conference - Welcome and Overview' . Cambridge: MIT LAI.

183.Murman, E. 2000c. 'Enhancing Enterprise Value: LAI Executive Board Meeting' . Cambridge, MA: MIT LAI.

184.Murman, E., Allen, T., Bozdogan, K., Cutcher-Gershenfeld, J., McManus, H., Nightingale, D., Rebentisch, E., Shields, T., Stahl, F., Walton, M., Warmkessel, J., Weiss, S. and Widnall, S. 2002. *Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative*: Palgrave Publishers Ltd.

185.Murman, E., Walton, M. and Rebentisch, E. 2000. 'Challenges in the Better, Faster, Cheaper Era of Aeronautical Design, Engineering, and Manufacturing (LAI Report to Appear in the Aeronautical Jounral)' . Cambridge: Massachusetts Institute of Technology Lean Aerospace Initiative.

186.Myers, S.C. 2000. 'Enhancing Enterprise Value: An LAI Plenary Conference - Value to Investors' . Cambridge: MIT Sloan School.

187.Nadler, D.A. and Nadler, M.B. 1998. *Champions of Change: How CEO's and their Companies are Mastering the Skills of Radical Change*: Jossey-Bass.

188.Nagel, S. and Neef, M. 1990. *Operations Research Methods: As Applied to Political Science and the Legal Process*: SAGE Publications.

189.NAICS_WWW 2002. 'North American Industry Classification System (NAICS)' : U.S. Census Bureau.

190.Nanus, B. 1992. *Visionary Leadership: Creating a Compelling Sense of Direction for Your Organization*: Jossey-Bass.

191.Nelson, R.L. 2002. 'Breaking Down the Walls' *LAI Plenary Conference: Enterprise Value - The New Lean Horizon*. Century City, CA: MIT LAI.

192.Nelson, R.R. 1959. 'The Simple Economics of Basic Scientific Research'. *Journal of Political Economy* 67: 297-306.

193.Nightingale, D. 2000. 'Enterprise Transition-to-Lean Implementation Roadmaps' . Cambridge: MIT LAI.

194.Nightingale, D. 2000b. 'LEM Vision' . Cambridge: MIT LAI.

195.Nightingale, D. 2000c. 'Lean Enterprise Team Meeting Overview' . Cambridge: MIT LAI.

196.Nightingale, D. 2000d. 'Enterprise Value Stream' . Cambridge: MIT LAI.

197.Nightingale, D. 2001a. 'Growing the Lean Community: An LAI Plenary Conference - LESAT Lean Enterprise Self- Assessment tool' . Cambridge: MIT LAI.

198.Nightingale, D. 2001b. 'Growing the Lean Community: An LAI Plenary Conference - Enterprise Transition to Lean Roadmap' . Cambridge: MIT LAI.

199.Nightingale, D. 2002. 'Enterprise Value Stream Mapping at MIT' . Cambridge: MIT LAI.

200.Nightingale, D. 2002b. 'Lean Enterprise Vision - A Stakeholder Perspective' *Enterprise Value Stream Mapping Workshop*. Seal Beach, CA.: Massachusetts Institute of Technology Lean Aerospace Initiative.

201.Nightingale, D. 2002c. 'LAI Research: An Evolution Over Phases' . Cambridge: MIT LAI.

202.Nightingale, D. 2002d. 'Enterprise Value: The New Lean Horizon' *LAI Plenary Conference: Enterprise Value - The New Lean Horizon*. Century City, CA.: MIT LAI.

203.Nightingale, D. 2003. 'Pioneering the Future of Aerospace: Focusing on the Total Enterprise' *LAI Plenary Conference*. Dayton, Ohio: LAI.

204.Nightingale, D., Bozdogan, K., Milauskas, R., Mize, J., Taneja, A. and Tonaszuck, D. 2000. *Transitioning to a Lean Enterprise: A Guide for Leaders*. Cambridge: Massachusetts Institute of Technology Lean Aerospace Initiative.

205.Nightingale, D., Cool, C., Brown, K., Mize, J., Shields, T. and Hallam, C. 2001. *Lean Enterprise Self-Assessment Tool Facilitator's Guide (v1.0)*. Cambridge: Massachusetts Institute of Technology, Lean Aerospace Initiative.

206.Nightingale, D.J. and Mize, J.H. 2002. 'Development of a Lean Enterprise Transformation Maturity Model'. Journal of Information Knowledge Systems Management (IKSM), December.

