

Benchmarking Semiconductor Manufacturing

**A Research Program at the
University of California
at Berkeley**

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Agenda

- Introduction to CSM Program
- Purpose of the study
- General plan for the study
- Fabs studied
- Manufacturing metric scores
- Summary of best practices

CSM Program

Originally funded by Alfred P. Sloan Foundation, now jointly funded by Sloan and the world industry

\$325,000 received from companies in US, Japan, Korea and Taiwan, \$100,000 more anticipated this year

Charter: Measure manufacturing performance and identify underlying determinants of performance in the semiconductor industry

Benchmark wafer fabrication across industry

Carry out focus studies of important practices

CSM Program (cont.)

Program staff

- 12 faculty and senior research staff, and 22 graduate students from the College of Engineering, the Haas School of Business, the Dept. of Economics, and the Institute of Industrial Relations at U. C. Berkeley

Time frame: July 1991 - Dec. 1999 and beyond

Purpose of This Study

Strategic View: The University should teach and research manufacturing issues

Join Business and Engineering faculty and students in a common enterprise to understand and improve manufacturing competitiveness

Tactical View: The University, as an impartial, noncompetitive entity, can accomplish more than others

- Gain wider and more open access to world industry

Products of CSM Program

Benchmarking reports (“Main Phase” reports)

- Comparative scores for factory metrics
- Identification of managerial, organizational and technical practices underlying good performance

Focus study reports (MS and PhD projects)

- Techniques for defect analysis, scheduling, process development, factory organization, etc.

Research Dissemination

- **Benchmarking reports** (most recent: August `96)
- **Focus study reports** (more than 30 reports to date)
- **Industry and conference presentations**
- **Extension classes for industry managers**
- **<http://euler.berkeley.edu/esrc/csm/index.html>**

Benchmarking Progress

- **29 wafer fabs studied to date:**

Hyundai and Samsung in Korea

TSMC and UMC in Taiwan

NEC, Oki, LSI Logic, Toshiba and Tohoku in Japan

AMD, Cypress, DEC, Delco, Harris, IBM, Intel, LSI Logic,
Lucent, Motorola, NSC, Sony, Sony/AMD & TI (2) in USA

DEC, ITT, Lucent and NSC (2) in Europe

- **Most fabs are 6-inch lines of 1985 - 1992 vintage** (6 fabs are 5-inch lines and 2 are 4-inch lines)

Factory Data Collection

- 100-page Mail-Out Questionnaire (MOQ)
- **3-4 years of fab history** (plus updates every 2 years)
 - equipment and facilities
 - headcount and human resources data
 - process technologies, production volumes, yields, cycle times
- Data entered into relational database
- **Technical metric scores computed** (defect density, equipment productivity, cycle time, etc.)

Fab Categories

- **Advanced CMOS Logic (“CMOS Logic”)**
 - Submicron digital logic products
- **Advanced CMOS Memory (“Memory”)**
 - Submicron digital memory products
- **Medium Scale Integration (“MSI”)**
 - Bipolar, Analog, BiCMOS products 1.0 - 10 micron

