

Customer-Focused Manufacturing in the Switching Systems Business Unit

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The manufacture of switching systems for the growing worldwide telecommunications market demands not only the development of a world-class, customer-focused manufacturing operation, but also continual improvement and global management of those systems. This paper describes how the development and improvement of products and manufacturing processes will link the most important priorities of U.S. and international telecommunications customers with the operational priorities of AT&T's Switching Systems Business Unit (SSBU). Also demonstrated in this paper are the significant effects these efforts are having on the operation metrics of the SSBU's customers.

Introduction

Because of the nature of its product line, manufacturing in the SSBU is highly focused on the customer. Most products are manufactured "to order" as integrated hardware/software solutions, and are typically installed by AT&T personnel on each customer's premises. As a result, SSBU manufacturing is sensitive to customer priorities expressed in survey responses from both U.S. and international customers. (See Panel 1 for definitions of abbreviations, acronyms, and terms.)

The SSBU's customers are very service oriented and endeavor, in turn, to respond to their customers' requests for timely and reliable communication services. Responses to the SSBU's 1992 customer survey suggested that the two most important priorities in their relationship with the SSBU are "product quality and reliability" and "responsiveness." Acting on this information, the SSBU is striving to align the priorities of its manufacturing operation with those of its customers.

Manufacturing for Quality and Reliability

The quality and reliability of a product are determined by the robustness of the design, its components, and the manufacturing process platforms used to produce it. The successful convergence of these elements in the product realization process and their

extension into a continuous quality improvement process result in quality products that meet or exceed customer expectations.

During the early stages of product realization and subsequent process/product evolution, engineers use three key processes to ensure a level of product and process quality that leads to high reliability. These processes are design for manufacturability (DFM), environmental stress testing (EST), and concurrent engineering.

Design for Manufacturability. DFM ensures compatibility between product designs and manufacturing processes. The DFM process is begun early in the conceptual stages of product design, when key process and product technology decisions will have a significant influence on the cost, quality, and long-term reliability of a product. These early decisions will have the greatest impact on the number and complexity of manufacturing process steps: The fewer process steps, the better the product's inherent quality and reliability, and the lower its cost. Dominant characteristics that determine the number and complexity of manufacturing process steps are product technology and packaging.

The most significant product technology change driven by DFM was the transition to surface-mount technology, whose content in 5ESS[®] circuit packs grew from 5 percent in 1987 to more than 70 percent in 1994. This

change spurred many quality and reliability improvements. Surface-mount technology increased the control and reduced the complexity and variability of manufacturing processes. The in-line nature of surface-mount-technology manufacturing processes significantly reduced material handling, and also reduced process errors by introducing automated in-process controls.

DFM of surface-mount technology circuit packs demands a significant level of interaction between designers and manufacturing engineers early in the product realization process. The selection of components, their placement on the circuit pack, and the shape of the soldering pads on the printed wiring board are all critical to the design of a manufacturable product. In many instances, nonfunctional "process characterization" circuit packs are designed and used to determine the optimal manufacturing process parameters and design parameters to be used on the actual product. Data collected during the characterization process is also used to develop DFM guidelines.

The DFM process for circuit packs culminates with detailed product reviews between the designer and the product/process engineers. In the case of 5ESS switching equipment, these detailed reviews take place on the designer's computer-aided design (CAD) system. At the factory, manufacturing engineers can move components and adjust printed wiring board path routing in real time with the assistance of the designer on the CAD system. This process results in successful product realization, even if designers are not located at the factory.

DFM also played a significant role in simplifying, reducing the cost, and improving the quality of systems test. Early in the development of the SM-2000, the newest evolution of the 5ESS switch, the requirements for system test were developed along with the product design. This DFM activity between the manufacturing engineers and the systems designers influenced the SM-2000 hardware and software design, as well as the approach to system test in the factory.

Switch modules for the 5ESS switching system were traditionally limited in size from 1 to 5 cabinets. SM-2000, however, introduced the concept of a switch module with from 1 to 80 cabinets of equipment. Testing of such a large and variable configuration would have introduced major manufacturing problems. Just the logistics of assembling an 80-cabinet system for test would be a challenge. The facilities and procedures

Panel 1. Abbreviations, Acronyms, and Terms

CAD — computer-aided design
CAR — customer assistance request
CPIT — Circuit Pack Improvement Team
DFM — design for manufacturability
DQI — Device Quality Issue
ESS — environmental stress screening
EST — environmental stress testing
FCC — Federal Communications Commission
JIT — Just in Time
ppm — parts per million
QIT — Quality Improvement Team
6-sigma quality level — <3.4 ppm defects
TQC — Total Quality Control

needed to accommodate the full range of possible configurations would also be large and complex.

