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LEAN TRANSFORMATION IN THE U.S. AEROSPACE INDUSTRY: APPRECIATING INTERDEPENDENT SOCIAL AND TECHNICAL SYSTEMS

Joel Cutcher-Gershenfeld

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Joel Cutcher-Gershenfeld
Massachusetts Institute of Technology
1 Amherst Street, E40-247
Center for Technology, Policy and Industrial Development, MIT
Cambridge, MA 02139
617-253-5777 – joelcg@mit.edu

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Abstract

Lean practices and principles build on a half-century of successive initiatives aimed at transforming social and technical systems in organizations. While they are seen as central to the revitalization of the U.S. aerospace industry, there is great variation in the degree to which lean initiatives emphasize just technical/manufacturing systems versus additional social and enterprise dimensions. Based on a national random sample survey of 362 U.S. aerospace facilities, this paper examines factors that account for the incidence of lean practices and the impact on outcomes relevant to key stakeholders. While structural factors such as industry sector, facility size and others have limited explanatory power, two process factors – organizational learning and the value placed on intellectual capital – do account for the increased presence of lean practices. In examining employment outcomes, facilities higher just on the technical/manufacturing aspects of lean have a significant and negative impact on job growth, while facilities higher around the social systems associated with lean have significant and positive employment growth. This finding is consistent with the views of critics of the more narrow technical, manufacturing-oriented approaches to lean as a threat to employment and it validate proponents of a broader value-creating approach to lean as a way of growing the enterprise. Enterprise dimensions of lean (including both social and technical aspects of lean) have a positive impact on productivity. Examining outcomes relevant to multiple stakeholders and various factor inputs produces a more complete understanding of the limitations and potential for lean transformation in the aerospace industry.

Key Words: *Lean transformation, social and technical systems, aerospace industry*

Introduction

Throughout the past half century there has been a succession of major systems change initiatives designed to transform work and organizations. These include the human relations movement of the 1950s, the socio-technical systems design experiments of the 1960s and 1970s, the quality of work life and total quality management initiatives of the 1980s, and a current array of initiatives involving organizational learning, lean manufacturing and lean enterprise transformation, Six Sigma, and others. All of these initiatives have emerged in one way or another in response to the combination of mass production, the division of labor in organizations, and the bureaucratic organizational form – which marked the first half of the past century and were linked to initiatives such as scientific management and the civil service reform movement.[1] All of the more recent initiatives emphasize (in varying degrees) participation, teamwork, problem solving, learning, continuous improvement, flow of material and services, delivery of value, and a systems mindset. An enduring challenge associated with all of these initiatives involves understanding the interdependence of the social and technical systems in organizations – as elements of the change initiatives and dimensions on which the outcomes can be assessed. The broad purpose of this paper is to focus on one of the more comprehensive current initiatives – those building on lean practices and principles – in the context of a particularly relevant industry – aerospace – in order to build deeper understanding around this social and technical interdependence.

Lean practices and principles are central to the success of competitive leaders in many sectors of the economy, whether it is the way Toyota manages quality and production flow in its

[1] While we are today critical of these as segmented, mechanistic initiatives, they were embraced at the time as advantageous relative to craft and patronage based work/organizational systems.

manufacturing operations or the way Dell provides high volume customization in personal computers. In the U.S. aerospace industry, many facilities are involved in the implementation of these practices and principles, though few have completed the transformation into fully lean operations. Moreover, this industry, notorious for what are considered wasteful practices in both military and commercial sectors, is now under pressure to deliver better products in faster and less expensive ways. Aerospace is also one of the world's prestige industries, representing an importance source of export dollars for the US and EEU, as well as a leading symbol of technological progress for many nations. As such, aerospace provides a unique opportunity to examine the factors driving lean transformation, as well as the implications for outcomes relevant to key stakeholders.

Background

The term "lean" was initially popularized by the book *The Machine the Changed the World* (Womack, Jones and Roos, 1990). This word crystallized a broad range of practices and principles where continuous improvement was made possible through the systematic elimination of waste, the reduction of in-process inventory, the use of just-in-time delivery, in-station process control, continuous improvement suggestions, systems thinking, and other related elements (Krafcik, 1989; Womack and Jones, 1996). Lean practices and principles encompass long-standing quality principles (Deming, 1987; Juran, 1999) and more recent developments, such as Six Sigma (Ekes, 2001).

Although the Japanese operations from which the term was initially fashioned always gave prominence to the social or intangible aspects of lean systems (Imai, 1986; Shimada and MacDuffie, 1986; Monden, 1988; Ohno, 1998; Kenny and Florida, 1995; Cutcher-Gershenfeld, et. al., 1998), many applications of lean practices and principles have focused more narrowly on the technical or physical aspects of lean systems (such as inventory delivery systems and "andon" quality control lights and information boards). Indeed, the term "lean" has become so associated with narrowly focused cost cutting initiatives – emphasizing layoffs and outsourcing – that it sometimes generates fear in the workforce and in communities where lean initiatives are announced. The central thesis driving this paper is that the social and technical aspects of lean implementation are interdependent. Taken together, there is the potential for the sort of systemic transformation originally intended; advanced separately, there is the risk of unstable or incomplete outcomes.

The aerospace industry provides a useful context to examine lean implementation. It is a diverse sector of the economy that encompasses airframes, engines, space and missiles, avionics and a vast array of second and third tier suppliers. There are great competitive challenges in both the civilian and military parts of the industry, driven by the end of the Cold War, the rise of global competition, the development of new materials and new technologies, and the emergence of what are termed "dominant designs" in many segments of the market (Utterback, 1996). In this mix, lean practices and principles have been highlighted as central to the revitalization of the industry. For example, Norman Augustine, retired Chairman and CEO of Lockheed Martin, called for the application of principles from *The Machine that Changed the World* (1990) to this industry, commenting that, "The U.S. aerospace industry has restructured what it is, now it must restructure what it does and how it does it" (Murman, et. al., 2002). Indeed, in the industry there is still great variation in practice and an ongoing debate among practitioners as to the full applicability of lean principles derived from high-volume automotive production systems.

