

Quality and Productivity in Injection Mold Tool Construction: A View From Manufacturing

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In today's consumer electronics market, being first to the marketplace is paramount to success. The need for early entry into the market has its origin in the rapid evolution of the electronics industry. The saying "It's obsolete by the time you get it home" suggests the desire that drives consumers back to the marketplace for the products with the latest features. Early entry into the market can mean the difference between financial success or failure of any electronic customer premises product. It is generally recognized that the first six months in the life cycle of a low-end consumer product can represent 50 percent of the product's opportunity for return on investment. The Shreveport plant's tooling efforts extend throughout AT&T. Tooling is provided for the Consumer Products, General Business Systems, Business Communications Systems, and Network Products business units. These divisions are all involved with customer premises terminals that have product life cycles of one to four years.

Introduction

In the world of electronics, plastic injection mold tool production plays a major role in the interval (i.e., the time) needed to introduce new products. This tooling interval has been the focus of a team at AT&T's Shreveport, Louisiana, manufacturing plant. This team, formed in 1988, was challenged to reduce tooling costs by 40 percent, and tooling interval by 50 percent, and still provide the highest quality tooling available.

The benefits of maintaining a total design and construction entity within AT&T are significant. First, such an entity leaves control of our destiny in our hands, not in the hands of others. Second, if this team succeeded, AT&T would have a first rate domestic tooling source able to meet the needs of the 1990s and beyond. This domestic tooling source would give AT&T a distinct advantage over its competition by eliminating the problems and hidden costs associated with foreign tool sourcing. In addition, keeping the tooling phase within the company would eliminate a major potential source for loss of intellectual property.

The Previous Process

Before the current tooling process began, the typical sequential process in the development cycle of plastic parts was as follows (see Figure 1):

- AT&T Bell Laboratories developed conventional two-dimensional part design, i.e., like designs drawn on a piece of paper. Models were made, and a tool manufacturer was selected based on quotes.
- The tool manufacturer began tool design, but often requested changes in parts to improve design. Such requests were difficult to grant because part design is considered complete, and any changes would require assembly analysis and formal documentation. Some changes were requested because the inconsistent dimensions of the two-dimensional designs were discovered only after the manufacturer began work. The inconsistent dimensions were resolved; but now, while testing was proceeding, several part design changes were requested by part designers, and the design was changed yet again.
- When the tool design was complete, it was