207.Nightingale, N. 2001. 'Institution of 10X Continuous Improvement at Textron (Guest Lecture/Presentation in Integrating the Lean Enterprise, MIT 16.852)' .

208.NIST 2002. 'Baldridge National Quality Program: Why Apply?' . Gaithersburg, MD: National Institute of Standards and Technology, Technology Administration, United States Department of Commerce.

209.Ohno, T. 1988. *Toyota Production System: Beyond Large Scale Production*: Productivity Press.

210.Ohno, T. and Mito, S. 1988. *Just-In-Time for Today and Tomorrow*: Productivity Press.

211.OI_WWW 2002. 'History of Lean' : Optiprise Incorporated.

212.Ortega, J. 2001. 'Job Rotation as a Learning Mechanism'. *Management Science* 47: 1361-1370.

213.Oster, S.M. 1999. *Modern Competitive Analysis*: Oxford University Press.

214.Oxford_WWW 2001. 'Dictionary Definition of Strategy' : Oxford Online Dictionary.

215.Paulk, M.C., Weber, C.V., Curtis, B. and Chrissis, M.B. 1997. *The Capability Maturity Model: Guidelines for Improving the Software Process*. Reading, MA: Addison-Wesley.

216.PDBPR 1998. 'Hewlett-Packard Division Chief Uses Strategic Outsourcing to Stay Lean, Focused, and Competent' : Product Development Best Practices Report.

217.Pickard, J. 1995. 'Learning that is Far From Academic'. *People Management* 1: 32.

218.Pindyck, R.S. and Rubenfeld, D.L. 1998. *Microeconomics*: Simon and Schuster.

219.Pinker, E.J. and Shumsky, R.A. 2000. 'The Efficiency-Quality Trade-Off of Cross-Trained Workers'. *Manufacturing & Service Operations Management* 2: 32-48.

220.Pitts, J.F. 2000. 'Enhancing Enterprise Value: An LAI Plenary Conference - Creating Value Across the Enterprise' : Northrop Grumman ESSS.

221.Pollack, A. 1999. 'Aerospace, Following Toyota's Example, Gets Lean' *New York Times*. New York.

222.Polonsky, M.J., Schuppisser, S.W. and Beldona, S. 2002. 'A Stakeholder Perspective for Analyzing Marketing Relationships'. *Journal of Market-Focused Management* 5: 109-126.

223.Porter, M.E. 1979. 'How Competitive Forces Shape Strategy'. *Harvard Business Review* March-April.

224.Porter, M.E. 1985. 'Technology and Competitive Advantage' *Competitive Advantage*. NY, NY: The Free Press.

225.Porter, M.E. 1987. 'From Competitive Advantage to Corporate Strategy'. *Harvard Business Review* May-June 1987.

226.Porter, M.E. 1996. 'What is Strategy?' *On Competition*. Boston: Harvard Business Review.

227.Porter, M.E. 1998. *On Competition*: Harvard Business School Press.

228.Proctor, P. 1998. 'Boeing Shapes 737-900, Battles Production Woes: Concurrent Design and Engineering of four 737 models is boosting efficiency.' *Aviation Week and Space technology*.

229.Quinn, F.J. 'The Payoff in Supply Chain Management' : Supply Chain Management Review.

230.Rahn, R.D. and Kiran, A.S. 2001. *Advanced Flow Manufacturing: Flow and Lean Manufacturing for the 21st Century*. Boulder: Flow Publishing.

231.Rea, L.M. and Parker, R.A. 1997. *Designing and Conducting Survey Research: A Comprehensive Guide*: Jossey-Bass.

232.Rebentisch, E. 2000. 'Creating Value Across the Enterprise: Pathways to a Robust and Prosperous US Aerospace Enterprise' . Cambridge: Massachusetts Institute of Technology Lean Aerospace Initiative.

233.Reid, P.C. 1990. *Well Made in America: Lessons From Harley-Davidson on Being the Best*: Mc-Graw Hill Publishing Company.

234.Robbins, S.P. 1994. *Essentials of Organizational Behavior*.

235.Robbins, S.P. 1998. *Organizational Behavior: Concepts, Controversies, and Applications*: Prentice-Hall International.

236.Robbins, S.P. 2001. *Organizational Behavior*: Prentice-Hall.

237.Romer, P.M. 1990. 'Endogenous Technological Change'. *Journal of Political Economy* 98: S71-S101.

238.Rosenberg, N. 1990. 'Why do Firms do Basic Research (with their own money)?'. *Administrative Science Quarterly* 19: 165-174.