To overcome system test complexity, system designers and manufacturing engineers engaged in DFM activities that influenced both the hardware and software design of the SM-2000. As a result, the hardware was designed to accommodate the testing of manageable segments of a switch module, while ensuring complete functional testing coverage. Systems diagnostic software was written to concurrently test twice as many functional elements in the switch module.

Developments resulting from this interaction led to significant improvements in system test, not only for the SM-2000, but also for systems that were still in production. In particular, the software diagnostic concepts being developed for the SM-2000 were also used to test traditional switch modules.

Effective DFM on the SM-2000 ensured not only a successful introduction on a very aggressive production program, but also led to significant improvements in manufacturing the traditional switch module. The time required to test a 5ESS switch module has been reduced by more than 75 percent since 1989.

Environmental Stress Testing

EST is an effective method for improving product quality and reliability. Products that contain weaknesses may survive normal factory testing but, later, may cause latent field failures. Acceleration techniques, such as EST, can reveal these flaws before the product is

shipped from the factory. EST can also expose instances of product variability that may cause a malfunction under certain conditions.

EST uses various methods to measure a product's robustness, including temperature cycling, humidity, voltage variation, power cycling, and shock or vibration. Although EST is applicable throughout a product's manufacturing life cycle, it is most effective when designers and manufacturing engineers use it early in the product realization process. During this period, product changes are less costly. In contrast, performing environmental stress screening (ESS) on 100 percent of the product during high-volume manufacture is generally not cost-effective, but may be required to achieve high initial field reliability.

An EST sampling plan, coupled with a rigorous component qualification program, can identify product deficiencies and opportunities for improving both quality and reliability. It is essential to correct these problems and prevent their recurrence using failure mode analysis and root cause analysis.

Application of EST/ESS techniques in Switching Systems products is evident in the introduction into manufacture of the 1B24 duplex processor, which is used in the 4ESS™ toll switch, and the 3B21 duplex processor, which is used in the 5ESS local switch. Both processors are incorporated into their respective switches in a similar manner, but the 1B24 processor is retrofitted into an existing, live 4ESS switch to replace the older 1A processor. Because it is placed in a live switch, the 1B24 processor undergoes both EST and ESS procedures to ensure that its initial field reliability will be very high.

During the prototype and early production phases, the 1B24 processor circuit packs were subjected to temperature and voltage extremes well beyond their specified operating ranges. Besides providing design verification, this work established safety limits beyond which the environmental stress would render the product unusable. This phase exposed such problems as programmable logic devices whose timing was adversely affected by temperature, memory devices with ball bond weaknesses, open transformers caused by nicked wires, and cables with insufficient plating and solder. Many of these problems could have existed in the early production processors if the EST had not been performed.

To enhance the reliability of each processor shipped, every production circuit pack is environmental-

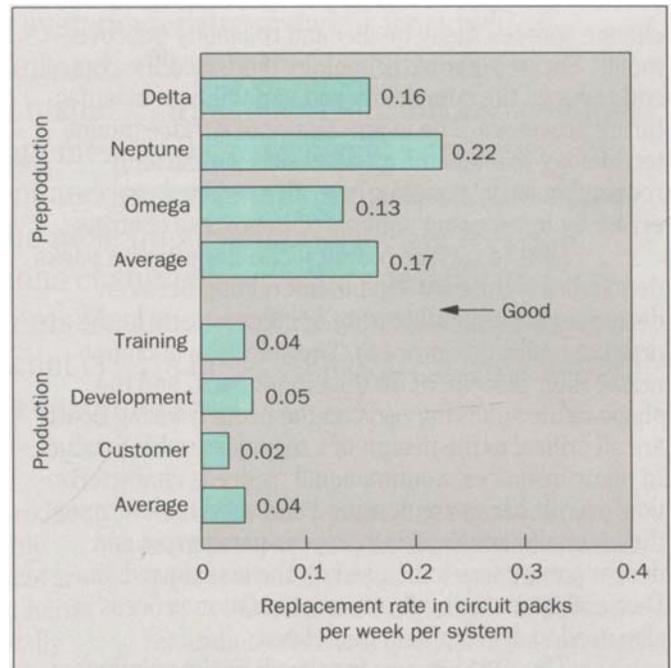


Figure 1. Reliability performance of the 1B24 processor circuit packs described in replacement rates as of June 14, 1994. The replacement rate was required to be below 0.5 circuit pack per week per system. Early production model results are shown at the top.

ly stressed—using temperature cycling, temperature step and soak profiles, and power cycling—to stimulate weak components to fail. Finally, each completed processor receives a burn-in test while it is being tested by diagnostics and performance software.