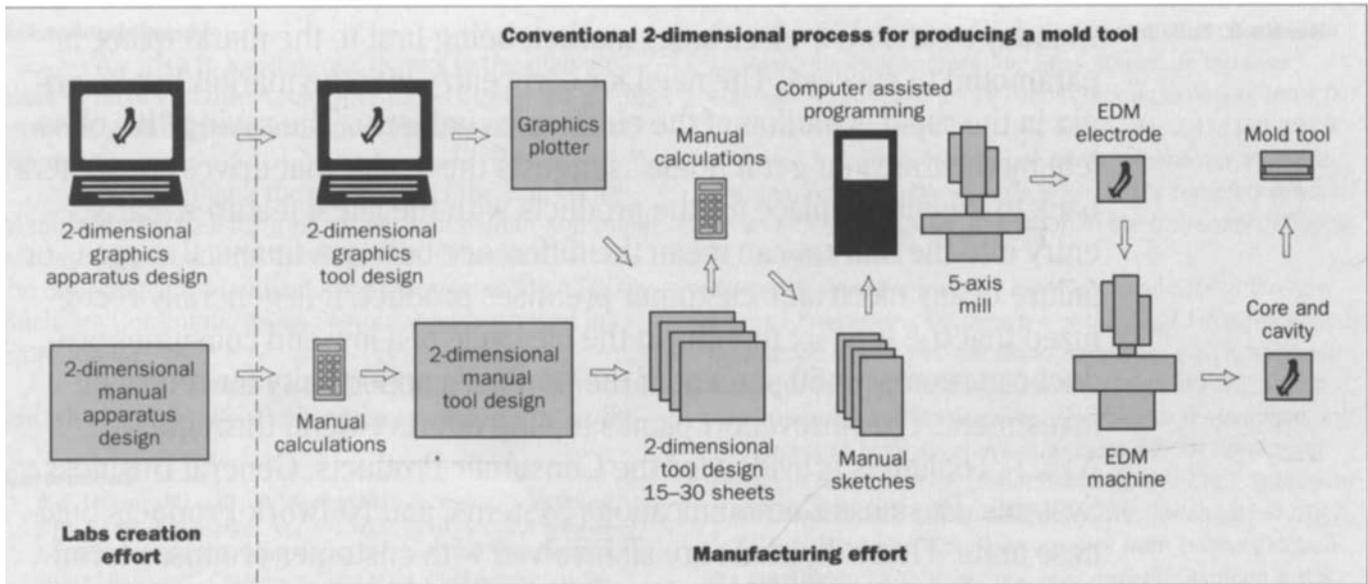


Figure 1. The conventional two-dimensional process for producing a mold tool.

released to the toolmaker for construction. Additional inconsistent dimensions often would be discovered: some because of the two-dimensional piece part drawings, and some because of the two-dimensional tool drawings. Once the inconsistent dimensions were resolved, any tool details or electrodes made using inconsistent dimensions had to be scrapped.

- The toolmaker would produce multiple two-dimensional hand drawings for each phase of all details to be constructed, including drawings for rough stock cutting, milling, grinding, electrode construction, and electrical discharge machining (EDM) work. (Electrode designs generally include many critical manual calculations.) One or more of these drawings often included mistakes made because of human error.
- When tool construction was complete, tool made samples were produced. But low confidence in the accuracy of the two-dimensional process led to a time-consuming and expensive manual inspection of all parts.

The result of this process was 20 to 28 weeks of intense manual effort for toolmakers, milling, drilling, grinding, and EDM personnel. This effort—common throughout the tooling industry—was beset by changes

Panel 1. Acronyms in This Paper

CAD	computer aided design
CAE	computer aided engineering
CAM	computer aided machining
CIM	computer integrated manufacturing
CMM	coordinate measuring machine
CNC	computer numerical control
DMIS	dimensional measuring interface specification
EDM	electrical discharge machining
GRIP	graphics interactive programming
SPC	statistical process control

and reworks at both Shreveport and its contract tooling shops. Each step contributed to long tooling intervals and exorbitant tooling costs.

New Process

When the traditional manual, sequential process was recognized as unacceptable, Shreveport engineers decided in 1988 to proceed with a bold vision to reengineer the tool design and manufacturing process. The essence of this vision was concurrent engineering with three-dimensional computer graphics as the basis for design and manufacturing. Concurrent engineering, as the name implies, is the concurrent effort performed by all persons involved in a project. Figure 2 shows this new process, sometimes referred to as a *computerized paperless system*.