Figure 2.1. Memory Fab Line Yield

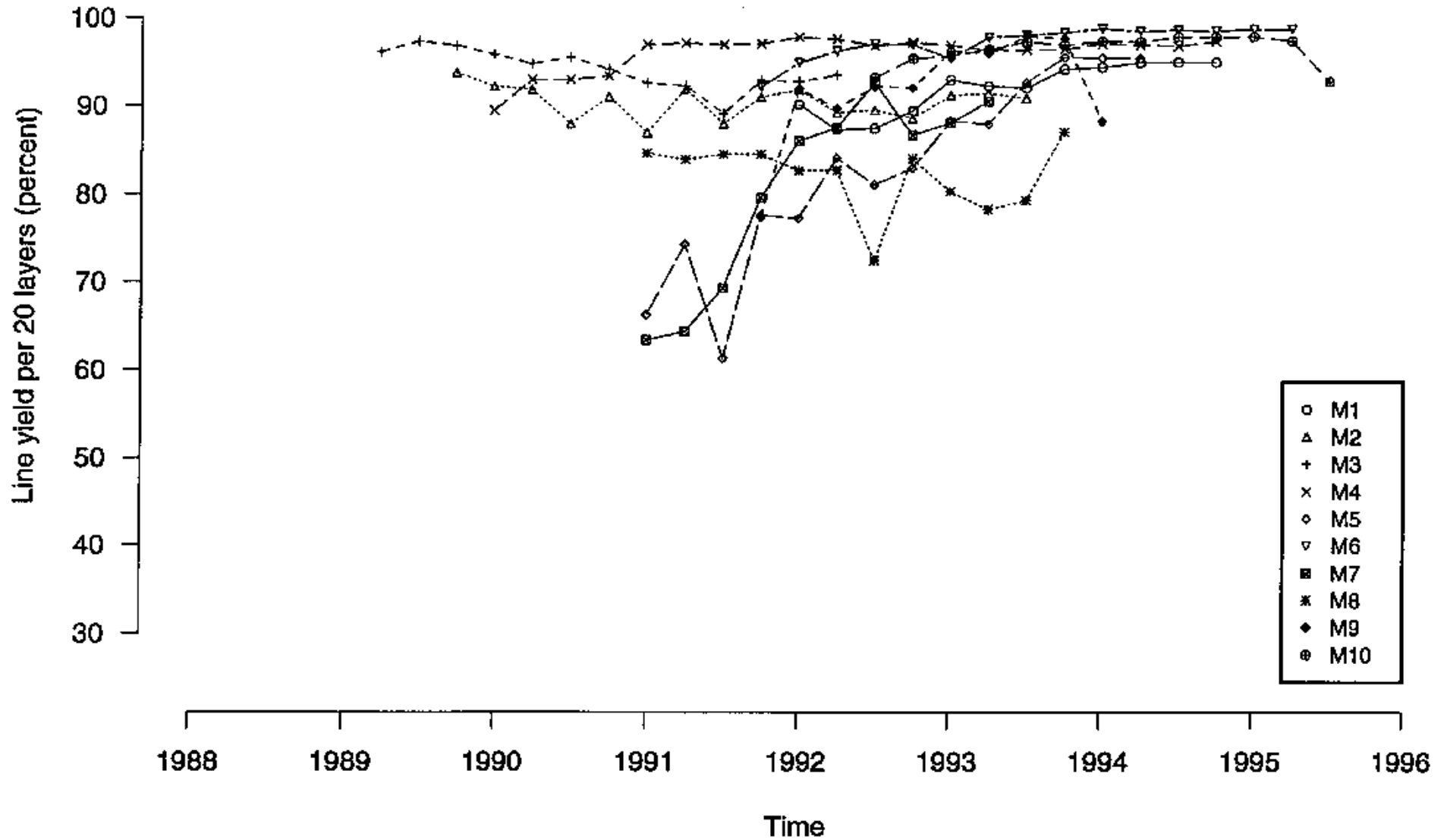


Figure 2.3. Memory Fab Defect Density

0.7 - 0.9 micron CMOS process flows

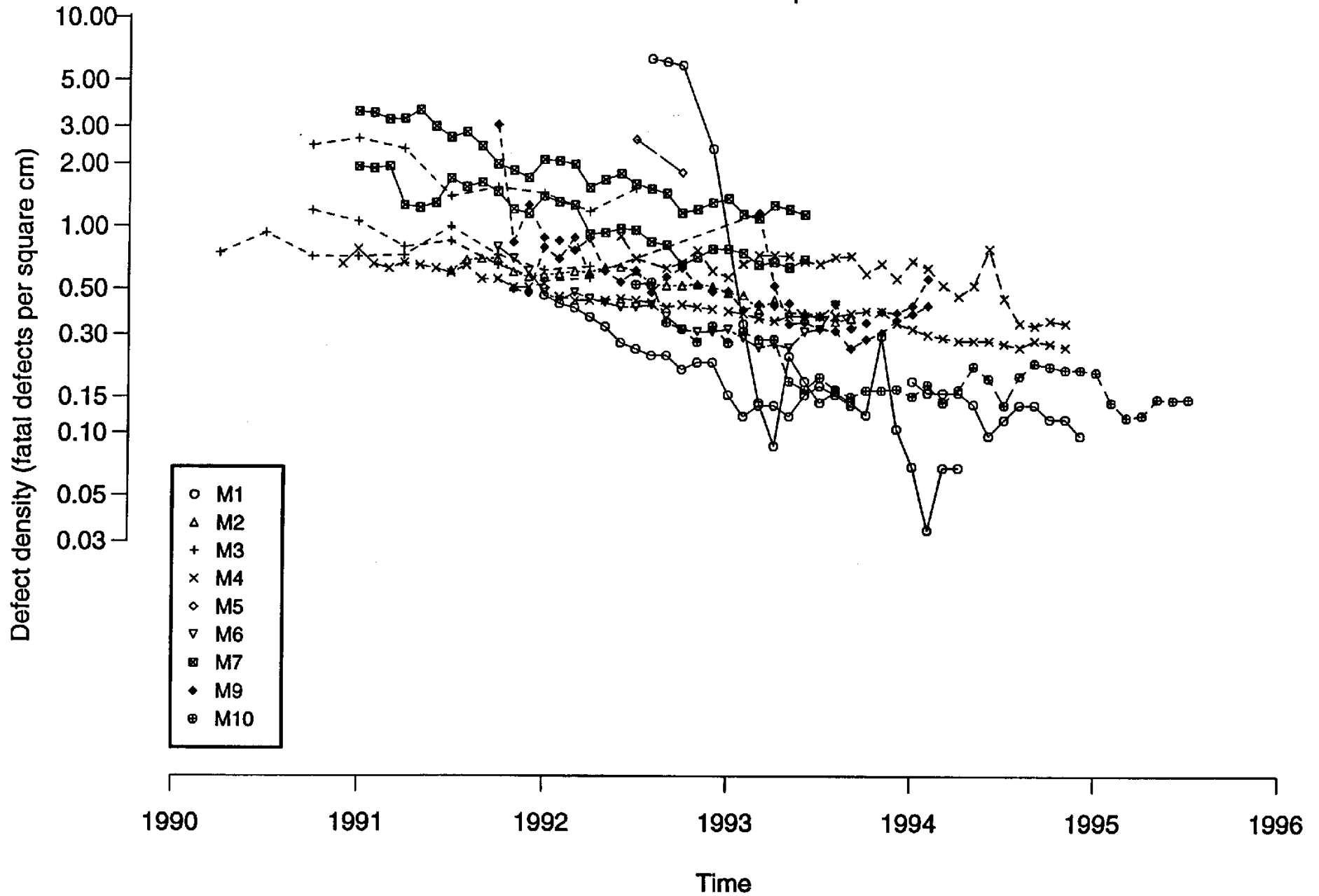


Figure 2.5. Memory Fab Integrated Yield

0.45 - 0.6 micron CMOS process flows

