

The S-Curve Effect of Lean Implementation

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There is currently no theory that explains the pattern of change in a plant's performance as it implements a lean program. Does it improve at a declining, increasing, or constant rate, or in some other pattern? We use empirical data from the implementation of the Volvo Group's lean program worldwide to develop a grounded theory to explain this pattern. We find that the pattern roughly follows an S-curve shape: as a plant progresses in its implementation of lean production, its operational performance improves slowly first, then grows rapidly, and finally tapers off. The initial stage can be characterized by "exploration", during which the plant is essentially discovering and experimenting with lean principles, and the later stages by "exploitation", during which the plant is realizing their benefits. We derive the grounded theory from quantitative internal company data and find additional qualitative support for it from our visits to 45 Volvo plants on 5 continents and 210 interviews with employees in these plants and Volvo headquarters. The S-shape pattern has important implications. Practitioners must assess a plant's maturity in lean implementation and adjust their targets, action plans, and expectations accordingly. Scholars must take the position of the plant on the S-curve into consideration when they analyze the impact of lean programs.

Key words: Lean production; production improvement; operational performance; grounded theory

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1. Introduction

There is a strong consensus that implementing a lean program is a prolonged investment that pays off if done correctly. However, since there is no clear end point to the implementation of a lean program, its benefits must be measured while it is being implemented. The literature is surprisingly silent on how these benefits should occur. No theory has been proposed to explain how the performance of a plant should change as it continues on its journey of implementing a lean program. Should its performance improve at a declining, increasing, or constant rate, or in some other pattern? That is the research question we address in this study.

This is an important question because lean production has become the *de facto* improvement program in the industry (Holweg 2007, Schmenner 2015, Womack et al. 1990), and incorporates the elements of many production improvement concepts (Schonberger 2007). Shah and Ward (2003), for example, conceptualize lean production as consisting of four inter-related bundles: just-in-time, total quality management, total productive maintenance, and human resource management practices. The literature

suggests a strong and positive correlation between the application of any of these practices and performance (e.g., see the meta-reviews of the literature by Sousa and Voss 2002, Nair 2006, Mackelprang and Nair 2010). However, it is not apparent at what rate these benefits occur.

Several studies have suggested that the performance improvement can be nonlinear (Banker et al. 2001, Davies and Kochhar 2002, Easton and Rosenzweig 2012, Nair et al. 2011). For example, Jayaram et al. (2010), in their sample of 394 plants, found that the duration of a total quality management program positively affects its returns—implying that more experience in implementation increases the potential benefits. Similarly, Easton and Rosenzweig (2012) suggested that organizational experience increases the chance of success of six sigma programs, and Swink and Jacobs (2012) found that prior experience with quality programs in the plant contributes to their success. These studies imply that the benefits of these programs are likely to increase as they are implemented more thoroughly. On the other hand, Schmenner and Swink (1998), Vastag (2000), and Li and Rajagopalan (2008) suggested that there can be decreasing returns on investments in production

improvement programs. Therefore, the issue is not settled, and as Nair et al. (2011) pointed out, there is a need for more research into understanding how the level of maturity of a plant in implementing an improvement program affects the benefits it derives from it. Speculating that this relationship can be nonlinear, Easton and Rosenzweig (2012, p. 490) suggested that “examining [the] nonlinear issues [in the relationship between implementation of a program and improvement in performance] in more detail seems worthy of future research.”

That is what we set out to do in this study. We use the grounded theory methodology (Eisenhardt 1989, Glaser and Strauss 1967) to develop a theory that explains how the performance of a plant changes as it implements a lean program. A grounded theory is built directly from empirical data. The Volvo Group, a global manufacturer of trucks, buses, powertrain applications, and construction equipment, gave us access to its internal documents containing detailed quantitative information about the implementation of its corporate lean program, called the Volvo Production System (VPS). In 2012, Volvo Group had 67 plants, but to derive our grounded theory, we used data from only 30 plants because these plants had been assessed not only for the extent of their implementation of the VPS but also for their operational performance (which had been added in the latest version of the assessment process). We also collected qualitative data by visiting 45 plants (which included 26 of the 30 plants that provided the quantitative data) and interviewed 210 managers in these plants and Volvo’s headquarters. We use the qualitative data to assess support for and explain the grounded theory.

In the next section, we explain the research methodology and describe our dependent and independent variables as well as how they are measured. In section 3, we analyze the empirical data, from which we find two main phases in plant-level lean implementation and derive the grounded theory, suggesting an S-shape pattern in the relationship between lean implementation and plant operational performance. In section 4, we discuss whether the S-shape pattern is supported by the literature and the additional qualitative data from visits and interviews. In the final section, we present our conclusions and discuss the implications of the “S-curve theory” for practitioners and scholars.

2. Research Method and Empirical Data

Gauging the extent of implementation of a lean program in a plant, as well as assessing the performance

of the plant, requires careful observation, measurement, and tracking of a large number of variables. Voss et al. (2002), Yin (2003), Siggelkow (2007), Barratt et al. (2011), and Ketokivi and Choi (2014), among others, suggested that case research is often the most realistic approach in such situations. A case study is “an empirical research that primarily uses contextually rich data from bounded real-world settings to investigate a focused phenomenon” (Barratt et al. 2011, p. 329). Following this advice, we use the case study approach to collect rich empirical data to build our grounded theory—that is, by letting the real-world data directly suggest the theory (Eisenhardt 1989, Glaser and Strauss 1967). As such, we are also responding to the repeated calls for empirically based theory building in operations management (Boer et al. 2015, Hayes 2000, Meredith 1998, Schmenner and Swink 1998, Schmenner et al. 2009, Singhal et al. 2014).

The case study in this research is the implementation of Volvo Group’s corporate lean program, the VPS, in its worldwide network of factories. In 2012, the Volvo Group had 67 factories on 6 continents producing trucks, buses, construction equipment, and powertrains for heavy vehicles and aerospace and marine applications. (Note that the Volvo Cars division has not been a part of the Swedish Volvo Group since 1999.) The data coming from only one firm is of course a limitation, but it has the advantage of controlling for many contingencies (corporate culture, industry, and technology, among other factors). It also allows for collecting the rich data that is needed for this research.

Following the methodology for building grounded theory (Eisenhardt 1989), the next step is to define the independent and dependent variables. We do that below.

2.1. The Independent Variable: Plant Maturity in VPS Implementation

We define the maturity of the lean program as the combination of the breadth and depth of its implementation in the plant. By *breadth*, we mean how widely the lean principles have spread in different parts of the plant—that is, how many areas, departments, teams, operators, and other entities in the plant have started to implement the lean program. By *depth*, we mean how thoroughly these entities are applying the lean principles.