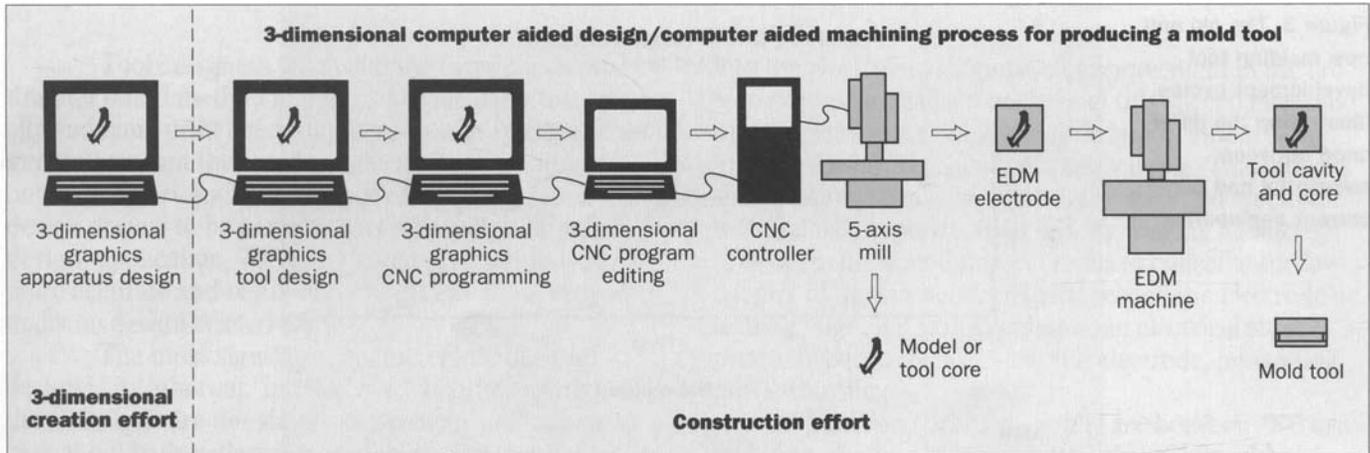


Figure 2. Three-dimensional CAD/CAM process for producing a mold tool.

Communication in the New Process. The new system and its concurrent engineering concepts had to be integrated into AT&T's developing network of computer systems and change management control procedures. *Communication* is the key to the concept's success. The preferred communication mode among people from different disciplines is face-to-face meetings. However, because the sources of new products coming to Shreveport are spread across the country, face-to-face communication is not always practical. Many modes of communication had been previously used, including telephone, mail, and facsimile transmission. Electronic data transfer was primarily via a DECnet[®] networking software system that interconnects most AT&T sites that provide work to Shreveport. (DECnet is a registered trademark of Digital Equipment Corporation.) This electronic data transfer is suitable for data movement, but fails to provide a user-friendly online method of communication.

A T-1 satellite link has been installed between the Shreveport Works and Middletown, New Jersey facility of AT&T Bell Laboratories. This link allows simultaneous viewing of graphical data so people at different locations can view a computer graphics image during design reviews. This approach to reviewing product designs is similar to a face-to-face meeting.

Resolving System Incompatibilities. The most serious problem threatening full implementation of this new process is the incompatibility of graphics systems used across AT&T. The most intelligent computer graphics databases used today are referred to as *solids*. Virtually all graphics systems can create solids databases, but to date there is no way to translate solids from other

systems into the UNIGRAPHICS[®] system for manufacturing. (UNIGRAPHICS is a registered trademark of the EDS Corporation.) Generally, such databases are first converted into three-dimensional wire frame, a less intelligent database, and only then are translated into a UNIGRAPHICS database. But the advantages of using solids for tool design and construction are lost when this conversion is performed.

Concurrent Engineering

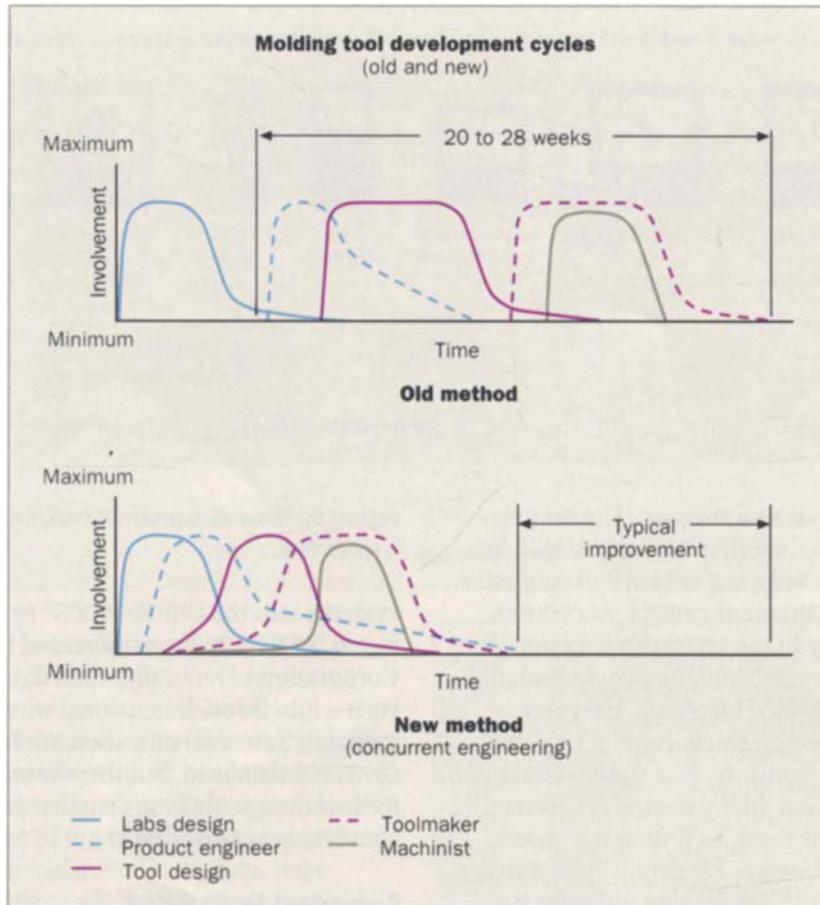
As this paper previously indicated, concurrent engineering involves the concurrent effort performed by all persons involved in a project. Figure 3 depicts the old and new processes, and illustrates the move from sequential to concurrent engineering. With respect to tooling, this process includes three major operations:

