Minimalist Manufacturing:

Leveraging Process Knowledge for Strategic Benefit

W. David Lee

„We are overwhelmed and swimming in reports on every SKU, machine, shift.“.. .“We need to increase capacity this year.“... „I need to prepare for new product introduction next year. And the CEO says that we must change with the times and become a more responsive learning organization – able to respond more quickly to the marketplace.“.. .“I don’t know where to start. But I know there is a problem on line 7, so that is what I need to look at first.“... „We need to fill the trucks.“

– ADL Minimalist Manufacturing .Forum, December 1994

These comments reflect the challenges facing today’s general managers. On the one hand, their factories must master the production process in order to produce more and better products – while using the same assets. On the other, they need to be able to change flexibly – and fast – to produce new products.

In short, we stand at the beginning of a new era in which competition will be based on the ability of the manufacturing organization to continually acquire and implement process knowledge. Already we are seeing a fundamental shift in the goal of the factory from just getting today’s product out to developing process mastery while getting the product out. To help companies meet this new goal, Arthur D. Little is working with Professor Ramchandran Jaikumar of the Harvard Business School to implement the approach he has developed, called Minimalist Manufacturing.

What Minimalist Manufacturing Does

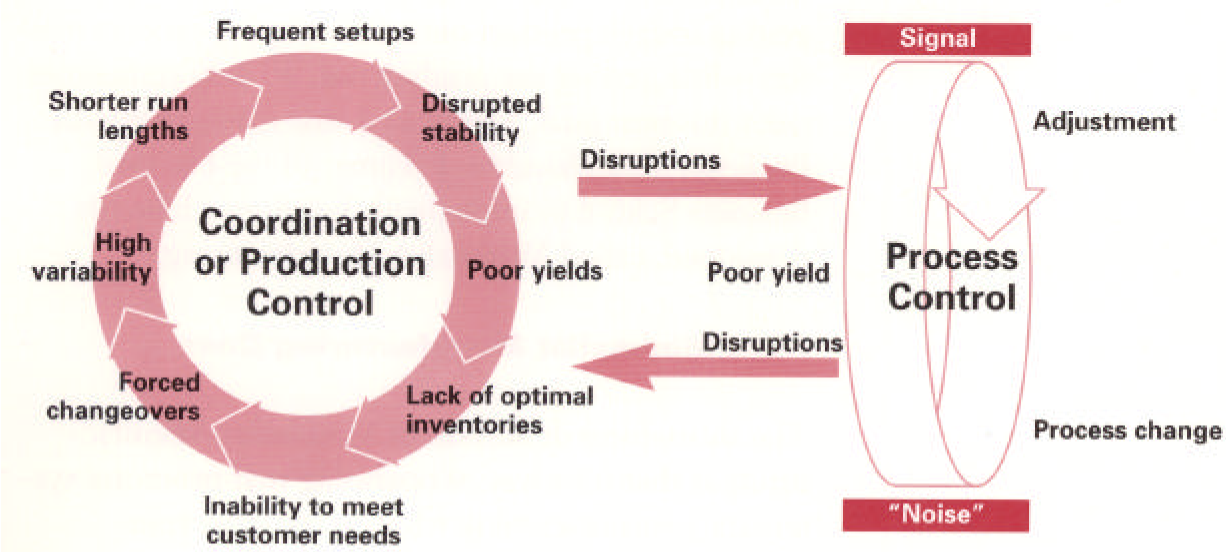
The short-form definition of Minimalist Manufacturing is that it’s a way of operating that promotes systematic process learning while at the same time ensuring maximum production. Minimalism generates more high-quality products now – as well as shop-floor learning and process mastery for the future.

A more comprehensive definition of Minimalist Manufacturing might be, „a set of principles, architecture, and methodologies for manufacturing management based on reducing disruptions, using the factory as a laboratory, and applying systematic problem-solving approaches to the manufacturing process.“ Minimalist Manufacturing provides an integrated framework for managing production control (what products to make when, with process control, and how to make them).

As the name suggests, Minimalism uses minimal resources and focuses only on statistically significant events. It promotes competitive advantage through the accumulation and leveraging of process knowledge, and it achieves savings through an order-of-magnitude reduction in the number of operational disruptions. Disruptions arise in both production control and process control, as well as in the interactions between them (Exhibit 1).