Figure 1 shows the proven reliability of the 1B24 processor. Results of an early production model are shown on the left. As more solutions for the problems described were realized, processor reliability increased. Results to date suggest that the 1B24 processor is twice as reliable as the mature 1A processor it replaces.

The 5ESS 3B21 processor was subjected to both design verification and EST evaluations of early production. Although circuit simulation was used heavily in the product design, these studies revealed some marginal noise and impedance mismatch. Both high and low temperature and voltages were used to detect and identify marginal operation. Early correction of these problems resulted in a more robust product that has less variability across its operating environment.

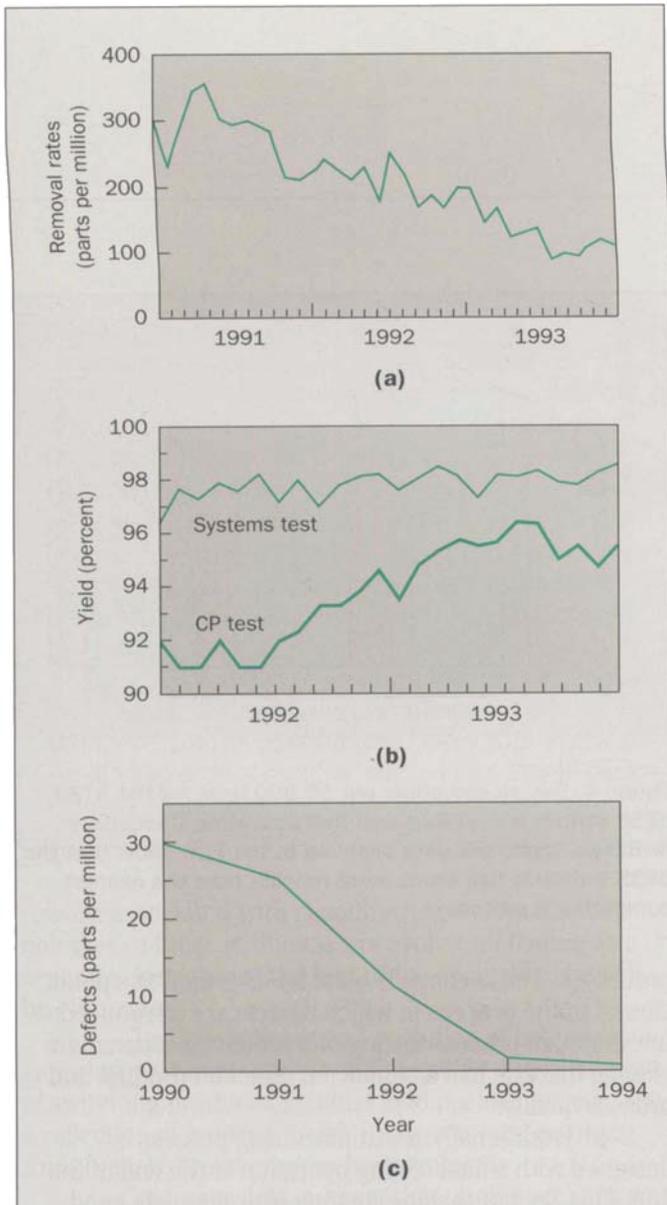


Figure 2. (a) Component removal rates for the 5ESS switch. Removal rates declined by more than 70 percent between 1991 and 1993. (b) Circuit pack yields for the 5ESS switch. (c) Line unit solder yields for the 5ESS switch from 1990 to 1994. Low solids flux and a nitrogen blanket in the wave solder process have been implemented, with significant results, on all 5ESS circuit pack assembly lines.