- Product design
- Tool design
- Tool construction.

The ultimate, or best, variation of this process is the simultaneous start and finish of all three operations. In reality, there will presumably always be some overlap between the finish of product design and the completion of tool construction.

In this developing process of plastic part production, a team of experts is formed shortly after concept development has been completed. This team includes one or more representatives from each area involved in the part production process. Teams typically include

Figure 3. The old and new molding tool development cycles, illustrating the difference between sequential and concurrent engineering.



persons from the following disciplines:

- System and part design
- Product database creation, manufacturing engineering, and assembly engineering
- Tool design and tool design database creation
- Tool making
- Computer numerical control (CNC) programming
- Inspection.

Ideally, team members assemble in a face-to-face meeting or view the design electronically during the review. Generally, the industrial designer's sketches or preliminary three-dimensional databases are used as the basis for this review. Once a spirit of cooperation is achieved and all team members begin to work toward a common goal, nothing short of the best product in the shortest time possible will result.

The results of these team meetings have been threefold:

- Camaraderie between team members has led to a free exchange of information throughout the project.
- The expected results have been fully understood by all parties.
- Agreement has been reached on the best possible design.

Three-Dimensional Tool Design

Injection mold tool design at the Shreveport Works has made tremendous advances with the introduction of computer graphics. The development of GRIP (graphics interactive programming) programs to complement the UNIGRAPHICS software has lifted much of the burden from the designers. These programs, written in a format similar to Fortran, were created at Shreveport, and tailored to the way the facility designs tools. These special programs graphically create all commonly used details encountered in mold tool design.

Tool designers who used the two-dimensional drafting board method had to make calculations manually and hand-print every dimension on the design. This generally meant thousands of calculations, resulting in potential errors such as transposed numbers. Tool design proved to be perfect as a CAD (computer aided design) application. The CAD designs are significantly more accurate and result in more precise tools with virtually no design-related errors.

The most significant characteristic of a CAD design is its inherent "intelligence." In other words, these designs are not simply pictures for toolmakers to look at but truly reflect the original design created by the piece part designer. Simply speaking, tool designers start with the original three-dimensional computer file created by a lab designer, and instruct the computer to recalculate all dimensions to compensate for plastic shrinkage during cooling. They then create the remaining mold design around the modified file. Using GRIP programs, most commercial components are automatically created for the designers. This new method of allowing the computer to do all calculations has eliminated manual calculations and hand printing of dimensions.

Tool designs created at Shreveport are not totally paperless. They now typically contain only those dimensions required to complete conventional machining. Shreveport toolmakers are in a transition from paper drawings to computer access where they create any two-dimensional documentation they feel they need. The goal is to eliminate most dimensions and let toolmakers create those dimensions required for operations not under CNC control, such as sawing and grinding.

Electrode Design and Machining by CAD/CAM

The EDM process is a widely used operation that has significantly improved the toolmaking industry. The two most common versions of this process are wire EDM and EDM sinking. The wire EDM process uses a thin conductive wire to electrically erode complex openings in tool steel. It is integrated with computer programming to help machine the complex three-dimensional openings in mold tools.

There are two versions of EDM sinking. In the older, conventional process, electrodes simply move straight down as they erode openings in a work piece. The newer EDM process is called *orbital EDM sinking*. In it, the electrode moves in a horizontal orbit as it plunges

into the work piece. Significant improvement in the erosion process is realized because of this special electrode motion. The prime reason for this improvement is the improved swarf (i.e., sludge) removal rate. This swarf is the contamination generated as the steel and electrode material first vaporize, then solidify. During an internal EDM burn, the contamination tends to collect at the lowest part of the cut between the steel and the electrode's leading edge. If it is not removed, an electrical short occurs between the steel and the electrode, preventing further burning.