Exhibit 1

Minimalism Eliminates Disruptions Between Production and Process



For example, insufficient inventories of a certain product may force a company to do an unplanned product changeover, disrupting the product in process. Operators must then adjust the process controls until the desired performance is achieved, creating an instability in the process for a while and producing off-specific action products. Because of the changeover disruptions, the product that was originally on the line suffers a longer-than-normal run time, and the production schedule must be revised to accommodate the lower yields.

Our experience has shown that applying Minimalist Manufacturing principles to a range of manufacturing processes yields dramatic results:

• **Fewer disruptions.** Minimalism creates immediate bottom-line benefits by decreasing disruptions and increasing yield and throughput. Reduction in disruptions maintains the process flow, decreases shop-floor inventory, and reduces work-in-process.

• **Increased process knowledge.** Under a Minimalist framework, shop-floor personnel constantly build process knowledge. Over a wide range of education levels, cultural backgrounds, and company cultures, Minimalism fosters rapid, sustained problem-solving based on engineering and statistically validated approaches. Greater process knowledge is a competitive weapon for responding to new product features, quick changeovers, and reduced cost.

• **Fewer data.** While process knowledge increases, the amount of data needed to run the plant decreases.

• **Heightened morale.** Production staff embrace Minimalist improvement programs because the programs combine their practiced knowledge with engineering, control logic, and statistical models in a set of tools that the shop-floor staff feel comfortable with – and use. Morale increases steadily as more employees become involved in the Minimalist program. They see fewer interventions, fewer random data, and clearer paths for improving their functions.

• **Faster absorption and implementation.**

The rate of absorption and implementation of new knowledge proves very high with the Minimalist approach, because workers are involved in a knowledge-building process as part of normal production operations.

• **A bigger bottom line.** Enhanced problem-solving ability, robust process knowledge, and production flexibility also mean long-term bottom-line benefits.

Through extensive study and hands-on experience, Arthur D. Little has delineated a set of Minimalist Manufacturing principles that bring about these dramatic results.

Principle 1: Identify and Separate Disruptions

In work on the practical issues of shop-floor improvement programs and in our study of organizational learning, we have identified one primary factor that inhibits improvement in both production and process mastery: disruptions, also known as „things-gone-wrong“ (TGW). You know that your TGW are out of control when your manufacturing operation suffers repeated on-time delivery problems, low or variable first-pass yields, or variable throughput. However, it’s hard to identify the underlying causes of TGW because, in a typical manufacturing operation, too many things are changing at the same time.

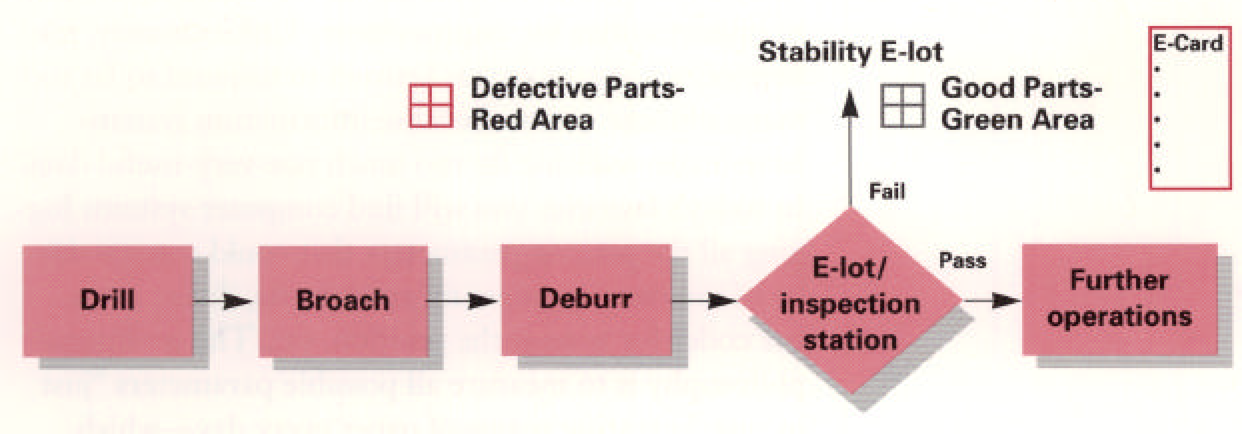
Therefore, the first step is to isolate disruptions in the production process, distinguishing random disruptions („noise“) from systematic ones. Initially, we ignore the former, minimizing the information on the shop floor in order to focus on fixing the systematic TGW

This focus allows us to achieve the fastest possible learning from the process and to make the biggest impact on improving the process.

