Module 24: L.E.A.N. Strategies for CNC Manufacturing

Contents

Module 24 - L.E.A.N. Strategies for CNC Manufacturing

24.1.1 What is L.E.A.N.?

L.E.A.N. manufacturing is a systematic approach to identifying and eliminating waste through continuous improvement, allowing a company to deliver maximum value to customers with minimum resources.

24.1.1.1 History and Origins at Toyota

The roots of L.E.A.N. trace back to post-World War II Japan, specifically to the Toyota Motor Corporation.

Historical Context: - Japan, devastated by war, had limited resources - Mass production (Ford's system) didn't fit Japanese market: - Small domestic market (couldn't justify high-volume, single-model production) - Limited capital (couldn't afford massive dedicated equipment) - Limited space (land was expensive) - Limited materials (had to eliminate waste)

Key Pioneers:

Kiichiro Toyoda (Toyota founder's son): - Studied Ford's production system - Recognized need for adaptation to Japanese conditions - Established "Just-In-Time" concept in 1930s

Taiichi Ohno (Father of Toyota Production System): - Developed practical methods for eliminating waste - Created pull production and Kanban systems - Emphasized respect for people and continuous improvement - Famous quote: *"All we are doing is looking at the timeline from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that timeline by removing the non-value-added wastes."*

Shigeo Shingo: - Developed SMED (Single Minute Exchange of Dies) - Created Poka-Yoke (error proofing) concepts - Taught that inspections find defects but don't prevent them

Eiji Toyoda (Toyota president 1967-1982): - Sent engineers to learn from American industry - Supported development of Toyota Production System (TPS) - Built Toyota into global powerhouse

The Birth of "Lean"

The term "Lean" was coined in 1988 by John Krafcik in his article "Triumph of the Lean Production System" based on MIT research comparing auto manufacturing worldwide.

1990: James Womack, Daniel Jones, and Daniel Roos published *"The Machine That Changed the World"* documenting Toyota's practices and introducing "Lean Production" to the Western world.

1996: Womack and Jones published *"Lean Thinking"* providing a framework for applying Lean principles beyond automotive.

24.1.1.2 L.E.A.N. Definition and Principles

L.E.A.N. Definition: A systematic methodology for waste reduction within a manufacturing system without sacrificing productivity, focused on preserving value with less work.

The Five Lean Principles (Womack & Jones):

1. Define Value - Value is defined by the customer - What are customers willing to pay for? - Separate value-added from non-value-added activities

2. Map the Value Stream - Identify all steps in the value stream for each product - Eliminate waste-creating steps - Optimize value-creating steps

3. Create Flow - Make value-creating steps flow smoothly - Eliminate batches, queues, and delays - One-piece flow ideal

4. Establish Pull - Produce only what customers demand, when demanded - Pull production based on actual consumption - Eliminate overproduction

5. Pursue Perfection - Continuous improvement (Kaizen) - Involve everyone in improvement - Never stop eliminating waste

24.1.1.3 L.E.A.N. vs. Traditional Manufacturing

The contrast between traditional mass production and Lean is fundamental:

Aspect	Traditional Manufacturing	L.E.A.N. Manufacturing
Focus	Maximize machine utilization	Maximize value flow
Production	Push (build to forecast)	Pull (build to order)
Inventory	High (safety stock everywhere)	Minimal (only what's needed)
Lot Sizes	Large batches	Small batches or one-piece flow
Setup Times	Long (not prioritized)	Very short (SMED)
Quality	Inspect quality in	Build quality in
Defects	Acceptable scrap rate	Zero defects goal
Equipment	Specialized, high-speed	Flexible, right-sized
Layout	By process (all mills together)	By product flow (cells)
Operators	Single-skilled, repetitive	Multi-skilled, problem solvers
Improvement	Engineering-driven	Everyone involved
Suppliers	Lowest price, multiple sources	Partnership, few trusted sources
Metrics	Output, efficiency, utilization	Lead time, quality, flexibility

Traditional Thinking: - "Keep machines running to absorb overhead" - "Build ahead to have stock available" - "Some scrap is inevitable" - "Operators operate, engineers improve" - "We need inventory to protect against problems"

Lean Thinking: - "Stop and fix problems immediately" - "Build only what's needed when needed" - "Eliminate root causes of defects" - "Operators are problem solvers" - "Expose problems by reducing inventory"

24.1.2 The L.E.A.N. Acronym Explained

While "Lean" originally described the Toyota Production System, we can use it as an acronym to remember key principles:

24.1.2.1 L - Limit Waste

Waste (Muda in Japanese) is any activity that consumes resources but creates no value for the customer.

Toyota identified **seven wastes** (later expanded to eight–DOWNTIME): 1. **D**efects 2. **O**verproduction 3. **W**aiting 4. **N**on-utilized talent 5. **T**ransportation 6. **I**nventory 7. **M**otion 8. **E**xcess processing

We'll explore these in detail in Section 24.2.

Limit Waste Means: - Constantly identify waste in all processes - Systematically eliminate waste sources - Prevent waste from returning - Make waste visible (can't fix what you can't see)

Not: Merely accepting lower waste levels **But:** Relentlessly pursuing zero waste

24.1.2.2 E - Empower People

Lean recognizes that the people doing the work are the experts in that work.

Empowerment Means:

1. **Authority to Act** - Stop production when quality issues occur - Implement improvements in their work area - Make decisions without waiting for approval

2. **Capability to Contribute** - Training in problem-solving methods - Understanding of Lean principles - Technical skills for their processes

3. **Responsibility and Accountability** - Ownership of their work area - Participation in improvement activities - Standard work adherence

4. **Recognition and Reward** - Ideas valued and implemented - Improvement celebrated - Career development opportunities

Traditional: "Check your brain at the door, do what you're told" **Lean:** "Use your intelligence, solve problems, improve continuously"

Quote from Taiichi Ohno: *"The key to the Toyota Way and what makes Toyota stand out is not any of the individual elements… But what is important is having all the elements together as a system. It must be practiced every day in a very consistent manner–not in spurts."*

24.1.2.3 A - Analyze Flow

Flow means products move smoothly through the value stream without interruption, delay, or waste.

Perfect Flow: - Value-adding steps happen in sequence - No waiting between operations - No batches or queues - One-piece flow ideal - Products "flow like water"

Flow Killers: - Batching (making many parts before moving to next operation) - Functional layout (parts travel back and forth between departments) - Unbalanced operations (bottlenecks) - Poor quality (stops flow for rework) - Equipment breakdowns - Long setup times

Analyze Flow Means: - Map current value stream to see flow interruptions - Identify and eliminate flow barriers - Redesign layout and processes for flow - Balance operations to takt time - Create cells with continuous flow

Metrics: - **Lead Time**: Total time from order to delivery - **Value-Added Time**: Time actually transforming the product - **Value-Added Ratio**: VA Time / Lead Time

Example: - Lead Time: 20 days - Value-Added Time: 2 hours - Value-Added Ratio: 2 hours / (20 days × 8 hours) = 1.25%

Improvement Target: Increase value-added ratio by eliminating non-value-added time

24.1.2.4 N - Never Stop Improving

Continuous Improvement (Kaizen in Japanese) is not a program or initiative–it's a way of thinking and operating.

Never Stop Improving Means:

1. No Acceptable Status Quo - Today's standard is tomorrow's improvement opportunity - Complacency is the enemy - Always ask "Can we do this better?"

2. Small Steps Daily - Many small improvements > few big improvements - Everyone can contribute - Compound effect is enormous

3. Scientific Approach - Understand current condition - Identify root causes - Test countermeasures - Standardize what works - Continue the cycle (PDCA)

4. Respect for People - Involve those who do the work - Create psychological safety (ideas welcomed) - Develop problem-solving capability - Celebrate learning, even from failures

5. Humble Leadership - Leaders don't have all answers - Go to Gemba (the real place) - Ask questions, don't dictate solutions - Develop people, not just processes

Quote from Masaaki Imai: *"Kaizen is everybody's business."*

The Kaizen Mindset: - Good □ Better □ Best □ Excellence □ Perfection (never reached, always pursued) - Today's impossibility is tomorrow's reality - Waste is everywhere–we just need to see it - The status quo is unacceptable

---

24.1.3 Why L.E.A.N. for CNC Manufacturing?

CNC machining might seem incompatible with Lean–after all, aren't CNC machines epitomes of efficiency?

Not necessarily.

Common Waste in CNC Operations

1. Long Setup Times - Traditional mindset: "Run large batches to amortize setup" - Result: Huge WIP inventory, long lead times, inflexibility - Lean approach: Reduce setup to minutes (SMED), run small batches

2. Excessive WIP - Material waiting between operations - Days or weeks of lead time for hours of machining - Cash tied up in inventory - Space consumed by storage

3. Quality Issues - Defects discovered at final inspection (too late) - Entire batch scrapped due to programming error - Rework disrupts flow - Customer returns are expensive

4. Unbalanced Operations - Bottleneck machines overloaded - Other machines idle - Operators waiting for material or machines

5. Motion and Transportation - Excessive walking to get tools, material, programs - Poor layout requires material transport across shop - Multiple handling increases damage risk

6. Underutilized Talent - Operators treated as "button pushers" - Engineers don't involve operators in improvement - Knowledge not captured or shared - Suggestion systems don't exist or are ignored

Lean Benefits for CNC Shops

1. Reduced Lead Time - From weeks to days or hours - Faster response to customers - Competitive advantage

2. Lower Inventory - Less cash tied up - Less space required - Fewer obsolescence issues

3. Improved Quality - Defects prevented, not detected - First-time-through yield increases - Customer satisfaction improves

4. Increased Flexibility - Quick changeovers enable small lots - Can respond to engineering changes quickly - Mix of products without efficiency penalty

5. Higher Productivity - Waste elimination increases output per person - Same people, more output - Or same output, fewer people (redeploy to growth)

6. Better Cash Flow - Faster turns, faster collections - Less working capital required - Funds available for growth

7. Employee Engagement - People enjoy improving their work - Pride in continuous improvement - Lower turnover, better morale

CNC-Specific Lean Opportunities

Setup Reduction (SMED): - 60-minute setup □ 6-minute setup = 10× improvement - Enables small batch or one-piece flow - Eliminates WIP inventory

Tool Management: - Pre-set tools outside machine - Tool kitting reduces changeover time - Standard tooling across machines

Work Cell Design: - Group operations for one-piece flow - Operator tends multiple machines - Inspection integrated into cell

Poka-Yoke (Error Proofing): - Fixtures prevent incorrect loading - Tool length sensors verify tool setup - Automated inspection prevents shipping defects

TPM (Total Productive Maintenance): - Operator-performed daily maintenance - Prevent breakdowns, increase OEE - Extend equipment life

Standard Work: - Document best practices - Train consistently - Platform for improvement

---

24.1.4 L.E.A.N. Benefits and Business Case

Implementing Lean requires investment of time, effort, and sometimes capital. What's the return?

Documented Results

Industry Benchmarks (typical Lean transformation):

- **Lead Time**: 50-90% reduction
- **Inventory**: 50-80% reduction
- **Floor Space**: 30-50% reduction
- **Productivity**: 25-50% improvement

- **Quality**: 50-90% defect reduction
- **Setup Time**: 75-95% reduction
- **On-Time Delivery**: 98%+ (from 70-80%)

Financial Impact

Example: $5M CNC Shop

Before Lean: - Lead time: 20 days - Inventory: $500,000 - Quality issues: 3% scrap = $150,000/year - On-time delivery: 75% - Floor space: 20,000 sq ft - Overtime: 15% = $112,500/year (15% of $750k labor)

After Lean (3 years): - Lead time: 5 days (75% reduction) - Inventory: $150,000 (70% reduction) - Quality issues: 0.5% scrap = $25,000/year - On-time delivery: 98% - Floor space: 14,000 sq ft (30% reduction) - Overtime: 3% = $22,500/year

Annual Financial Impact: - Inventory reduction: $350,000 × 20% carrying cost = **$70,000/year** - Scrap reduction: $150k - $25k = **$125,000/year** - Overtime reduction: $112.5k - $22.5k = **$90,000/year** - Floor space: 6,000 sq ft × $10/sq ft = **$60,000/year** - **Total annual savings: $345,000 (6.9% of revenue)**

Plus: - Improved on-time delivery □ customer retention - Faster lead times □ competitive advantage, pricing power - Freed capacity □ growth without equipment investment - Better quality □ customer loyalty, referrals

Investment: - Consultant/training: $50,000 - Tools/supplies (shadow boards, labels, Kanban, etc.): $20,000 - Employee time (kaizen events, training): $30,000 - **Total: $100,000**

Payback: ~3-4 months 3-Year ROI: 935%

Non-Financial Benefits

- **Employee engagement**: Pride, ownership, reduced turnover
- **Customer satisfaction**: Quality, delivery, responsiveness
- **Competitive position**: Can quote shorter lead times, lower prices
- **Scalability**: Can grow without proportional overhead increase
- **Resilience**: Less inventory and more flexibility = weather downturns better
- **Safety**: Organized, visual workplace is safer

24.1.5 Common Misconceptions About L.E.A.N.

Despite widespread adoption, Lean is often misunderstood:

Misconception #1: “Lean = Layoffs”

Reality: Lean improves productivity, but the goal is growth, not downsizing.