Electrode orbits generally are between .006 and .050 inch. As the electrode moves through its circular orbit, it will burn only on the side nearest the steel, while the opposite side will be an orbit diameter away. This gap allows the swarf to be readily flushed out, significantly reducing burn time.

There are two major challenges associated with orbiting an electrode. The first, constant, problem is the degree of complexity added to the design of orbiting electrodes because every feature on an orbiting electrode is moving in an equal-size orbit. Thus, perfectly sharp outside corners on the electrode create circular corners within the steel, while inside sharp corners produce external sharp corners. Electrode corners that contain outside fillets (i.e., curved edges) will generate fillets in the steel that are larger than those on the electrode. Electrode corners containing inside fillets will produce fillets in the steel that are smaller than those on the electrode (Figure 4).

Features such as tilted planes, though their shape does not change, must be shifted out of position a distance equal to the orbit radius. The design for orbiting electrodes is so complex that most manual designs contain only one or two features per electrode.

The second challenge of orbiting electrodes is their programming and machining. UNIGRAPHICS software contains an advanced computer graphics machining package well suited to producing complex orbital electrodes containing large numbers of features.

These complex CAD/CAM (computer aided machining)-produced electrodes are the major time-saver in CAD/CAM tool production. By combining many features on one electrode, multiple setups and multiple EDM burns are reduced. Because these computer-generated electrodes are created from the computer image of the original part, dimensional errors are greatly reduced.

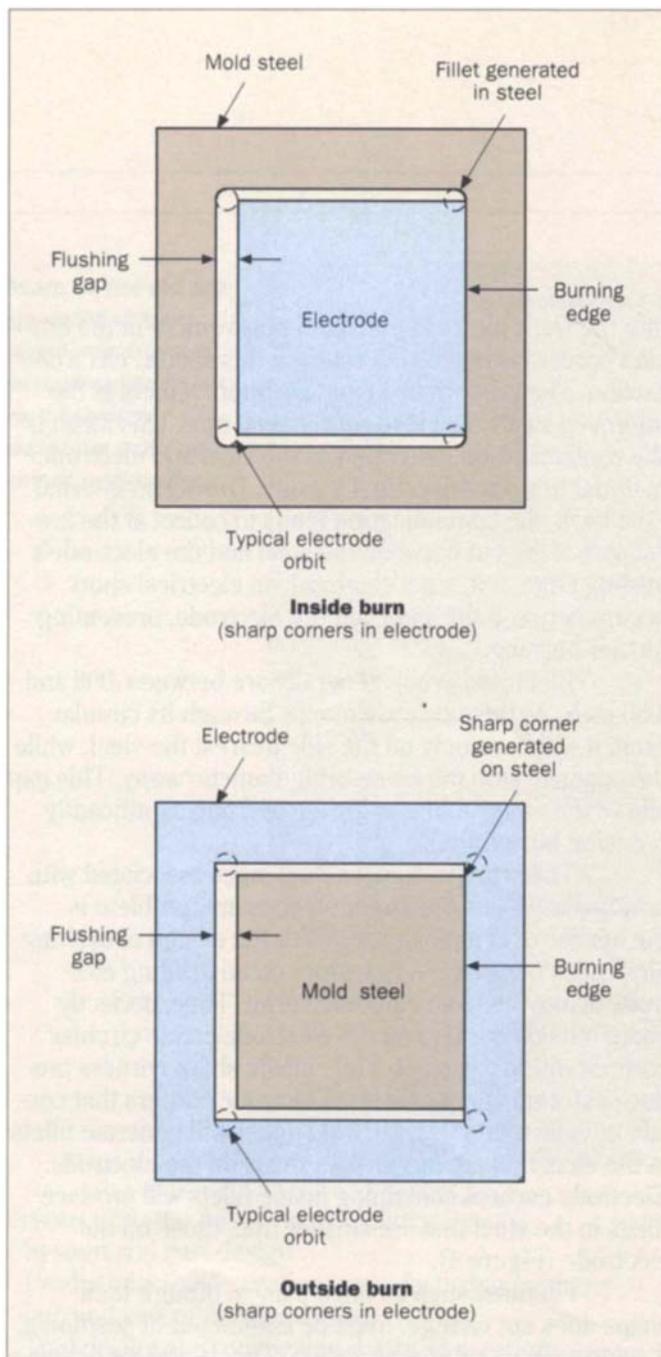


Figure 4. A comparison of the resulting difference between inside and outside orbital EDM machining.