The E-lot and E-card System. One of the easiest ways to begin to understand the Minimalist system for avoiding disruptions is by taking a look at the „E-lot,“ which is a physical buffer system for „exceptions.“ At each station on the line, a good-parts (green) basket is stocked with enough pre-inspected replacement parts to meet the need for a statistically acceptable level of random defects expected at that production point over a given period. Unless the green basket is depleted, there is no intervention in the process and the line continues smoothly. If the good-parts basket is depleted, it signals a systematic disruption or problem that qualifies for a problem-solving effort. Exhibit 2 shows the E-lot as employed in a discrete-part production system with 100 percent inspection. An inspector detects a bad part or defect, separates it from the line, and places it in a red (bad) basket, replacing it in the flow with a good preassembled part from a green (good) basket. In this way, production continues at the desired rate, without interruption, and only good parts flow down the line. Meanwhile, workers complete „exception“ cards or „E-cards“ for every defect. E-cards provide information on things-gone-wrong and are a highly effective means of root-cause analysis and effective problem-solving.

Exhibit 2

Implementation of an E-lot System



For example, a multinational company producing electronic instrumentation was suffering from relatively high defect levels that interrupted production flow. Localized problem-solving, while somewhat effective, did not produce sustainable or robust improvement. Work-in-process remained relatively high and cycle times (average time between incoming material and products shipped) remained long.

Management introduced an E-lot system, which immediately created a continuous flow of good products while isolating the defects that were causing production-line disruptions. As the production flow stabilized, the E-cards pointed to systematic process problems in both fabrication and assembly. The system also helped to identity and correct problems' root causes. As a result, the number of E-lots grew fewer, production continued to flow smoothly, and the remaining process problems were easily isolated and solved.

Principle 2: Look at the World Statistically

Any factory represents a „noisy" environment. There are an enormous number of things going on, of which relatively few offer really valuable information leading to opportunities for improvement. Unfortunately, production management has learned to respond to far too many of these events, because information systems have made available far too much not-very-useful data. In today's factories you will find computer systems logging all the process parameters that could conceivably be of interest – product measurements, defect rates, bar codes for time at the position, etc. The traditional philosophy is to measure all possible parameters „just in case," creating reams of paper every day – which, over time, disappear into archives. What is needed is statistical screening or filtering to reduce the noise from the system so that managers can focus on die real, systematic problems. Minimalist Manufacturing provides techniques – such as the E-lot system described above – for qualifying all observations statistically, ignoring or setting aside random events (again, „noise") as much as possible, and focusing information systems only on statistically significant disruptions or variations.

This approach represents a new information management paradigm in which the structure of information and knowledge is created as part of production and process control, and the system produces data on statistically relevant events. Here's the process: separate the disruptions, filter them for the ones that are statistically relevant, and then focus your attention only on these. In short, create production management systems that concentrate only on things-gone-wrong. Remove information on things-going-right from your system – if they're going right, you know what they're doing.

In the case of the electronic-instrumentation production facility, the sharpening of focus made for rapid problem-solving. Vexing defect problems that had thwarted analysis were solved in a matter of days – permanently. For example, a complex electrical hysteresis problem, known to result from a variety of process-step variations, was quickly traced and solved using the E-lot architecture. (A significant advantage of the E-card data-structure and the discipline of the E-lots methodology is that they eliminate ad hoc process tweaking, which muddies the information needed for disciplined problem-solving.) The results of E-lot and E-card implementation proved dramatic (Exhibit 3). The defect reduction raised the first-pass yield (number of complete units produced without any rework) from 50 percent to over 90 percent in just six months, and it continued to improve thereafter. The Minimalist approach also reduced cycle time from 55 days to just 13 days.