Volvo has a formal and standardized process for assessing the combination of the breadth and depth of implementation of each element of the VPS in its plants worldwide. The VPS is an elaborate and meticulously documented system. It is comparable to similar corporate lean programs used in many other large

multinational manufacturing companies (Netland 2013). It has six principles, using the labels “The Volvo way,” “Teamwork,” “Process stability,” “Just-in-time,” “Built-in-quality,” and “Continuous improvement” (see Appendix A, Table A1 for a more detailed description). These principles are consistent with the prevailing definition of “lean as bundles of practices” in the literature (Cua et al. 2001, Furlan et al. 2011, Shah and Ward 2003). Each VPS principle consists of 3–5 “modules,” and each module has 2–7 “key elements,” bringing the total to 103 key elements. A plant’s maturity in VPS implementation (i.e., its VPS Audit Score) is essentially based on measuring the breadth and depth of implementation of these 103 key elements across the plant.

Each plant is audited approximately every two years. The audit is performed at the plant by a team of experts. Typically, two or three certified VPS assessors from the corporate VPS office, together with two to four certified or in-training assessors from other Volvo plants, perform the audit. The on-site process usually lasts four full days, during which the team carries out a thorough and elaborate set of measurements following a standard procedure. The team scores the plant on the key elements, each by using a five-point Likert scale designed specifically for that particular element.

The implementation scores for each lean principle and the entire plant are then computed by taking a series of simple averages. First, the implementation score for each module is computed by taking the simple average of the scores for the key elements in that module. Second, the score for implementation of each of the six principles is computed by taking the simple average of the scores of the modules that are included in that principle. Finally, the implementation score for the entire plant (called the “VPS Audit Score”) is computed by taking the simple average of the six VPS principles. (Further details of the audit process are both proprietary and beyond the scope of this study. Nevertheless, to illustrate how the audit is done, we provide a representative sample of three of the 103 key elements in Appendix A, Table A2.)

While the overall VPS Audit Score of the plant is our primary independent variable, we also use the score for each of the six lean principles in the plant as an independent variable to increase the precision and robustness of our analysis.

Between 2011 and 2013, 30 plants had been assessed with the latest version of the audit. We use the audit results only for these plants because this version included data about plant performance, our dependent variable (see next section). Given the level of rigor that Volvo has devoted to these audits, we believe that the data collected in this process are reliable and consistent measures of the maturity of the

plant in implementing the VPS program (as well as plant performance, our dependent variable discussed in the next section). To conceal sensitive information, we have normalized the scores by converting the actual scores (0–5) to z-scores (i.e., number of standard deviations from the mean of the sample).

2.2. The Dependent Variable: Plant Operational Performance

We use the plant’s operational performance, instead of its financial performance, to reduce the confounding effect of factors that are unrelated to the lean program (for example, market development, currency fluctuation, or changes in transfer prices). As mentioned earlier, the latest version of the VPS audit, introduced in 2011, contained a new section that measures the plant’s operational performance in six areas: safety, quality, delivery, cost, environment, and people. The plant’s performances along these six areas are gauged by a mix of objective and subjective metrics (i.e., quantitative and qualitative measures), which are combined by the assessment team and converted to a 4-point Likert scale. Examples of the objective metrics include “lost time accident rate” (one of the metrics for gauging safety), “quality defects parts-per-million” (a metric for gauging quality), “delivery precision” (a measure for gauging delivery), “hours per unit” (a measure for gauging cost), “energy use” (a measure for gauging environment), and “employee turnover” (a measure for gauging people). Assigning a rating on a Likert scale allows the assessment team to combine the relevant quantitative and qualitative metrics in each of the six areas, as well as to account for any possible differences in how different plants measure the same metric. We use the simple average of these six scores to measure the plants’ overall operational performance.

2.3. Methods for Investigating the Relationship between Independent and Dependent Variables

The next step in building a grounded theory is to observe and analyze the relationship between the dependent and independent variable *without any prior hypotheses*. In other words, a grounded theory is built on first observing the relationship revealed in the empirical data and then investigating whether this relationship is supported by extant theories (Eisenhardt 1989, Glaser and Strauss 1967). This sequence is different from the more common research methodology that first derives its hypotheses from extant theories and then investigates whether the data support (or reject) the hypotheses.

We used a simple yet powerful technique, called *locally weighted regression* (LOESS), to detect the relationship between our dependent and independent variables. LOESS is a nonparametric technique for

fitting the best curve depicting the relationship between two variables (Cleveland and Devlin 1988). It is a versatile procedure for data exploration and analysis in the social sciences (Jacoby 2000). A major advantage of LOESS is that it does not need *a priori* specification of a fit function, which makes it particularly useful for the grounded theory research methodology. LOESS discerns the pattern from the empirical data without the interference of the researcher.

A limitation of LOESS is that it does not provide a goodness of fit measure for the patterns it suggests. Therefore, we conducted additional tests. We used hierarchical cluster analysis to derive clusters of plants based on their lean maturity, and ran curve estimation and regression analyses in the resulting clusters to derive the pattern between maturity in VPS implementation and plant operational performance.

2.4. Qualitative Data: Plant Visits and Interviews

As mentioned earlier, we visited 45 Volvo plants on 5 continents and conducted 210 semi-structured interviews with managers at different levels in these plants and Volvo's headquarters. Although these visits included plants beyond the 30 used in the quantitative analyses in this study (some were related to investigation of other research questions), they provided additional qualitative data about our dependent and independent variables. Augmenting quantitative data with qualitative data in building grounded theory is encouraged (Eisenhardt 1989, Suddaby 2006, Voss et al. 2002). Eisenhardt (1989, p. 538) suggested that "quantitative evidence can indicate relationships which may not be salient to the researcher" and "qualitative data are useful for understanding the rationale or theory underlying relationships." Mintzberg (1979, p. 589) concurred: "We uncover all kinds of relationships in our hard data, but it is only through the use of soft data that we are able to explain them." This is how we use the observations from our plant visits and interviews to see if they support—and provide explanation for—the grounded theory derived from our quantitative data.

All plant visits started with an introduction to the plant, a plant tour, and several interviews with managers. Depending on the size of the plant, we interviewed three to eight persons (including senior managers, production managers, line managers, VPS personnel, and union representatives or shop floor operators). Most interviews were 30–60 minutes long, some held in the managers' offices and some on the shop floor. During the plant tours, we had the opportunity to walk through the shop floor, talk to production workers and supervisors, and observe, first-hand, the extent of implementation of many of the VPS practices in different areas. We took extensive

notes during each plant visit. We also took many photos and obtained data from other sources about the plant (e.g., company presentations, press releases, and internal reports), and prepared detailed reports after each visit. The case reports, amounting to a total of over 400 pages, are careful records of the qualitative data we collected about each plant we visited. This is a rich collection, which we are using to investigate also other research questions. We use it here to appraise and augment the grounded theory proposed in this study.