Prehardened Steel Tools

Another significant interval reducing technique, now recommended by the Shreveport Works, is using prehardened tool steels. These steels are normally used to tool short to intermediate life products. The life expectancy of such tooling varies greatly with the intricacy of the piece part and the care taken by molding personnel. Each tool must be evaluated for potential use of these steels. Cores and cavities made of these steels are typically created on CNC milling machines using computer

graphic-generated CNC programs. As a result, major time savings are realized because the multiple cycles of heat treating, grinding, and EDM work are reduced. These efficiencies are multiplied if changes are required.

Computer Controlled Coordinate Inspection

Although CAD/CAM processes control design, programming, and machining of most tooling parts, there are intermediate steps where inaccuracies can jeopardize the tool quality. The potential problems are caused by factors such as cutter size variation, cutter deflection (bending), cutter wear, milling machine setup, and electrode setup. To ensure that each step of the tool construction process stays within acceptable dimensional guidelines, computer controlled inspection is performed at three intermediate steps:

- As electrodes are completed on a five-axis CNC milling machine, they are compared to the electrode configuration in the computer database.
- Tool cores and cavities of each tool are inspected after EDM and are compared to the tool design database.
- Finally, the plastic parts created by each tool are inspected to verify they conform, within acceptable limits, to the original plastic part database.

These inspection programs, much like the CNC milling programs, are created interactively within the UNIGRAPHICS system. The inspection program generator (UGTODEMIS, or Unigraphics TO DMIS), a UNIGRAPHICS module, generates an intermediate file in DMIS (Dimensional Measuring Interface Specification) standard format. This DMIS format file is then postprocessed into machine-readable form to control a Brown & Sharpe motorized Validator® CMM (coordinate measuring machine) that automatically inspects each detail. These inspection programs are retained for future quality checks on the tool and plastic parts.

System Integration

The system of three-dimensional computer graphics design, analysis, and manufacturing has led to extensive system integration (see Figure 5). CAE (computer aided engineering) is a general category of computer programs that assist in engineering all phases of product development. CAM (computer aided machining) refers to the many computer supported machining operations. CIM (computer integrated manufacturing) relates to integrating computers with manufacturing operations.