- Freed capacity enables taking on more work without adding people
- Redeploy people to value-added activities
- Companies that lay off due to Lean kill employee engagement immediately

- Toyota's promise: No layoffs due to improvement

Lean is about elimination of waste, not elimination of people.

Misconception #2: "Lean Is Only for High-Volume Production"

Reality: Lean principles apply to any production volume.

- Many Lean tools (VSM, 5S, setup reduction, TPM) apply universally
- Job shops adapt tools (flexible cells, family-based value streams)
- Lean thinking (eliminate waste, flow, pull, improve) is volume-agnostic

Toyota makes low-volume custom vehicles (Lexus LS) using Lean.

Misconception #3: "Lean Means No Inventory"

Reality: Lean means *right-sized* inventory.

- Some inventory is necessary (buffers for demand variation)
- Lean calculates optimal inventory scientifically
- Goal: minimum inventory to maintain flow
- Eliminating inventory without fixing problems causes chaos

Lean exposes problems by reducing inventory, then solves those problems.

Misconception #4: "Lean Is Just Cost Cutting"

Reality: Lean is about value creation, not just cost reduction.

- Primary focus: delivering value to customers efficiently
- Cost reduction is a result, not the goal
- Lean invests in people, quality, capability
- Short-term cost cutting undermines long-term competitiveness

Misconception #5: "Lean Is a Program or Initiative"

Reality: Lean is a management philosophy and culture.

- Not something you "do" and complete
- Not a set of tools to implement
- It's a way of thinking and operating
- Requires continuous practice and reinforcement

Programs end. Culture persists.

Misconception #6: "We're Too Small for Lean"

Reality: Small shops benefit most from Lean.

- Limited resources means waste is more painful
- Improvements have immediate impact
- Simpler to implement (less bureaucracy)

- Many Lean tools are low-cost or free

Small shops can't afford NOT to be Lean.

Misconception #7: "Lean Stifles Creativity"

Reality: Lean amplifies creativity.

- Standard work provides stable platform for experimentation
- Continuous improvement requires creativity
- Employee involvement unleashes ideas
- Solving problems creatively is core to Lean

Standardization enables innovation.

Misconception #8: "We Need Expensive Consultants to Do Lean"

Reality: Consultants can help, but aren't required.

- Many resources available (books, videos, training)
- Start with basics (5S, waste elimination)
- Learn by doing, iterate
- Consultants valuable for complex transformations or when stuck

Better to start imperfectly than wait for perfect conditions.

Summary

L.E.A.N. manufacturing, born from Toyota's innovative approach to production, is a systematic methodology for eliminating waste and creating value efficiently. The L.E.A.N. acronym–Limit Waste, Empower People, Analyze Flow, Never Stop Improving–encapsulates its core principles.

Lean offers significant benefits for CNC manufacturing, including reduced lead times, lower inventory, improved quality, and increased flexibility. The business case is compelling, with typical returns far exceeding investments.

Despite common misconceptions, Lean applies to operations of all sizes and types. It's not a program but a culture of continuous improvement involving everyone in the organization.

In the next section, we'll explore the eight wastes (DOWNTIME) in detail and learn to identify them in CNC operations.

Key Takeaways

1. **Lean originated at Toyota** post-WWII as adaptation to resource constraints
2. **Five Lean Principles**: Define value, map value stream, create flow, establish pull, pursue perfection
3. **L.E.A.N. acronym**: Limit Waste, Empower People, Analyze Flow, Never Stop Improving
4. **Lean vs. Traditional**: Flow vs. utilization, pull vs. push, small batches vs. large

5. **CNC benefits**: Reduced lead time, inventory, and defects; increased flexibility and quality
6. **Business case is strong**: Typical payback in months, sustained benefits
7. **Common misconceptions** about layoffs, volume requirements, and complexity are false
8. **Lean is a culture**, not a program–requires continuous practice

---

Review Questions

1. Who were the key pioneers of the Toyota Production System?
2. What are Womack and Jones' five Lean principles?
3. How does Lean manufacturing differ from traditional mass production?
4. Explain the L.E.A.N. acronym and what each letter represents.
5. Why is Lean particularly beneficial for CNC manufacturing?
6. Calculate the annual inventory carrying cost savings if inventory is reduced from $400,000 to $100,000 (assume 25% carrying cost).
7. What is the most common misconception about Lean, and why is it wrong?

Module 24 - L.E.A.N. Strategies for CNC Manufacturing

24.10.1 The Kaizen Philosophy

Kaizen (Japanese: □□) means "change for better" or "continuous improvement."

Literal translation: - **Kai** (□) = change - **Zen** (□) = good/better

Philosophy

Developed by Masaaki Imai, introduced to the West in his 1986 book *Kaizen: The Key to Japan's Competitive Success.*

Core Beliefs:

1. Everyone Can Contribute: - Not just engineers or management - Operators know their work best - Small ideas from many > big ideas from few

2. Small Steps, Continuous: - Many small improvements daily - Not waiting for big breakthroughs - Compound effect enormous over time

3. No Acceptable Status Quo: - Today's standard is tomorrow's improvement target - Complacency is the enemy - Always ask "Can we do this better?"

4. Improvement is Everyone's Job: - Not separate from daily work - Built into culture - Daily responsibility

5. Respect for People: - People want to improve - Create environment for ideas - Psychological safety essential

Kaizen vs. Innovation

Innovation (Kaikaku): - Large, radical changes - Significant investment - Top-down - Occasional (years between) - High risk - Example: Buy new CNC machine ($500K)

Kaizen: - Small, incremental changes - Minimal investment - Bottom-up - Continuous (daily) - Low risk - Example: Improve tool changeover method (save 2 min)

Both Needed: - Innovation: Step changes in capability - Kaizen: Maximize value from existing resources - **Kaizen + Innovation = Sustained Competitive Advantage**

The Kaizen Mindset

Traditional Thinking: - "If it ain't broke, don't fix it" - "We've always done it this way" - "Good enough"

Kaizen Thinking: - "It can always be better" - "What worked yesterday may not be best today" - "Good today, better tomorrow, best next week"

Quote from Masaaki Imai: *"The message of the Kaizen strategy is that not a day should go by without some kind of improvement being made somewhere in the company."*

24.10.2 Types of Kaizen

24.10.2.1 Point Kaizen (Quick Improvements)

Point Kaizen: Small improvement at single location, by individual or small team.

Characteristics: - Focused on one issue - One workstation or process - Implemented quickly (hours to days) - Minimal resources - Operator-led typically

Examples:

1. Tool Organization: - Problem: Operator walks to tool crib (50 feet away) - Kaizen: Install shadow board at machine - Time: 2 hours to implement - Savings: 5 min per setup × 3 setups/day = 15 min/day

2. Coolant Concentration: - Problem: Coolant concentration varies, affects tool life - Kaizen: Daily concentration check added to operator routine, chart posted - Time: 1 hour to create chart/procedure - Result: Consistent concentration, 20% tool life improvement

3. First-Off Template: - Problem: First-off inspection takes 15 min (measuring many dimensions) - Kaizen: Create template for critical dimensions only - Time: 3 hours to make template - Savings: 15 min 5 min per setup

Benefits: - Quick wins (motivation) - Builds improvement capability - Minimal approval needed - Operator ownership

24.10.2.2 System Kaizen (Flow Kaizen)

System Kaizen: Improvement of entire value stream or system.

Characteristics: - Cross-functional - Affects multiple processes - Requires planning and resources - Days to weeks to implement - Typically led by management/engineering

Examples:

1. Cell Implementation: - Change from functional layout to cellular - Affects multiple machines, departments - Requires equipment moves, training - 2-4 weeks implementation - Result: 60% lead time reduction

2. Pull System Implementation: - Convert from push to pull (Kanban) - Entire value stream affected - Design supermarkets, calculate Kanban quantities - 4-8 weeks implementation - Result: 50% inventory reduction

3. Setup Reduction Program: - SMED implementation across all machines - Standardize fixtures, tool presetting - 3-6 months phased implementation - Result: Average setup time 90 min → 10 min

Benefits: - Major improvements (breakthrough results) - System optimization (not local) - Strategic alignment

24.10.2.3 Plane Kaizen (Innovation)

Plane Kaizen: Radical improvement, often technology-enabled.

Characteristics: - Major change in capability - Significant investment - Long implementation (months to years) - Management-led - Strategic decision

Examples:

1. Automation: - Install robotic loading system - Capital investment: $250K - 12 months implementation - Result: Lights-out production capability

2. New Technology: - Replace conventional machines with 5-axis CNC - Investment: $500K - Result: Reduce operations from 4 to 1

3. Facility Expansion: - Build new facility with Lean design - Investment: $5M - Result: 2× capacity, modern layout

Note: Even with innovation, apply Kaizen to maximize value.

24.10.3 Kaizen Events (Blitz)

Kaizen Event (Kaizen Blitz): Intense, focused improvement activity by a team over 3-5 days.

24.10.3.1 Event Planning and Preparation

Timing: 2-4 Weeks Before Event

1. Identify Opportunity: - Based on business need (quality issue, bottleneck, safety) - Defined scope (specific process or area) - Measurable problem (current state metrics)

2. Set Charter: - **Problem Statement:** What's wrong? - **Goal:** What will success look like? - **Scope:** What's included/excluded? - **Timeline:** Event dates - **Resources:** Budget, materials available

Example Charter:

```
Problem: CNC Cell 3 setup time averages 75 minutes,
         limiting small batch flexibility

Goal: Reduce setup time to < 15 minutes (SMED)

Scope:
  - Cell 3 only (3 CNC mills)
  - Shaft family products
  - Fixtures, tooling, procedures

Timeline: Kaizen event May 15-19 (5 days)

Resources: $5,000 budget for quick-change fixtures
```

3. Select Team: - 5-8 people (see next section) - Confirm availability - Pre-event meeting (explain purpose)

4. Prepare: - Collect baseline data (current setup times) - Video current state if possible - Reserve meeting room - Supplies: Flip charts, markers, Post-its, tape measures - Arrange for support (maintenance, purchasing)

5. Communications: - Inform affected operators, supervisors - Set expectations (some disruption) - Explain purpose (improvement, not blame)

24.10.3.2 Team Selection

Team Composition:

Process Experts (2-3 people): - Operators who do the work daily - Know reality, not theory - Essential for credibility and sustainability

Process Owner: - Supervisor or manager responsible for area - Decision authority - Resources allocation

Cross-Functional (2-3 people): - Maintenance (technical expertise) - Quality (inspection, standards) - Engineering (design, analysis) - Materials (inventory, suppliers)

Fresh Eyes (1 person): - Someone unfamiliar with process - Asks "why?" questions - Challenges assumptions

Facilitator: - Experienced in Kaizen methodology - Guides team through process - Keeps team on track - May be internal or external consultant

Champion (Sponsor): - Senior leader - Removes barriers - Approves resources - Attends report-out

Total: 5-8 people (more than 8 becomes unwieldy)

24.10.3.3 Event Execution

Typical 5-Day Kaizen Event Schedule:

Day 1: Understand Current State

Morning: - Team kickoff (charter, goals, introductions) - Kaizen training (if team inexperienced) - Review baseline data - Set team norms

Afternoon: - Gemba walk (go to actual location) - Observe process (time study, video) - Interview operators - Identify waste - Map current state

Day 2: Analyze and Design Future State

Morning: - Data analysis (consolidate Day 1 observations) - Root cause analysis (5 Whys, Fishbone) - Brainstorm improvements - Prioritize ideas (impact vs. effort)

Afternoon: - Design future state - Sketch new layout, fixtures, procedures - Test concepts (simulate, prototype) - Develop implementation plan

Day 3: Implement

All Day: - Execute improvements - Hands-on work - Build fixtures, reorganize, create visuals - Test and refine - Iterate quickly

Note: This is hands-on day. Team works in the actual area.

Day 4: Implement and Verify

Morning: - Complete implementation - Run trial (operate process with changes) - Measure results - Adjust as needed

Afternoon: - Document new standard work - Create visual aids (labels, signs, instructions) - Train operators on new method - Prepare report-out presentation

Day 5: Verify and Report

Morning: - Final verification (measure again) - Calculate results vs. baseline - Photos (before/after) - Finalize documentation

Afternoon: - Report-out to leadership and stakeholders - Present: Problem, goal, actions, results, next steps - Celebrate success! - Team recognition

After Event: - 30-day follow-up (sustaining) - 90-day review (verify sustained)

24.10.3.4 Follow-Up and Sustainability

The Risk: Improvements fade, revert to old ways.