3. Analysis

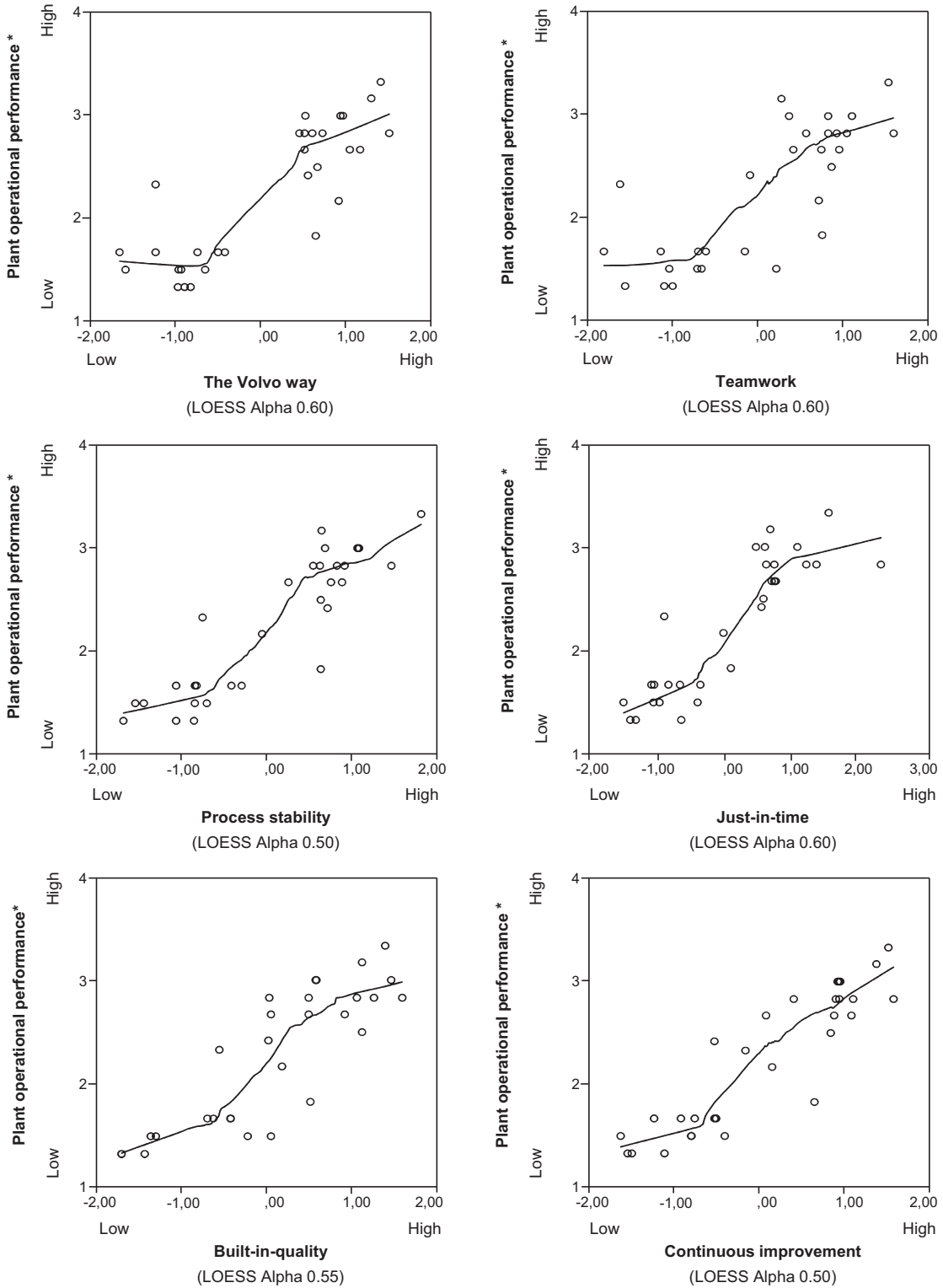
3.1. Discerning the Pattern with Locally Weighted Regression

As explained, we first employ LOESS to discern the patterns from the quantitative data. We used SPSS software to draw scatter plots with LOESS curves. In SPSS, only the kernel function and the smoothing parameter, alpha, need to be designated. The kernel function decides the form of the weighted distance calculation in LOESS. We use the Epanechnikov kernel function, which has robust properties (Gasser et al. 1985). (We tested the robustness of the results by experimenting with alternative LOESS kernel functions—uniform, Gaussian, and triweight kernel distributions—and the patterns were practically the same.) The alpha specifies the percentage of the data points that are included in each "local neighborhood," where a "neighborhood" is a set of points in close proximity (depending on the alpha, it can be a small or large number of points). For example, for our data set of 30 plants, an alpha of 0.25 means that about 8 plants belong to each neighborhood (~25% of 30), and an alpha of 0.75 means that each neighborhood contains about 23 plants (~75% of 30). Using the kernel function as a smoothing algorithm, LOESS computes a center for each neighborhood that minimizes the weighed distances between the center and the points in that neighborhood. A curve is then drawn through these local neighborhood centers.

Jacoby (2000) explains that choosing the smoothing parameter is a subjective process, in which the researcher compromises between a jagged pattern for small alphas and a smoother but less precise pattern for large alphas (a larger alpha gives a smoother curve because it averages out more points). Jacoby suggests that a reasonable value for alpha in most cases is somewhere between 0.40 and 0.80. It is important to note that alpha is not a goodness of fit measure; it is a parameter for discerning a sensible pattern for the relationship between two variables.

We use LOESS to examine the relationship between the extent of implementation of each of the six lean principles in VPS and the plant's operational perfor-

Figure 1 LOESS Curves Fitted to Scatter Plots of Plant's Operational Performance Vs. Maturity in Implementation of Six VPS Principles ($N = 30$ Plants)



Notes. Plant operational performance is the average audit score of Safety, Quality, Delivery, Cost, Environment, and People. All LOESS curves estimated with the Epanechnikov kernel function.

mance. Figure 1 shows the scatter plots of the 30 plants with fitted LOESS curves with alpha values between 0.50 and 0.60. The horizontal axes are the normalized VPS audit scores for each principle, and the vertical axes are the plant operational performance (average of performance scores in safety, quality, delivery, cost, environment, and people). While the shapes of the curves are not perfect, all resemble an S shape.

The VPS Audit Score is the average of the scores for these six principles, and, as Figure 2 shows, the LOESS curve fitted for the aggregated VPS score also resembles an S-shape pattern.

While all these fitted LOESS curves resemble an S shape, we do not have measures for their goodness of fit. Therefore, we performed additional tests.

3.2. Cluster Analysis and Parametric Regression Analysis

We first conducted a hierarchical cluster analysis using VPS implementation maturity as the clustering variable. We used the squared Euclidean distance method of determining distance between clusters, and the furthest neighbor method for clustering. (We repeated this analysis with other distance and clustering methods, and the results were the same.) We then performed parametric regression analyses in the resulting clusters.