239.Rother, M. 1998. 'Crossroads: Which Way Will You Turn on the Road to Lean?' in Liker, J.K. (ed.) *Becoming Lean: Inside Stories of US Manufacturers*: Productivity Press.

240.Rother, M. and Shook, J. 1998. *Learning To See: Value Stream Mapping to Add Value and Eliminate Muda*. Brookline: Lean Enterprise Institute.

241.Rouse, W.B. 2001. *Essential Challenges of Strategic Management*: John Wiley and Sons.

242.Ruffa, S. 2000. 'Lean Manufacturing Offers Remedy to Spare Parts Crisis' *National Defense (www)*.

243.Saville, D.J. and Wood, G.R. 1991. *Statistical Methods: The Geometric Approach*: Springer-Verlag.

244.Schein, E.H. 1980. *Organizational Psychology*. Englewoods Cliffs: Prentice-Hall.

245.Schein, E.H. 1983. 'Organizational Culture: A Dynamic Model' . Cambridge, MA: Massachusetts Institute of Technology.

246.Schein, E.H. 1989. 'Organization Development: Science, Technology, or Philosophy? (Invited Address to the Academy of Management, Organization Development Division, New Orleans, August 15, 1989).' . Cambridge, MA: Massachusetts Institute of Technology.

247.Schein, E.H. 1992. *Organizational Culture and Leadership*. San Francisco: Jossey-Bass Publishers.

248.Schein, E.H. 1995. 'Organizational and Managerial Culture as a Facilitator of Inhibitor of Organizational Transformation (Presented to the Inaugural Assembly of Chief Executives and Employers in Singapore, June 29, 1995)' . Cambridge, MA: Massachusetts Institute of Technology.

249.Schein, E.H. 1995b. 'Kurt Lewin in the Classroom, in the Field, and in Change Theory: Notes Toward a Model of Managing Learning (Invited Paper for a special issue of Systems Practice edited by Susan Wheelan, March 1995)' . Cambridge, MA: Massachusetts Institute of Technology.

250.Schein, E.H. 1995c. 'The Leader of the Future (Prepared for the Drucker Foundation volume on Leadership, April 1, 1995)' . Cambridge, MA: Massachusetts Institute of Technology.

251.Schein, E.H. 1999. *The Corporate Culture Survival Guide: Sense and Nonsense About corporate Change*. San Francisco: Jossey-Bass Publishers.

252.Schein, E.H., Schneier, I. and Barker, C.H. 1961. *Coercive Persuasion: A Socio-psychological Analysis of the "Brainwashing" of American Civilian Prisoners by the Chinese Communists*. New York: W.W. Norton & Company.

253.SEI_WWW 2002. 'Capability Maturity Model for Software (SW-CMM)' : Carnegie Mellon Software Engineering Institute.

254.Senge, P.M. 1990. *The Fifth Discipline: The Art and Practice of the Learning Organization*: Doubleday.

255.Serven, L.B.M. 1998. *Value Planning: The New Approach to Building Value Every Day*: John Wiley and Sons, Inc.

256.Shah, N. and Davidz, H. 2002. 'LEAP - Lean Effects on Aerospace Programs' *LAI Plenary Conference: Enterprise Value - The New Lean Horizon*. Century City, CA: MIT LAI.

257. Sheffi, Y. 2001. ' Supply Chain Management under the Threat of International Terrorism'. *International Journal of Logistics Management* 12.

258. Shields, T. 2001. 'Growing the Lean Community: An LAI Plenary Conference - Production Operations Transition To Lean'. Cambridge: MIT LAI.

259. Shingo, S. 1989. *A study of the Toyota Production System From an Industrial Engineering Viewpoint*: Productivity Press.

260. Shook, J. and Verble, D. 2001. 'Organization and Leadership for Effective Value Stream Management' *LEI/University of Michigan 7th Annual Lean Manufacturing Conference*. Dearborn: Lean Enterprise Institute.

261. Siekman, P. 2000. 'Glass Act: How a Window Maker Rebuilt Itself' *Fortune*.

262. Simchi-Levi, D. and Simchi-Levi, E. 2001. 'The Effect of e-Business on Supply Chain Strategy'. Cambridge: Massachusetts Institute of Technology.

263. Slack, R.A. 1999. 'The Lean Value Principle in Military Aerospace Product Development' *Lean Aerospace Initiative*. Cambridge: Massachusetts Institute of Technology.

264. Slywotzky, A.J. 1996. *Value Migration: How to Think Several Moves Ahead of the Competition*: Harvard Business School Press.