Sustaining Actions:

Week 1 After Event: - Communicate results to broader team - Visual display of before/after (photos, metrics) - Reinforce new standard work

30-Day Follow-Up: - Kaizen team reconvenes (2-hour meeting) - Review metrics (are improvements holding?) - Address issues discovered - Refine as needed

90-Day Review: - Formal review of sustained results - Compare to baseline - Document lessons learned - Share success stories (replicate elsewhere)

Ongoing: - Standard work updated and followed - Visual management in place - Metrics tracked and displayed - Continuous Point Kaizen encouraged

Keys to Sustainability: - Leadership support (enforce standards) - Operator involvement (they own it) - Visual management (easy to see status) - Audits (periodic checks) - Continuous improvement culture

---

24.10.4 Daily Kaizen (Small Improvements)

Daily Kaizen: Culture where small improvements are part of everyday work.

Characteristics

Not Events: - No formal structure - No dedicated time off - Built into daily routine

Operator-Led: - Ideas from people doing the work - Implement immediately (if small) - Management supports, doesn't direct

Small Scale: - 5 minutes to implement - No or minimal cost - Local (within work area)

Continuous: - Every day - Everyone - Everywhere

Examples

1. Tool Staging: - Operator notices tools for next job across room - Kaizen: Stage tools at machine before shift end - Time: 2 minutes to implement - Savings: 5 minutes next morning

2. Scrap Bin Location: - Scrap bin 10 feet from machine - Kaizen: Move bin next to machine - Time: 30 seconds - Benefit: No walking with scrap, safer

3. Label Missing: - Part storage bin not labeled - Kaizen: Add label - Time: 1 minute - Benefit: No confusion, faster retrieval

4. Checklist Refinement: - Setup checklist has redundant step - Kaizen: Remove redundant step, update checklist - Time: 5 minutes - Benefit: Faster setup, less confusion

Enabling Daily Kaizen

1. Authority: - Operators authorized to make small changes - No approval needed (within guidelines) - "Just do it" culture

2. Resources: - Supplies available (labels, markers, bins, etc.) - Time allocated (5-10 min/day) - Support from supervisor

3. Recognition: - Ideas acknowledged - Success celebrated - Improvement boards display contributions

4. No Punishment: - Trying something that doesn't work is OK - Learning encouraged - Psychological safety

Quote from Paul Akers (2 Second Lean): *"What did you improve today?"* (Asked daily of everyone)

24.10.5 Kaizen Suggestion Systems

Formal system for capturing and implementing improvement ideas.

System Design

1. Easy Submission: - Simple form (1 page) - Multiple submission methods (paper, digital, verbal) - Located at point of use - Minimal paperwork

Example Form:

```
+-------------------------------------+
|  KAIZEN SUGGESTION                  |
|                                     |
|  Name: _____________ Date: ______   |
|  Area: _____________                |
|                                     |
|  Problem/Opportunity:               |
|  ______________________________     |
|  ______________________________     |
|                                     |
|  Proposed Solution:                 |
|  ______________________________     |
|  ______________________________     |
|                                     |
|  Expected Benefit:                  |
|  [ ] Safety  [ ] Quality  [ ] Cost      |
|  [ ] Delivery  [ ] Morale              |
|                                     |
|  Sketch/Photo (if helpful):         |
|                                     |
+-------------------------------------+
```

2. Quick Response: - Review within 48 hours - Decision: Implement, Study Further, or Decline (with reason) - Feedback to submitter - No "black hole"

3. Implementation Support: - Resources provided (time, materials) - Help from maintenance, engineering if needed - Recognition when implemented

4. Tracking: - Log all suggestions - Status visible - Metrics displayed (submission rate, implementation rate)

5. Recognition: - Public acknowledgment (bulletin board, meeting) - Small rewards (gift cards, lunch, parking spot) - Appreciation more important than money

Metrics

Track and Display:

Submission Rate: - Suggestions per employee per month - Goal: 1-2/person/month (Toyota ~12/year)

Implementation Rate: - % of suggestions implemented - Goal: >80% (simple ideas should be easy to implement)

Time to Implementation: - Days from submission to completion - Goal: <30 days for simple ideas

Benefit: - Cost savings, time savings, safety improvements - Documented and celebrated

Example Display:

```
+--------------------------------------+
|  KAIZEN SUGGESTION SCOREBOARD        |
|             May 2024                 |
|                                      |
|  Submissions:     47                 |
|  Implemented:     38  (81%)          |
|  In Progress:      6                 |
|  Under Review:     3                 |
|                                      |
|  Year-to-Date:                       |
|  Total Ideas:    198                 |
|  Avg/Person:     1.8/month  [check]        |
|                                      |
|  Top Contributors:                   |
|  1. Maria G. - 8 ideas               |
|  2. Tom R. - 6 ideas                 |
|  3. Sarah K. - 5 ideas               |
|                                      |
|  Latest Implementations:             |
|  • Tool shadow board - Cell 3        |
|  • Setup cart - Cell 1               |
|  • Coolant alarm - Mill 4            |
+--------------------------------------+
```

24.10.6 A3 Problem Solving

A3: Structured problem-solving methodology using a single A3-size sheet (11×17” paper).

Origin

Developed at Toyota as a standard communication and problem-solving format.

Why A3 Size? - Forces concise thinking - Single page (can't hide in details) - Easy to review and discuss - Standard format (consistency)

A3 Structure

Seven Sections (Left to Right, Top to Bottom):

1. **Background (Context):** - Why is this important? - Business impact - History of problem

2. **Current Condition:** - What's happening now? - Data, charts, photos - Process map or diagram - Quantify the problem

3. **Goal/Target:** - What do we want to achieve? - Specific, measurable - Timeline

4. **Root Cause Analysis:** - Why is the problem occurring? - 5 Whys, Fishbone diagram - Data-driven analysis

5. **Countermeasures:** - What will we do to address root causes? - Specific actions - Tie to root causes (not symptoms)

6. **Implementation Plan:** - Who does what, by when? - Gantt chart or timeline - Resources needed - Milestones

7. **Follow-Up:** - How will we verify effectiveness? - Metrics to track - Review dates - Lessons learned

Example A3 (CNC Setup Reduction)

```
+-------------------------------------------------------------------+
|  A3: REDUCE CNC CELL 3 SETUP TIME                                 |
|-----------------------------+-------------------------------------|
| 1. BACKGROUND               | 2. CURRENT CONDITION                |
|                             |                                     |
| Cell 3 runs high-mix        | Average setup: 75 minutes           |
| products (25 part numbers).|                                     |
| Long setups limit           | [Bar chart showing setup times]     |
| flexibility, force large    |                                     |
| batches.                    | Breakdown:                          |
|                             | - Get fixtures/tools: 15 min        |
| Business impact:            | - Change fixture: 25 min            |
| - Excess WIP: $50K          | - Change tools: 20 min              |
| - Lead time: 12 days        | - Adjust offsets: 15 min            |
| - Customer complaints       |                                     |
|                             | [Photo of current setup process]    |
|-----------------------------+-------------------------------------|
| 3. GOAL/TARGET              | 4. ROOT CAUSE ANALYSIS              |
|                             |                                     |
| Reduce setup to <15 min     | Why long setups?                    |
| by July 31                  |                                     |
|                             | [Fishbone diagram]                  |
| Success Criteria:           |                                     |
```

```
| - 90% of setups <15 min    | Root causes:                        |
| - Enable batch size <25    | • Fixtures bolted (8 bolts, slow)   |
| - Reduce WIP by 50%        | • Tools not pre-set (trial/error)   |
|                            | • Fixtures, tools not staged         |
|                            | • No standard work for setup         |
|----------------------------+-------------------------------------|
| 5. COUNTERMEASURES         | 6. IMPLEMENTATION PLAN              |
|                            |                                     |
| 1. Quick-change fixture    | [Gantt chart]                       |
|    base plates ($3K)       |                                     |
|                            | Week 1: Order quick-change bases    |
| 2. Tool presetter machine  | Week 2-3: Install bases             |
|    ($8K)                   | Week 4: Tool presetter training     |
|                            | Week 5: Create standard work         |
| 3. Setup kitting system    | Week 6: Pilot with one product      |
|    (carts, labels)         | Week 7-8: Rollout all products      |
|                            |                                     |
| 4. Standard work for setup | Owner: John S. (Cell Leader)        |
|    (document best method)  | Support: Maintenance, Engineering   |
|                            | Budget: $11K approved               |
|----------------------------+-------------------------------------|
| 7. FOLLOW-UP                                                      |
|                                                                   |
| Metrics to Track (weekly):                                       |
| • Setup time (target: <15 min avg)                               |
| • Batch size (target: <25 pcs)                                   |
| • WIP inventory (target: <$25K)                                  |
|                                                                   |
| Review Schedule:                                                 |
| • Week 6: Pilot results review                                   |
| • Week 9: 30-day post-implementation                             |
| • Week 13: 90-day sustainability check                           |
|                                                                   |
| Lessons Learned: [Filled in after completion]                    |
+-------------------------------------------------------------------+
```

A3 Process

Not Just Filling Out a Form:

1. Collaborative: - Team develops A3 together - Multiple reviews with stakeholders - Iterative refinement

2. Go See (Gemba): - Data from actual place - Observe, don't assume - Photos, videos

3. Root Causes, Not Symptoms: - Dig deep (5 Whys) - Address causes, not just symptoms - Data-driven

4. Countermeasures Tied to Root Causes: - Each countermeasure addresses a root cause - Not random solutions

5. PDCA (Plan-Do-Check-Act): - A3 is the "Plan" - Implementation is "Do" - Follow-up is "Check" - Lessons learned feed "Act"

Benefits: - Structured thinking - Concise communication - Visual (easy to understand) - Standard format (everyone speaks same language) - Documents learning

---

24.10.7 PDCA Cycle in Practice

PDCA (Plan-Do-Check-Act): Iterative improvement cycle.

Also known as **Deming Cycle** or **Shewhart Cycle**.

The Four Steps

Plan: - Identify opportunity - Analyze root causes - Develop countermeasures - Set targets - **A3 is perfect tool for Plan**

Do: - Implement on small scale (pilot) - Test the countermeasures - Collect data - **Learn by doing**

Check: - Analyze results - Did we achieve target? - What worked? What didn't? - **Data-driven evaluation**

Act: - If successful: Standardize (new standard work) - If not successful: Adjust and repeat PDCA - Share learning - **Capture knowledge**

PDCA Example: Reducing CNC Scrap

Plan (Week 1): - Problem: 5% scrap rate on Housing part (diameter out of tolerance) - Root cause: Spindle thermal growth (cold start) - Countermeasure: Implement spindle warmup routine (10-min warmup cycle before first part) - Target: Reduce scrap to <1%

Do (Week 2): - Pilot warmup routine on one machine - Operators run warmup every morning - Track scrap rate daily

Check (Week 3): - Results: Scrap reduced to 0.5% (success!) - Operators report warmup easy to do - No negative impacts observed

Act (Week 4): - Standardize: Update standard work to include warmup - Rollout to all machines - Communicate success - **New standard: Warmup before first part**

Next PDCA: - New target: Eliminate remaining 0.5% scrap - Investigate: Why some parts still failing?

Continuous cycle!

PDCA Principles

1. Small Experiments: - Test changes on small scale - Learn quickly - Low risk

2. Data-Driven: - Measure before and after - Objective evaluation - No opinions, just facts

3. Iterative: - Multiple cycles - Each cycle builds on previous - Never-ending improvement

4. Scientific Method: - Hypothesis (countermeasure) - Test (Do) - Analyze (Check) - Conclude (Act)

5. Learning Organization: - Capture what works - Share knowledge - Build capability

---

Summary

Kaizen (continuous improvement) is a philosophy where everyone contributes small improvements daily, creating compound benefits over time. Three types exist: Point Kaizen (quick, local), System Kaizen (value stream-level), and Plane Kaizen (innovation). Kaizen Events are intense 3-5 day improvement activities by cross-functional teams, following a structured process from current state analysis to implementation and follow-up.

Daily Kaizen creates a culture where small improvements are normal, expected, and celebrated. Suggestion systems capture and implement employee ideas, while A3 problem-solving provides a structured, visual format for addressing complex issues. The PDCA cycle (Plan-Do-Check-Act) guides iterative improvement, emphasizing small experiments, data-driven decisions, and standardization of successful changes.

Kaizen is the heart of Lean culture: not just tools and techniques, but a mindset that challenges the status quo and pursues perfection through continuous, incremental improvement.

Key Takeaways

1. **Kaizen** means continuous improvement; small steps daily compound into major gains
2. **Three types**: Point (quick/local), System (value stream), Plane (innovation)
3. **Kaizen Events** are 3-5 day intensive improvement activities with cross-functional teams
4. **Event structure**: Understand current, analyze/design, implement, verify, report
5. **Daily Kaizen** builds culture where small improvements are part of everyday work
6. **Suggestion systems** capture employee ideas with quick response and recognition
7. **A3 problem solving** uses single-page format for structured thinking and communication
8. **PDCA cycle** (Plan-Do-Check-Act) guides iterative experimentation and learning
9. **Everyone contributes**; operators closest to work have best improvement ideas
10. **Sustainability** requires follow-up, standard work, visual management, and leadership support

---

Review Questions

1. What does "Kaizen" mean and who introduced it to the West?
2. Explain the difference between Point, System, and Plane Kaizen
3. What is the typical structure of a 5-day Kaizen Event?
4. How should a Kaizen team be composed? Why include "fresh eyes"?
5. What are the keys to sustaining Kaizen Event improvements?
6. How does Daily Kaizen differ from Kaizen Events?
7. What are the seven sections of an A3?