The Circuit Pack Improvement Team (CPIT), a cross-organizational Quality Improvement Team (QIT), has been in place since 1988 to address product and process issues for the 5ESS switch. The key external customer metrics that shape this team's activities are circuit pack returns per 10,000 shipped, and circuit pack returns per 1000 lines per month. Because these customer metrics have long cycle times, the team focused on three predictive internal metrics that have a strong correlation with the external metrics: component removal rates, solder defects, and circuit pack yields.

The CPIT team monitors these key metrics on both newly introduced products and mature products. If the metrics deviate from the predicted values in any area, the team establishes an action item and follows it to resolution. One of the processes that the engineers use in response to a metric problem is the Device Quality Issue (DQI) process.

The team developed the DQI process, a streamlined and closely controlled process, to improve component removal rates at circuit pack test. DQI reports are issued as dictated by a pareto list generated from test statistics. The suppliers of the suspect components must perform failure mode analysis on their parts, leading to a possible process improvement either at the suppliers' location or the manufacturing location, or to a design change to improve operating margins.

The DQI process has reduced the removal rates of components for the 5ESS switch by more than 70 percent in the last three years, as shown in Figure 2a. This reduction leads to a corresponding reduction in rework in the manufacturing process. Correlation studies indicate a relationship between the level of rework performed during manufacturing and the long-term reliability of a product.

Another measure of the overall impact of the improvements driven by CPIT is in the circuit pack yield metrics. Figure 2b shows how first-pass yields of circuit

Reliability calculations predicted that the field failure rate of 3B21D circuit packs would be 50 percent of its predecessor. However, early field return data for the 3B20D indicates a significantly better reliability performance than was predicted.

Concurrent Engineering

Concurrent engineering is the development and optimization of manufacturing processes prior to or concurrent with new product design. Key manufacturing processes—such as circuit pack assembly, circuit pack test, equipment assembly, and system test—are influenced by the quality and reliability requirements of the customer. There is also a strong correlation between manufacturing processes and related process metrics, and the demonstrated reliability of switching products.

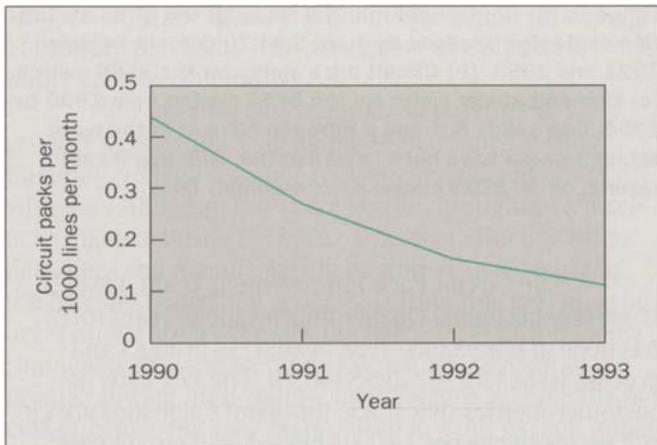


Figure 3. Return rate of the 5ESS circuit pack. The 5ESS switch circuit pack replacement rates have decreased from 0.42 circuit pack per 1000 lines per month to 0.11 between 1990 and 1993.

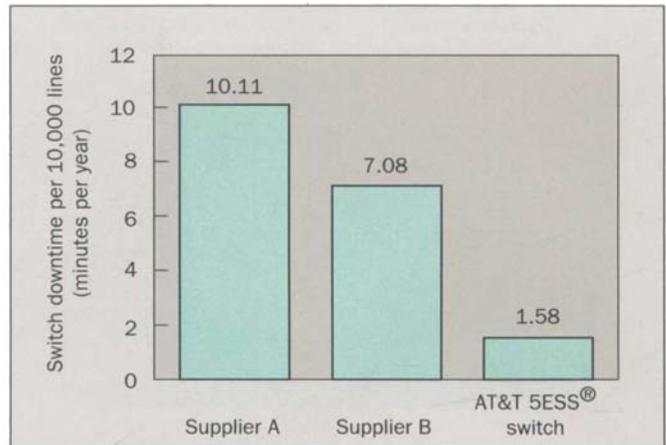


Figure 4. Switch downtime per 10,000 lines for the AT&T 5ESS switch and all Regional Bell Operating Companies' switches. Customer data supplied to the FCC show that the 5ESS switch is five times more reliable than the nearest competitor's switch.

packs improved in both the circuit pack test and systems test operations. These improvements will likely lead to enhancements in the field reliability of SSBU products.