The cluster analysis returns two clusters of plants: Cluster 1 and Cluster 2. The first cluster consists of 13 plants with levels of VPS implementation (z-scores) from -1.50 to -0.37. One of these plants (at z-score -0.89) is identified as an outlier using the outlier

labeling rule with a multiplier of 2.2 (Hoaglin and Iglewicz 1987, Hoaglin et al. 1986); hence, it is not included in subsequent analysis. The second cluster consists of 17 plants with levels of VPS implementation (z-scores) from 0.19 to 1.61 (none of these plants are outliers).

A curve estimation analysis on each cluster suggests a linear model as best fit in Cluster 1 and a quadratic model in Cluster 2. They are shown in Figure 3, and Table 1 summarizes the regression models of each cluster. We note that the small sample sizes in each cluster call for caution in interpreting these results (De Beuckelaer and Wagner 2012), but the results seem to confirm an S shape.

For Cluster 1, we find a simple linear regression model ($F(1, 10 \text{ d.f.}) = 4.264, p = 0.066$) to be statistically significant at the 0.10 significance level, with an R^2 of 0.299. For Cluster 2, we find a quadratic model to have the best fit with the data ($F(1, 14 \text{ d.f.}) = 4.666, p = 0.028$) and to be statistically significant at the 0.05 significance level, with an R^2 of 0.40.

The two clusters also suggest the presence of two phases in the implementation of a lean program. Plants in Cluster 1 seem to be in an exploration phase, during which their operational performance improves at a slow rate, and those in Cluster 2 in an exploitation phase, during which their operational performance improves at a rapid rate until it eventually tapers off. We will discuss these phases in the next section, but taken together, they confirm an “S-curve” pattern: a slow rate of performance improvement in the beginning of lean implementations, followed by a rapid improvement rate as the lean

Figure 2 LOESS Curve Fitted to a Scatter Plot of a Plant's Operational Performance and Its Maturity in Overall VPS Implementation

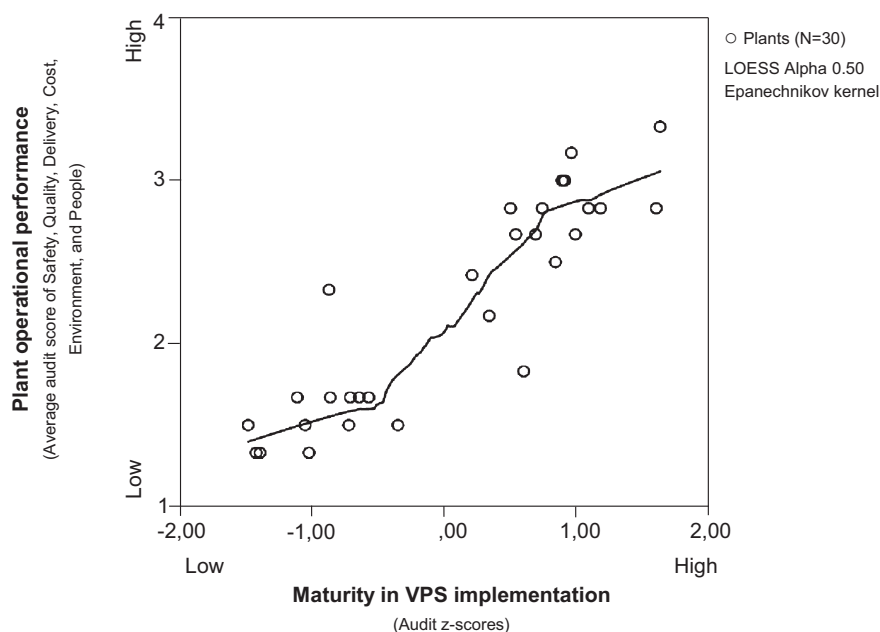


Figure 3 Results of Parametric Regression Analyses on Cluster 1 and Cluster 2

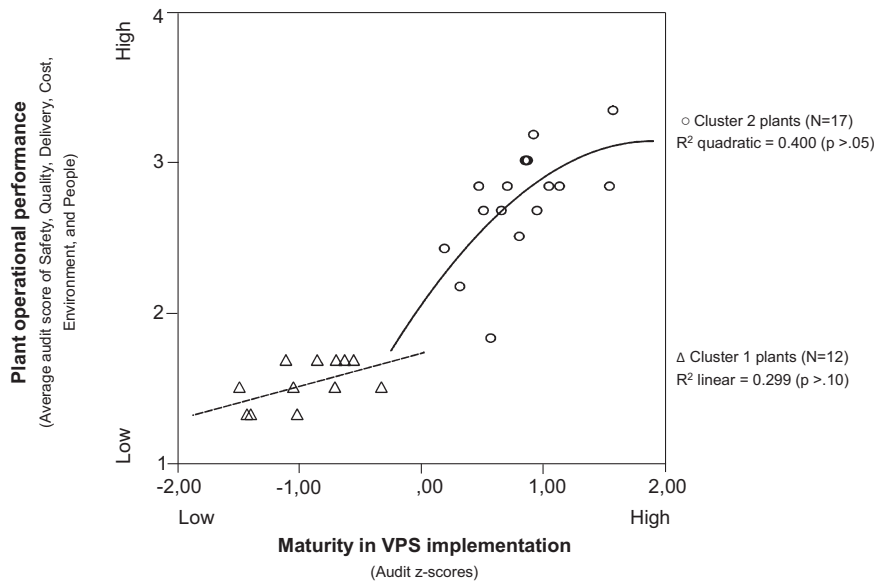


Table 1 Regression Model Summaries and Parameter Estimates: Relationship Between Operational Performance and VPS Maturity for Plants in Cluster 1 and Cluster 2

Cluster	Regression model	Constant	b1	b2	Sign	R ²
1	Linear	1.734	0.213		0.066	0.299
2	Quadratic	2.052	1.104	-0.284	0.028	0.400

implementation progresses, and, eventually, a slow improvement rate again. Next, we discuss whether this pattern is supported by existing theories and the qualitative data from our plant visits and interviews.

4. Discussion

4.1. Theoretical Support for the S-Curve

Does the S-curve pattern of performance improvement from lean implementation find support in existing theories? We find that it does. The S-curve pattern is supported by the combined effect of theories that explain how new practices diffuse in an organization (i.e., the spread of the practice) and those that explain the effect of the intensity of their applications (i.e., the depth of implementing the practice).

4.1.1. The Spread of Lean Practices in a Plant. The theory of organizational inertia provides an explanation for why the spread of lean practices can be slow at first. Organizational inertia is the tendency of an organization to continue on its current trajectory (Hannan and Freeman 1977). It suggests that resistance to change is strongest at the start and dissipates gradually as the organization adopts the change (Burns and Stalker 1961, Coch and French 1948). This process is particularly relevant in the case

of lean practices, which prescribe deep changes in the plant, ranging from modifying daily practices to inculcating a new culture. These “behavioral” reasons suggest that resistance to adopting lean practices would be at its highest level at the outset.