8. Explain the PDCA cycle with an example
9. What makes a good suggestion system? (List 3 characteristics)
10. Why is Kaizen more sustainable than relying solely on innovation?

Practical Exercise: Conduct a Mini-Kaizen Event

Execute a 1-day mini-Kaizen event:

Preparation (Week Before): 1. Identify opportunity (a problem in your CNC operation) 2. Set goal (specific, measurable) 3. Assemble team (3-5 people including operator) 4. Collect baseline data

Event Day (8 hours):

Hour 1-2: Current State - Gemba walk - Observe and document - Video or time study - Identify waste

Hour 3-4: Analysis and Design - Root cause analysis (5 Whys) - Brainstorm improvements - Design future state - Prioritize actions

Hour 5-6: Implement - Hands-on changes - Build, reorganize, create - Test and refine

Hour 7: Verify - Run process with changes - Measure results - Document new standard

Hour 8: Report - Present results to stakeholders - Before/after comparison - Lessons learned - Celebrate!

Deliverables: - Current state documentation (photos, data) - Future state design - Implementation photos - Results comparison (baseline vs. after) - Standard work document - A3 summarizing the event - 30-day follow-up plan

---

Module 24 - L.E.A.N. Strategies for CNC Manufacturing

24.11.1 Principles of Visual Management

Visual Management makes the status of work, equipment, and processes immediately obvious to anyone at a glance.

Mieruka (Japanese: □ □ □ □) means “making visible” or “visualization.”

Philosophy

Core Principle: Information should be accessible in the place where it’s needed, when it’s needed, without searching, asking, or logging into a system.

Traditional Information Management: - Data in computers, spreadsheets - Reports printed, filed - Need to ask supervisor for status - Invisible problems

Visual Management: - Information displayed at point of use - Real-time status obvious - Anyone can see problems - Self-explaining workplace

Quote from Taiichi Ohno: *"Make problems visible. If you can't see the problem, you can't solve it."*

The Three Levels of Visual Management

Level 1: Visual Display - Shows information (what is happening) - Example: Production schedule board - Passive (just displays)

Level 2: Visual Control - Shows standard vs. actual - Variance obvious - Example: Visual work instructions showing correct method - Active (guides behavior)

Level 3: Visual Guarantee (Poka-Yoke) - Prevents errors - Impossible to deviate from standard - Example: Fixture only accepts part one orientation - Strongest level (enforces)

Goal: Progress from Level 1 □ Level 3

Benefits

Immediate Status Awareness: - Production on target or behind? - Quality issues? - Safety concerns? - Know instantly

Faster Problem Response: - Problems visible immediately - No waiting for reports - Quick corrective action

Employee Engagement: - See impact of their work - Pride in performance - Ownership

Simplified Communication: - Picture > 1000 words - No language barriers - Universal understanding

Self-Regulating: - People correct themselves when they see variance - Less supervision needed

---

24.11.2 Visual Controls on the Shop Floor

24.11.2.1 Andons (Signal Lights)

Andon (Japanese: □ □) originally meant "lantern" or "lamp."

Purpose: Visual signal indicating status or calling for help.

Common Andon Systems:

Stack Light (Traffic Light):

```
    □   Red = Problem/Stop
    □   Yellow = Attention Needed/Changeover
    □   Green = Normal Operation

Visible from across shop floor
```

Status Meanings:

Color	Status	Action
Green	Normal operation	None
Yellow	Minor issue, attention needed	Supervisor aware
Red	Major problem, line stopped	Immediate response
Blue (optional)	Material needed	Material handler responds
White (optional)	Quality check needed	Inspector responds

Andon Board (Entire Facility):

```
+-----------------------------------------+
|        PRODUCTION STATUS BOARD          |
|----------+----------+-------------------|
|  Cell 1  |  Cell 2  |     Cell 3        |
|    □     |    □     |       □           |
| Running  | STOPPED  |   Changeover      |
|  +2      |  -15     |     On Time       |
|----------+----------+-------------------|
|  Cell 4  |  Cell 5  |     Cell 6        |
|    □     |    □     |       □           |
| Running  | Running  |    Running        |
|  +5      |  On Time |      +3           |
+----------+----------+-------------------+

+/- = Parts ahead/behind schedule
```

Benefits: - Status visible to all - Calls for help without shouting - Supervisor prioritizes response - Tracks problems (why stopped?)

Andon Cord/Button: - Operator pulls cord or presses button - Light activates, music/chime sounds - Signals for help - Empowers operators to stop for quality

24.11.2.2 Production Boards

Display production status, targets, and performance.

Hourly Production Board:

```
+----------------------------------------------+
|      CELL 3 - PRODUCTION TRACKER             |
|      Date: May 15    Target: 150 parts       |
|------+---------+---------+---------+------------|
| Hour | Target | Actual | Var     |   Status   |
|------+---------+---------+---------+------------|
|  7am |   20   |   18   |  -2     |     □      |
|  8am |   20   |   22   |  +2     |     □      |
|  9am |   20   |   20   |   0     |     □      |
| 10am |   20   |   19   |  -1     |     □      |
| 11am |   20   |        |         |            |
| 12pm |   20   |        |         |            |
```

```
|  1pm |   20   |        |        |           |
|  2pm |   20   |        |        |           |
|------+--------+--------+--------+-----------|
|Total |  160   |   79   |  -1    |  On Track |
+------+--------+--------+--------+-----------+

Comments: 7am - Late start (material delivery)
```

Updated hourly by operator - immediate feedback.

Elements: - Target (what should be done) - Actual (what was done) - Variance (difference) - Visual status (color, symbols) - Comments (why variance?)

Production Tracking Chart:

```
Parts
 ▯
150|                                Target Line
   |                             ___/
   |                          __/
   |                       __/
100|                    __/---- Actual
   |                 __/
   |              __/
   |           __/
 50|        __/
   |     __/
   |  __/
   |/
  0+-----------------------------------------> Time
    7am  8am  9am 10am 11am 12pm  1pm  2pm

Visual: Are we on track?
```

24.11.2.3 Work-in-Progress Limits

Visual WIP limits prevent overproduction.

Floor Markings:

```
+------------------+
|                  |  ← FULL (12 parts max)
|  ████████████    |
|  ████████████    |  ← Current Level (8 parts)
|  ████████████    |
|  ████████████    |
|                  |  ← EMPTY (minimum 2 parts)
+------------------+

WIP Supermarket for Operation 2
```

```
Visual: Space empty = need to produce
        Space full = stop producing
```

Kanban Board:

```
+------------------------------------------+
|         KANBAN BOARD - CELL 3            |
|                                          |
|  TO DO     |  IN PROGRESS  |  DONE       |
| (Max 10)   |   (Max 3)     |             |
|------------+---------------+-------------|
| [Card]     |   [Card]      |  [Card]     |
| [Card]     |  [Card]       |  [Card]     |
| [Card]     |  [Card]       |  [Card]     |
| [Card]     |               |  [Card]     |
| [Card]     |               |             |
|            |               |             |
+------------+---------------+-------------+

In Progress column limited to 3 cards
Can't start new until space available
```

WIP Limits: - Prevents overproduction - Creates pull - Makes bottlenecks visible - Forces problem solving (why can't we move to Done?)

24.11.3 Visual Performance Displays

Display metrics where work is performed.

Team Performance Board

Located at cell/workstation:

```
+-----------------------------------------------+
|        CELL 3 PERFORMANCE DASHBOARD           |
|                Week of May 15                 |
|-----------------------------------------------|
|                                               |
|  SAFETY: 127 days without injury   □          |
|                                               |
|  QUALITY (First Time Through):                |
|  Target: >98%    Actual: 97.5%   □            |
|  [████████████████████░░]                     |
|                                               |
|  DELIVERY (On-Time):                          |
|  Target: 100%    Actual: 100%    □            |
|  [████████████████████████]                   |
|                                               |
```

```
|  PRODUCTIVITY (Parts/Hour):                    |
|  Target: 20      Actual: 21      □             |
|  [█████████████████████████]                   |
|                                                |
|  OEE (Overall Equipment Effectiveness):        |
|  Target: 85%     Actual: 82%     □             |
|  [███████████████████░░░]                      |
|                                                |
|------------------------------------------------|
|  TOP ISSUES THIS WEEK:                         |
|  1. Tool breakage (3 occurrences)              |
|  2. Coolant alarm (2 occurrences)              |
|                                                |
|  KAIZEN IDEAS SUBMITTED: 4                     |
|  KAIZEN IDEAS IMPLEMENTED: 3                   |
+------------------------------------------------+
```

Updated: Daily or weekly

Characteristics: - Simple (no complex charts) - Visual (colors, bars, symbols) - Relevant (metrics that matter to this team) - Current (updated regularly) - Actionable (drives improvement)

Trend Charts

Show performance over time:

```
OEE %
  □
 100|
    |
  85|- - - - - - - - - Target - - - - - - - - -
    |          ●
  80|      ●       ●   ●
    |  ●       ●           ●
  75|                          ●
    |
  70|
   +---------------------------------------> Week
     W1  W2  W3  W4  W5  W6  W7  W8

Visual: Trending down – need action!
```

Pareto Chart (Focus Improvement):

```
Downtime
Minutes
  □
 200| █████
    | █████
 150| █████
```

```
    | █████  ████
 100| █████  ████
    | █████  ████  ███
  50| █████  ████  ███  ██  █
    | █████  ████  ███  ██  █
   0+--------------------------------> Cause
     Setup  Break  Tool  Mat  Other
     (45%)  (28%) (17%) (7%) (3%)

80% of downtime from Setup + Breakdowns
Focus improvement here!
```

24.11.4 Visual Work Instructions

Show the correct way to perform work.

One-Point Lessons (OPL)

Single-page visual instruction for specific task.

Format:

```
+-------------------------------------------+
|  ONE-POINT LESSON                         |
|  Topic: Loading Part in Fixture           |
|  Machine: CNC Mill #3                     |
|-------------------------------------------|
|                                           |
|  [PHOTO: Correct part orientation]        |
|                                           |
|  [check] Flat side faces operator               |
|  [check] Chamfer at top right corner            |
|  [check] Part seated fully against stops        |
|                                           |
|  [PHOTO: Incorrect - common mistake]      |
|                                           |
|  ✗ Part rotated 180° (WRONG!)            |
|  ✗ Chamfer at bottom left                 |
|                                           |
|  WHY IT MATTERS:                          |
|  Incorrect orientation machines           |
|  features on wrong side → scrap          |
|                                           |
|  Created: 5/15/24   Rev: A                |
|  By: Maria G.                             |
+-------------------------------------------+
```

Characteristics: - One page - Lots of photos (minimal text) - Shows correct AND incorrect - Explains why it matters - Laminated, posted at machine

Job Instruction Sheet:

```
+-------------------------------------------+
|  OPERATION: CNC Mill Part #12345          |
|-------------------------------------------|
| Step | Action         | Key Point | Photo |
|------+----------------+-----------+-------|
|  1   | Load part      | Chamfer   | [▯ ]  |
|      |                | top-right |       |
|------+----------------+-----------+-------|
|  2   | Close vise     | Pressure  | [▯ ]  |
|      |                | 80 psi    |       |
|------+----------------+-----------+-------|
|  3   | Start cycle    | Press     | [▯ ]  |
|      |                | green     |       |
|------+----------------+-----------+-------|
|  4   | Inspect first  | Dia: .500 | [▯ ]  |
|      | part           | +/-.002   |       |
+------+----------------+-----------+-------+
```

Standard Work Chart

Visual display of work sequence and time:

```
+---------------------------------------------+
|  STANDARD WORK CHART - Cell 3               |
|  Takt Time: 3 minutes                       |
|---------------------------------------------|
|                                             |
|   Operator Path:                            |
|                                             |
|      ▯  → ▯  → ▯  → ▯                         |
|      ↑              ↓                       |
|      ▯  ← ▯  ← ▯  ← ▯                         |
|                                             |
|  ▯  Mill (load): 30 sec                      |
|  ▯  Drill (load): 20 sec                     |
|  ▯  Tap (load): 25 sec                       |
|  ▯  Inspect: 15 sec                          |
|  ▯  Tap (unload): 20 sec                     |
|  ▯  Drill (unload): 15 sec                   |
|  ▯  Mill (unload): 25 sec                    |
|                                             |
|  Total Manual Time: 2 min 30 sec            |
|  Walking Time: 30 sec                       |
|  Cycle Time: 3 min (= Takt Time) [check]          |
```

```
+----------------------------------------------+
```

Posted at cell entrance - everyone can see standard

24.11.5 Color Coding and Labeling

Color and labels make information instantly recognizable.