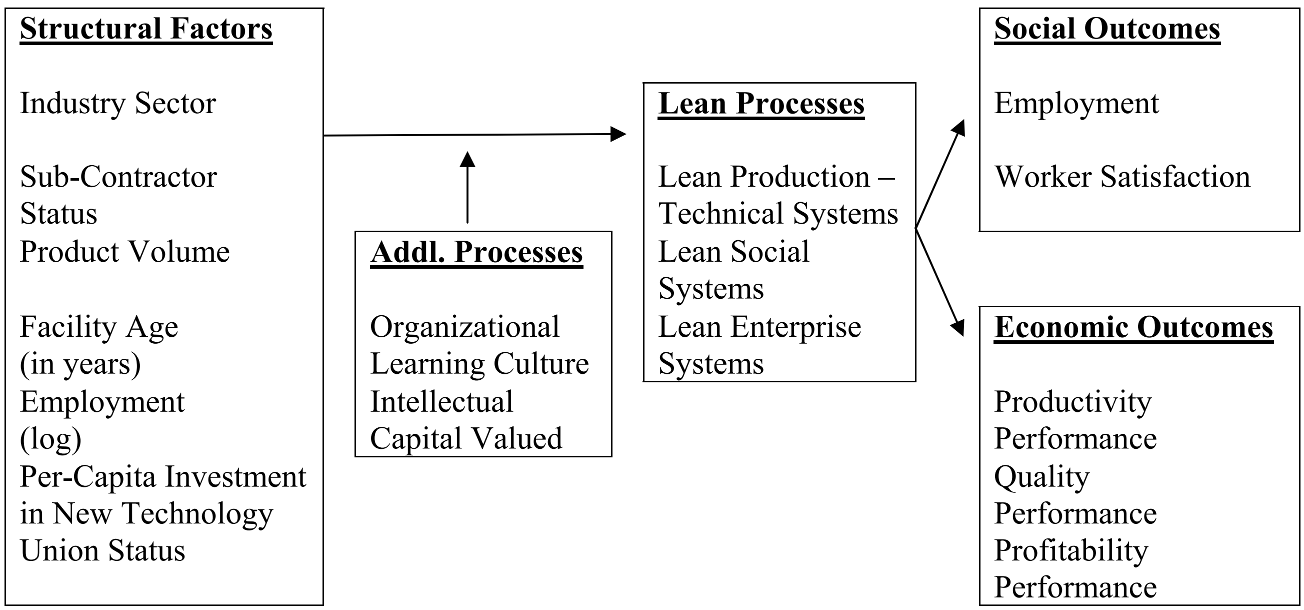
Moreover, there is also significant debate around the relative impacts of the social and technical dimensions of "lean." Employees and their union representatives have been critical of narrowly focused technical lean manufacturing initiatives that have sought to eliminate waste and improve operations largely through reductions in in-process inventory, improvements in material flow, increased preventative maintenance and other means. Such efforts have been criticized as biased toward cost cutting that reduces "head-count," rather than increasing value or growing the operations. This is particularly troubling given the massive job loss in this sector – from over 1.3 million jobs in 1990 to under 800,000 jobs in 2002 (Buffenbarger, 2002). Conversely, a recent book produced by MIT's Lean Aerospace Initiative – entitled *Lean Enterprise Value* – presents propositions emphasizing the integration of social and technical dimensions of lean, as well as the importance of people in effectuating lean value (Murman, et. al., 2002). The analysis in this paper speaks directly to one of the five core principles in the book, which states that "people, not just processes, effectuate lean value."

At a more general level, there is a long history of emphasizing the social and technical dimensions of complex systems (Trist, 1978; Pava, 1983), though comparatively little systematic research examining such issues at an industry or other higher level of aggregation. This research represents an important opportunity to build beyond the body of case study scholarship built by socio-technical researchers in an earlier era and an important contribution to current explorations of complex engineering systems (MIT Engineering Systems Division, 2002).

Overall Research Questions and Model

This paper examines the factors that explain the incidence of lean practices and principles, as well the consequences for social and economic performance outcomes. The overall model guiding the analysis is presented in Figure 1, which provides a conceptual map of all the key variables utilized in the analysis.

Figure 1
Model for Analysis of the Causes and Consequences
of Social and Technical Systems Associated with Lean Transformation



The purpose of presenting the full model here is to provide an orientation to the overall focus of the research. The specific ways in which these variables are operationalized is presented in more detail later in the paper. The first part of the paper concerns what can be termed the causal factors associated with the prevalence of the technical aspects of lean production systems, the social systems associated with lean principles and practices, and other overall enterprise aspects of lean. For this analysis, the three types of lean processes serve as the dependent variables. The structural factors are utilized to predict these various lean outcomes. Two additional process factors are also used in the analysis to help predict the incidence of the three dimensions of lean. These are process factors that could be the entire focus of research in their own right (which is being conducted in parallel with the analysis presented here), but they are examined in this research as potential complementary aspects to lean transformation.

The second part of the analysis concerns the impact of all the structural and process factors on various outcomes. Both social and economic performance outcomes are considered, reflecting what might be considered a balanced scorecard approach to organizational performance (Kaplan, 1996).

A National Aerospace Facility Survey

The data for this paper are derived from two national, random-sample surveys of aerospace facilities in the United States. The first survey was conducted in 1999 and features responses from 194 facilities. The second survey, which is the basis for most of the research presented in this paper, was conducted in 2002 and features responses from 362 facilities. In both cases, the samples were drawn from McGraw-Hill's National Aerospace Directory, which involved mailings to approximately 2,500 facilities each time. In both surveys, approximately 300 surveys were returned as having bad addresses or (in a smaller number of cases) as companies that were no longer in the aerospace industry. Subsequent telephone follow-up with approximately 900 of the first sample and 400 of the second sample revealed a large number of surveys that never completed the journey from the mail room to the office of the senior manager, as well as a smaller number of respondents who only had a small proportion of business in the aerospace industry. While it is difficult to estimate the full weighting to give to the various reasons for non-response, the first survey can be conservatively assumed to have between a 10% and 15% response rate, while the second can be conservatively assumed to have between an 18% and 23% response rate.

The facilities in the sample have an average size of 558 employees, though the range is from very small operations with less than ten employees to some very large operations which are really complexes that have over 20,000 employees. The average facility in this sample was built in 1976, with a range that is quite broad, including some brand new operations and some that date back before World War II. On average, the facilities in this sample have about 30 percent of their sales to their largest customer, with an average of 5.4 major government programs and 8.9 major commercial programs at each facility. Approximately 15 percent of the facilities are unionized in this sample. Also, the distribution of production operations in these facilities reflects the low volume nature of this industry, with 60 percent of the facilities reporting that their primary product involves low volume production, 32 percent reporting medium volume and only 8 percent reporting high volume for their primary product. The distribution across major sectors of this industry is as follows:

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

This distribution is roughly consistent with the distribution of operations in the industry.[2]

The advantages of these data sets is that they may be the first national random sample surveys of work practices, lean principles, organizational outcomes and related factors for the aerospace industry. As well, the respondents are highly knowledgeable, with an average of 24 years experience in aerospace. Nearly 40 percent of the respondents hold the titles "president" or

[2] Precise industry distributions are hard to estimate since firms span multiple sectors through acquisitions and shifts in business strategy. Many firms also span aerospace and other industries.

"CEO," approximately another 40 percent of the respondents hold the titles of "vice president of operations" or "plant/facility/operations manager," and the balance of respondents hold other senior functional titles. On average, the respondents have undergraduate degrees and some graduate education.