Improvements in the quality of soldering have also reduced rework in the manufacturing processes. Recent advances in soldering have reduced the defect level to the point where no solder touch-up operation is required.

While fine tuning of the operational parameters in the solder process have reduced the defects from the 1000-parts per million (ppm) level of the early 1980s to below the 100-ppm level of the late 1980s, two recent breakthroughs lowered the quality levels to below 10 ppm, and finally to a consistent 6-sigma (<3.4 ppm) level. These changes were the use of low solids flux, coupled with a nitrogen blanket soldering process. Improvements in the solderability of printed wiring boards and electronic components also played a significant role in reaching 6-sigma quality levels in wave soldering.

The use of low solids flux and a nitrogen blanket in the wave solder process was implemented on all of the 5ESS circuit pack assembly lines at the end of 1992. The results have been significant. Figure 2c portrays the effect of these process changes.

Robust process controls are needed to maintain the improvement gains that were made in products and

processes. These controls must be instituted at a point closest to the process in which defects are introduced. Integrated in-process testing of a product is a paradigm change that has had a significant effect on product and process quality.

Traditionally, a manufacturing process is designed with a final testing operation at the end of the line. This "end of the line" testing process sorts good product from bad product and provides some feedback for process control. Unfortunately, such delayed feedback precipitates many types of repetitive defects and limits potential improvements in circuit pack first-pass yields. Integrated in-line testing changed this process from a "sorting good product from bad" operation to a real-time process control and improvement tool.

Teradyne Z1860 test sets with automatic board handlers were integrated into the assembly lines at two critical points in the process: (1) after surface-mount-test component placement/reflow, and (2) following progressive assembly/wave solder. These points were chosen to minimize the amount of product in process when a problem is encountered. (Teradyne is a registered trademark of Teradyne Corporation.)

The introduction of integrated in-line testing eliminated all in-circuit testing downstream from the circuit pack assembly operation and significantly reduced

Panel 2. The Darwin Algorithm

Genetic algorithms can provide efficient search heuristics for a wide range of applications. Their use in optimizing the traveling salesperson problem—the problem of routing a salesperson to his or her customers in the optimum manner—continues to receive attention because, while the problem is easily expressed, it is difficult to compute. “What is the optimal manufacturing sequence for a given set of shop orders?” is a similar problem that is answered by Darwin.

Darwin is a software program that uses a genetic mutation algorithm to discover a “near optimum” sequence from all possible sequences with which a set of shop orders could be started on a circuit pack manufacturing line.

rework associated with repetitive errors. As the technologies of these in-line testers evolve, all testing as a separate operation at the end of the assembly line will be eliminated.

The development and evolution of robust manufacturing processes improved the quality and reliability of switching products. Product field performance is also a reflection of internal metric improvements resulting from DFM, EST, and process improvements.

Customer data suggest that circuit pack returns and switch downtime decreased as the manufacturing processes improved. Data provided through the Reliability Review Forum and to the Federal Communications Commission (FCC) confirm that the SSBUs' efforts have been successful. The 5ESS switch circuit pack replacement rates have decreased from 0.42 circuit pack per 1000 lines to 0.11 in the past four years, as shown in Figure 3. Data supplied to the FCC by customers show that the 5ESS switch is five times more reliable than the nearest competitor's switch (Figure 4).

Manufacturing for Responsiveness

Customer research for these products indicates that “responsiveness” comprises two elements. First, customers want to receive their switches soon after placing an order. Order processing intervals and manufacturing cycle times are key to this element of responsiveness. Second, they want issues concerning field opera-

tion of their telecommunications equipment to be resolved by the supplier in the shortest possible time. These customer issues are called customer assistance requests (CARs).

Switching systems manufacturing has been sensitive to both elements of responsiveness. The 5ESS manufacturing cycle times between 1984 and 1990 dropped by 75 percent and then leveled off. Just when engineers at the Oklahoma City Works thought they could achieve only marginal improvement, benchmarking studies revealed that major competitors had shorter manufacturing intervals. As a result, in 1991 the Oklahoma City Works received a challenge to: (1) reduce the 5ESS total in-factory interval by more than 50 percent, and (2) reduce the assemble-to-order interval by 75 percent.