Principle 3: Systematically Learn

Learning on the factory floor has to combine statistical understanding, physical understanding, and control understanding (Exhibit 4). Any effort to understand the shop-floor processes from just one of these perspectives will not generate sustainable solutions. Typically, when process problems present themselves frequently enough to warrant attention – whether the factory employs a Taguchi, fishbone, or other organized problem-solving approach – the focus is on developing a physical model to link the process parameters with the defect or observed problem.

Minimalist Manufacturing teaches that the control and statistical frames of reference must be integrated into the problem-solving process, in part because process control itself may be the cause of some of the disruptions. In Minimalist Manufacturing, a logical control model isolates control-driven disruptions and variations, and a statistical model isolates random variations. For each key process, there should be three models: physical, statistical, and control. Each element is critical for understanding the others:

• The physical model is the basis of process mastery and knowledge.

• The statistical model validates the physical model and shows the specific interrelationship among important process parameters.

• The control model provides a framework for understanding the causes-and-effect of the various control elements that affect the physical model parameters.

Exhibit 3

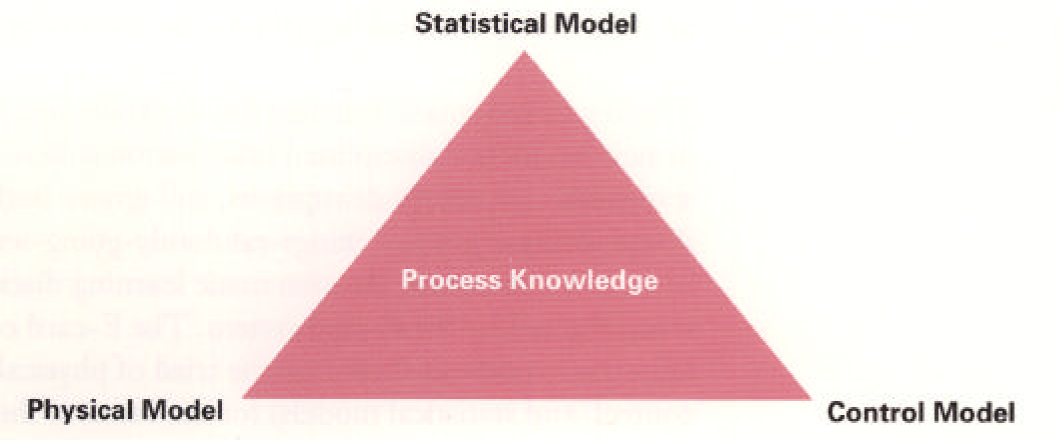
Achievements Based on Minimalism

	At Start of ADL-Led Program	After 6 Months	3 Months After Client Assumed Leadership
First-Pass Yield	~50	91%	95%
Cycle Time	55 days	13 days	13 days
Work in Progress	6 months	1.5 months	1.5 months
Number of Problems Solved	n/a	5	1-2/month

In a wire-drawing factory, the manufacturer was experiencing wire fractures that resulted in downtime and lost output. Over the years the company had come up with many explanations for the fractures, but the problem persisted. Numerous operator adjustments were the norm, and each shift coming on duty would encounter a new set of process settings. Under these circumstances, it was impossible to relate the fractures to their root cause. The company decided to try a Minimalist approach.

Exhibit 4

The Minimalist Manufacturing Triad



The implementation team chose a production line for the Minimalist application, and the learning began. First the team created a disciplined control policy to minimize operator-generated disruptions. Then they developed a physical model of the drawing process tailored to the specific operations and built statistical analysis into the data collection. As disruptions diminished, factors that systematically affected fractures emerged – and were remedied. Subtle variations in the machine settings and wire lubrication system surfaced as critical process-control factors, and new policies and techniques were designed and established.

The results were dramatic. At the beginning of the Minimalist work, the factory averaged 10 fractures per ton. After systematic learning on the shop floor – integrating physical, statistical, and control models – the number of fractures dropped a hundredfold to 0.1 per ton – a rate 15 percent better than the firm's competitors. Furthermore, the company was able to transfer its Minimalist approach to another plant and achieve capacity utilization of 95 percent, up from 65 percent, while reducing the staff work/tasks in the new plant from 320 to 90. And this company became the only profitable company in its entire industry.

Such systematic learning requires a disciplined approach. To achieve process knowledge, the production system (including scheduling) has to be coordinated, so that disruptions from setups and changeovers do not obscure the building of process knowledge.