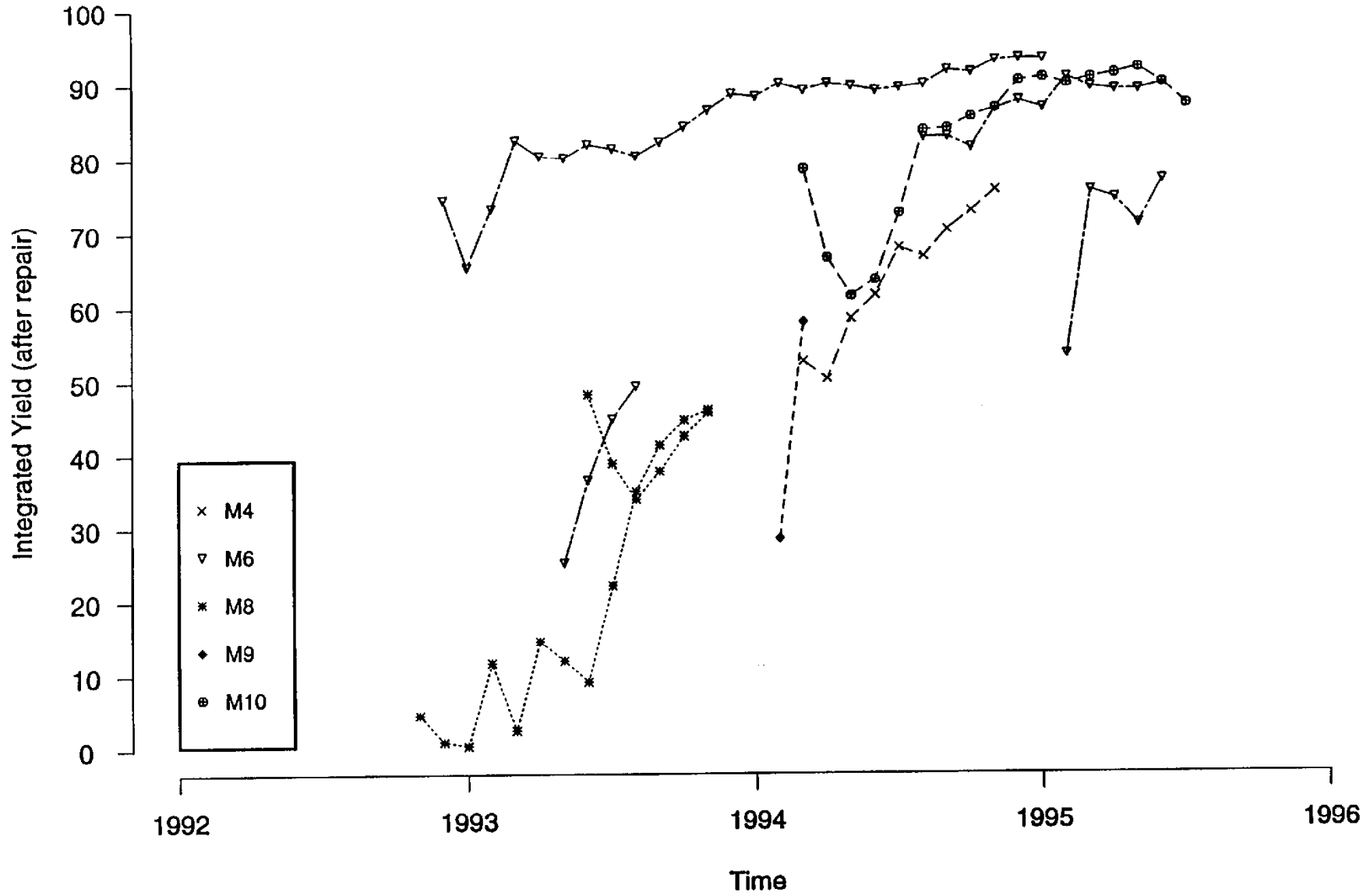


Figure 2.6. Memory Fab Integrated Yield

0.7 - 0.9 micron CMOS process flows

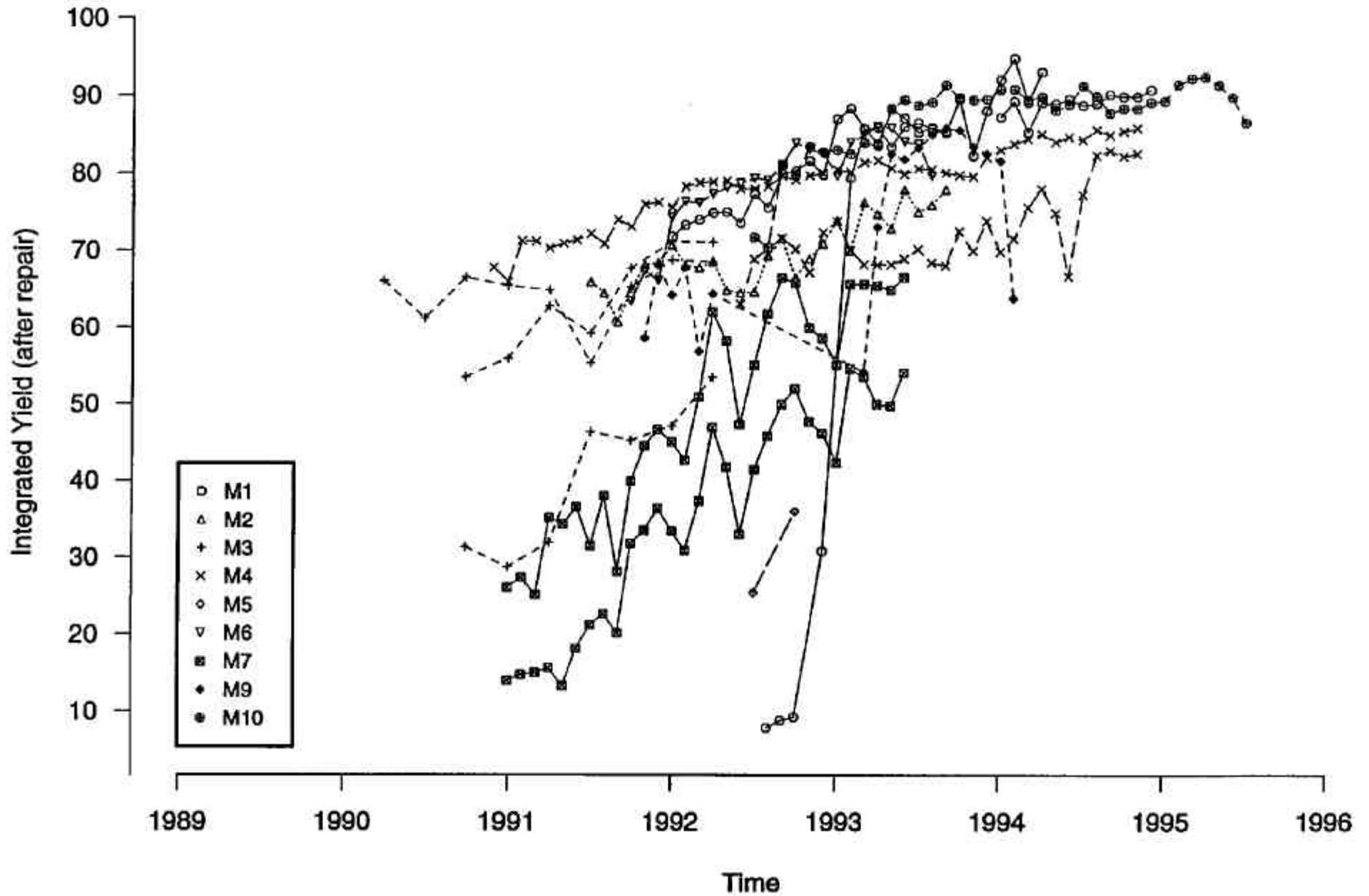


Figure 2.8. Memory Fab 5X Stepper Productivity

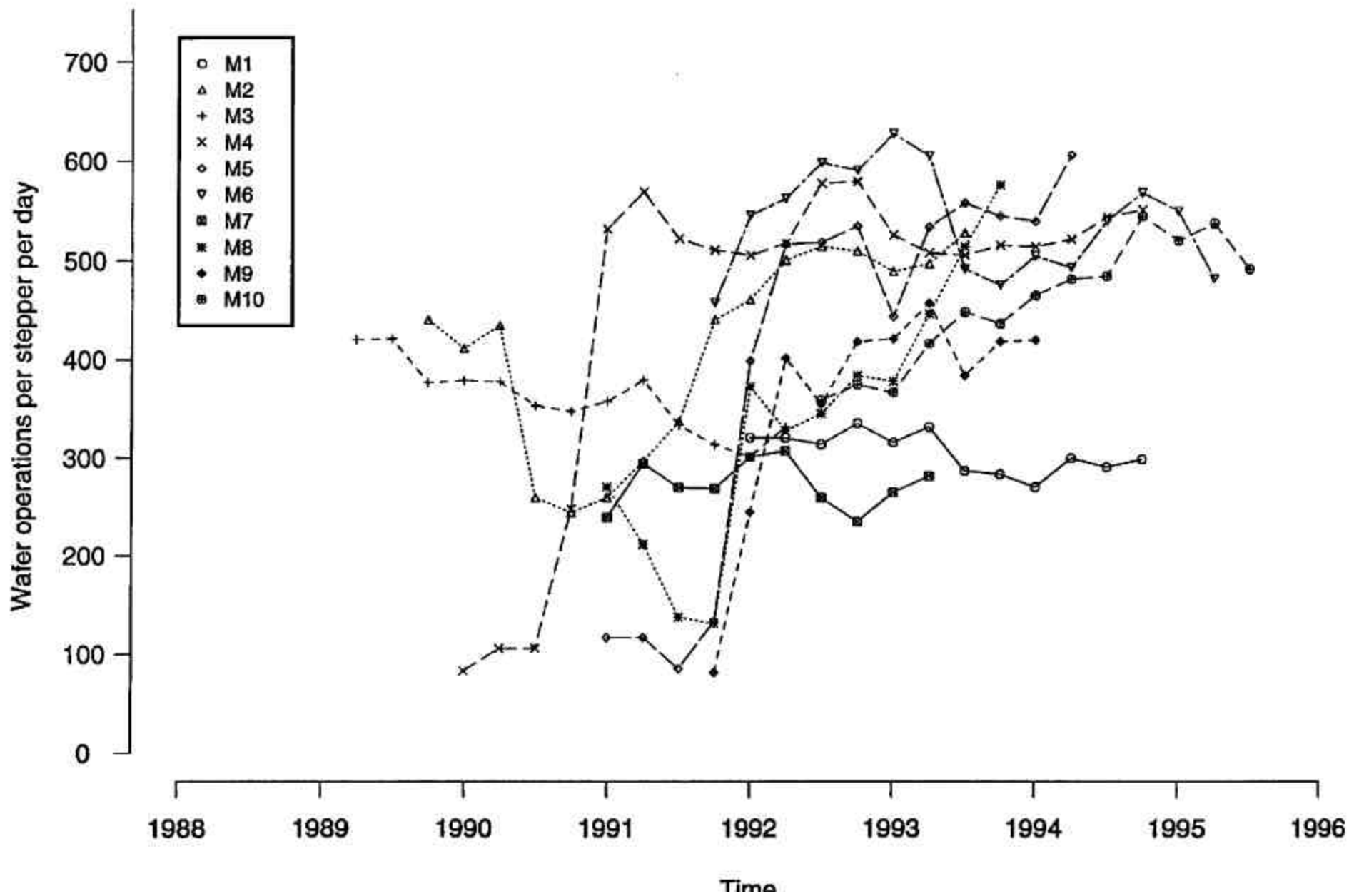


Figure 2.11. Memory Fab Integrated 5X Stepper Throughput