Still, there are limitations to the data. First, these are two cross-sectional surveys. While there is a panel of firms who responded to both surveys, the analysis presented here does not focus on this panel (in order to maintain sufficient degrees of freedom for the multivariate analysis). Second, these are responses from single respondents at the facility level. This means that the data will reflect a predominantly managerial bias and that interdependencies across facilities (such as customer-supplier relations or cross-divisional relations within a larger company) will only be seen from one perspective. Third, there are always threats of common method bias with any research based on a single survey. Although the presence of two rounds of surveys with consistent findings on factors that would not be expected to change does help to reduce these concerns, the data within each survey does have this threat to validity. Fourth, key outcome variables are measured as single items. While these outcomes can be combined together into highly reliable scales, some important distinctive information is lost in the process – so the single items are used. Fifth, the first survey was conducted during a period in which industry sales were growing, but facing declining investment by Wall Street. The second survey was conducted after the events of September 11, 2001, during a period of recession in the commercial sector and some expansion in the military sector. The reader is urged to bear in mind these factors when interpreting the findings from this research.

Social, Technical and Enterprise Dimensions of Lean Implementation

At a superficial level, lean is one of many change initiatives found in the aerospace industry and in many other sectors of the economy. As Table 1 suggests, the most common change initiatives in this industry are employee involvement (EI) and total quality management (TQM), both initiatives that are no longer in the public spotlight but still prevalent in just over half of the facilities. Of all the initiatives, only two show substantial growth from 1999 to 2002, which are lean production and kaizen improvement initiatives (a targeted application of certain lean principles).[3]

Insert Table 1 About Here
Organizational Change Initiatives in the U.S. Aerospace Industry: 1999 and 2002

While the relative distribution of initiatives is instructive, it is hard to know what respondents have in mind when they indicate the presence of lean initiatives. As a result, a more detailed set of questions was posed on specific aspects of lean systems. Of these questions, four involved what can be thought of as traditional technical aspects of lean, focused on manufacturing operations. These have been combined into a "Lean Manufacturing – Technical Systems Scale," which is as follows:

[3] Note that the Japanese concept of kaizen is commonly understood based on its literal translation, which involves continuous improvement based on knowledge (Imai, 1986; Cutcher-Gershenfeld, et. al., 1998). This suggests an incremental approach to change. In fact, the term as been used very differently in the aerospace industry, where people refer to "kaizen events" comparable to more discrete re-engineering initiatives, which are almost the opposite of a traditional kaizen approach. In either case, however, there is a focus on key lean principles of waste reduction in order to enable increased flow of material and information.

Lean Manufacturing – Technical Systems Scale *(scale reliability alpha = .60)* with four questions concerning:

- Minimal "in-process" inventory
- Reducing cycle times
- Preventative maintenance
- In-process inspection

A second set of six items involve the social and more intangible aspects of lean, which have been combined into the following "Lean Social Systems Scale:"

Lean Social Systems Scale *(scale reliability alpha = .80)* with six questions concerning:

- Flexible job assignments
- Job rotation
- High levels of worker responsibility on the job
- Extensive formal group process training
- Emphasis on the continuous improvement
- High trust between management and employees

These ten items have been combined with five additional items spanning across the enterprise (beyond manufacturing to include product development and the supply chain) to form the "Lean Enterprise Scale," which is as follows:

The full Lean Enterprise Scale *(scale reliability alpha = .88)* with the above ten items and these five additional factors:

- Simultaneous/concurrent engineering
- Engineering organized by integrated product or process teams (IPTs)
- Scheduling on a "pull" basis driven by customer orders
- "Flow" of material or design ideas -- no wasted steps
- Tightly integrated suppliers

Note that the use of the term "enterprise" reflects an expanded view of lean, which can encompass a particular program, such as the network of suppliers and prime contractors associated with the F-22, or a multi-program enterprise, such as the Lockheed Martin Corporation (Murman, et. al., 2002). While other levels of "enterprise" are possible, the point here is that these are practices that reach beyond a given facility and link to a supply chain or a product value stream.

These three scales will serve as the dependent variables in the first analysis and as independent variables (along with the structural and other process variables) in the second analysis. In each case, it is a six point scale for which a "1" represents "not found at all in this facility," a "3" and "4" represents "partly true of this facility," and a "6" represents "completely true of this facility." Respondents were also offered the chance to indicate any item as "not applicable."

Bivariate Analysis of Factors Predicting Lean Practices

In trying to predict the incidence of social, technical and enterprise lean practices in the aerospace industry, we will first compare the means for the three lean scales with a number of structural variables. This will help to introduce how these variables have been constructed and examine first-order or primary effects. Where there are hypotheses around expected relationships among the variables it will be indicated in the text. Then we will turn to multivariate analysis taking all of the variables into account at the same time.

The bivariate analysis of means begins with the major sectors of the industry. Since the lean concepts were first codified in the auto industry, which features high volume production, and since lean practices are also found the computer electronics business, we would anticipate the utilization of lean principles to be in high use in the avionics sector. This involves computer electronics and it is the highest volume portion of the industry. In fact, there is little difference across sectors of the economy when it comes to lean practices. For example, the average response on the six-point lean enterprise scale for the airframes and mechanical systems sector was 3.9; aircraft engines and propulsion was 4.0; space, launch and missiles was 3.9 and avionics was 3.8. The differences among these responses are not statistically significant, suggesting that the prevalence of lean practices across different sectors of the industry does not vary considerably by sector and, on average, the utilization of the practices is only partial. There were also no significant differences across sectors for the Lean Manufacturing/Technical Scale and for the Lean Social Systems Scale (though the average response on the Lean Manufacturing/Technical Scale was slightly higher, at 4.1, for all sectors). Similarly, there were no significant differences on any of the three lean scales comparing sub-contractors with what are known as the prime or original equipment manufacturers (OEMs).

Just as we would have expected there to be differences between avionics and other sectors, we would also expect lean practices to be more prevalent in high volume operations. In fact, the mean for the Lean Enterprise Scale in both high and medium volume operations is 3.9, while it is 3.8 for low volume operations – a difference that is not statistically significant. There are also no significant differences for the Lean Manufacturing/Technical Scale and for the Lean Social Systems Scale.

It is hard to make predications for how facility size would be expected to influence the incidence of lean practices and principles. On the one hand, implementation is much easier in a smaller facility. On the other hand, there are generally more resources available for implementation and an increased potential for corporate initiatives around lean in a larger facility. In fact, the means in Table 2 suggest that there are some differences based on size, with the differences among the means on the Lean Enterprise Scale being statistically significant. While the patterns are less clear in comparisons based on facility age for the Lean Enterprise Scale and the Lean Manufacturing/Technical Scale, there is a clear and statistically significant trend for facility age and the Lean Social Systems Scale – with the newer facilities more likely to feature more of the social system practices. Note that the upcoming multivariate analysis uses the log of employment for facility size since the very largest facilities represent substantial outliers with respect to the bulk of facilities which have under 250 employees.