The key to systematic learning builds on the first two principles: focus a disciplined information system on statistically important disruptions, and ignore both things-going-right and things-randomly-going-wrong. In an E-lot structure, the systematic learning discipline is maintained by the E-card system. The E-card contains the hypothesis (based on the triad of physical, control, and statistical models) for the cause of the systematic disruption. The worker completes the E-Card when he or she detects any defect or variation in the process. Rather than gathering all possible data, the E-card focuses attention on the factors that could logically cause the variation. With a minimal number of E-cards, a statistically significant root cause can be proved and appropriate remedial steps taken.

Principle 4: Create an Integrated Production- and Process-Control Architecture

The power of the E-lot and E-card approach and the integration of the knowledge triad (statistical, control, and physical models) provide the means for process mastery. However, these measures prove effective only if they are implemented in harmony with the production-management system. This system, driven by customer orders – and trying to balance the production cycle-time and the material lead time – controls the scheduling and sequencing of production, managing shop-floor inventories and dictating product changeovers and production setup. If the production-management system creates disruptions, it becomes nearly impossible to achieve sustainable shop-floor improvements.

Short run-times and forced product changeovers cause disruptions on the shop floor, inhibiting process improvements. Inventories to buffer production flow can ease the production-planning problem, but they create time delays among processes and can impede cause-and-effect analysis during problem-solving.

When a company is trying to learn systematically and to improve a process permanently, the production-management system must act in harmony with process-control improvement. The E-lot system is an example of an integrated process-control architecture created under Minimalist principles. As mentioned earlier, the E-lot structure ensures a smooth, steady flow of good parts down the line. However, where physical E-lots prove impossible, as in continuous processes, a different structure is needed, though the objectives and learning tools – E-cards – don't change.

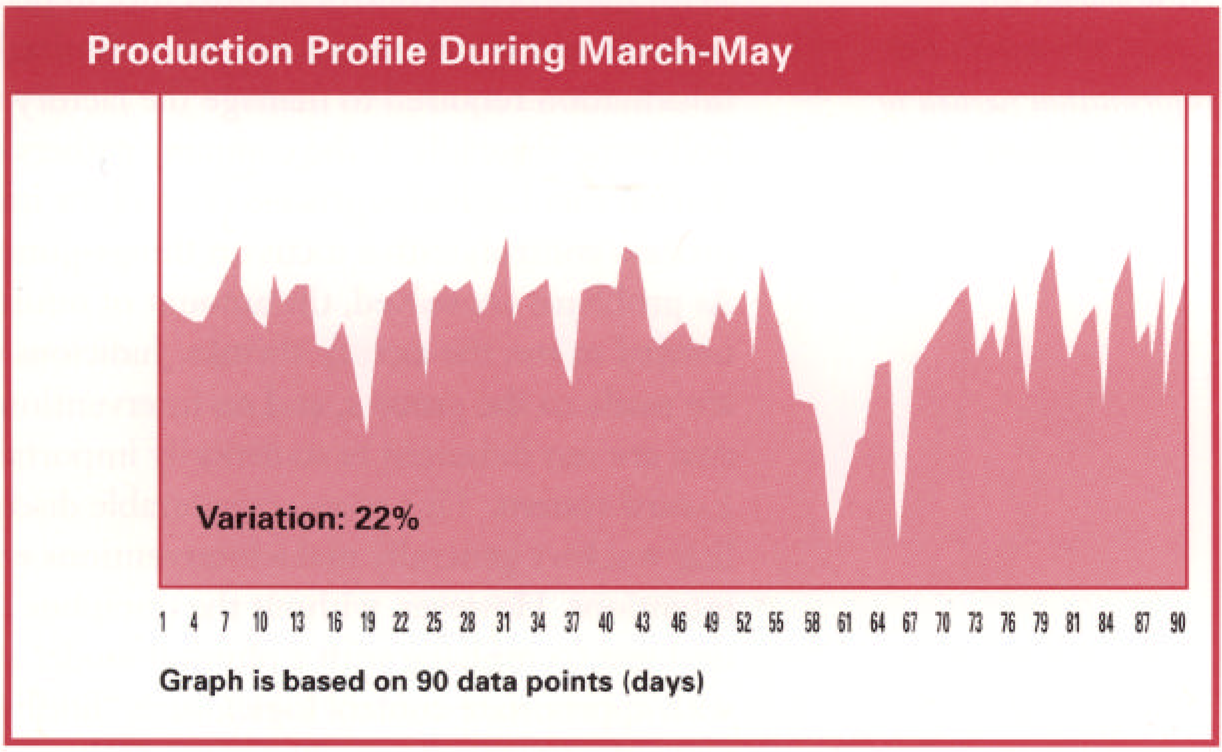
For example, a glucose factory had highly varied output, with a standard variation of 22 percent. The operators in the control room monitored 2,000 input points and constantly adjusted 40 controls. A Minimalist system was built into the plant, complete with a physical model of the key processes and the key process parameters. As the plant operated, the model was enhanced by means of statistical correlation, and then a new control approach was created. This was the tricky part. To create a statistical and control model relating the key physical parameters under actual operating conditions, the production control needed to be integrated with the plans for building process knowledge.