Theories from the field of epidemiology can also help explain how lean practices spread in a plant. While we certainly do not consider lean to be a disease, the epidemiology theory for the spread of infectious diseases provides insight into how a phenomena spreads in a bounded environment (like a plant). Omran (1971) has shown, both analytically and empirically, that infectious diseases spread through a population in an S-curve pattern: It starts in a few susceptible individuals, spreads slowly first, then very rapidly, then less rapidly, and finally, with most of the population infected, the rate of spread tapers off. Implementation of a lean practice can follow a similar pattern. It is often introduced in a few pilot areas, strategically chosen partly because they are less resistant to change and can show quick and visible improvements (i.e., they are among the more susceptible groups). As more areas adopt the practice, more positive results become visible, convincing the other units in the plant (even those among the less susceptible groups) to implement the practice. Gradually, with fewer areas in the plant left to adopt the practice (the “least susceptible” or “immune” groups), there are fewer new entrants, and the rate of spread of the practice slows down.

Relatedly, the S-curve has been used to explain the pattern of spread of many other phenomena: growth of population, bacteria, crime and terrorism, change in the environment, and particle acceleration, among others. In the field of management, it

has been suggested for the spread of innovations in society (Rogers 1962), development of new technology (Christensen 1992), maturity of the notion of manufacturing strategy (Skinner 1996), and others. Note that, in all these cases, the S-curve is used to explain the pattern of spread of a phenomenon through time. Our S-curve explains the relationship between two variables—the pattern of change in performance of the plant as it implements more of a lean program.

The effect of a lean program depends not only on its spread in the plant (which, according to the mentioned theories, follows an S-curve itself), but also on the depth of its application in the areas that have begun implementing it.

4.1.2. The Depth of Lean Implementation in a Plant. Zangwill and Kantor (1998, p. 917) suggest that learning curve theory can explain the benefits of lean programs: “Connecting the concepts of continuous improvement with the concept of the learning curve [...] makes sense because in the industrial context, these concepts are different, yet symbiotic.” Indeed, implementing a lean production system is essentially a tool for accelerating the learning rate in a plant. Learning curves were first described by Wright (1936), who found that the time needed for producing parts for airplanes was reduced by a predictable pattern each time the same part was produced. The theory suggests that, as an organization gains more experience in producing a product, its performance improves rapidly at first and then levels off (Baloff 1971, Yelle 1979). This pattern fits the popular notion that “low-hanging fruits” become scarcer as the plant becomes more mature in implementing the lean program.

This is in line with the theory of “performance frontier,” which suggests that there is a limit to how much a system’s performance can improve. Schmenner and Swink (1998, p. 108) defined a performance frontier as “the maximum performance that can be achieved by a manufacturing unit given a set of operating choices.” They suggested that the law of diminishing returns applies to improvements in a plant’s performance. As the plant approaches the performance frontier, more and more resources need to be invested in order to achieve additional benefits (Schmenner and Swink 1998, Vastag 2000). Zangwill and Kantor (1998, p. 917) also suggested that “the effectiveness of the continuous improvement effort depends upon the amount of improvement remaining, according to a power law.”

Both the learning curve theory and the theory of performance frontier suggest that the rate of improvement in performance declines with deeper implemen-

tation of lean practices. In other words, as an area in a plant follows the lean practices more thoroughly, it gets closer to its performance frontier, and thus improves at increasingly slower rates.

4.1.3. The Combined Effect of Spread and Depth of Lean Implementation in a Plant. To sum up, in the early stages of implementation, the theories of organizational inertia and epidemiology explain why lean practices spread slowly in the plant. Even if the few areas that have adopted them may improve their performance quickly (as predicted by the learning curve theory), their impact on the plant’s overall performance is limited. In the next stage, as lean practices spread in different areas of the plant at an accelerated rate (predicted by the epidemiology theory) and most of the new areas are still at the initial parts of their learning curves (hence realizing rapid improvements), a plant’s overall performance increases rapidly. The same theories also explain why the rate of improvement declines in the latter stages: There are fewer new areas left to adopt the practices, and the effect of learning tapers off as each area approaches the limits imposed by the performance frontier theory.

4.2. Qualitative Field Support for the S-curve

Our visits to 45 plants in the Volvo Group (which included 26 of the 30 plants that provided the quantitative data for our grounded theory) offer an additional opportunity to investigate the validity of the S-curve pattern. First we present the overall picture that emerges from all the visits, before we discuss relevant anecdotal evidence from plants in different maturity stages.

We had the VPS Audit Scores for almost all these plants (and we estimated the scores for the few that were missing, with the help of managers from Volvo). Gauging the level and rate of improvement of the plant’s performance was admittedly a subjective process. We tried to minimize the risk of error by asking multiple questions during the interviews aimed specifically at getting information about each of the measures that comprised the plant’s overall operational performance (as defined by the VPS, described in subsection 2.2). We also interviewed several persons at different levels in the plant to mitigate the risk of potential bias of individual respondents. Since our focus was on the operational performance measures (and not the financial ones), the interviewees usually had first-hand knowledge of these performance measures.

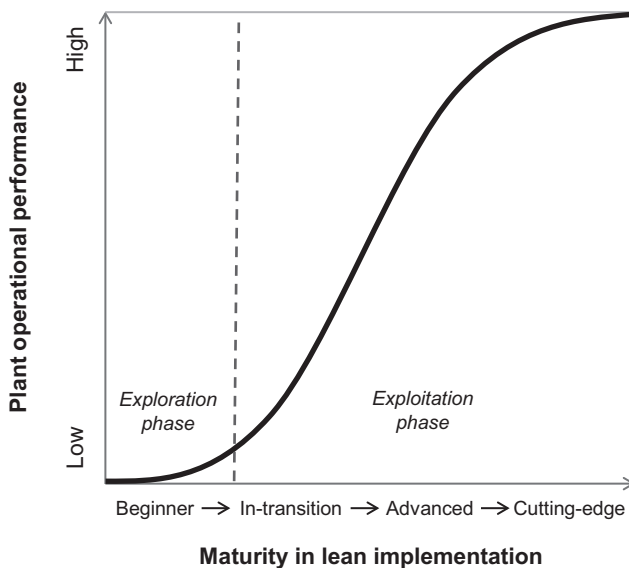
Moreover, we had the opportunity to make direct observations during our plant tours, and, in those plants that produced similar products, sometimes compare their performance directly. For example,

the average lead-time for delivering a make-to-order truck for truck assembly plants was typically six months for plants at the beginning of their VPS implementation, improving to three months for plants that had started progressing with implementation, then six weeks for plants that had implemented most of the VPS, and finally four weeks for the plants that were considered to be among the best in the Volvo Group. Although it was difficult to collect much directly comparable performance data from different plants (since they often used different methods to measure the metrics), there were many signs that hinted they were on different parts of an S-curve.

We also find strong support for the pattern shown in Figure 3 (which is based only on the analysis of our quantitative data) in the qualitative data. Of the 45 plants we visited, 13 were clearly in the exploration phase: They had the lowest VPS Audit Scores, and also showed operational performance well below average. The other 32 plants, with higher VPS Audit Scores and performance levels, were in various stages of the exploitation phase, and seemed to follow a pattern similar to the curve-linear one shown in Figure 3.