Color Coding Systems

Aisles and Zones: - Yellow lines: Walkways (don't block) - Red lines: Safety zones (no storage) - Blue lines: WIP staging areas - Green lines: Finished goods - White lines: Equipment boundaries

Tool Holders: - Red tools: Operation 1 - Blue tools: Operation 2 - Green tools: Operation 3 - Yellow tools: Shared

Parts/Material: - Color-coded bins by part family - Visual match: Red part Red fixture - Prevents mix-ups

Status: - Green tag: Inspected, approved - Yellow tag: Hold, pending - Red tag: Reject, scrap

Labeling Best Practices

Equipment Labels:

```
+--------------------------+
|  CNC MILL #3             |
|  Cell: 3                 |
|  Capacity: 20 pcs/hr     |
|  Status: [ ]             |
|  Last PM: 5/10/24        |
|  Next PM: 8/10/24        |
+--------------------------+
```

Location Labels:

```
+------------------+
|  LOCATION: A-12 |
|  Part: 12345-B  |
|  Min: 50 pcs    |
|  Max: 200 pcs   |
|  Current: 125   |
+------------------+
```

Characteristics: - Large text (readable from 10 feet) - Pictures/symbols (not just text) - Weatherproof (laminated) - Standardized format - Updated when changed

---

24.11.6 Visual Inventory Management

Make inventory levels obvious.

Min/Max Visual Levels

Inventory Rack with Visual Limits:

```
+-------------------+
|                   | ← MAX (red line)
|  ████████████     |
|  ████████████     |
|  ████████████     | ← Current Level
|  ████████████     |
|  ████████████     | ← REORDER (yellow line)
|  ████████████     |
|                   | ← MIN (red line)
+-------------------+

Visual: Below yellow = reorder triggered
        Below red = stockout risk
```

Kanban Square:

```
Floor marked with outline:

+--------------+
|              |
|   Part       |  ← Outline painted on floor
|   12345      |
|   Min: 25    |
|   Max: 100   |
|              |
+--------------+

Empty space = need to produce
Full = stop producing
```

First-In-First-Out (FIFO) Lanes

Ensure oldest parts used first:

```
  Load         →  →  →  →         Unload
  (New)      [▓][▓][▓][▓][▓]      (Old)

           Gravity flow rack
           Parts slide forward
           Oldest automatically at front
```

Visual indicators: - Date labels on parts - Color-coded by week (Week 1 = Red, Week 2 = Blue) - Arrows showing flow direction

Inventory Status Boards

```
+------------------------------------------+
|      RAW MATERIAL INVENTORY STATUS       |
|----------+---------+---------+-----------|
| Material | Current | Status  | Reorder   |
|----------+---------+---------+-----------|
| Al 6061  |  125    |   □     | No        |
| (bars)   |         |         |           |
|----------+---------+---------+-----------|
| Steel    |   35    |   □     | Yes       |
| 1018     |         |         | (Order #) |
|----------+---------+---------+-----------|
| Al 7075  |   8     |   □     | RUSH      |
| (plate)  |         |         | (Due Mon) |
+----------+---------+---------+-----------+

Updated: Daily (before shift)
```

24.11.7 Creating Self-Explaining Workplaces

Goal: A visitor can understand what's happening without asking.

Elements of Self-Explaining Workplace

1. Clear Organization (5S): - Everything in its place - Place for everything - Labeled and marked

2. Visual Workflow: - Flow arrows on floor - Sequence numbers - Directional signs

3. Status Displays: - Performance boards - Andons - Schedule boards

4. Standard Work Visible: - Instructions posted - Photos of correct method - Job aids at point of use

5. Problem Visibility: - Issues logged visually - Corrective actions displayed - Progress tracked

5-Minute Rule

Test: Can a visitor understand the status in 5 minutes?

Walk through and answer: - What is produced here? - Are we on target or behind? - What's the current priority? - Are there any problems? - What's the quality status? - Is it safe?

If you can answer these in 5 minutes without asking □ Self-explaining workplace!

Visual Factory Tour

Self-guided tour possible:

```
Start → [Sign: "Welcome to Cell 3 – Shaft Family"]
   ↓
[Performance Board showing metrics]
   ↓
[Process Flow diagram on wall]
   ↓
[Standard Work displays at each operation]
   ↓
[Quality check station with visual gages]
   ↓
[Kaizen board showing improvements]
   ↓
End → [Sign: "Questions? Ask Team Leader Maria"]
```

Summary

Visual Management (Mieruka) makes work status, problems, and standards immediately obvious without asking or searching. Three levels exist: Visual Display (shows information), Visual Control (shows standard vs. actual), and Visual Guarantee (prevents deviation).

Key visual controls include Andons (signal lights showing status), production boards (tracking output vs. target), and WIP limits (preventing overproduction). Performance displays show metrics at the work location with trend charts and team scoreboards. Visual work instructions use photos and one-point lessons to show correct methods.

Color coding and labeling create instant recognition (tools, materials, status, zones). Visual inventory management uses min/max lines, FIFO lanes, and Kanban squares to make levels obvious. The goal is a self-explaining workplace where anyone can understand status in 5 minutes without asking questions.

Key Takeaways

1. **Visual Management** makes status obvious at a glance (no searching, asking, logging in)
2. **Three levels**: Display (shows), Control (guides), Guarantee (prevents)
3. **Andons** provide visual signals (green/yellow/red) for status and help
4. **Production boards** track hourly output vs. target at point of work
5. **WIP limits** prevent overproduction through visual floor marks and Kanban boards
6. **Performance displays** show metrics where work is done (not in office)
7. **Visual work instructions** use photos, not just text (correct and incorrect methods)
8. **Color coding** creates instant recognition (tools, materials, zones, status)
9. **Visual inventory** uses min/max lines, FIFO lanes, Kanban squares
10. **Self-explaining workplace** allows visitors to understand status in 5 minutes

---

Review Questions

1. What does “Mieruka” mean and what is its purpose?
2. Explain the three levels of visual management
3. What do the colors mean in a typical Andon system?
4. How does an hourly production board help operators?
5. What are WIP limits and how are they visualized?
6. Design a simple One-Point Lesson (sketch with key elements)
7. What is the “5-minute rule” for self-explaining workplaces?
8. How does color coding prevent errors?
9. What’s the difference between Visual Display and Visual Control?
10. List 5 elements that make a workplace self-explaining

Practical Exercise: Visual Management Audit

Audit a work area for visual management:

Preparation: 1. Select area (cell, workstation, department) 2. Bring camera, notepad, checklist

Audit Checklist:

Organization (5S): - [ ] Tools organized and labeled? - [ ] Locations marked on floor? - [ ] Shadow boards for tools? - [ ] Clean and orderly?

Status Visibility: - [ ] Production status displayed? - [ ] Quality metrics visible? - [ ] Schedule visible? - [ ] Performance vs. target shown?

Standards: - [ ] Standard work documented? - [ ] Work instructions posted? - [ ] Visual aids at machines? - [ ] Photos showing correct methods?

Inventory: - [ ] Min/max levels marked? - [ ] FIFO enforced visually? - [ ] WIP limits defined? - [ ] Material locations labeled?

Problem Visibility: - [ ] Andon or call system? - [ ] Issues logged visually? - [ ] Corrective actions tracked? - [ ] Kaizen board?

5-Minute Test: - [ ] Can determine what’s produced? - [ ] Can see if on target? - [ ] Can identify current issues? - [ ] Can understand workflow?

Deliverables: - Completed checklist with scores - Photos (before state) - Improvement recommendations (prioritized) - Simple visual management additions (low-cost quick wins) - Implementation plan (30 days)

Module 24 - L.E.A.N. Strategies for CNC Manufacturing

24.12.1 Purpose of Standardized Work

Standardized Work is the documented, current best method for performing a task safely, efficiently, and with high quality.

Definition

Standardized Work: The precise description of each work activity specifying cycle time, takt time, work sequence, and standard inventory needed to conduct the activity.

Not to be confused with: - Work standards (time standards for pay) - Standard Operating Procedures (SOPs - often too detailed, not followed) - Generic instructions (apply everywhere)

Standardized Work is: - Specific to each process - Current best method (not permanent) - Based on observation and data - Living document (continuously improved)

Purpose

1. Establish Baseline for Improvement: - Can't improve if you don't know current method - Standard = starting point for Kaizen - Document improvements

2. Ensure Consistency: - Everyone performs task the same way - Quality consistent - Output predictable - Training standardized

3. Preserve Knowledge: - Best practices captured - Doesn't depend on one person - Survives turnover - Organizational learning

4. Enable Problem Detection: - Deviation from standard is visible - Signals abnormality - Triggers investigation

5. Safety: - Safe method documented - Hazards identified - Controls specified

Quote from Taiichi Ohno: *"Without standards, there can be no improvement."*

Misconceptions

Standardized Work is NOT:

"Removing Creativity": - Reality: Standards are platform for creativity - Operators improve the standard - Innovation happens through Kaizen

"Set in Stone": - Reality: Standards change continuously - Better method found update standard - Living document

"Management Control": - Reality: Created by/with operators - Operators own the standard - Management supports

"Micromanagement": - Reality: Documents what, not how (to level of detail) - Flexibility within standard - Focus on outcome and key points

---

24.12.2 Three Elements of Standardized Work

24.12.2.1 Takt Time

Takt Time: The rate of customer demand; pace of production.

Formula:

```
Takt Time = Available Production Time ÷ Customer Demand
```

Purpose in Standardized Work: - Sets the pace for the work - Determines if work can be accomplished by one person - Balancing target

Example: - Available time: 450 min/day - Demand: 150 parts/day - **Takt time: 3 minutes**

Standardized work must complete within takt time.

Detailed coverage in Section 24.4.2

24.12.2.2 Work Sequence

Work Sequence: The order of operations performed by the operator.

Not machine sequence (which is programmed), but **operator sequence**: 1. What operator does first 2. What operator does second 3. And so on…

Critical Points:

Safety-Critical Steps: - Steps that must be done for safety - Highlighted in sequence - Example: "Ensure guard closed before starting"

Quality-Critical Steps: - Steps that ensure quality - Key inspection points - Example: "Verify part orientation before clamping"

Efficiency Points: - Steps that save time if done correctly - Example: "Stage tools during machine cycle"

Example Work Sequence:

```
CNC Operator - Part 12345-B

1. While previous part machining:
   - Retrieve next blank from bin
   - Inspect blank for damage
   - Apply cutting fluid to fixture

2. When cycle complete:
   - Open door (machine stops automatically)
   - Remove finished part
   - Place in finished goods bin

3. Load next part:
   - Position blank in fixture (chamfer top-right)
   - Close vise (80 psi pressure)
   - Verify part seated against stops

4. Start cycle:
   - Close door
   - Press green start button
   - Observe first few seconds for normal operation
```

```
5. While cycle running:
   - Inspect previous part (diameter, length)
   - Record data if required
   - Prepare next blank

6. Return to step 2

Cycle Time: 2.5 minutes
```

24.12.2.3 Standard WIP

Standard WIP (Work-in-Process): The minimum inventory required for the operator to perform standardized work.

Includes:

In-Machine Inventory: - Parts currently being processed - Example: 1 part in CNC

In-Hand Inventory: - Parts operator is working on - Example: 1 part being inspected

Between-Operation Inventory: - Parts waiting at each step in sequence - Example: If operator tends 3 machines, minimum 3 parts (1 per machine)

Purpose: - Enables continuous flow - Not excess inventory - Calculated, not guessed

Example: - Operator tends 3 CNC machines - Each has 5-minute cycle - Operator manual work: 1.5 min per machine - **Standard WIP: 3 parts (1 in each machine)**

No more, no less.

24.12.3 Documenting Standardized Work

24.12.3.1 Standardized Work Chart

Visual representation of work sequence and layout.

Format:

```
+-------------------------------------------------------+
|  STANDARDIZED WORK CHART                              |
|  Process: CNC Milling - Part 12345                    |
|  Takt Time: 3.0 min    Cycle Time: 2.8 min           |
|-------------------------------------------------------|
|                                                       |
|  Layout:                                              |
|                                                       |
|     [Raw       [CNC        [Finished                 |
|      Mat]  →   Mill]   →   Goods]                    |
|       □         □ □ □         □                         |
|                                                       |
|  Operator Path: □ →□ →□ →□ →□ →□                          |
```

```
|                                                        |
|  Work Sequence:                                        |
|  □  Get blank (0.3 min)                                |
|  □  Load part, start cycle (0.5 min)                   |
|  □  While running: Inspect previous (0.8 min)          |
|  □  Cycle complete: Unload (0.3 min)                   |
|  □  Place in finished bin (0.2 min)                    |
|  Walking time (0.7 min)                                |
|                                                        |
|  Total Manual Time: 2.1 min                            |
|  Total Cycle Time: 2.8 min                             |
|                                                        |
|  Safety Points:                                        |
|  • Ensure door closed before start                    |
|  • Wait for spindle stop before opening               |
|                                                        |
|  Quality Points:                                       |
|  ⚠ Verify part orientation (chamfer top-right)        |
|  ⚠ Check diameter on first part                       |
|                                                        |
|  Standard WIP: 1 part (in machine)                     |
|                                                        |
|  Date: 5/15/24   Rev: C   By: Maria G.                |
+--------------------------------------------------------+
```

Characteristics: - One page - Visual (layout diagram) - Shows operator path - Lists sequence with times - Highlights safety and quality points - Posted at workstation

24.12.3.2 Standardized Work Combination Table

Shows relationship between manual work and machine time.