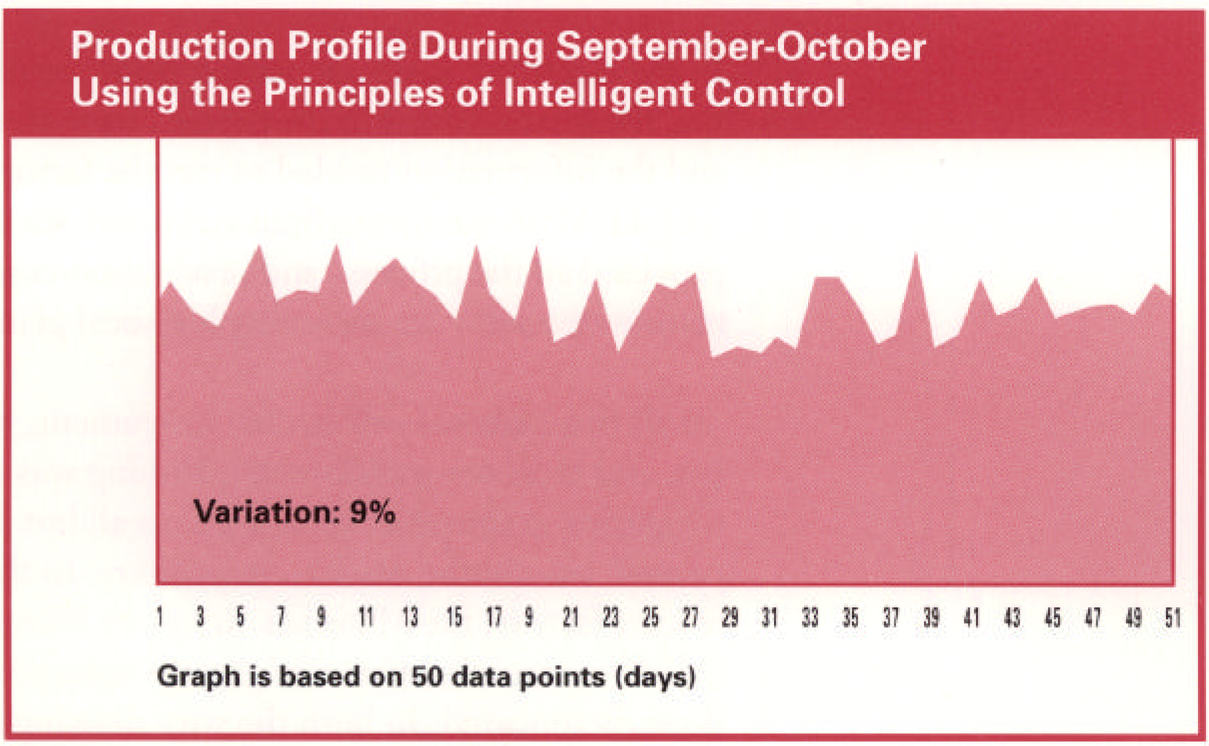
Coordination between the production-planning and process-control systems proved essential. The case team developed new scheduling rules for finished goods and for the ordering and management of raw materials. Disruptions caused by production-control changes were minimized, and the task of building process knowledge began. In a few months, the company gained a thorough understanding of the true process characteristics. The number of critical parameters was reduced from 2,000 to 40, and the number of controlled parameters from 40 to 5. The production output stabilized.