The project to achieve such aggressive goals was named “Tempo” because it is in the factory where the design, material, and order streams converge and must be orchestrated. To aggressively reduce these intervals, the streams had to be synchronized with many process improvements.

A Process Management Team that involved every organization in the factory, the Tempo committee addressed the interval reduction project. Four QITs addressed the many process issues identified by the Tempo committee.

The Tempo Process Management Team partitioned the interval reduction project into two classes of initiatives: (1) critical initiatives requiring external assistance, and (2) factory process initiatives. Critical external initiatives included product drawing structure, order information quality, product technology transition to surface-mount technology, and information systems developments.

Factory processes were examined using simulation and other analytical tools; from them, a model of the optimal process was developed. Process improvements needed to achieve the required intervals were identified, and interval goals for each of the factory processes were established, especially those on the critical path. The most significant process improvements are shown in Table I.

The critical external initiatives needed for the Tempo project were addressed by AT&T Bell Laboratories, Regional Engineering, and several Information Systems Development organizations. Improvements were made in the structure of product

documentation—to simplify ordering of the 5ESS switch—and a process was established to assess and to improve the quality of ordering information. The surface-mount technology content of the 5ESS circuit packs was increased to 70 percent; a number of changes were made in information systems to support the reduced intervals.

As a result of these efforts, AT&T's Oklahoma City Works was able to manufacture and deliver 5ESS switches within the Tempo objective intervals. Manufacturing operations demonstrated this capability for more than 60 percent of the orders delivered in December 1993, in addition to shipping record orders for the month.

Responsiveness to CARs is the second element that affects customers' perception of "responsiveness." The major customers of the Oklahoma City Works have designated intervals within which a CAR must be resolved, and they are closed only by agreement of the customer representatives. The resolution intervals of manufacturing CARs are tracked: The interval for normal-priority CARs ranges between 45 and 120 days, whereas high-priority CARs typically require a 30-day resolution interval.

Figure 5 shows the resolution interval for manufacturing CARs. From 1991 through 1993, performance at the Oklahoma City Works has improved by 27 percent, consistently exceeding its customers' most stringent requirements.

Manufacturing for the Global Customer

The SSBU manufactures 5ESS switching products in 15 factories located in every region of the world, for delivery to customers in more than 50 countries. Whether a global customer is building a basic communication infrastructure or enhancing a current network with advanced communication capabilities, product quality/reliability and timely delivery are priorities. Switching Systems manufacturing operations in Spain are an example of customer-focused manufacturing in the global marketplace.

AT&T is one of three suppliers of telecommuni-

Table I. Interval-Reduction-Project Process Improvements

Operation	Process Improvement
Material management	—Integrated interactive scheduling —Optimized circuit pack buffers
Circuit pack assembly	—Optimization of assembly and test sequence using a genetic algorithm (see Panel 2) —Assembly line automation projects —Surface-mount technology conversion of product
Cable manufacturing	—Reduced process and transportation interval (50 percent)
Equipment assembly	—Reduced process interval (50 percent)
Systems test	—Reduced systems test interval (38 percent)

cations equipment to Telefonica, the sole voice network provider in Spain. Manufacturing operations were established in Tres Cantos, Spain, to serve the Spanish and European telecommunications markets.

AT&T Network Systems in Spain made significant progress in delighting its customer with quality products and the highest level of service. The manufacturing lines in the Tres Cantos factory are designed to provide this level of service despite a continually changing volume and mix of products. The Total Quality Control/Just in Time (TQC/JIT) philosophy incorporated in the operation, along with their recent ISO-9000 certification, ensures the quality, reliability, and timely delivery of Switching Systems products from the Tres Cantos factory.

The volatility of product demand in the international markets, coupled with the need to respond quickly to changes in customer orders, motivated engineers in the Tres Cantos factory to develop unique processes and expertise in reconfiguring customer orders. In 1993, for example, after manufacturing a large switch for one customer whose project was subsequently delayed, the engineers reconfigured elements of the switch to satisfy critical orders from four other customers—in just five working days. Customer satisfaction always improves when this level of responsiveness is displayed by manufacturing.