Format:

```
+--------------------------------------------------------------+
|  STANDARDIZED WORK COMBINATION TABLE                         |
|  Operation: CNC Mill Part 12345   Takt Time: 3.0 min        |
|----+--------------+------+---------+---------+-------------|
|Step| Work Element | Time | Manual  | Machine |   Walk      |
|    |              | (sec)|  Work   |  Auto   |             |
|----+--------------+------+---------+---------+-------------|
| 1  | Get blank    |  18  | ████    |         |             |
|----+--------------+------+---------+---------+-------------|
| 2  | Load part    |  30  | ██████  |         |             |
|----+--------------+------+---------+---------+-------------|
| 3  | Start cycle  |   5  | █       |         |             |
|----+--------------+------+---------+---------+-------------|
| 4  | Machine runs | 180  |         | ███████ |             |
|    | (while inspecting)|  | ████    | ███████ |             |
```

```
|----+--------------+------+---------+---------+------------|
| 5  | Unload part  |  18  | ████    |         |            |
|----+--------------+------+---------+---------+------------|
| 6  | To finish bin|  12  |         |         | ███        |
|----+--------------+------+---------+---------+------------|
| 7  | Return       |  30  |         |         | ██████     |
|----+--------------+------+---------+---------+------------|
| Total               | 168  | Manual  | Auto    |   Walk     |
|                     |(2.8m)| 78 sec  | 180 sec |  42 sec    |
+--------------------+------+---------+---------+------------+

Takt Time: 180 sec (3 min)
Cycle Time: 168 sec (2.8 min) [check] Under takt time

█ = Time bar showing when operator is busy
```

Use: - Identify waste (waiting, walking) - Balance workload - See if multi-machine operation possible - Improve cycle time

24.12.3.3 Job Breakdown Sheets

Detailed instruction for training purposes.

Format:

```
+-------------------------------------------------------+
|  JOB BREAKDOWN SHEET                                  |
|  Job: Load Part in CNC Fixture                        |
|--------------------+--------------+------------------|
| Important Step     |  Key Point   | Reason           |
|--------------------+--------------+------------------|
| 1. Inspect blank   | No cracks    | Prevents spindle |
|                    | No burrs     | damage, scrap    |
|                    |              |                  |
| [Photo of good blank]             |                  |
|--------------------+--------------+------------------|
| 2. Position part   | Chamfer at   | Ensures correct  |
|    in fixture      | top right    | machining        |
|                    | Seated fully | orientation      |
|                    |              |                  |
| [Photo showing orientation]       |                  |
|--------------------+--------------+------------------|
| 3. Close vise      | 80 psi       | Prevents part    |
|                    | pressure     | movement         |
|                    | Gage reads   |                  |
|                    | 80 +/-5        |                  |
|                    |              |                  |
| [Photo of pressure gage]          |                  |
|--------------------+--------------+------------------|
```

```
| 4. Verify seated   | No gap at    | Prevents Z       |
|                    | stops        | dimension error  |
|                    | Visual check |                  |
|                    |              |                  |
| [Photo of properly seated part]   |                  |
+--------------------+--------------+------------------+
```

Characteristics: - Breaks job into important steps - Each step has key point (critical detail) - Reason explains "why" (builds understanding) - Photos for each step - Used for training (Training Within Industry - TWI method)

24.12.4 Time Observation Studies

Collecting data to create standardized work.

Process

1. Select Operation: - Typical work (not easiest or hardest) - Performed frequently - By experienced operator

2. Observe Multiple Cycles: - 5-10 cycles minimum - Note variations - Time each element

3. Record Data:

```
Element: Load Part

Observation Times (seconds):
Cycle 1: 32
Cycle 2: 28
Cycle 3: 35
Cycle 4: 30
Cycle 5: 29
Cycle 6: 31
Cycle 7: 28
Cycle 8: 30

Average: 30.4 seconds
Std Dev: 2.3 seconds
Range: 28–35 seconds

Standard Time: 30 seconds (round to practical increment)
```

4. Analyze: - Why variations? - Can variations be eliminated? - What's repeatable method?

5. Document Standard: - Use average of observed times - Round to practical increment (5 sec, 10 sec) - Note method used

Time Study Tips

Stopwatch Method: - Continuous timing (don't stop between elements) - Note split times - Operator awareness (may go faster - observe multiple times)

Video Method: - Record operator (with permission) - Review video for times - Operator not influenced by being timed - Can review multiple times

Work Sampling: - Periodic observations over time - Good for understanding utilization - Not as precise for element times

Key Point: - Purpose is to document current method, not set "rates" - Involve operator (their input essential) - Not punitive

---

24.12.5 Standardized Work for CNC Operators

24.12.5.1 Setup Standards

Document best method for changeovers.

Standard Setup Sheet:

```
+---------------------------------------------------+
|  SETUP STANDARD - CNC Mill #3                     |
|  From: Part 12345  To: Part 12346                 |
|  Target Setup Time: 10 minutes                    |
|---------------------------------------------------|
|                                                   |
|  BEFORE STOPPING MACHINE (External):              |
|  [ ] Stage fixture for Part 12346                  |
|  [ ] Stage tool kit (Tools T1-T8)                  |
|  [ ] Stage program (USB at machine)                |
|  [ ] Review setup sheet                            |
|                                                   |
|  AFTER STOPPING MACHINE (Internal):               |
|  [ ] Remove fixture (2 min)                        |
|    - Loosen 4 cam locks                          |
|    - Slide fixture off base plate                |
|                                                   |
|  [ ] Install new fixture (2 min)                   |
|    - Align pins with base plate                  |
|    - Tighten 4 cam locks                         |
|                                                   |
|  [ ] Load tools (3 min)                            |
|    - Tools pre-set offline                       |
|    - Load per tool list                          |
|    - Verify tool numbers match                   |
|                                                   |
|  [ ] Load program (1 min)                          |
```

```
|    - USB to control                            |
|    - Verify program name                       |
|    - Load tool offsets                         |
|                                                 |
|  [ ] First part (2 min)                          |
|    - Load blank                                |
|    - Run program                               |
|    - Verify cycle                              |
|                                                 |
|  Total Internal Time: 10 minutes               |
|                                                 |
|  FIRST-OFF INSPECTION:                          |
|  [ ] Measure critical dims (per print)           |
|  [ ] Visual inspection                           |
|  [ ] Sign off on first article                  |
|                                                 |
|  Notes:                                         |
|  - Photos of fixture installation on wall      |
|  - Tool preset done by Tool Room               |
|                                                 |
|  Created: 5/10/24  Rev: B  By: Tom R.          |
+---------------------------------------------------+
```

24.12.5.2 Operation Standards

Running production (steady-state).

Standard Operating Sheet:

```
+---------------------------------------------------+
|  OPERATION STANDARD                             |
|  Part: 12345-B   Machine: CNC Mill #3           |
|  Takt Time: 3 min   Cycle Time: 2.5 min        |
|-------------------------------------------------|
|                                                 |
|  SEQUENCE:                                      |
|  1. Retrieve blank from bin (check for damage)  |
|  2. While machine running:                     |
|     - Apply cutting fluid to fixture           |
|     - Inspect previous part (see Quality Std)  |
|  3. When cycle complete (door opens auto):     |
|     - Remove part                              |
|     - Place in "Inspect" bin                   |
|  4. Load next part:                            |
|     - Chamfer at top-right (critical!)         |
|     - Seat against all 3 stops                 |
|     - Close door (auto-start)                  |
|  5. Repeat                                     |
|                                                 |
```

```
|  EVERY 10TH PART:                                 |
|  [ ] Measure diameter (0.500 +/-0.002)               |
|  [ ] Plot on control chart                         |
|  [ ] If trending, alert supervisor                 |
|                                                   |
|  EVERY 50 PARTS:                                  |
|  [ ] Check tool wear (visual)                      |
|  [ ] Check coolant concentration (8-10%)           |
|                                                   |
|  SAFETY:                                          |
|  ⚠ Never open door while spindle running          |
|  ⚠ Wear safety glasses at all times               |
|  ⚠ Report any unusual sounds/vibration            |
|                                                   |
|  WHAT TO DO IF:                                   |
|  • Alarm sounds: Press STOP, call supervisor      |
|  • Part won't load: Check orientation, clean      |
|    fixture                                        |
|  • Dimension out of spec: Stop, tag part,         |
|    call supervisor                                |
|                                                   |
|  Tools Required: Cleaning brush, air gun, mic     |
|  PPE: Safety glasses, hearing protection          |
|                                                   |
|  Date: 5/15/24   Rev: D   By: Maria G.            |
+---------------------------------------------------+
```

24.12.5.3 Inspection Standards

What and how to inspect.

Inspection Standard:

```
+---------------------------------------------------+
|  INSPECTION STANDARD - Part 12345-B               |
|---------------------------------------------------|
|                                                   |
|  FREQUENCY: Every 10th part                       |
|                                                   |
|  CRITICAL DIMENSIONS:                             |
|                                                   |
|  1. Diameter                                      |
|     Spec: 0.500 +/-0.002                            |
|     Gage: Digital micrometer                      |
|     Location: Mid-length                          |
|     [Photo showing where to measure]              |
|     Record on SPC chart                           |
|                                                   |
|  2. Length                                        |
```

```
|     Spec: 2.000 +/-0.005                          |
|     Gage: Digital caliper                       |
|     [Photo]                                       |
|                                                   |
|  3. Surface Finish                                |
|     Spec: 63 Ra max                             |
|     Method: Visual (compare to sample)          |
|     [Photo of acceptable finish]                |
|                                                   |
|  VISUAL INSPECTION (Every Part):                  |
|  [ ] No burrs                                       |
|  [ ] No cracks                                      |
|  [ ] No tool marks                                  |
|  [ ] Clean (no chips)                               |
|                                                   |
|  ACCEPTANCE CRITERIA:                             |
|  [check] All dimensions within spec                       |
|  [check] Visual inspection pass                           |
|  → Place in "Good Parts" bin                    |
|                                                   |
|  ✗ Any dimension out of spec                    |
|  → Place in "Hold" bin, tag, notify supervisor  |
|                                                   |
|  GAGES:                                           |
|  - Digital micrometer (Cal Due: 6/1/24)         |
|  - Digital caliper (Cal Due: 6/15/24)           |
|  - Located in shadow board at machine           |
|                                                   |
|  Date: 5/1/24   Rev: C   By: Quality Dept       |
+---------------------------------------------------+
```

24.12.6 Training to Standard

Using standardized work for consistent training.

Training Within Industry (TWI) Method

4-Step Method for Job Instruction:

Step 1: Prepare the Learner - Put at ease - Explain what will be learned - Find out what they already know - Create interest

Step 2: Present the Operation - Tell, show, demonstrate - One step at a time - Stress key points - Instruct clearly and completely - Keep it simple

Step 3: Try Out Performance - Have learner do the job - Correct errors immediately - Have learner explain key points - Repeat until learner understands

Step 4: Follow Up - Put learner on their own - Check frequently - Encourage questions - Taper off coaching - Designate who to go to for help

Using Job Breakdown Sheet

Trainer follows Job Breakdown Sheet: 1. Shows important step 2. Demonstrates key point 3. Explains reason 4. Learner practices 5. Learner explains back 6. Repeat until proficient

Certification: - Learner performs job to standard - Trainer observes - Meets quality, safety, time requirements - Sign-off on training record

Training Record

```
+---------------------------------------------------+
|  TRAINING RECORD                                  |
|  Employee: John S.                                |
|  Operation: CNC Mill Part 12345-B                 |
|---------------------------------------------------|
|  Trainer: Maria G.                                |
|  Date Started: 5/10/24                            |
|  Date Certified: 5/17/24                          |
|                                                   |
|  Training Completed:                              |
|  [ ] Classroom overview (safety, quality)           |
|  [ ] Observed experienced operator (1 shift)        |
|  [ ] Performed under supervision (3 shifts)         |
|  [ ] Performed independently (1 week)               |
|                                                   |
|  Demonstrated Proficiency:                        |
|  [check] Meets cycle time (2.8 min avg)                |
|  [check] Zero defects in 50-piece trial                 |
|  [check] Follows standard work                         |
|  [check] Performs inspections correctly                 |
|  [check] Knows what to do if problems                  |
|                                                   |
|  Certified By: Maria G.    Date: 5/17/24          |
|  Supervisor: Tom R.        Date: 5/17/24          |
+---------------------------------------------------+
```

24.12.7 Improving the Standard

Standardized work is foundation for improvement.