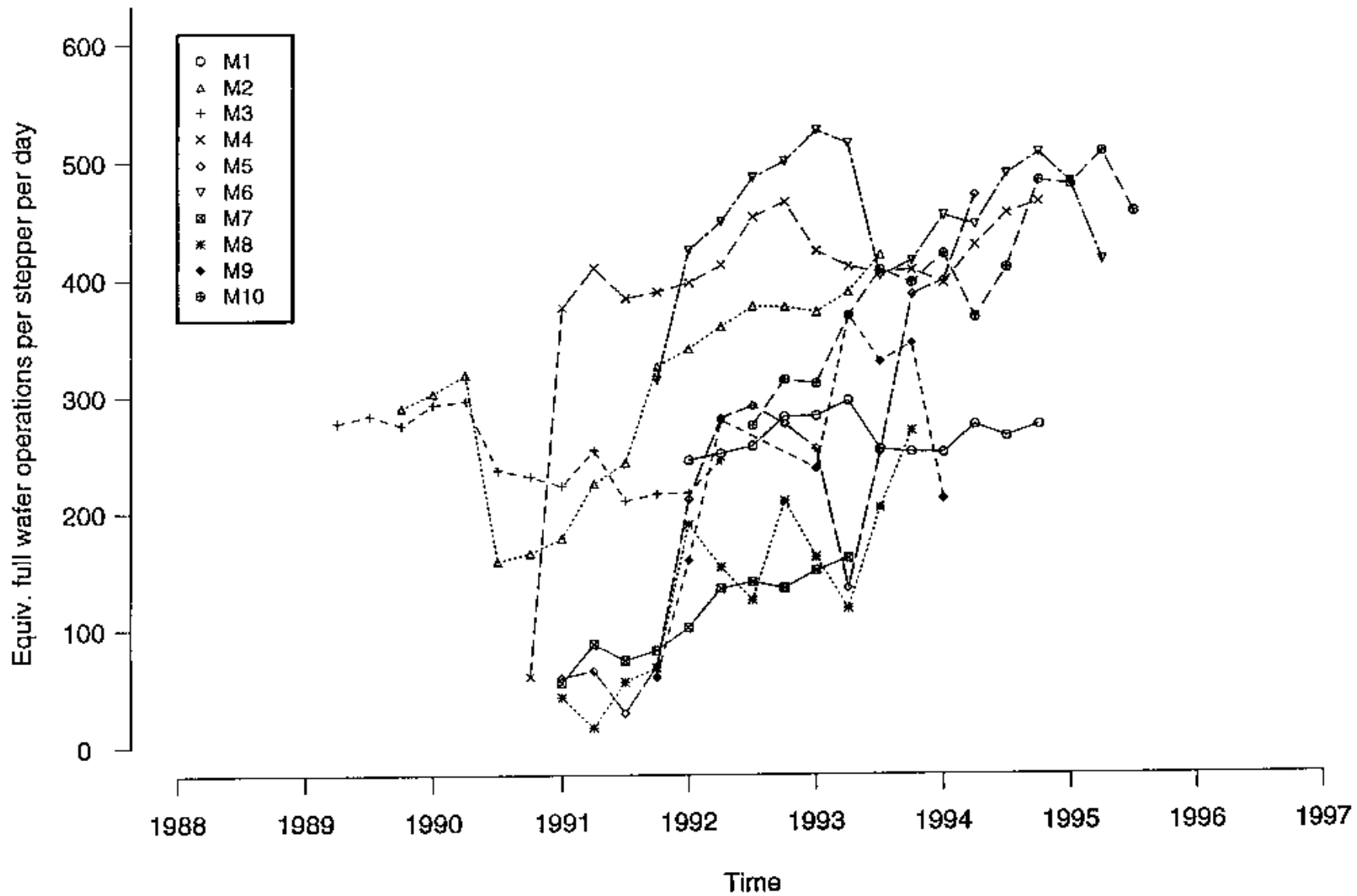


Figure 2.13. Memory Fab Direct Labor Productivity

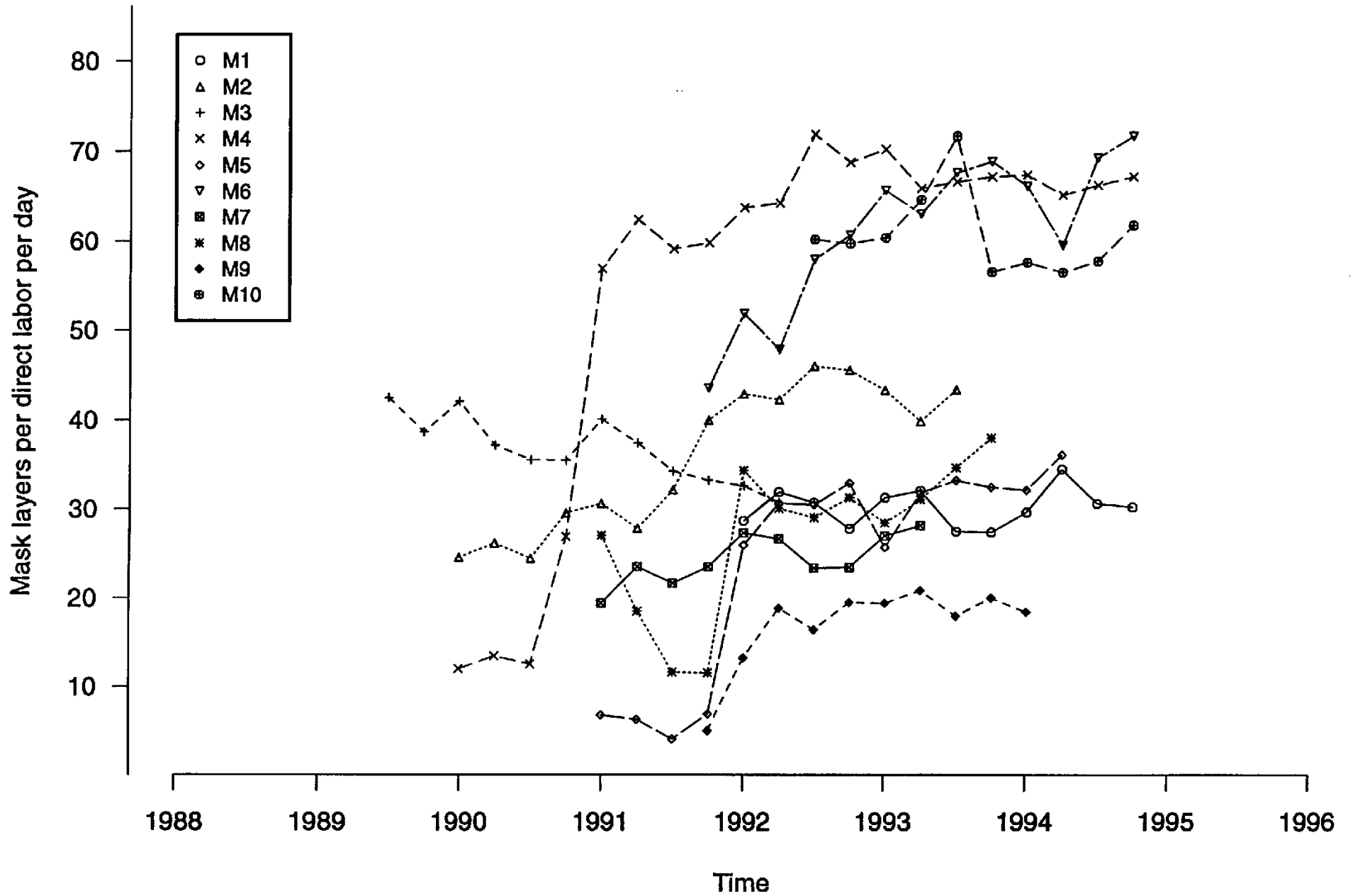


Figure 2.14. Memory Fab Total Labor Productivity

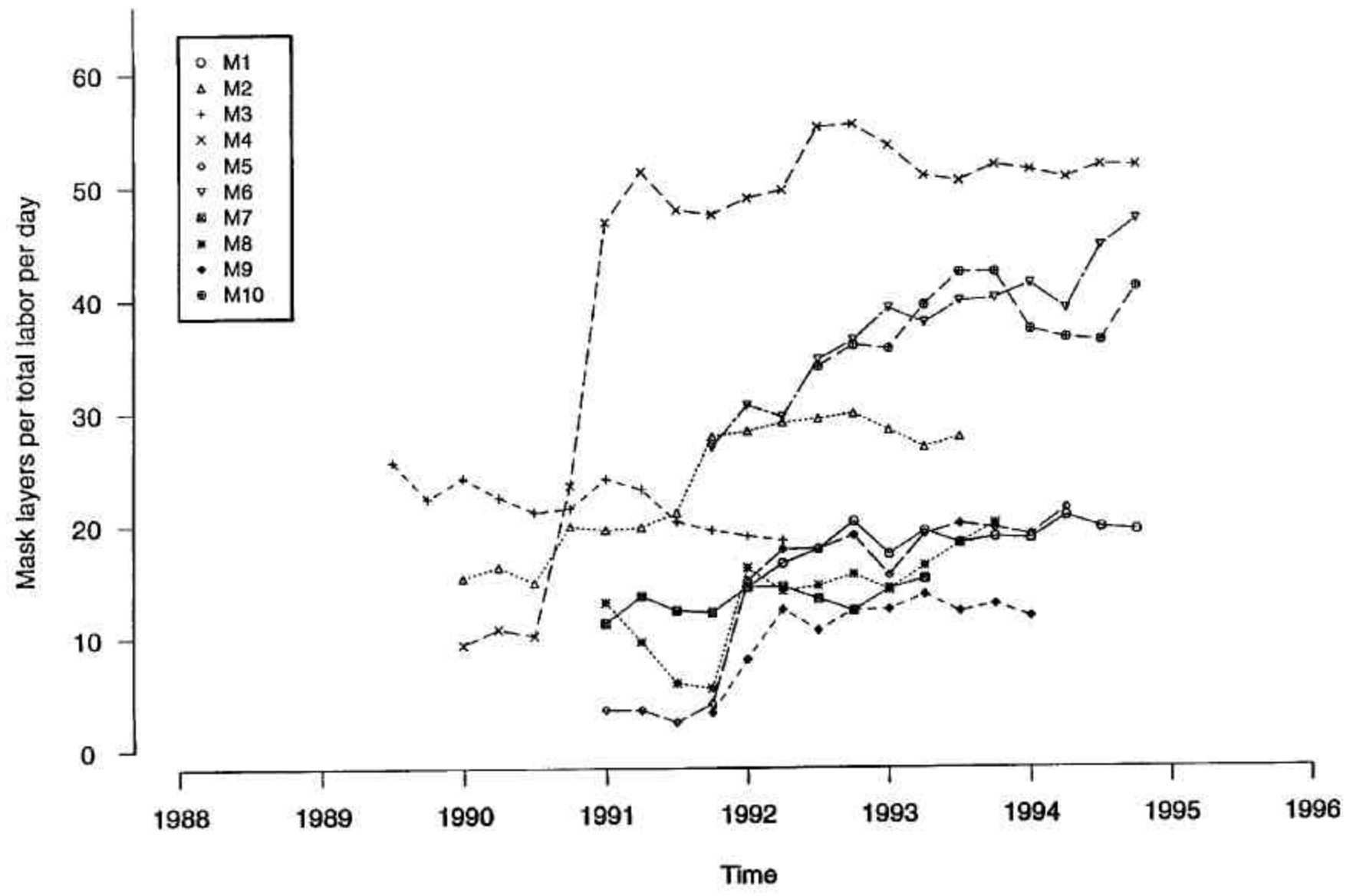


Figure 2.15. CMOS Logic Fab Line Yield