265. Smith, B.A. 2000a. '717 Final Assembly Line Poised to Ride on Rails' *Aviation Week and Space Technology (www)*.

266. Smith, J. 2001. 'Heijunka Planning for Internal Operations and Supply Base' *LEI/University of Michigan 7th Annual Lean Manufacturing Conference*. Dearborn: Lean Enterprise Institute.

267. Smith, T. 2000b. *Technology and Capital in the Age of Lean Production*: State University of New York Press.

268. Snedecor, G.W. and Cochran, W.G. 1980. *Statistical Methods*: Iowa State University Press.

269. SOCE 2003. 'Society of Concurrent Product Development'.

270. SPSS 1999. 'SPSS 11.0 and User Guide'. Chicago: SPSS Inc.

271. Stallkamp, T. 2001. 'Partnerships in the Extended Enterprise (Keynote Address)' *LEI/University of Michigan 7th Annual Lean Manufacturing Conference*. Dearborn Michigan: LEI.

272. Stanke, A.K. 2001. 'A Framework for Achieving Lifecycle Value in Product Development' *Aeronautics and Astronautics*. Cambridge: Massachusetts Institute of Technology.

273. Stec, D. 2001. 'Fallacies and Realities of Reverse On-Line Auctions' *LEI/University of Michigan 7th Annual Lean Manufacturing Conference*. Dearborn: Lean Enterprise Institute.

274. Stephan, P.E. 1996. 'The Economics of science'. *Journal of Economic Literature* XXXIV: 1199-1235.

275. Sterman, J.D. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World*: Irwin, McGraw-Hill.

276. Stewart, T.A. 1999. *Intellectual Capital: The New Wealth of Organizations*: Doubleday.

277. Strong, E.P. and Smith, R.D. 1968. *Management Control Models*: Holt, Reinhart and Winston.

278. Suzaki, K. 1987. *The New Manufacturing Challenge: Techniques for Continuous Improvement*: The Free Press (Simon and Schuster).

279. Suzaki, K. 1993. *The New Shop Floor Management: Empowering People for Continuous Improvement*: The Free Press.

280. Taneja, A. 2000. 'Knowledgemediaries' . Cambridge: MIT LAI.

281. Tanis, E.A. 1987. *Statistics I: Descriptive Statistics and Probability*: Harcourt, Brace and Jovanovich.

282. Tanis, E.A. 1987b. *Statistics II: Estimation and Tests of Hypotheses*: Harcourt, Brace and Jovanovich.

283. Teece, D.J. 1987. 'Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy.' in Teece, D.J. (ed.) *The Competitive Challenge*. Cambridge, MA: Ballinger Publishing.

284. Teece, D.J. 1998. 'Capturing Value from Knowledge Assets: The New Economy, Markets for Know-How, and Intangible Assets'. *California Management Review* 40: 55-79.

285. Thornton, A.C., Donelly, S. and Ertan, B. 2000. 'More than Just Robust Design: Why Product Development Organizations Still Contend with Variation and its Impact on Quality' . Cambridge: Massachusetts Institute of Technology.

286. TMC_WWW 2001. 'History of Toyota' : Toyota Motor Company.

287. Tonaszuck, D.M. 1999. 'The Impact of Leadership on Systematic Organizational Change' *System Design and Management*. Cambridge: Massachusetts Institute of Technology.

288. TST 1992. 'The Software Toolworks Multimedia Encyclopedia' : The Software Toolworks.

289. Tzu, S. 1983. 'The Art of War' in Clavell, J. (ed.) .

290. U.S._Census_Bureau 2001. 'Statistical Abstract of the United States: 2001' : U.S. Department of Commerce, Economics and Statistics Administration.

291. UK_LAI_WWW 2003. 'United Kingdom Lean Aerospace Initiative Home Page' : UK Lean Aerospace Initiative.

292. Ulrich, K.T. and Eppinger, S.D. 2000. *Product Design and Development*: McGraw-Hill Higher Education.

293. unknown 1994. 'Suppliers Beware! The Gap is Widening.'. *Journal of Manufacturing Engineering* 113.

294. unknown 1997. 'Lean' Manufacturing systems have big payoff' *Purchasing*.

295. unknown 2001. 'Let The Bad Times Roll' *The Economist*.

296. Useem, J. 2000. 'Boeing Vs. Boeing: America's Export Champion is Going Head-to-Head with a Company even Tougher than Airbus - Itself.' *Fortune*.

297. Utterback, J.M. 1994. *Mastering the Dynamics of Innovation: How Companies Can Seize Opportunities in the Face of Technological Change*. Boston: Harvard Business School Press.