As the plant operated, management was able to validate the new control approach. The average throughput increased 15 percent and the variation decreased 75 percent (Exhibit 5). This entire process was accomplished in four months, with no additional capital needed. In addition, the company eliminated 88 percent of the active control loops.

Exhibit 5

The Impact of Minimalism in a Glucose Factory





Principle 5: Minimize Controls, Interventions, and Information

With the process-control architecture in place, controls and interventions can be minimized and information required to manage the factory reduced. Following Principle 2, the company gathers only infomation that facilitates process control (or improved process control) with a focus on things-gone-wrong. As problems are solved, the amount of information needed to run the factory shrinks. Judicious changes are made to the process, and no interventions are made that are not indicated as statistically important by the E-card system. This takes considerable discipline, as line workers generally make interventions with good intentions. However, without the discipline of a statis tical test (complying with a physical model and done with appropriate control logic), such „fiddling“ can make the process worse. For example, in our study of one plant, we found that nearly 390 interventions out of 400 did just that!

In the electronic instrumentation plant mentioned earlier, the interventions in the process were eliminated and the information needed to run the factory cut tenfold. With the throughput stabilized, the E-cards provided all the process- and production-control infomation necessary for incoming logistical planning.

In all three plants – electronic instrument, wire drawing, and glucose – production planning was greatly simplified as the process disruptions all but disappeared – as did the need for expediters. In the electronics factory, the Materials Resource Planning (MRP) system function was greatly reduced as disruptions disappeared. In both the wire drawing and the glucose factories, control-room functions and Distributed Control System requirements diminished by one-half and one-third, respectively.

Principle 6: Involve People Through Learning

All the elements of Minimalist implementation involve the production staff in a learning environment. In our experience, production staff members respond well to this scientific approach. For example, in the electronic instrument factory, the new culture rewarded individual creative problem-solving. Workers rapidly accepted the Minimalist approach because they gained better understanding of the process and enhanced their involvement in it. The statistical screening removed some of the noise and confusion on the shop floor, the physical models created a clear picture of the underlying process elements, and the control logic guided the operator into making appropriate control decisions.

Exhibit 6.

Implementing Minimalist Manufacturing: Five Workshops

Workshop 1	• Explain the overall improvement objective and its importance to the organization and to the individuals. Define the roles of the various people involved. Explain management commitment.
Workshop 2	• Introduce Minimalist principles and architecture. • Use a case study of a previous implementation as a teaching tool. • Outline the initial deaggregation of the plant into segments and design synchronous flow. • Present a detailed explanation of the architecture to be used: physical E-lot, logical E-lot, and E-card design. • Have the shop-floor staff and management break up into teams and design the placement and logic behind the E-lots and E-cards. • Share approach among teams and outline roll-out.
Workshop 3	• Develop a detailed plan for implementation. • Define roles and responsibilities precisely.
Workshop 4	• Hold mid-course review—including, for example, relocating E-lots to reflect problems already solved. • Plan next steps.
Workshop 5	• On completion of implementation, review the improvements. Make plans for continuous improvement.

Furthermore, the Minimalist architecture, by minimizing both disruptions and information, allows problem-solving techniques espoused in Kaizen and TQM to achieve their full potential. The Minimalist framework integrates the worker and production management in a way that brings about rapid problem-solving while maintaining production volume.

Generally, a workshop/team format strongly supports the improvement program. It can be useful to bring the shop-floor staff together in a sequence of workshops, as outlined in Exhibit 6.

The Promising Future

This article provides only a brief overview of Minimalist Manufacturing. Still a relatively new technique, it is already fostering robust and significant improvements in a wide range of operations:

- Increased capacity or throughput without expenditure of additional capital
- Products that exceed nameplate ratings
- Increased first-pass yields
- Improved process capability (with sustained production)
- Increased capacity and yields
- Reduced variability

We are confident that the benefits of Minimalism will only increase with our own understanding of it, and that it will eventually be seen as one of this century's most important manufacturing innovations.

[1]*Kumar Rajaram and Ramchandran Jaikumar,* „Minimalist Manufacturing in Refining Operations" *(unpublished document).*

W. David Lee is a Vice President of Arthur D. Little, Inc., and a Director of its Management Consulting activities, focusing on manufacturing improvement programs in a wide range of industries.