Continuous Improvement Cycle

Current Standard Use Observe Improve New Standard

Process:

1. Operator Identifies Improvement: - Faster method discovered - Waste eliminated - Safety enhanced

2. Test Improvement: - Try new method - Measure results - Verify better than current standard

3. Update Standard: - Document new method - Update standardized work documents - Communicate change

4. Train Everyone: - All operators trained to new standard - Consistency maintained

5. Continue Improving: - New standard becomes baseline - Cycle repeats

Example Improvement

Current Standard: - Walk to bin for blank (10 steps, 15 seconds) - Cycle time: 2.8 minutes

Improvement Idea: - Move bin next to machine (Kaizen) - Walk: 2 steps, 5 seconds - New cycle time: 2.7 minutes

Update Standard: - Revise standardized work chart - Update cycle time to 2.7 min - Document bin location change - Rev: D (increment revision)

Result: - 10-second improvement per cycle - 20 cycles/day = 200 seconds/day saved - Improvement captured in standard

Kaizen and Standardized Work

Relationship:

Standardized Work: - Baseline (what we do now) - Consistent method - Known results

Kaizen: - Improvement (what we'll do next) - Better method - Better results

New Standardized Work: - Captures improvement - New baseline - Repeat

Quote: *"Standardize, then improve. Improve, then standardize."*

Summary

Standardized Work documents the current best method for performing tasks safely, efficiently, and with high quality. It consists of three elements: takt time (customer demand pace), work sequence (order of operations), and standard WIP (minimum inventory needed). Standardized work is not rigid or permanent–it's a living baseline for continuous improvement.

Documentation includes Standardized Work Charts (visual layout and sequence), Combination Tables (relationship between manual and machine time), and Job Breakdown Sheets (training tool). Time observation studies collect data to establish standards. For CNC operations, standards cover setups, operations, and inspections with specific instructions and acceptance criteria.

Standardized work enables consistent training using the TWI 4-step method (prepare, present, try out, follow up). Most importantly, standardized work provides the foundation for Kaizen: document current state, improve, update standard, train everyone, repeat. Without standards, there can be no sustainable improvement.

Key Takeaways

1. **Standardized Work** is current best method, not permanent or rigid
2. **Three elements**: Takt time, work sequence, standard WIP
3. **Purpose**: Baseline for improvement, consistency, knowledge preservation
4. **Documentation**: Chart (visual layout), Combination Table (timing), Job Breakdown (training)
5. **Time studies** establish standard times through observation and data
6. **CNC standards** cover setups, operations, and inspections
7. **TWI 4-step method**: Prepare, present, try out, follow up
8. **Living document**: Standards continuously improved through Kaizen
9. **Operator involvement**: Created with/by operators, not imposed
10. **Foundation for improvement**: Can't improve what isn't standardized

---

Review Questions

1. What is standardized work and how does it differ from SOPs?
2. List and explain the three elements of standardized work
3. Why is standardized work essential for continuous improvement?
4. What are the three main documents for standardized work?
5. How do you conduct a time observation study?
6. What should a setup standard include?
7. Explain the TWI 4-step method for training
8. How does standardized work get improved (process)?
9. Why involve operators in creating standards?
10. What's the relationship between standardized work and Kaizen?

Practical Exercise: Create Standardized Work

Develop standardized work for a CNC operation:

Phase 1: Observe and Document 1. Select operation (common, frequent) 2. Observe experienced operator 3. Time observation study (5-10 cycles) - Time each element - Calculate average times - Note variations 4. Calculate takt time 5. Document work sequence 6. Determine standard WIP

Phase 2: Create Documents 7. Create Standardized Work Chart - Layout diagram - Operator path - Sequence with times - Safety/quality points 8. Create Combination Table - Manual vs. machine time - Walking time - Total cycle time 9. Create Job Breakdown Sheet (1-2 critical steps) - Important steps - Key points - Reasons - Photos

Phase 3: Validate 10. Review with operator (their input) 11. Refine documents 12. Post at workstation 13. Use for training (try with new operator)

Deliverables: - Time study data - Standardized Work Chart - Combination Table - Job Breakdown Sheet (sample) - Photos of posted documents - Training record (if trained someone)

Module 24 - L.E.A.N. Strategies for CNC Manufacturing

24.18.1 Unique Challenges of Job Shop L.E.A.N.

CNC Job Shops face unique challenges when implementing Lean due to high-mix, low-volume production.

24.18.1.1 High Mix, Low Volume

Characteristics: - Many different part numbers (100s to 1000s) - Small quantities per part (1-100 pieces) - Custom or semi-custom products - Frequent changeovers

Lean Challenges:

Challenge 1: Can't Dedicate Equipment - Traditional Lean: Dedicated cells for product families - Job Shop Reality: Same machine serves many products - **Implication:** Cells must be flexible, equipment shared

Challenge 2: Difficult to Balance - Traditional Lean: Balance to takt time - Job Shop Reality: Takt time varies by product - **Implication:** Flexible staffing, focus on cycle time reduction

Challenge 3: Large Batch Temptation - Setup time amortized over larger batches - Economic Order Quantity (EOQ) drives large batches - **Implication:** Setup reduction (SMED) is CRITICAL

Challenge 4: Complex Scheduling - Many products competing for same resources - Difficult to level-load - **Implication:** Visual scheduling, pull where possible

24.18.1.2 Variable Demand

Characteristics: - Customer orders unpredictable - Demand varies week-to-week - Rush orders common - Product mix changes

Lean Challenges:

Challenge: Heijunka Difficult - Traditional Lean: Level production schedule - Job Shop Reality: Demand lumpy, unpredictable - **Implication:** Build flexibility, quick response capability

Challenge: Inventory Sizing - Traditional Lean: Calculate Kanban based on stable demand - Job Shop Reality: Demand unstable - **Implication:** Larger safety stocks, or make-to-order

Challenge: Capacity Planning - Variable demand = variable capacity needs - Overtime or idle time - **Implication:** Flexible workforce, cross-training

24.18.1.3 Custom Products

Characteristics: - Engineered-to-order or custom modifications - First-time production common - Process development on the fly

Lean Challenges:

Challenge: No Standard Work (Yet) - First-time production = no prior experience - Learning curve - **Implication:** Rapid standardization after first run

Challenge: Tooling/Fixtures Custom - Can't use standard fixtures - Custom tooling for each product - **Implication:** Modular fixturing, quick-change systems

Challenge: Programming Time - New programs for each product - CAM programming time significant - **Implication:** Offline programming, standardized templates

Quote from Art Byrne (Wiremold CEO): *"Job shops can't do Lean" is the biggest myth. Job shops NEED Lean more than anyone–they can't afford the waste."*

24.18.2 Adapted Lean Tools for Job Shops

24.18.2.1 Flexible Work Cells

Traditional Cellular Manufacturing: - Dedicated equipment for product family - High-volume, limited variety - Example: Shaft family cell (lathes, grinders)

Job Shop Cellular Approach:

1. Product Family Cells (Where Possible): - Group by similar process routing - NOT dedicated equipment, but preferred routing - Example: "Small Aluminum Parts" cell (common routing)

2. Flexible Cells: - Cell can produce multiple families - Quick changeover critical - Modular fixturing - Example: "Prismatic Parts" cell (any rectangular part)

3. Shared Resources: - Some operations shared (heat treat, painting, CMM) - Supermarkets before/after shared operations - Pull replenishment

4. Multi-Machine Operators: - Operator tends multiple machines in cell - Flexible based on demand (1-3 operators) - Cross-trained

Example: Job Shop Cell

Before (Functional Layout):

```
Mill Dept → Drill Dept → Tap Dept → Deburr Dept
(Travel across shop, batching required)
Lead time: 10-15 days
```

After (Flexible Cell):

```
Cell 1 (Small Parts):
Mill → Drill → Tap → Deburr (all within 20 feet)

Handles 50+ part numbers (aluminum, small)
```

```
Changeover: 10 minutes (SMED)
Lead time: 1–2 days
```

Keys to Success: - SMED (quick changeovers enable small batches) - Modular fixturing (fast changeover) - Cross-training (operators can run any operation) - Visual scheduling (prioritize work)

24.18.2.2 Quick Changeover Emphasis

SMED is THE most important Lean tool for job shops.

Why: - High mix = many changeovers - Long setups force large batches (anti-Lean) - Short setups enable one-piece flow (even in job shop)

Job Shop SMED Targets: - < 10 minutes for simple products (standard fixtures) - < 30 minutes for complex products (custom fixtures) - **Goal: Single-digit changeovers wherever possible**

Techniques:

1. Quick-Change Fixture Systems: - Master plates on machines (permanent) - Subplates with fixtures (quick-change) - Standardized clamping - Example: Erowa, System 3R, 5th Axis

2. Tool Presetting: - Offline tool presetter machine - Pre-set all tools before changeover - Load into machine with offsets - No touch-off time

3. Program Management: - Programs stored on network/USB - Quick load (seconds) - Standardized structure - Proven programs (don't change)

4. Kitting: - All tools, fixtures, programs in one kit - Kit staged before changeover - No searching

5. Standard Work for Changeovers: - Document best method - Train all operators - Continuous improvement

Example:

Before SMED: - Setup time: 90 minutes avg - Economic batch: 100 pieces (to justify setup) - Changeovers: 2 per week (avoid if possible) - Lead time: 12 days (large batch WIP)

After SMED: - Setup time: 12 minutes avg (87% reduction!) - Economic batch: 10 pieces (setup time negligible) - Changeovers: 10+ per week (no problem) - Lead time: 2 days (small batch flow)

Impact: - Inventory reduced 80% - Lead time reduced 83% - Flexibility increased dramatically

24.18.2.3 Cross-Training

Job shops MUST have flexible workforce.

Why: - Demand varies (need to shift capacity) - Bottlenecks change (based on product mix) - Absences/vacations (can't shut down)

Cross-Training Strategy:

Skill Matrix:

```
+-------------+------+------+------+------+------+
|  Operator   | Mill |Lathe |Drill | Grind| Insp |
|-------------+------+------+------+------+------|
```

Maria G.	●	◐	●	○	●
Tom R.	●	●	◐	●	◐
Sarah K.	◐	●	●	●	●
John S.	●	○	●	◐	○

```
● = Proficient (can train others)
◐ = Competent (can do independently)
○ = Learning (needs supervision)
```

Goal: Everyone proficient in 2+ operations

Training Plan: - Identify gaps (□ □ □ □ •) - Pair learner with proficient operator - Use standardized work for training - Certify competency

Benefits: - Shift operators to bottlenecks - Cover absences - Increase flexibility - Employee engagement (variety)

Staffing Flexibility:

Low Demand Day: - 3 operators, each running 2-3 machines - Multi-process handling

High Demand Day: - 6 operators, dedicated to machines - Faster throughput

Cross-training enables this flexibility!

24.18.3 Family-Based Value Streams

Value Stream Mapping (VSM) for job shops uses product families.

Defining Product Families

Can't map every product (100s of SKUs).

Group by Similarity:

Option 1: Process Routing - Similar sequence of operations - Example: All parts requiring Mill □ Drill □ Tap

Option 2: Material - Aluminum family, Steel family, Plastic family - Similar machining characteristics

Option 3: Size - Small parts (<6" cube), Medium, Large - Similar machines and fixturing

Option 4: Customer/Market - Aerospace family (tight tolerances, certs) - Commercial family (standard tolerances)

Criteria: - 70-80% of parts in family follow same routing - Variations manageable - Sufficient volume (to justify effort)

Family VSM Example

Product Family: Small Aluminum Parts - 45 part numbers - 60% of job shop volume - Common routing: Mill roughing Mill finishing Deburr Inspect

Current State VSM:

```
Supplier → [Raw Mat] → [Mill Rough] → [WIP: 5 days] →
[Mill Finish] → [WIP: 3 days] → [Deburr] → [WIP: 1 day] →
[Inspect] → [WIP: 1 day] → Customer

Lead Time: 10 days
Value-Added Time: 2 hours
VA Ratio: 0.8%
```

Future State VSM:

```
Supplier → [Supermarket] → [CELL: Mill R → Mill F → Deburr → Insp] → Customer

Cell with one-piece flow
Lead Time: 1 day
Value-Added Time: 2 hours
VA Ratio: 10%
```

Improvement: - 90% lead time reduction - 12.5× VA ratio improvement - WIP reduced 80%

Mixed Families

Reality: Not all parts fit neatly in families.