Insert Table 2 About Here
Means for Lean Practices – Technical, Social and Enterprise – by Facility Size and Age
2002 National Aerospace Facility Survey

		Lean Enterprise Scale	Lean Production -- Technical Systems	Lean Social Systems
Facility Size	Under 250 employees	3.8	4.1	3.9
	250-1,000 employees	4.1	4.1	3.9
	Over 1,000 employees	4.0	4.3	3.8
Facility Age	Earliest to 1959	3.7	4.1	3.7
	1960-1969	3.9	4.0	3.8
	1970-1979	3.7	4.0	3.9
	1980-1989	4.0	4.3	4.2
	1990-present	3.9	4.1	4.0

Investment in new technology is an important control factor since performance outcomes could be a result of these investments rather than lean production systems. Respondents were asked to rate new investments over the prior three years across five categories, which were "none," "Under $500K," "$500K-$5 Million," "$5 Million-$25 Million," and "Over $25 Million." For this analysis, an estimate of per-capita investment was calculated with facility employment and the mid-point of each of the designated ranges.[4] It might be predicted that per-capita investment would correlate with lean practices, since new investment might be expected to be made in the most advanced facilities. In fact, the comparison of means is significant in the opposite direction for all three variables. For example, the Lean Enterprise Scale mean for per-capita investment of zero to fifty dollars is 3.9, while it is 3.7 for fifty to one-hundred dollars, and 3.2 for investments of over one-hundred dollars. A possible interpretation of this unexpected

[4] A value of $35 Million used at the high end since there is no midpoint – this represents an equivalent increment above the prior two values.

finding would be that substantial capital investments are being made in factors other than lean systems and that these investments may even undercut the utilization of lean practices. For example, there is some anecdotal evidence that investments in Material Resource Planning (MRP) and Enterprise Resource Planning (ERP) systems may represent an alternative claim for such investment dollars.[5] These findings are also consistent with research in U.S. manufacturing that documents increased per-capital investment by small firms relative to large firms, with more large firms allocating capital instead to dividends for shareholders (Weller, 2003).

It is not clear what to expect for unionized operations. On the one hand, there is substantial research suggesting that, on average, unionized facilities are more productive than non-union facilities (Freeman and Medoff, 1984). On the other hand, unionized operations have a reputation for having more restrictive work rules that can serve as a barrier to lean implementation. In fact, we see that the Lean Enterprise Scale for unionized operations is slightly higher (at 4.0) than for non-union operations (at 3.8), but this difference is not statistically significant. Similarly, there is an opposite relationship for the Lean Social Systems Scale (3.8 for unionized operations versus 3.9 for non-union operations) that is also not

[5] A recent conference of MIT's Lean Aerospace Initiative featured a debate around whether Material Resource Planning (MRP) and Enterprise Resource Planning (ERP) initiatives are complements with lean initiatives or competing for scarce resources, with clear concerns surfacing about each making competing claims for scarce resources – despite many complementary aspects of the two. Also, among the respondents to this survey, approximately 29 percent reported both lean and MRP initiatives, with 36 percent reporting one or the other and 35 percent reporting both – which at least suggests that this could be a candidate initiative that would compete for per-capita investment dollars.

statistically significant. There are no differences between union and non-union operations for the Lean Manufacturing/Technical Scale (4.1 for both).

Two additional process scales have been included in this analysis (separate from the three lean scales). The first, is a scale comprised of six questions on the organizational learning culture or climate. This scale is based on a set of questions developed by Tannenbaum (1994) and cover the following matters:

- Employees have the opportunity to learn new skills
- Employees are encouraged to try different approaches to solve problems
- Employees are rewarded for using on the job what they have learned in training
- Supervisors and co-workers help reschedule work so employees can attend training
- Employees are open to new ideas and suggestions
- Training is encouraged to develop the skills needed for advancement

A second scale concerns the value given to various aspects of intellectual capital, including:

- Patents
- Copyrights
- Proprietary processes
- Technological leadership
- Unique expertise/skills in the workforce
- Investments in Research & Development
- Investments in training
- Investments in organization development
- Knowledge generated by collaborative work
- Front line knowledge about products and services
- Capability of suppliers
- Relationships with suppliers
- Knowledge created with strategic partners

Both scales are highly reliable (alpha of .86 and .85 respectively) and they each represent aspects of an organization's climate that can be expected to be enablers for the implementation of lean principles and practices. In fact, there is a positive and significant relationship between each of these scales and the three dimensions of lean. For example the mean response on the Lean Enterprise Scale for respondents disagreeing with the Learning Culture Statements is a 2.7, compared with 3.6 for those neither agreeing nor disagreeing, and a 4.4 for those agreeing with these questions. The relationship is similar for the Intellectual Capital Scale, with a mean response on the Lean Enterprise Scale of 3.1 among those indicating that the above items are "not important" or "somewhat important," compared to a 3.8 for those rating these items as "important," and a 4.4 for those rating them as "very important" or "extremely important." These findings suggest that these two process factors are indeed highly interdependent with lean principles and practices.

Multivariate Analysis of Factors Predicting Lean Practices

Three dimensions of "lean" have been highlighted for analysis in this paper – the technical dimensions of lean production systems, the social dimensions of lean and a combined scale with the social, technical and additional enterprise dimensions of lean. Table 3 presents multivariate analysis of the factors influencing the degree to which facilities would be high on each of these dimensions. In each case, two models are presented – one including just structural variables and one also including the process scales on intellectual capital and the process scale on learning culture.[6] This analysis will serve to test which of the bivariate relationships hold up when other factors are considered simultaneously.

Insert Table 3 About Here
Factors Predicting Lean Practices – Technical, Social and Enterprise
OLS Regression Analysis

[6] OLS analysis is utilized since we are interested in predicting the degrees to which the various dimensions of lean are found – a continuous dependent variable.

There are just two structural factors predicting lean manufacturing practices. The first model suggests that the technical aspects of lean are more likely in larger facilities (based on the number of employees), which is consistent with expectations. Note, however, that this factor is no longer significant when we add the two process variables – the intellectual capital scale and the learning culture scale, which probably reflects the fact that the scales on valuing intellectual capital and fostering a learning culture are more likely to be higher in larger facilities. In both models, the technical aspects of lean are less likely where per capita investment is high, which is consistent with the analysis of means, but not consistent with initial expectations. The negative relationship with per capita investment holds in the second model, when we add process variables – suggesting that further analysis is needed into this interrelationship. The two process variables substantially increase the explanatory power of the model, each having a positive and significant impact.