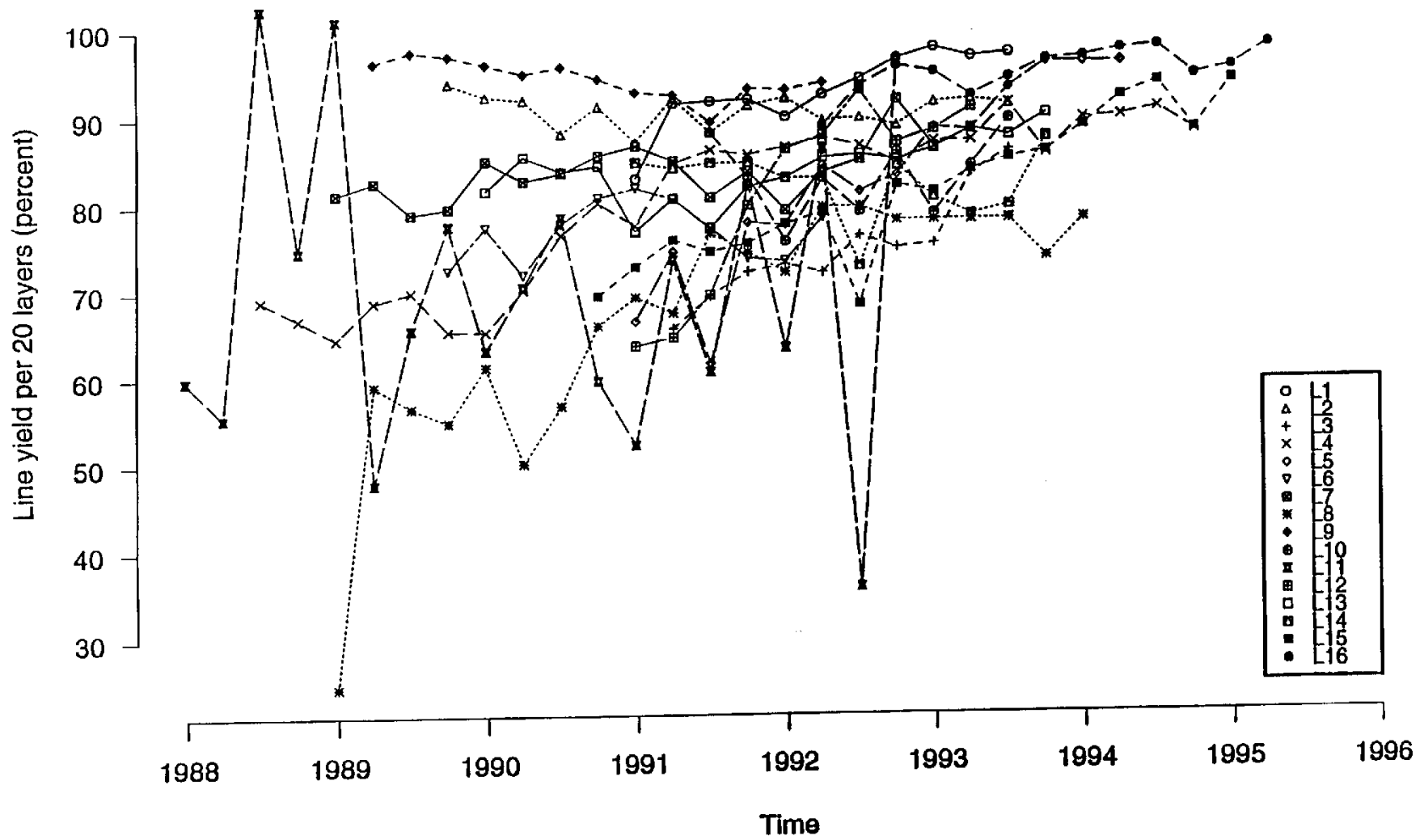


Figure 2.19. CMOS Logic Fab Integrated Yield

0.7 - 0.9 micron CMOS process flows

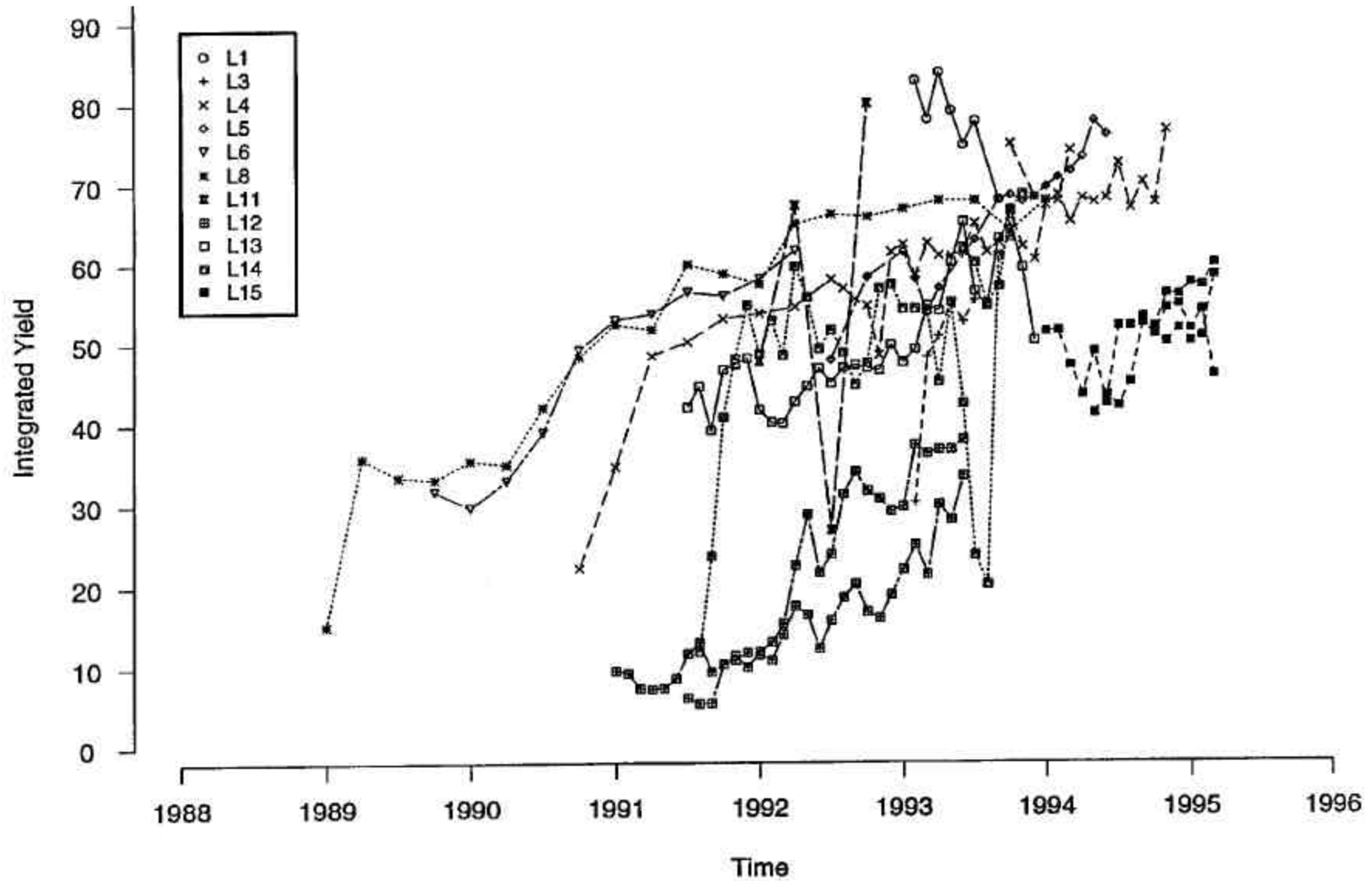


Figure 2.25. CMOS Logic Fab Integrated 5X Stepper Throughput

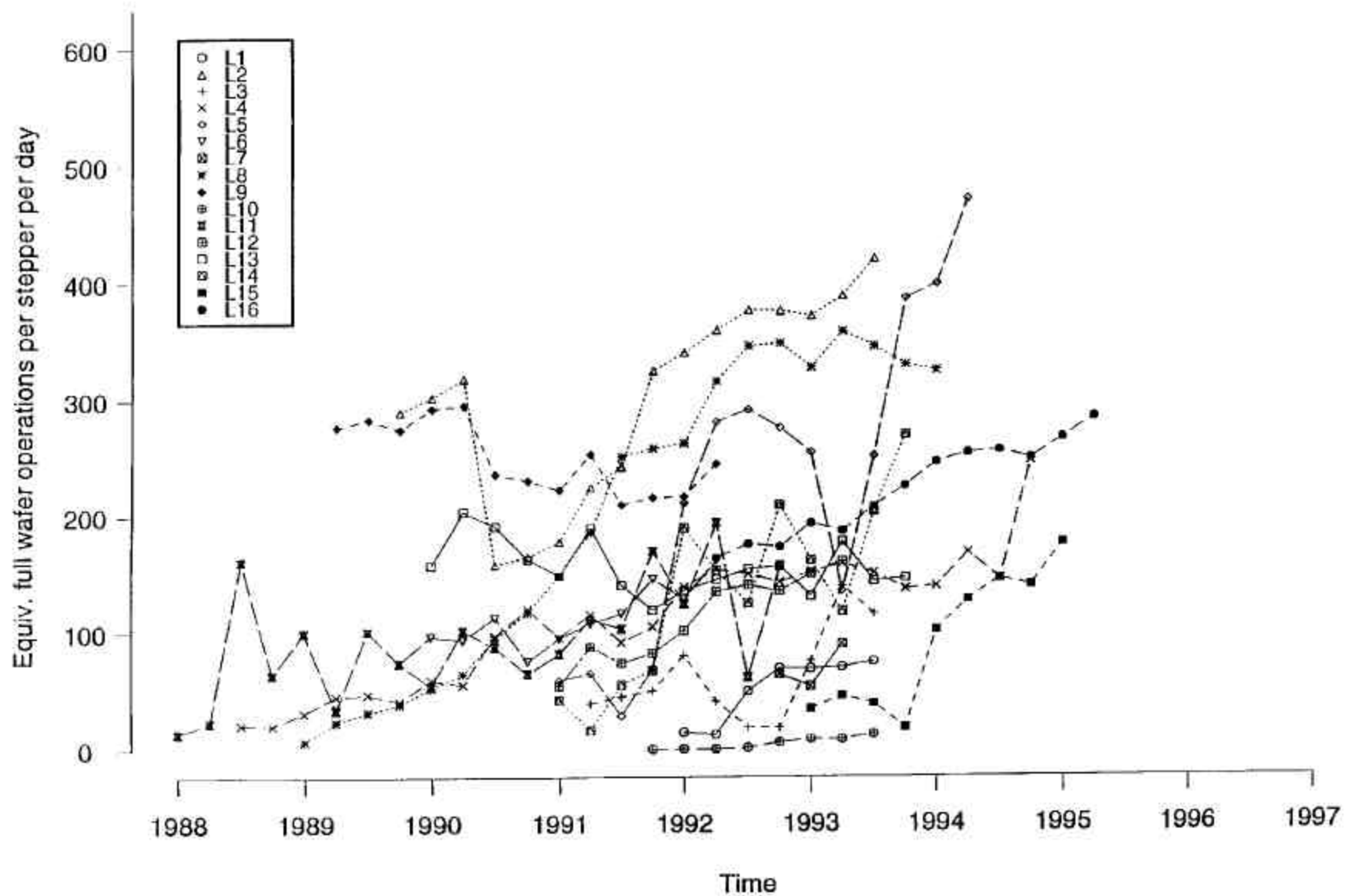