The visits also provided abundant anecdotal evidence that supported the S-curve pattern. We describe a selection of the most relevant ones in the next sections. The best way to describe them is to divide the plants into four subgroups, or “stages”: Beginner, In-transition, Advanced, and Cutting-edge. Beginners are the plants that are in the exploration phase, while the other three are in the exploitation phase (see Figure 4).

Figure 4 The S-Curve Theory: Relationship Between Maturity in Lean Implementation and Operational Performance in a Plant



4.2.1. The Beginner Stage: Initial Flat Part of the S-Curve. The 13 plants in the exploration phase were all in the Beginner Stage. There were several signs of organizational inertia in these plants. Many had started implementing lean practices in pilot areas of the plant, but as one VPS manager explained, “In the pilot area, we start to see very good results, but it remains to transfer the learning to other areas.” In other plants, the resistance toward change was even more palpable: “VPS is developed for the truck division, it does not fit us,” expressed one manager. “We have a history of change rather than improvements,” was a comment by a plant manager in another plant. Some of these plants were clearly under pressure: “If we do not improve during 2012, we will have serious problems in the market,” suggested yet another plant manager. It was evident that the efforts made in most of these plants did not transfer to substantial productivity improvements on the plant level.

We noted that the passage of time alone did not make plants transit beyond the Beginner Stage. Some plants had been in the exploration phase for many years. A production line manager in one plant expressed the concern that his plant was not moving forward with implementation: “The plant is restarting on the same issues every year.” We also observed that a few of the plants in this stage, which reported having had good progress with lean implementations in the past, apparently had regressed back to the Beginner Stage at a later time. One quality manager in one of these plants explained that recurring plant management shifts had reset the lean implementation in the plant: “We start over again every time we get a new plant manager.”

4.2.2. The In-Transition Stage: Steep Ascent Part of the S-Curve. Fourteen of the 32 plants in the exploitation phase could be regarded as being in this stage. They had implemented the VPS more thoroughly than the beginners, but not as much as the other 18 plants that were also in the exploitation phase. Their rapidly improving performance level seemed to suggest that they may be benefiting from the so called “low-hanging fruits” (quick fixes with quick results). A senior manager with 32 years of experience in a plant commented, “This plant has seen radical improvements and most of it over the last two years [due to increased attention to the VPS].” These plants can be considered to be in-transition because a palpable change of culture in the plant seemed to be in the air: “VPS has allowed us to achieve a breakthrough cultural shift in this plant,” reported a VPS manager in one of the plants. A plant manager in another plant shared a similar story: “It is the first time over the last two years that we have a focus and have moved forward.” Interestingly,

despite rapid increases in their operational performance measures, most of these managers seem to realize that they were still in the early stages of lean implementation. “We see ourselves as playing in the third league, compared to Toyota [which in its implementation of its lean program] plays in the first league. Our ambition is to advance up to that league,” admitted a VPS manager in one of these plants.

4.2.3. The Advanced Stage: Steep Rise but Decelerating Part of the S-Curve. There were also 14 plants in the Advanced Stage. These plants had relatively high VPS Audit Scores and showed high performance levels. In some cases, it was evident that they had already gone through the Beginner Stage and In-transition Stage. A truck assembly plant in this group illustrated this well: The plant’s operational performance metrics were among the best in the Volvo Group. “The progress was slow for the first 2 years,” reported the plant’s VPS manager, and added, “It was very slow...but as improvements started to come, people began believing in it and we moved forward.” In that plant, delivery precision and product quality, for example, improved significantly from 2007 through 2009 and continued to improve, but at a decreasing rate, from 2009 through 2011.

We observed a similar pattern in several other plants in this stage. They seemed to have succeeded in creating a “lean culture”. They continually set higher targets for themselves, especially after the low-hanging fruits had been picked, and kept the momentum by focusing on comprehensive improvement projects with long-term results. “The work put in over the years in the implementation of the [VPS] system is reflected in the excellent results we now get,” submitted the general manager of one of the plants. Implementing these projects took time, but they often shifted the plant’s operational performance measures to considerably higher levels. The rate of improvement in these plants (and the ones that were in-transition) generally confirmed the steep part of the S-curve.

4.2.4. The Cutting-Edge Stage: Flat Part at the End of the S-Curve. Among the 32 plants in the exploitation phase, four plants stood out with the highest level of VPS implementation. These plants were top performers in their product segments, even considered to be among the best in the industry. One of them was a truck and bus assembly plant long recognized in the Volvo Group for its operational excellence. It had embarked on the lean journey almost a decade earlier (before the introduction of the VPS, but following similar principles), and had continued to keep the momentum since then. However, as the

plant manager mentioned, “The leaner we have become, the harder it has become to sustain a high rate of improvement.”

The other three plants in this stage had similar stories. Confirming the limit imposed by the theory of performance frontier, a senior manager in one of these plants commented, “We started 10 years ago by copying others. At some level, we had copied all the best practices, and from there on needed to start pushing the frontier ourselves, which is harder.” These four plants were clearly at the top flat part of the S-curve: They had high performance levels that were improving less rapidly.

4.3. The S-curve Theory

The discussions in the preceding sections indicate that the S-curve pattern, which is derived directly from our empirical quantitative data (Figures 1, 2, and 3), is supported by existing theories and our qualitative data. Therefore, we propose the following theory:

As a plant implements a lean program more thoroughly, its operational performance improves in an S-curve pattern.

A graphic representation of this theory is depicted in Figure 4. The figure also shows the two phases of lean transformation (exploration and exploitation) and the corresponding four maturity stages (Beginner, In-transition, Advanced, and Cutting-edge).

4.4. Separating the Effects of Lean and Other Programs on Operational Performance

Lean manufacturing is almost never the first improvement program introduced in a plant, and it is not intended to preempt or replace other improvement programs. Therefore, there may be other improvement programs going on in the plant while it implements lean. This raises the question of how the effect of the lean on performance can be isolated from the rest.

It is practically impossible to do that accurately. However, in many cases, the question is almost moot. Many of the typical production improvement programs—for example, six sigma, just-in-time, total productive maintenance, quality programs, safety and housekeeping—are essentially also integral parts of lean. Therefore, their effects on a plant’s performance can be considered to be a part of the effect of lean, and a plant’s experience in such programs affects its score for maturity in lean implementation. Hence, their effects are largely reflected in both our independent variable (extent of lean implementation) and dependent variable (operational performance).

This issue can become important if a plant uses an improvement program with practices and principles that are clearly different from those prescribed by a lean production system. Such a program can hypothetically affect the operational performance without

affecting the score for lean implementation. At Volvo, we looked for the presence of such programs during our visits and interviews. We found very few plants that seemed to have any such parallel programs. The differences between these programs and the VPS were mostly in the degree of emphasis and sequencing of activities. For example, a few plants had put a high priority on cost reduction. Almost all these plants were in the exploration phase of the VPS implementation. As plants moved to the exploitation phase, they seemed to convert more fully to the lean practices that are prescribed by the VPS, modifying their legacy programs or sometimes abandoning them altogether.