298. Uzair, K.M. 2001. 'Development of a Framework for Comparing Performance Improvement Programs' *System Design and Management*. Cambridge: Massachusetts Institute of Technology.

299. Vaughn, M. 2001. 'Summary of Research Conducted by the (LAI) Manufacturing Systems Team' . Cambridge: MIT LAI.

300. Veech, Davis S. M.U. 2001. 'Learning in a Lean System' : University of Kentucky.

301. Velocci, A.L. 2000. 'Primes Pressing Suppliers to Adopt Lean Practices' *Aviation Week and Space Technology*.

302. Velocci, A.L. 2002. 'Strong Momentum Sets Top Performers Apart' *Aviation Week and Space technology*.

303. Wall, T. 2001. 'The Journey Towards Lean: A Partnership in the Transformation into a Lean Enterprise' *LEI/University of Michigan 7th Annual Lean Manufacturing Conference*. Dearborn: Lean Enterprise Institute.

304. Ward, A., Fleischer, M. and Sobek, D. 2001. 'Supplier/Customer Partnerships for Lean Product and Manufacturing System Development' *LEI/University of Michigan 7th Annual Lean Manufacturing Conference*. Dearborn: Lean Enterprise Institute.

305. Ward, Y. 2001. 'Accounting for Lean in Aerospace' . Bath, England: University of Bath School of Management as part of the UK Lean Aerospace Initiative for the Society of British Aerospace Companies (SBAC).

306. Ward, Y. 2001b. 'Aerospace Measures Up - Aerospace Metric Results' . Bath, England: University of Bath School of Management as part of the UK Lean Aerospace Initiative for the Society of British Aerospace Companies (SBAC).

307. Ward, Y. and Graves, A. 2001. 'Lean Performance Measurement for Aerospace' . Bath, England: University of Bath School of Management as part of the UK Lean Aerospace Initiative for the Society of British Aerospace Companies (SBAC).

308. Ward, Y. and Haque, B. 2001. 'Performance Metrics for Lean Implementation' . Bath, England: University of Bath School of Management and the University of Warwick Manufacturing Group, as part of the UK Lean Aerospace Initiative for the Society of British Aerospace Companies (SBAC).

309. Wei, Y.-F. 2001. 'Concurrent Design for Optimal Quality and Cycle Time' . Cambridge.

310. Weiss, D.J. 1976. 'Multivariate Procedures' in Dunnette, M.D. (ed.) *Handbook of Organizational and Industrial Psychology*. Chicago: Rand McNally College Publishing Company.

311. Wheatley, M. 1998. 'Pile it Low, Sell it Fast'. *Management Today*: 68-70.

312. Wheelwright, S.C. and Clark, K.B. 1992. *Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality*. New York: The Free Press, Macmillan Inc.

313. Wibberley, M. 1993. 'Does "Lean" Necessarily Equal Mean'. *Personnel Management* 25: 32.

314. Wiggins, R.R. and Ruefli, T.W. 2002. 'Sustained Competitive Advantage: Temporal Dynamics and the Incidence and Persistence of Superior Economic Performance.'. *Organization Science* 13: 82-105.

315. Womack, J. 2001. 'Lean Thinking for the Extended Value Stream' *LEI/University of Michigan 7th Annual Lean Manufacturing Conference*. Dearborn: Lean Enterprise Institute.

316. Womack, J. 2002. 'LEI's Indicator that Can't Lie: Doing the Math' . Brookline: Lean Enterprise Institute.

317. Womack, J. 2003. 'Here's to Toyota' : LEI.

318. Womack, J.P. and Jones, D.T. 1994. 'From Lean Production to the Lean Enterprise'. *Harvard Business Review*: 93-103.

319. Womack, J.P. and Jones, D.T. 1996. *Lean Thinking: Banish Waste and Create Value in Your Corporation*: Simon and Schuster.

320. Womack, J.P., Jones, D.T. and Roos, D. 1990. *The Machine That Changed the World: The Story of Lean Production*: Harper Perennial.

321. Wordsmyth 2001. 'Dictionary Definition of Strategy' : The Wordsmyth Educational Dictionary-Thesaurus (Online).

322. Worthy, J.C. 1994. *Lean But Not Mean: Studies in Organization Structure*: University of Illinois Press.

323. Younossi, O., Kennedy, M. and Graser, J.C. 2001. 'Military Airframe Costs: The Effects of Advanced Materials and Manufacturing Process' : RAND.