Figure 2.26. CMOS Logic Fab Cycle Time Per Layer

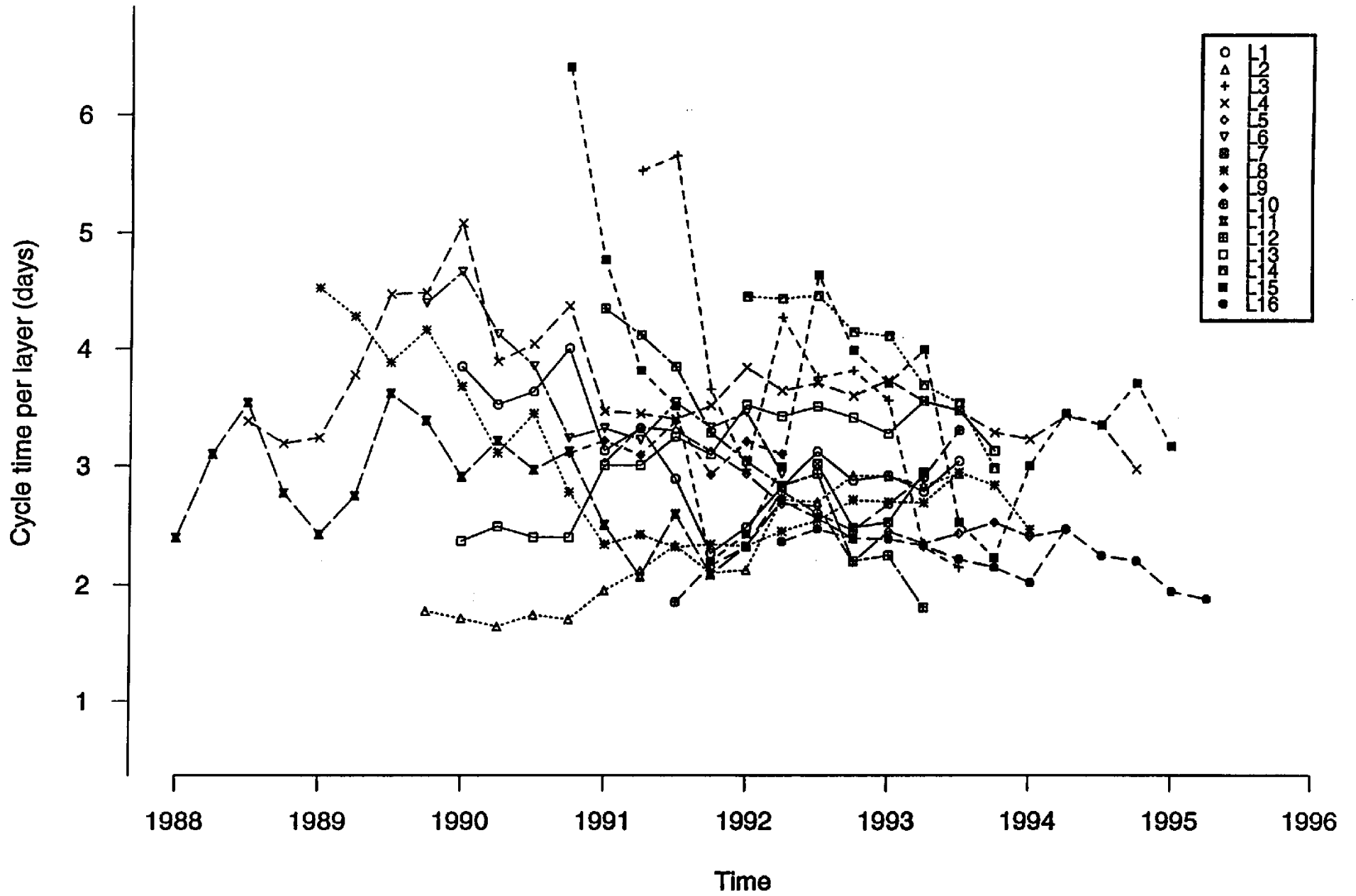
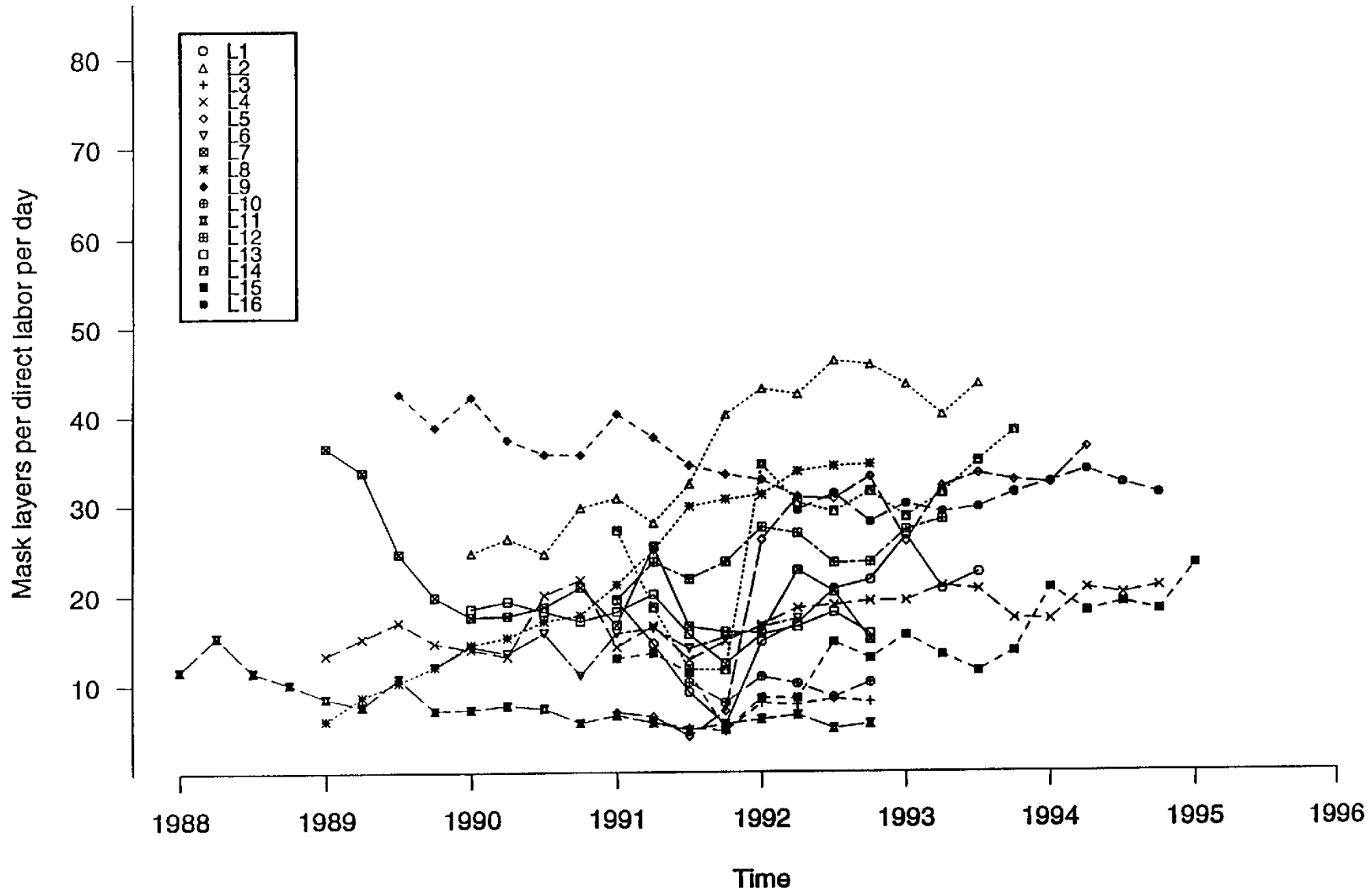


Figure 2.27. CMOS Logic Fab Direct Labor Productivity



Site Visit

- **Team of 6-8 faculty and graduate students, plus interpreter if required, for 2 or 3 day visit with a structured inquiry protocol**
- **Tour fab** (focus on evidence of self-measurement, communication, problem-solving activity)
- **Interview cross-section of organization** (managers, engineers, technicians, operators)
- **Discuss improvement activities and techniques**

Site Visit (cont.)