In short, in practice, there was only a small risk of confounding the effect of the lean program with the effect of other production improvement programs in the plants, especially as the plants moved to higher stages of implementation.

5. Conclusions

It is surprising that a fundamental question related to the implementation of lean programs in plants had not been adequately addressed: How does the performance of a plant change as it implements a lean program? Answering this question is important particularly because a lean journey in a plant never ends, and its benefits must be assessed while it is being implemented. Both practitioners and scholars need to know what to expect.

We find that plants that show progression in a lean journey go through two distinct phases: exploration and exploitation. Their operational performance measures do not improve rapidly during the exploration phase. However, as they move beyond exploration and into exploitation, their performance improves first very rapidly, then less rapidly, and finally at a slow rate. Taken together, these changes in performance resemble an S-curve. This has significant managerial and theoretical implications, which we discuss below.

5.1. Implications for Practitioners

When launching a corporate lean program, many multinational manufacturers often issue similar targets, policies, and action plans for their plants worldwide. The S-curve pattern suggests exercising caution in this practice. It suggests differentiating between plants based on the stage of their maturity in lean implementation. Those in the Beginner Stage should be given modest performance improvement targets, those in the In-transition Stage stretch targets, those in the Advanced Stage slightly less stringent stretch targets, and those in the Cutting-edge Stage modest targets.

Without the explanation provided by the S-curve pattern, some of these suggestions may seem questionable. For example, it may seem logical to set ambitious improvement targets for plants that are beginners. These plants need to close the wide gap in their performance compared to plants in later stages. However, the S-curve theory suggests that setting stretch targets for plants in this stage can backfire. Managers and operators in such plants may become discouraged and lose enthusiasm for lean or even question its usefulness. Furthermore, the slow rate of improvement in this stage might make impatient senior managers at the headquarters (who are not aware of the S-curve theory) deprive the plant of the resources and the time it needs to get through its exploration phase. A setback at this stage can be costly; it can not only push back the implementation of the lean program substantially in that plant, but also make it much harder to rejuvenate enthusiasm for it later. In our sample, we observed that it took a minimum of 2 years for a plant to move from the exploration phase to the exploitation phase. We also found that some plants were in the exploration phase for longer periods, which may have been due to failed attempts at implementation, or even because they had regressed back to it from the exploitation phase.

Moving from exploration to the first stage of exploitation, the In-transition Stage, can be an exciting and energizing time in a plant. Mere attention to the chronic problems and introduction of best practices often results in quick corrective actions and a jump in performance. As success stories are shared, more employees become convinced of the value of lean, and as more areas in the plant are affected, the plant's overall performance improves rapidly. The S-curve theory suggests that all this is normal. Managers, in the plants or at headquarters, should expect to see a rapid rise in performance and ensure that it would not usher in a sense of complacency (that the plant is doing more than enough).

As the plant continues to the Advanced Stage in lean implementation, managers should adjust their expectations and actions again. The S-curve theory suggests that performance should continue to improve but not as fast compared to when the plant was in the In-transition Stage. There are fewer low-hanging fruits and lessons to learn from other plants. Big improvements now require major and more extensive projects often involving the introduction of new systems, layouts, and equipment. This suggests that these plants should be given more resources and discretion by local managers to choose and carry out lean-related improvement projects.

A successful transition from the Advanced Stage to the Cutting-edge Stage means that the plant has reached the flat part at the end of the S-curve. Seeing

small improvements in performance, senior managers who are not aware of the S-curve theory may form negative views and eventually become reluctant to continue allocating sufficient resources to these plants. This would be a myopic decision for two reasons. First, when a plant outperforms competitors in the industry, it provides an opportunity for the company to leverage its capabilities strategically (as Toyota has done repeatedly). In other words, its potential value for the company extends beyond its walls and should not be measured only by improvements in its operational measures. Second, and perhaps more importantly, maintaining a high level of maturity in lean implementation requires continued support by top management. Reducing the allocated resources and management attention to the lean program can send a wrong signal, sap the organizational energy, and slide the plant to an earlier stage, which, according to the S-curve, can result in a steep drop in performance.

The discussion above clarifies that, when a company plans to launch a lean program in its global plant network, it is essential to establish a rigorous assessment method for measuring and tracking the maturity of lean implementation in plants. This important step may not receive the priority it deserves at the outset, especially since it is usually an expensive process. The elaborate assessment method used by Volvo (described in subsection 2.1) illustrates the substantial amount of resources that may need to be allocated to this task. There may be other alternatives, such as audits by external consultants or less expensive self-assessment schemes, but they must be carefully analyzed to ensure that they provide reliable assessments. A weak assessment process can cause serious damage to the morale in plants and discredit the entire lean program. On the other hand, an overly bureaucratic process can also create wide discontent. This is especially true for plants in the Beginner Stage and Cutting-edge Stage. Beginner plants may be overwhelmed by the sheer amount of new principles and practices to implement and be dissatisfied with low assessment scores. At the other end, cutting-edge plants may consider the assessment process to be of little value because it does not provide helpful advice for further improvement. This suggests that perhaps even the assessment process itself must be adjusted to fit the stage of maturity.

5.1. Implications for Researchers

The S-curve theory can reduce the risk of making inaccurate inferences while interpreting empirical data from lean implementation. Scholars have attributed differences in the effect of a lean program on the plant's operational performance on a variety of factors, such as plant size (e.g., Shah and Ward 2003, White et al. 2010), location (e.g., being in an advanced

or an emerging country) (e.g., Krafcik 1988, Newman and Nollen 1996), process technologies (e.g., being labor or machine intensive) (e.g., Benson et al. 1991), and unionization (e.g., Shah and Ward 2003), just to name a few. The S-curve theory suggests that the stage of implementation of the lean program in the plant might be among the most important factors that can explain the differences, perhaps trumping the effects of these other factors in some cases.

Relatedly, the S-curve theory can explain an otherwise puzzling observation. It is not unusual for large firms to see significantly different rates of improvement in performance from implementing a lean program in two very similar plants in their global networks (similar in products, size, location, process technology, labor relations, and many other attributes) even though they allocate similar levels of budgets, training support, and other resources. It may seem like a puzzle, or be written off to be due to the competence or commitment of local managers. The S-curve theory suggests that it may also be due to the different stages in lean implementation. If one plant is in the In-transition Stage and the other in the Beginner Stage, it would be normal for the former to show a much faster rate of improvement in its operational performance.