With this and other examples of customer-focused manufacturing for the global market occurring in operations worldwide, Switching Systems manufac-

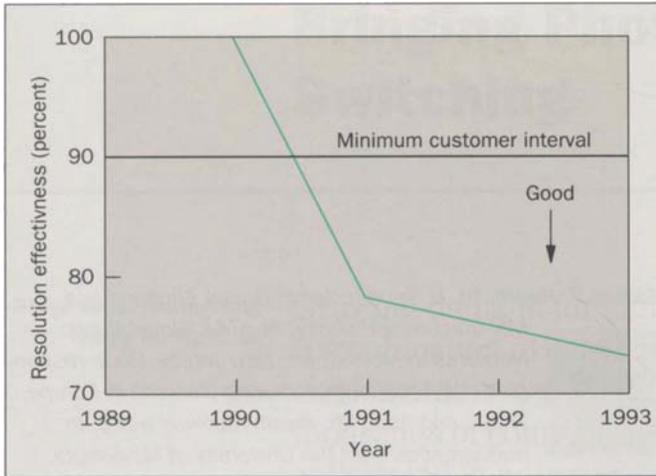


Figure 5. The resolution interval for manufacturing customer-assistance requests in the Oklahoma City Works. Performance from 1991 through 1993 has improved by 27 percent. The customers' most stringent requirements have been consistently exceeded since 1991.

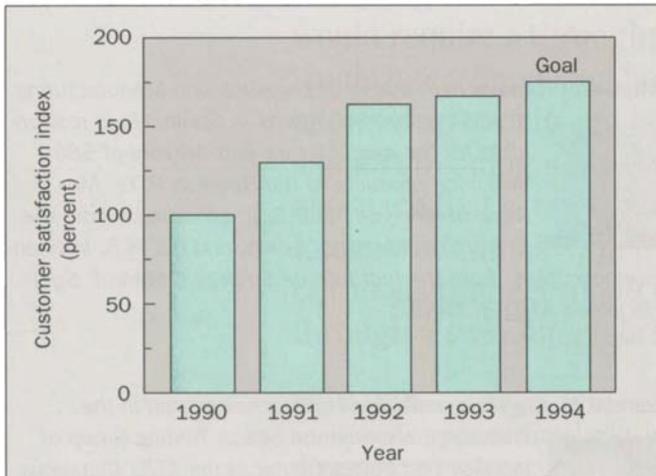


Figure 6. AT&T switching is making significant progress toward establishing manufacturing as a core competence. This is evident in steadily improving report card grades given to AT&T by its customers, despite rising customer expectations.

turing decided to promote manufacturing as a single synergistic asset. This decision to treat all manufacturing operations as a single entity led to the development of a Global Manufacturing Management process for Switching Systems.

Global Manufacturing Management

Many process/product improvements described in this paper are the result of the cooperative efforts of all 5ESS factories. Five engineering circles, with representation from each factory, were established to share best practices between factories and to work on common technology issues. This synergistic effort enabled Switching Systems to treat all 5ESS factories as a single global manufacturing asset.

In 1990, the Oklahoma City Works established a Global Engineering Control organization to manage product and process technologies for the 5ESS product line worldwide. The Global Engineering Control Center, with the participation of the international factories and the engineering circles, identified best-in-class processes. These processes have been standardized and are now used in all factories that manufacture the 5ESS switch.

Summary

Growing worldwide demand for switching products emphasizes the importance of manufacturing as a core competence for Switching Systems. For manufacturing to remain a core competence, a strong design and manufacturing synergy must promote robust products, manufacturing process platforms, and programs that will ensure their continuous evolution and improvement. Competitive manufacturing of world-class products that delight customers requires not only the development of world-class manufacturing, but also continuous evolution and improvement of the processes using global management.

SSBU manufacturing engineers develop process platforms before, or along with, the design of new products, and they strive to continuously improve them during the life of the products. These platforms strongly influence product architecture and design. This product and process synergy has a significant impact on product cost, quality, and long-term reliability. The standardization, application, and management of these platforms in switching manufacturing operations worldwide create a global manufacturing operation in which any product can be manufactured at any location for delivery to any customer.

The record growth of 5ESS production in the last three years, and the recognition by customers of its exceptional quality and reliability, suggest that AT&T switching is making significant progress toward establishing manufacturing as a core competence. This is also evident in steadily improving report card grades given to AT&T by its customers (see Figure 6), despite rising

customer expectations. What effect has customer focus in the SSBU had on the success of the business? A brief look at Northern Business Information data provides the answer. AT&T's switch market share in the U.S. has steadily increased, from 42 percent in 1990 to about 50 percent in 1993.

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