Sessions to discuss approach to problem areas

(yield improvement, equipment efficiency improvement, cycle time reduction, on-time delivery improvement, new process introductions)

Sessions to discuss problem solving resources (CIM

and information systems, process control, work teams, human resources development)

“Externalities” in Performance

- **Small fabs are bad fabs** (fabs with less than 6,000 wafer starts per week achieve inferior equipment and labor productivity scores)
- **Fabs that shut down relatively frequently** (or are periodically operated with skeleton crews) **are bad fabs**
- **Fabs that aren't kept fully loaded are bad fabs**

Determining Best Practices

- **Based on our notes from the Site Visits, we searched for practices (managerial, technical or organizational) that were *correlated* with the metric scores.**
- **Typically, a good practice positively influences several metric scores.** Participants tended to score well or score poorly across several metrics.
- **Even so, almost every participant had at least one practice that the other participants would benefit by adopting.**

Eight Basic Themes for Best Practices

- **Make manufacturing mistake-proof**
- **Automate information handling**
- **Integrate process, equipment and product data, and analyze statistically**
- **Develop a problem-solving organization**

Eight Themes (cont.)

- **Reduce the division of labor**
- **Secure the requisite talent**
- **Manage development and introductions of new process technology**
- **Schedule manufacturing activity**

Making manufacturing mistake-proof

- **Procedural checks and interlocks** (right lot, right machine)
- **Auto-recipe download**
- **SPC, auto- process disable if OOC**
- **In-line defect inspection**
- **Linked lithography cells**
- **Robotics and other modifications** to replace unreliable material handling

Automation of information handling

- **Computerized procedural checks, auto-recipe download**
- **Automated engineering data collection** (auto-capture & upload of metrology, SPC, process data)
- **Automated equipment tracking** (auto upload of machine event log data using SECS II interfaces)
- **Machine audio and visual alarms**

Integrated data analysis

- **Relational DB** with all WIP, equipment, process and test data
- **Convenient statistical tools** used by process engineers to pinpoint sources of die yield losses and to make rapid deployment of containment counter-measures
- **In-line defect inspection data** (review of wafer maps)
- **Automated equipment efficiency measurement** using data from machine event logs

Developing a problem-solving organization

- TQM and TPM teams of operators and technicians supported by engineers
- Training and mentoring:
engineer <- technician, technician <- operator
- Integration of manufacturing and engineering organizations (e.g., merging operators and techs)

Technical talent

- **Equipment engineering as strong as process engineering**
- **Support from equipment vendors**
 - Modifications to as-delivered equipment to improve yield and throughput

Reduced division of labor

- **Operators trained to do TPM maintenance, “5 S” clean-up and trouble-shooting**
- **Continuous improvement teams of operators and technicians**
- **“Key man” and “equipment owner” programs**
- **Joint equipment and process engineering organization**
- **Yield analysis by process engineers**

Manage new process development and transfer

- **Steady introduction of new process modules**
- **Staggered process and product introductions and wafer size changes**
- **“Copy exactly” policy**
- **Manufacturing engineers participate in final development, or ...**
- **Co-locate development and manufacturing staff**

Scheduling

- **Automated planning of fab-ins** consistent with equipment capacity and WIP, **target fab-out schedules** consistent with WIP and fab-ins
- **Automated delivery quotation**
- **Automated dispatching** based on WIP control and on prioritization of late lots
- **Automated shift scheduling** of bottleneck and complex equipment bays

Technological improvements

- **Linked lithography**
- **Micro-environments and associated automation**
- **Breaking up farm layout into sub-farms**
- **Automation, qualification and/or process control improvements that allow elimination of test runs and setups**

Summary of major findings

- **Wide variations in performance and focus**
- **Key operational practices:** process control, computerized data collection and yield analysis, TPM and equipment efficiency measurement, equipment modifications, automated planning and scheduling
- **Key organizational practices:** hand-off from development, reducing division of labor in fab

Summary of findings

- **Biggest single factor explaining performance is the focus or “religion” of organization:**
- TQM and process control
- Statistical analysis of yield vs. in-line data
- Cycle time reduction and on-time delivery
- TPM and equipment throughput
- **Weak performers in a given category do not have the relevant focus**

Summary of findings (cont.)

- TQM & process control is strong almost everywhere
- Statistical analysis of yield vs. in-line data is strong almost everywhere
- **Cycle time and on-time delivery focus is strong in US and Taiwan, weak in Japan, mixed in Korea and Europe**
- **TPM and equipment throughput focus is strong in Japan, weak in US and Europe, mixed in Korea**

Organizational differences

- **All companies moving to elevate technical responsibility of low-level workers and reduce division of labor**
- **US firms favor major re-organization of workforce**
 - Merge process and equipment engineering
 - “Module management,” “SSTs,” etc.
- **Japanese and Korean firms emphasize internal training and mentoring, elevation of job requirements, task-force teams**

Practices at U.S. firms vs. practices at *leading* Asian firms

- Managing process development and transfer - **mixed**
- Mistake-proofing and automation of information handling - **behind**
- Data collection, integration and analysis - **parity in die yield analysis, behind in equipment throughput analysis**
- Developing a problem-solving organization, reducing division of labor - **behind**
- Scheduling and cycle time management - **ahead**

Preliminary conclusions

- **Independent of technological differences, there are big performance differences among competitors.**
- **The various metrics have different importances in different businesses.**
- **Fast ramp of new production processes to high-yield, high-volume manufacturing is very important.**
- **Rates of improvement in yields and throughput are very important.**

Preliminary conclusions (cont.)

Fast improvement requires rapid problem identification, characterization and solution by a large, diverse team

Common Themes of Successful Approaches:

- Leadership and development of personnel
- Organizational participation, communication, accountability, responsibility for improvement
- Information strategy and analytical techniques to support improvement; **not** blind automation

Important industry trends

- **New participants in Taiwan, Singapore, Thailand, Malaysia, Korea and China**
 - Glut of memory fab capacity
- **High-performing “foundry” fabs in Taiwan and Singapore**
- **Tax deals offered by Oregon and Washington have made the greater Portland, OR area a new US center for fabrication**

Success of the fabless - foundry business model

- **Reduces power of product designers, enabling faster process development, process technologies that serve broader product families, and a focus on manufacturing**
- **Discipline of design rules set by process developer yields lower wafer costs and fewer product design iterations**
- **Some integrated companies are falling behind**

Program plans

- **Industry now funding further benchmarking studies**
 - study 20 8-inch fab lines over 3 years
 - maintain database on 6-inch fab lines
- **Sloan Foundation funding studies in 2 focus areas:**
 - Product design, process development and transfer to mass production
 - Equipment efficiency improvement, in-line yield analysis and scheduling