The second pair of models, examining factors predicting the social dimensions of lean highlights facility age – with these practices being more likely in newer facilities. This reflects the incorporation of these practices in the newer "green field" facilities, as well as the difficulty of transforming older "brown field" facilities along these lines. Also, in the first model of just structural factors, there is some indication of a reduced likelihood of these social dimension in the avionics sector, though this finding does not hold when we add into the analysis the two process scales for intellectual capital and learning culture. Interestingly, the per capita investment variable has a positive and significant relationship here. This is the opposite of what we saw in the technical dimensions of lean manufacturing and clearly calls for additional analysis. Finally, there is a strong, positive impact of the two process variables, which is as would be expected on the social dimensions of lean.

The final pair of models concerns the full range of lean enterprise practices. Here we again find that these practices are more likely in newer facilities. Also, the first model points to smaller facilities and the second model points to high-volume facilities as locations more likely to feature lean enterprise practices. Most importantly, we again see the positive, significant impact of the two process scales.

The dominant finding from this analysis is that lean practices are most likely to be found in facilities placing a high value on many dimensions of intellectual capital and in facilities featuring a positive, learning culture. This includes not just the social aspects of lean, but also the technical and enterprise dimensions. The normative implication of this finding would be for organizations seeking to implement lean practices and principles to also ensure that a high value is placed on intellectual capital and learning culture.

Assessing the Impact of Lean Practices and Other Factors on Social Outcomes

Despite the public debates over the impact of lean practices on social outcomes, virtually all research on this topic in the aerospace industry has been based on case studies (LARA, 2000-2002; Murman, et. al., 2002). These case studies clearly suggest that the social dimensions of lean are highly interdependent with the technical dimensions, but they still leave unresolved many important questions – particularly around the specific impact of lean practices on social outcomes such as employment and worker satisfaction. As was the case with the first set of models, we begin with first-order effects through the comparison of means and then turn to the multivariate analysis.

Table 4 presents the outcomes for all three lean scales for these two outcomes. With respect to both outcomes, the proponents of lean would predict a positive relationship, while some of the detractors might expect a negative relationship. In fact, the outcomes for worker satisfaction are positive and significant – with increased satisfaction associated with greater utilization of lean practices and principles. Note, however, that the satisfaction levels are relatively low even in the most favorable category.

There is a much more ambiguous picture around employment growth. Overall, the mean responses are between "no change" and "decreasing employment" – with a tendency toward a greater decline in employment in the case of the Lean Manufacturing/Technical Scale and even to some degree for the Lean Enterprise Scale. This contrasts with the responses when arrayed across the Lean Social Systems Scale, which has a reverse relationship. This is a key finding – confirming the critiques of the narrow, technical focus on lean manufacturing tools and highlighting the importance of the Lean Social Systems in attending to this key outcome for the workforce. It will be essential to see if this relationship holds up in the multivariate analysis.

Table 4
Means for Social Outcomes and Lean Practices – Technical, Social and Enterprise
2002 National Aerospace Facility Survey

In order to contribute to further understanding along these lines, three models have been included in Table 5. The first two focus on the impact of lean practices on employment, while the third examines the impact on the respondent's perception of worker satisfaction in the facility. It is important to note that the respondents are all senior facility managers. Thus, if there is a bias to the responses, it is likely to be a bias reflecting a managerial perspective. All three models have been run first with the scales for the social and technical dimensions of lean and then a second time with these two dimensions excluded and the lean enterprise scale included. This approach allows for an analysis of the separate impacts of the social and technical dimensions, as well as the combined impact of both (along with other lean enterprise practices).

Also, a logistics regression model is used here since we are interested in predicting the likelihood of the outcomes increasing versus no change and decreasing – which is best done with a bivariate dependent variable in which the item have been re-coded as "1" for "increasing" (a 4 or 5 on a five point scale) versus a "0" for all other values (a 1, 2, or 3 on the five point scale).

Insert Table 5 About Here
Factors Increasing the Likelihood of Social Performance Outcomes
Logit Regression Analysis

The first model assesses the impact of structural and process factors on employment growth (versus no change or declining employment). We see that employment growth is more likely in low volume operations and in larger facilities. Interestingly, employment growth is less likely in unionized operations, which is consistent with other research documenting systematic corporate strategies aimed at expanding nonunion operations, rather than unionized operations (Verma, 19??). This is also consistent with a common critique of union work rules as constraining employment growth. Note too that this finding is in a regression model holding constant for various lean practices (including flexible work practices), which may indicate that there is less likelihood of employment growth in unionized operations where there are not these lean practices in place.[7]

The most striking finding in this model, however, concerns the social and technical dimensions of lean. The technical lean manufacturing scale has a negative and significant impact on employment growth, while the scale comprised of the social aspects of lean has a positive and significant impact. This provides confirmation of the fears expressed by employees

[7] Note that this model has been run without the process factors and the strength of the union impact is reduced, though still signed negative and significant.

and their union representatives around a narrow, technical approach to lean having a negative impact on employment. The concern is that the lean focus on eliminating waste – without strong attention to the social dimensions – will end up as a cost-cutting initiative rather than a vehicle for growing the operation. The positive impact of the social dimension provides confirmation of the alternative argument, which is that a focus on employee knowledge, skills and a continuous improvement approach will help to increase employment. When both of these factors are combined together, along with other enterprise dimensions there is no significant impact either way, which suggests that the overall impact of a lean enterprise initiative will be neutral with respect to employment. While further research is needed to see if this find hold up in other analysis, these represent what may be the most important findings presented in this paper.

Given the important findings about employment growth, a second model has also been included in Table 5, which assessed a decline in employment (versus no change or growth). This will serve to assess whether the impact of these factors is just with respect to growth or whether it involves a decline in jobs. Here we see that a decline in employment is less likely in the space sector and the union impact holds here as in the first model. Most importantly, the reverse impacts of the social and technical dimensions holds here. On their own, the manufacturing/technical lean production practices increase the likelihood employment loss and the social systems aspects of lean reduce the likelihood of employment loss. Again, the overall set of lean enterprise practices are neutral with respect to employment loss.

One final social outcome is assessed here, which is worker satisfaction. Satisfaction is reported to be increasing in the aircraft and space sectors, which is not what would be expected given the layoffs and restructuring that has taken place in both sectors. In the fist model, satisfaction is also higher in larger facilities – a finding for which we would not have a prior prediction – and in facilities with higher per capita investment, which is as would be expected. Most importantly, the opposite relationship between the social and technical dimensions of lean holds here as well – facilities higher on the technical aspects of lean (and holding constant for the social aspects) are less likely to have increased worker satisfaction. At the same time, facilities higher on the social dimensions of lean are more likely to have increasing worker satisfaction. This is a relationship not visible through the simple bivariate comparison of means and that further reinforces the important interdependences between the social and technical dimensions of lean systems.