In short, we suggest that scholars can benefit from paying explicit attention to the stage of lean implementation in a plant when they analyze the effect of the lean program on the plant's performance. The very few scholars who have paid some attention to this point have generally taken the passage of time (since the introduction of improvement practices in the plant) to be the indicator of a plant's current maturity in the implementation of the improvement program (e.g., Banker et al. 2001, Browning and Heath 2009, Jayaram et al. 2010, Swink and Jacobs 2012). The S-curve theory clarifies that passage of time alone does not affect performance; it is the depth and breadth of implementation of lean practices in the plant. In other words, it is increase in the maturity in lean implementation that moves the performance of a plant up the S-curve; measuring this maturity by passage of time alone can be misleading since a plant can remain on the same point on the S-curve, or worse, backslide on it by regressing to its pre-lean practices.

5.2. Limitations and Future Research

While we had a unique opportunity to collect rich and rare empirical data, it was from only one company. This limitation is partly mitigated by the advantage of implicitly controlling for the effect of many confounding factors, such as industry, products, process technologies, availability of resources, company strategy, and corporate culture. Another limitation is that our sample size is small. In an ideal world, it

would have been desirable to control for the possible effect of other factors, such as plant location, production complexity, product characteristics, market characteristics, and others.

It is not easy to overcome these limitations if the research is to be based on rich empirical data. Studying the effects of a comprehensive program like lean requires collecting a vast quantity of longitudinal data about many variables. As discussed, a case-based research methodology is generally considered useful in these situations. But, longitudinal case studies require dedicated resources over a long period to collect rich data. A survey-based research methodology can perhaps overcome the small sample size problem, but raises serious questions about the accuracy and reliability of the data. Respondents to surveys would have to gauge many variables (often difficult to quantify) and rely on their memory to provide the longitudinal changes in them. Further, the survey-based research does not provide the opportunity for the researchers to make direct observations and discover subtle but important factors that they may have missed in their analysis. To be pragmatic, we need to do research on both these fronts—small sample case-based and large sample survey-based designs—and compare and triangulate the results.

The S-curve suggests some promising routes for future research. One route is about the validity and dynamics of the S-curve itself. For a start, researchers can test whether the S-curve theory can be validated in settings different from ours. If so, how does it behave across different industries, under different local conditions, and in different external environments? Future research could compare and contrast the shape of the S-curve in different industries and companies. For example, does it look different in labor-intensive versus machinery-intensive plants? The role of time in lean transformations is also important to clarify: How can we explain speed of progression and regression along the S-curve?

A second promising route for future research is how to manage the lean transformation along the S-curve. For example, how does a plant move from the exploration phase to the exploitation phase? A related question is what leadership style and managerial actions are the most effective ones in the different stages of a lean transformation. Yet another question is what managers should do if the plant has stagnated in a stage, or even regressed.

There are also questions about how to implement a lean program in a *network* of plants, especially if they are widely dispersed around the globe. First, what is the most effective way to assess their progress in implementing lean principles? For example, would a self-reporting system by plants be good enough to justify forgoing the expensive alternative of using

experts from outside the plant? Second, how should the headquarters support the efforts in plants that are in different stages of maturity in their lean implementation? It seems that the role of the headquarters becomes more complicated as a plant moves from the Beginner Stage to the Cutting-edge Stage.

As a final point, an intriguing question is whether the S-curve theory also can explain the effect of other corporate programs. For example, would the implementation of a corporate sustainability program result in an S-shape pattern of change in the relevant performance measures? We think it does, but we leave these promising questions for future research.

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Appendix: The Volvo Production System

Volvo launched the VPS in 2007. It is an elaborate and meticulously documented system, based on six lean principles: the Volvo way, Teamwork,

Table A1 The Structure of the Volvo Production System

VPS principle	Modules	No. of key elements	Cronbach alpha
The Volvo way	Leadership	4	0.818
	Safety and health	7	
	Environmental care	5	
Teamwork	Goal-oriented teams	7	0.934
	Cross-functional work	4	
	Organizational design	5	
Process stability	Standardized work	5	0.857
	Production leveling	6	
	Maintenance system	6	
	5S	4	
Just-in-time	Flexible manpower	3	0.950
	Pull system	3	
	Takt time	3	
	Continuous flow processing	6	
	Material supply	3	
	Zero defects	2	
	Quality assurance	3	
Built-in quality	Product and process quality planning	4	0.867
	Prioritizing	3	
Continuous improvement	Problem solving methods	4	0.943
	Design of improvement organization	4	
	Improvement approach	4	

Notes: Cronbach alpha based on data from the 30 plants with the latest audit.

Source: Volvo Group, 2013.

Table A2 Examples of Scales for the VPS Audit Process

P	M	Ke	1. Basic	2. Structured	3. Improving	4. Best-in-Industry	5. World-Class
Process stability	Workplace organization	5 steps (5S)	5S implemented to <i>Sustain</i> level (5th S), in at least one pilot area.	5S implemented to Sustain level (5th S), in key areas defined by the plant.	5S is established in all applicable areas of the shop floor, warehouse, and in the areas on the outside of the plant.	All areas of the facility have deployed 5S, including shop floor, and all support functions.	5S is totally engrained within the culture of the company, while still maintaining the highest execution in all areas.
Just-in-time	Continuous flow	Setup time/cost	Setup time/cost is known in the pilot area, and a formalized way of working with setup time/cost reduction is used (e.g., SMED).	Setup time/cost reduction is continuously carried out at bottleneck operations or costly changeover equipment.	Setup reduction is continuously carried out at all operations, and setup time reductions are used to reduce batch sizes and not only raising overall utilization.	Single-digit minute exchange of all dies.	Setup time/cost is insignificant, with one-touch exchange of all dies where appropriate.
Continuous improvement	Prioritization	Value stream mapping	Value stream mapping (VSM) is used to highlight waste and prioritize improvement actions. The plant can demonstrate at least one complete cycle of use.	VSM has been used for door-to-door plant (end-to-end) flow for at least one product family.	VSM is used on all product families (all areas) to understand the flow of material and information and associated wastes.	As level 1 for administrative/nonoperational processes or extended VSM for, for example, sale-to-cash process.	VSM is frequently used as in level 3 and level 4.

Notes: P, Principle; M, Module; Ke, Key Element. Table contains the scales for only 3 of the 103 key elements. Scale descriptions have been shortened. Source: Volvo Group, 2013.

Process stability, Built-in quality, Just-in-time, and Continuous improvement. Each principle contains 3–5 “modules,” which add up to 22 modules in total. Each module has 2–7 “key elements,” for a total of 103 key elements. Table A1 summarizes the principles, modules, and key elements. It also shows the Cronbach alphas, which all indicate a high correlation among the modules within each principle.

Volvo uses a 5-point scale to measure each of the 103 key elements in the plant: “1-Basic,” “2-Structured,” “3-Improving,” “4-Best-in-industry,” and “5-World-class.” The scores for the key elements are aggregated for each module, and scores for modules are aggregated into scores for each principle, and finally scores for principles are aggregated into the VPS Audit Score for the plant. Table A2 shows a representative sample of the scale defined for three key elements (selected from three of the six VPS principles).

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