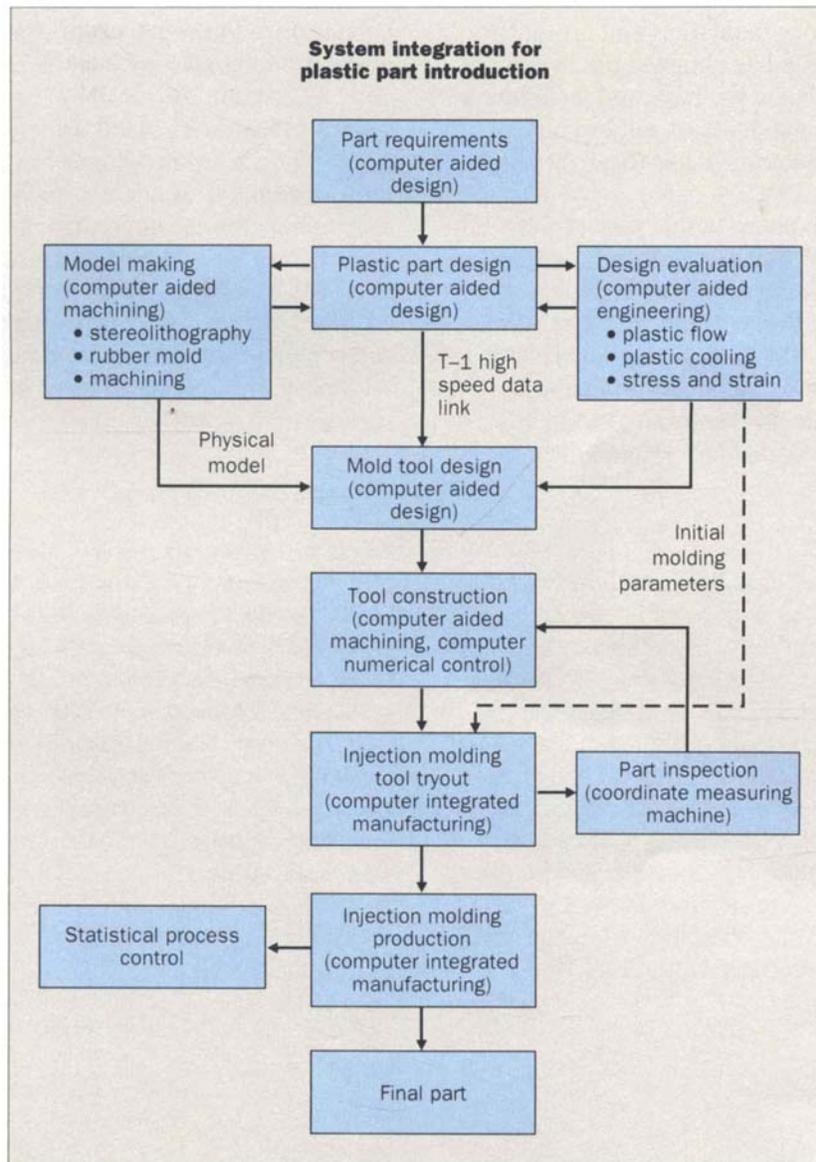


Figure 5. Representation of system integration for plastic part design, introduction and manufacturing, combining computer aided design (CAD), computer aided engineering (CAE), computer aided machining (CAM), and CIM (computer integrated manufacturing).

These integrated processes have been perfected at various AT&T locations. Consumer Products in Indianapolis, for example, has made great strides in model-making by developing stereolithography and rubber mold models. (Stereolithography is a computer-controlled process that uses a laser to harden liquid plastic to produce a model part.) AT&T Bell Laboratories at Holmdel is completing development of a means to analyze plastic flow within injection mold tools. At the Shreveport Works, the molding of plastic parts is now

highly CIM-integrated with computer downloading of molding parameters, online process control and scheduling, and automatic statistical process control (SPC) recording. Together, these tools make up an integrated system linking the Shreveport Works with design facilities in other parts of AT&T.

Results

Shreveport's initial plan—to reduce tooling cost by 40 percent and tooling interval by 50 percent—has

been achieved on numerous mold tools and is now the expected norm. The facility has obtained the necessary equipment, and has developed the tools and techniques to meet its goal. The remaining effort will be concentrated on training the employees to use these new tools and techniques.

The most difficult phase of this project was not procuring hardware or developing techniques, but solving the people issues. Everyone involved—manufacturing engineers, tool designers, CNC programmers, machine operators, and toolmakers—has had to adjust how they do their jobs. The new procedures require everyone to use the new software, terminals, and CNC machines to make the new system function as an advanced factory.

Continuous Improvement

The toolmaking process has been improving worldwide. Completing this project, while placing Shreveport on a par with industry leaders, is by no means the end of the work. AT&T must continue to improve its time to market and cost structure through system and organizational efficiency improvements. The planned addition of faster graphics workstations in 1992 promises to give Shreveport an additional enhancement in time to market and lowered tooling cost. Leading tool-making companies in the U.S., Europe, and Southeast Asia, are moving in the same direction as the Shreveport Works. This work, coupled with its special understanding of and relationship with AT&T Bell

Laboratories locations, makes the Shreveport Works the premier mold tool center in the company.

Acknowledgments

The fact this report was written from a manufacturing viewpoint should not imply that all efforts toward shortening interval and reducing tooling cost have been made by the manufacturing area alone. Credit is due to all AT&T Bell Laboratories locations now providing tooling work to Shreveport. The management, engineers and designers at Holmdel, Indianapolis, Middletown, and Whippany, have all contributed in various ways to the success of this project.

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