In additional to the three lean scales (social, technical and enterprise), facilities high on the learning culture scale are also more likely to have increasing worker satisfaction. While this factor did not show up as having a significant impact on employment growth or decline, it is both a key factor in explaining the presence of lean practices and in having an additional, separate impact on worker satisfaction.

Assessing the Impact of Lean Practices and Other Factors on Economic Outcomes

Although there is a well-established literature assessing the performance implications of various clusters of work practices (Cutcher-Gershenfeld, 1991; MacDuffie, 1995, Huselid, 1995; Delaney and Huselid, 1996; Ichniowski, Shaw, and Prennushi, 1997; Applebaum, et. al., 2000), there has been relatively little analysis of the economic performance implications of the full set of lean practices (including lean enterprise practices). Table 6 presents the means for measures of productivity, quality, and profitability. These are all single item questions in which respondents were asked to assess whether performance had been increasing, not changing or decreasing over the past three years. A five point scale was used in the question. All three variables indicate a positive and significant impact for the various dimensions of lean, though the magnitude of the impact is least with respect to profitability.

Table 6
Means for Economic Outcomes by Lean Practices – Technical, Social and Enterprise
2002 National Aerospace Facility Survey

	Changes in Productivity (1-5 Scale)	Changes in Quality of Product or Service (1-5 scale)	Changes in Profitability (1-5 scale)
Low on Lean Enterprise Scale	2.6	3.0	2.6
Medium on Lean Enterprise Scale	3.8	3.7	3.3
High on Lean Enteprise Scale	4.1	4.0	3.8

A multivariate assessment of these outcomes is presented in Table 7. The same lean models utilized in the analysis of social outcomes are used here, with two models for each of the three outcomes. As the first two models suggest, there is a clear relationship between aspects of lean and productivity. In particular, there is an independent positive impact of the social aspects of lean and a positive impact of the overall lean enterprise scale. Note as well that the technical aspects of lean have a positive sign – in contrast to the findings on the social outcomes. Also, these findings suggest that productivity gains are more likely in larger facilities.

Table 7
Factors Increasing the Likelihood of Increasing Economic Performance
Logit Regression Analysis

Interestingly, none of the lean factors are significant in explaining increases in quality performance, but the learning culture scale does of a significant and positive impact. This is consistent with the view that quality performance depends on an environment where learning new skills and approaches is valued.

Finally, none of the process factors has an impact on increasing profitability. The only factors at play here are size – larger facilities are more likely to report increasing profitability – and per-capita capital investment, which increases at the expense of profitability. Neither finding is surprising. The first suggests that there are economies of scale when it comes to profitability, while the second suggests that investment dollars come at the expense of profitability (at least in the short term). More importantly, lean practices and the other process scales are not tightly linked to profitability, which suggests a tension around the relative emphasis given to these practices in a weak investment climate.

Conclusion

The analysis in this paper has reviewed the causes and consequences of lean practices and principles for the U.S. aerospace industry. These concepts have been identified as essential to the future of the industry, but as challenging to implement (Murman, 2002). A picture emerges of partial transformation – with key insights into the social, technical and enterprise dimensions of the transformation.

Many structural factors provide relatively little predictive power in explaining the presence of lean practices and principles. This includes variation by sector of the industry, supplier status, union status, and even production volume. There is some predictive power based on facility size and age, though the strongest determinants of lean practices are not structural factors. Instead, it is two other process factors – the learning climate and the relative value placed on various aspects of intellectual capital – that best help to predict the incidence of lean practices. While the causality on these dimensions may run both ways, what is important is the finding of strong interrelationships. Too many lean implementation initiatives involve relatively fast implementation of technical and physical aspects of lean, such as new material handling systems and what are termed quality "andon" systems aimed at improving flow, reducing cycle time, and supporting in-station quality control. The implementation of the social and more intangible aspects of lean, such as teams or continuous improvement principles, is more difficult. The findings here clearly suggest that the technical aspects of lean and the combined social and technical dimensions (at the enterprise level) depend on process capability around learning and the valuing of intellectual capital.

The opposite impacts of the technical and social dimensions of lean on employment outcomes represents perhaps the most telling finding from this research. Narrowly focused lean initiatives – centered primarily on the technical and physical aspects of lean – have been criticized as likely to deteriorate into short term, "headcount" reduction cost-cutting initiatives. These finding provide support for this criticism. At the same time, the research provides validation for more broadly focused lean initiatives that emphasize the social as well as the technical dimensions, and that take into account enterprise relationships. The fact that all aspects of lean have a positive relationship to various performance outcomes makes the findings on the social outcomes even more important. It suggests that there is a need for strong advocacy on the social and enterprise dimensions, since other economic outcomes might be achieved in the short run just with attention to the technical, manufacturing oriented aspects of lean.

The aerospace industry continues to be a dynamic context for organizational and systems transformation. This research suggests that it will be process rather than structural factors that will drive this transformation. Moreover, the transformation of the industry in ways that attend to the interests of many key stakeholders depends on establishing an interdependent mix of social, technical and enterprise process capabilities.

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Table 1
Organizational Change Initiatives in the U.S. Aerospace Industry
1999 and 2002 National Aerospace Facility Surveys

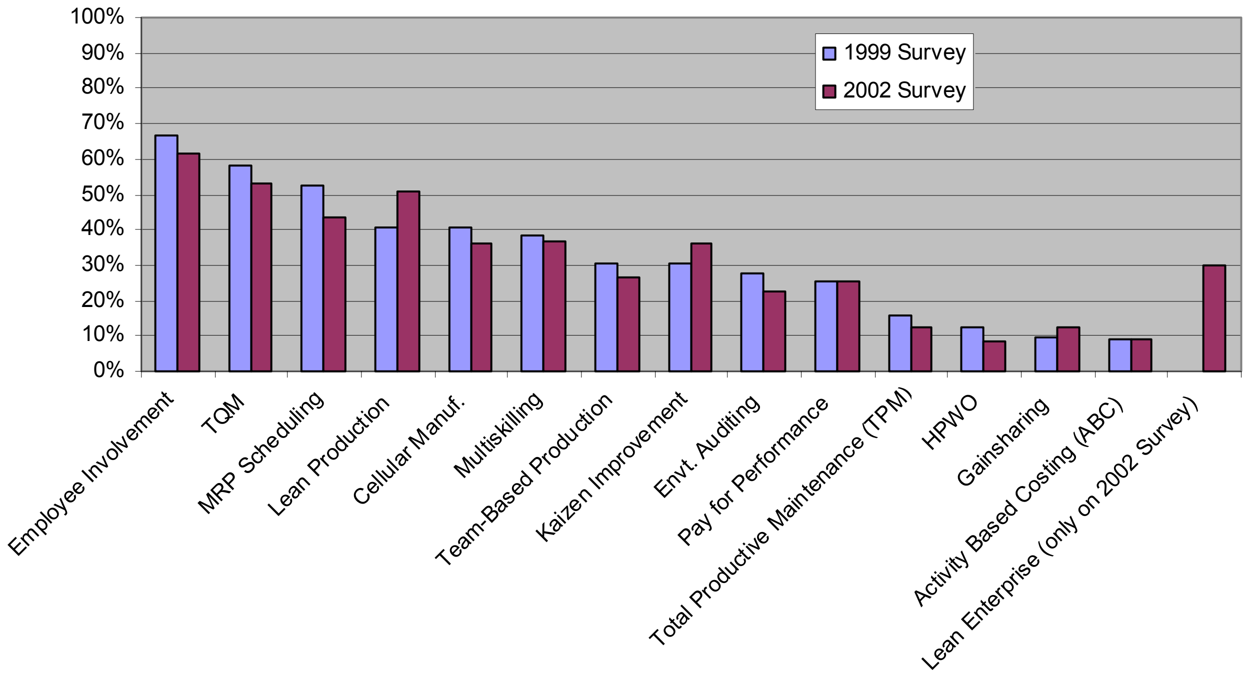

Table 3
Factors Predicting Lean Practices – Technical, Social and Enterprise
OLS Regression Analysis – 2002 National Aerospace Facility Survey

	DEPENDENT VARIABLES					
	Lean Production -- Technical Systems		Lean Social Systems		Lean Enterprise Scale	
	Beta (SE)	*Beta (SE)*	*Beta (SE)*	*Beta (SE)*	*Beta (SE)*	*Beta (SE)*
STRUCTURAL VARIABLES						
Sector: Aircraft frame & mech systems	-.126 .159	-4.132E-02 (.143)	-.176 .160	-1.121E-02 (.114)	-3.923E-02 .145	8.853E-02 (.111)
Sector: Aircraft propulsion/engine	1.405E-03 .196	7.202E-03 (.176)	.142 .198	.131 (.140)	.166 .179	.163 (.136)
Sector: Space, launch and missiles	-.126 .253	-4.769E-02 (.228)	-.132 .255	6.199E-02 (.182)	-9.624E-02 .231	4.248E-02 (.176)
Sector: Avionics and electronic systems	-7.346E-02 .170	-1.051E-02 (.153)	-.306 .171 *	-.168 (.122)	-.125 .155	-2.223E-02 (.118)
Second, Third and Lower Tier Sub-Contractor (1=yes; 2=no)	9.196E-02 .131	.207 (.119)	-1.090E-02 .132	.129 (.095)	8.354E-03 .120	.140 (.092) *
Product Volume -- Primary Product (1=low vol; 2=med vol; 3=high vol)	.119 .099	.148 (.089) *	4.193E-02 .100	6.306E-02 (.071)	6.459E-02 .090	9.094E-02 (.069)
Facility Age (in Years)	-4.279E-03 .003	-1.992E-03 (.003)	-1.033E-02 .004 **	-6.376E-03 (.003) **	-7.724E-03 .003 *	-4.524E-03 (.002) *
Log of employment	.198 098 *	8.414E-02 (.090)	9.314E-02 .098	-3.735E-02 (.072)	.201 .089 *	7.482E-02 (.070)
Approximate dollars of per capita investment in new technology (in thousands)	-4.530E-03 002 *	-3.183E-03 (.002) *	7.554E-04 .002	2.343E-03 (.002) *	-1.136E-03 .002	3.837E-04 (.002)
Unions Present (1=yes; 0=no)	-1.890E-02 .173	-7.517E-02 (.155)	9.326E-02 .174	4.445E-02 (.124)	.159 .157	.104 (.120)
PROCESS VARIABLES						
Learning Climate Scale (six item scale; Alpha=.86)	--	.192 (.063) **	--	.451 (.050) ***	--	.328 (.049) ***
Intellectual Capital Scale (thirteen item scale; Alpha=.85)	--	.397 (.100) ***	--	.361 (.079) ***	--	.395 (.077) ***
Constant	3.592 .339 ***	1.320 (.448) **	3.924 .341 ***	.419 (.357)	3.494 .308 ***	.521 (.346) *
Adj. R^2	.07	.22	.01	.51	.02	.44

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

Table 4
Means for Social Outcomes and Lean Practices – Technical, Social and Enterprise
2002 National Aerospace Facility Survey

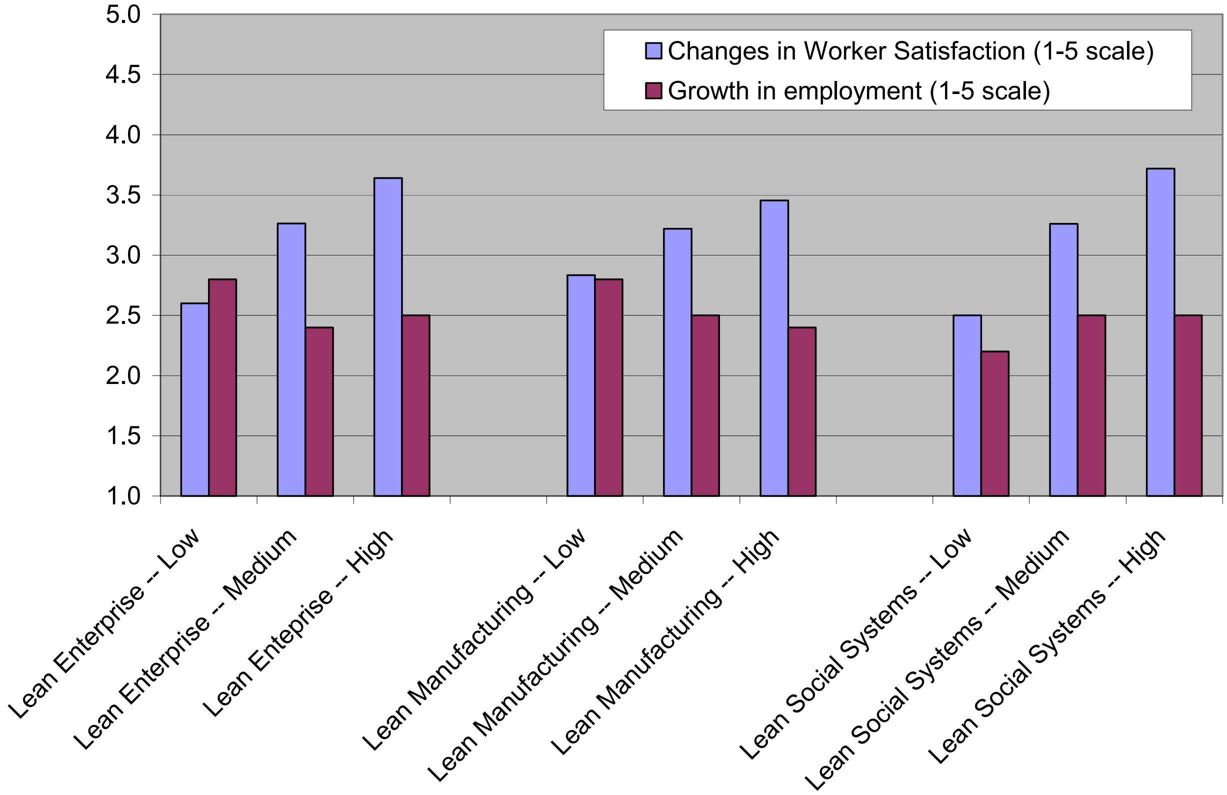

Table 5
Factors Increasing the Likelihood of Social Performance Outcomes
Logit Regression Analysis – 2002 National Aerospace Facility Survey

	DEPENDENT VARIABLES					
	Employment Increasing		Employment Declining		Worker Satisfaction Increasing	
	Beta (SE)	*Beta (SE)*	*Beta (SE)*	*Beta (SE)*	*Beta (SE)*	*Beta (SE)*
STRUCTURAL VARIABLES						
Sector: Aircraft frame & mech systems	.031 .418	.207 .450	-.042 .351	-.019 .389	.292 .380	.665 .424 *
Sector: Aircraft propulsion/engine	.170 .490	.312 .547	-.271 .418	-.269 .479	-.330 .472	-.024 .536
Sector: Space, launch and missiles	.421 .619	.349 .703	-1.002 .556 *	-1.048 .657 *	1.005 .595 *	1.055 .673 *
Sector: Avionics and electronic systems	.412 .476	.294 .493	-.305 .403	-.041 .426	.528 .439	.674 .470
Second, Third and Lower Tier Sub-Contractor (1=yes; 2=no)	.077 .348	-.104 .378	-.122 .296	-.081 .328	.213 .323	.438 .353
Product Volume -- Primary Product (1=low vol; 2=med vol; 3=high vol)	-.403 .247 *	-.465 .272 *	.110 .217	.147 .247	-.128 .240	-.121 .272
Facility Age (in Years)	.001 .009	-.002 .010	-.002 .008	-.001 .009	-.004 .009	-.003 .009
Log of employment	.752 .286 **	.500 .292 *	.114 .239	.158 .254	.388 .262 *	-.002 .274
Approximate dollars of per capita investment in new technology (in thousands)	.003 .005	.010 .006	.003 .004	-.005 .006	.007 .004 *	.009 .006
Unions Present (1=yes; 0=no)	-1.344 .549 **	-1.140 .553 *	.614 .425 *	.582 .447	-.251 .446	.291 .466
PROCESS VARIABLES						
Learning Climate Scale (six item scale; Alpha=.86)	-.272 .232	-.187 .230	-.091 .251	-.120 .291	.490 .228 *	.849 .249 ***
Intellectual Capital Scale (thirteen item scale; Alpha=.85)	.213 .305	.412 .344	.048 .192	.024 .195	-.024 .279	-.067 .319
Lean Production – Technical Systems (four Item scale; Alpha=.60)	-.534 .253 *	--	.595 .219 **	--	-.624 .241 **	--
Lean Social Systems (six Item scale; Alpha=.80)	.734 .318 *	--	-.408 .264 *	--	1.126 .307 ***	--
Lean Enterprise Scale (fifteen item scale: Alpha=.88)	--	.094 .300	--	.166 .262	--	.313 .289
Constant	-1.818 1.310	-1.825 1.388	-.879 1.120	-.638 1.220	-5.477 1.349 ***	-6.145 1.498 ***
Cox & Snell R^2	.081	.068	.059	.038	.192	.170
Nagelkerke R^2	.122	.099	.079	.051	.259	.229

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

Table 7
Factors Increasing the Likelihood of Increasing Economic Performance
Logit Regression Analysis – 2002 National Aerospace Facility Survey

	DEPENDENT VARIABLES					
	Productivity Performance Increasing		**Quality Performance Increasing**		**Profitability Performance Increasing**	
	Beta (SE)	*Beta (SE)*	*Beta (SE)*	*Beta (SE)*	*Beta (SE)*	*Beta (SE)*
STRUCTURAL VARIABLES						
Sector: Aircraft frame & mech systems	-.113 .436	-.030 .523	-.054 .375	.153 .433	.297 .362	.046 .418
Sector: Aircraft propulsion/engine	-.204 .519	-.029 .675	.101 .476	.233 .568	-1.188 .452 **	-1.313 .521 **
Sector: Space, launch and missiles	.349 .747	-.229 .832	.581 .644	.315 .705	-.133 .568	-.710 .671
Sector: Avionics and electronic systems	-.665 .464	-.549 .515	-.382 .427	-.333 .463	-.290 .410	-.423 .446
Second, Third and Lower Tier Sub-Contractor (1=yes; 2=no)	-.026 .362	-.006 .430	.311 .324	.297 .367	.216 .306	.310 .349
Product Volume -- Primary Product (1=low vol; 2=med vol; 3=high vol)	.329 .261	.326 .318	.256 .234	.229 .275	.040 .222	.061 .257
Facility Age (in Years)	-.007 .010	.011 .012	.004 .009	.009 .010	-.004 .008	-.002 .009
Log of employment	1.333 .323 ***	.893 .356 **	-.022 .259	-.395 .288	.898 .256 **	.776 .278 **
Approximate dollars of per capita investment in new technology (in thousands)	.003 .004	.000 .006	.002 .005	.001 .006	-.004 .005	-.017 .009 *
Unions Present (1=yes; 0=no)	-.346 .503	-.496 .578	-.109 .432	.266 .485	-.567 .415	-.413 .459
PROCESS VARIABLES						
Learning Climate Scale (six item scale; Alpha=.86)	-.067 .225	.126 .238	.481 .207 *	.597 .224 **	.247 .202	.275 .215
Intellectual Capital Scale (thirteen item scale; Alpha=.85)	.029 .292	-.111 .362	.246 .273	.372 .328	.127 .261	.305 .317
Lean Production – Technical Systems (four Item scale; Alpha=.60)	.118 .251	--	.151 .229	--	-.238 .220	--
Lean Social Systems (six Item scale; Alpha=.80)	.658 .306 *	--	.211 .274	--	.247 .266	--
Lean Enterprise Scale (fifteen item scale: Alpha=.88)	--	1.047 .342 **	--	.189 .300	--	.010 .277
Constant	-4.651 1.403 ***	-5.576 1.660 ***	-4.745 1.265 ***	-4.413 1.410 **	-3.158 1.205 **	-3.500 1.341 **
Cox & Snell R^2	.148	.167	.122	.131	.128	.149
Nagelkerke R^2	.219	.255	.169	.182	.170	.199

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