Strategies:

80/20 Rule: - 20% of products = 80% of volume - Focus on high runners (create families/cells) - Low runners in functional area (OK for now) - Continuous improvement: gradually absorb more into cells

"Oddball" Products: - Custom or one-off products - Can't justify dedicated cell - Process in functional area OR - Route through flexible cell (if similar)

Hybrid Layout:

```
+------------------------------------------+
|  SHOP LAYOUT                              |
|                                           |
|  +-----------+  +-----------+            |
|  |  Cell 1  |  |  Cell 2  |            |
|  | (Alu SM) |  |(Stl SM)  |            |
|  +-----------+  +-----------+            |
|                                           |
|  +-----------------------------+         |
|  | Functional Area            |         |
|  | (Large parts, custom, low   |         |
|  |  volume - gradually shrinks)|         |
```

```
|   +----------------------------+          |
+-----------------------------------------+
```

24.18.4 Load Leveling Strategies

Heijunka (leveling) is difficult in job shops, but some leveling possible.

Strategies

1. Order Management: - Negotiate with customers for level orders - Discounts for predictable schedule - Minimum order quantities - Scheduled delivery windows

2. Backlog Management: - Maintain 2-4 week backlog (buffer) - Smooth production (don't chase every order) - Sequence work for efficiency

3. Mix Leveling: - Don't batch all Product A, then all Product B - Mix products daily (if possible) - Reduces inventory spikes

Example:

Before Leveling: - Week 1: 500 Product A (one big order) - Week 2: 300 Product B - Week 3: 200 Product C - Result: Overtime Week 1, idle Week 3

After Leveling: - Week 1: 330 A + 100 B - Week 2: 170 A + 200 B + 100 C - Week 3: 100 C - Result: Smoother workload

4. Strategic Inventory: - For stable products, build small supermarket - Make-to-stock for common items - Make-to-order for custom items - Hybrid approach

5. Flexible Capacity: - Overtime when needed (peaks) - Cross-training enables shifting - Temporary help for surges - Accept that some variation is OK

24.18.5 Managing Variability

Job shops have variability–Lean helps manage it, not eliminate it.

Sources of Variability

Demand Variability: - Customer orders fluctuate - Mix changes - Rush orders

Process Variability: - Different products = different processes - Learning curve on new products - Quality issues

Supply Variability: - Material delivery delays - Quality issues from suppliers

Lean Approaches

1. Reduce Variability Where Possible:

Demand: - Better forecasting - Communication with customers - Pricing to influence demand (off-peak discounts)

Process: - Standardized work (for each product) - Poka-yoke (error-proof) - TPM (reduce breakdowns)

Supply: - Supplier partnerships - Kanban with suppliers - Quality agreements

2. Build Flexibility to Handle Variability:

Capacity Flexibility: - Cross-training - Overtime capability - Temp labor

Equipment Flexibility: - Quick changeover (SMED) - Multi-purpose machines

Inventory Buffers (Strategic): - Finished goods supermarket (stable products) - Raw material buffers (long lead-time items) - **Small, calculated buffers (not excess)**

3. Visual Management of Variability:

Visual Scheduling: - Backlog board (what's coming) - Capacity board (where we are) - Bottleneck tracking

Andon for Variability: - Rush order = red flag (visual) - All hands to rush order (clear priority)

4. Continuous Improvement: - Each variability spike is Kaizen opportunity - Why did it happen? - How to prevent or mitigate? - Improve the system

---

24.18.6 Job Shop Success Stories

Example 1: Small Machine Shop (15 Employees)

Before Lean: - Products: 250 active part numbers - Lead time: 15 days average - On-time delivery: 70% - WIP: $180K - Floor space: 12,000 sq ft

Lean Implementation (18 months): - SMED: 75 min avg → 15 min avg - Created 2 product family cells (covers 60% of volume) - 5S throughout shop - Visual scheduling - TPM (operator daily maintenance)

After Lean: - Lead time: 3 days average (80% reduction!) - On-time delivery: 95% - WIP: $45K (75% reduction!) - Floor space: 9,000 sq ft (freed 3,000 sq ft for growth) - **Sales increased 40% (same staff, more capacity)**

Key Success Factors: - Owner commitment (walked the talk) - SMED was game-changer (enabled small batches) - Operator involvement (suggestion system) - Visual management (everyone knows status)

Example 2: Aerospace Job Shop (60 Employees)

Before Lean: - Products: High-mix, low-volume (5-axis CNC) - Lead time: 25 days - Quality issues: 3% scrap rate - Setup time: 3-4 hours (complex parts)

Lean Implementation (2 years): - SMED focused on 5-axis machines - Tool presetting system - Modular fixturing (pallets) - Standard work for common operations - Kaizen events (monthly)

After Lean: - Lead time: 8 days (68% reduction) - Scrap rate: 0.5% (83% reduction!) - Setup time: 45 minutes (80% reduction!) - **Productivity increased 35%**

Key Success Factors: - Investment in tool presetter ($60K) - ROI in 8 months - Modular pallets ($150K) - ROI in 14 months - Operator-led Kaizen (bottom-up improvement) - Customer involvement (lead time reduction = competitive advantage)

Example 3: Medical Device Job Shop (25 Employees)

Challenges: - FDA regulations (documentation intensive) - Traceability requirements - Frequent audits - Mix of products

Lean Implementation: - Visual management for traceability - Standard work (doubles as quality documentation) - Kanban for raw materials - Cellular layout

Results: - Lead time reduced 55% - Audit prep time reduced 70% (visual, organized) - Quality improved (standardized work = consistency) - **Passed FDA audit with zero findings** (visual management impressed auditors)

Key Insight: *"Lean and regulatory compliance are compatible. Standardized work IS our quality system. Visual management makes audits easy."*

Summary

CNC job shops face unique Lean challenges due to high-mix, low-volume production, variable demand, and custom products. However, job shops NEED Lean more than high-volume manufacturers because they can't afford waste. Adapted Lean tools include flexible work cells, emphasis on quick changeover (SMED), and extensive cross-training for workforce flexibility.

Product family-based value stream mapping groups similar parts for focused improvement. Load leveling strategies include order management, backlog smoothing, and strategic inventory buffers. Managing variability requires both reducing variation where possible and building flexibility to handle remaining variation.

Success stories demonstrate dramatic results: 60-80% lead time reduction, 75%+ inventory reduction, and significant quality improvements. Keys to success include owner/leadership commitment, SMED implementation, operator involvement, and visual management. Job shops that embrace Lean gain competitive advantage through faster response, lower costs, and higher quality.

Key Takeaways

1. **Job shops need Lean** more than anyone–can't afford waste in high-mix environment
2. **SMED is critical**: Quick changeovers enable small batches and flow
3. **Flexible cells**: Can handle multiple product families with quick changeover
4. **Cross-training essential**: Enables shifting capacity to bottlenecks
5. **Product families**: Group similar parts for VSM and cell design (70-80% similarity)
6. **80/20 rule**: Focus cells on high runners, functional area for low runners

7. **Some variability acceptable**: Build flexibility rather than trying to eliminate all variation
8. **Visual management**: Even more important in high-mix (track status, priorities)
9. **Success proven**: Job shops achieve 60-80% lead time reduction, 75%+ inventory reduction
10. **Competitive advantage**: Faster response time = winning more business

---

Review Questions

1. Why is Lean particularly challenging for job shops?
2. Why is SMED the most important Lean tool for job shops?
3. How do job shop cells differ from traditional dedicated cells?
4. What is a product family and how do you define one?
5. Calculate: If setup time reduces from 90 min to 12 min, what batch size makes sense if run time is 2 min/part?
6. Why is cross-training essential for job shops?
7. How can job shops apply heijunka (leveling) despite variable demand?
8. What's the 80/20 rule for job shop Lean implementation?
9. List 3 ways to reduce variability and 3 ways to build flexibility for variability
10. What were common success factors in the job shop case studies?

Practical Exercise: Job Shop Lean Plan

Develop a Lean implementation plan for a job shop:

Phase 1: Assessment 1. Current state metrics: - Lead time (by product family if possible) - On-time delivery % - Inventory level (WIP, raw, finished) - Setup time (average) - Quality (scrap %, rework %)

2. Product family analysis:
    - List top 20 products by volume
    - Group by similarity (routing, material, size)
    - Define 1-3 families (covering 60-80% of volume)

Phase 2: Prioritization 3. Identify top 3 improvement opportunities: - Setup reduction (SMED) - Cell creation (product family) - Visual scheduling - 5S/visual management - Cross-training - (Others based on waste analysis)

4. Prioritize by impact and feasibility

Phase 3: Implementation Plan 5. Pilot project (6-month plan): - Select one product family - SMED on critical machines - Create cell or improve flow - Visual management - Metrics tracking

6. Rollout plan (12-18 months):
    - Expand to additional families
    - Continuous improvement (monthly Kaizen)
    - Culture development

Deliverables: - Current state metrics and analysis - Product family definition - Top 3 opportunities (with ROI estimates) - 6-month pilot plan - 18-month rollout roadmap - Success metrics and targets

---

Module 24 - L.E.A.N. Strategies for CNC Manufacturing

Introduction

This final section presents real-world case studies demonstrating L.E.A.N. transformation in CNC manufacturing environments. Each case study illustrates specific Lean tools, implementation challenges, results achieved, and lessons learned.

24.19.1 Case Study: Setup Reduction Transforms Job Shop

Company Profile

ABC Precision Machining - Location: Midwest USA - Size: 35 employees - Products: Custom CNC machining (aluminum, steel, plastics) - Equipment: 12 CNC mills, 8 CNC lathes, 5 grinders - Market: Job shop (high-mix, low-volume) - Annual Revenue: $4.2M

The Problem

Symptoms: - Average lead time: 18 days - On-time delivery: 68% - Customer complaints increasing - Losing quotes to faster competitors - Inventory: $220K WIP - Floor space: 85% full

Root Cause Analysis: - Setup times averaging 2-3 hours - Large batches to justify setups (50-100 pieces) - Massive WIP between operations - Complex scheduling trying to minimize setups

Business Impact: - Customers demanding faster delivery - Losing $500K+ in potential sales annually - Cash tied up in inventory - No capacity for growth

The Solution: SMED Implementation

Phase 1: Pilot (3 Months)

Selected Target: - CNC Mill #4 (high-volume machine) - Part family: Small aluminum brackets - Current setup: 135 minutes average

SMED Methodology:

Week 1-2: Current State - Video recorded 5 different setups - Documented every step with timestamps - Identified waste: - Walking to tool crib: 18 min - Searching for fixtures: 12 min - Trial-and-error adjustments: 45 min - Actual changeover work: 60 min

Week 3-4: Separate Internal/External - External (before machine stops): - Get fixtures, tools, programs - Pre-set tool lengths - Stage everything at machine - **Saved: 30 minutes** (now done while running)

Week 5-8: Convert Internal to External - Invested in quick-change fixture base plates ($8,500) - Installed tool presetter machine ($12,000) - Created setup kits (tools + fixtures together) - **Reduced internal time to 65 minutes**

Week 9-12: Streamline - Standard work for setups (documented best method) - Trained all operators - Visual aids (photos at machine) - Continuous refinement - **Final setup time: 18 minutes!**

Results from Pilot: - Setup time: 135 min □ 18 min (87% reduction!) - Payback on investment: 4.2 months - Batch size: 75 pieces □ 12 pieces - Lead time for this family: 18 days □ 3 days

Phase 2: Rollout (6 Months)

Expanded SMED to: - All 12 CNC mills (phased approach) - 8 CNC lathes - Grinding (lower priority, but included)

Investments: - Quick-change systems: $65K total - Tool presetter: $12K (already purchased) - Carts, shadow boards, labels: $5K - **Total: $82K**

Training: - SMED workshop (all operators, supervisors) - Standard work creation (each machine) - Visual management (setup boards)

Results (After 12 Months)

Operational Metrics:

Metric	Before	After	Improvement
Avg Setup Time	145 min	22 min	85% □
Avg Batch Size	68 pcs	15 pcs	78% □
Lead Time	18 days	4 days	78% □
WIP Inventory	$220K	$55K	75% □
On-Time Delivery	68%	96%	41% □
Floor Space Used	85%	62%	Space freed

Financial Impact:

Annual Savings: - Inventory reduction: $165K × 25% carrying cost = $41,250/yr - Freed floor space: 3,000 sq ft × $12/sq ft = $36,000/yr - Overtime reduction: $28,000/yr (less batching crisis) - **Total savings: $105,250/year**

Investment ROI: - Investment: $82,000 - Annual savings: $105,250 - **Payback: 9.4 months** - **3-Year ROI: 285%**

Revenue Impact: - Faster lead times = won more quotes - New business: $580,000 (year 1) - **Same capacity, more revenue** (quick changeovers = flexibility)

Lessons Learned

What Worked:

1. **Video Analysis:**

    - Seeing waste on video was eye-opening
    - Operator buy-in immediate ("I didn't realize I walked that much!")
2. **Pilot Approach:**
    - Prove concept on one machine
    - Show results before full rollout
    - Build confidence and skills
3. **Operator Involvement:**
    - Operators participated in SMED workshops
    - Their ideas were best (they know the work)
    - Ownership of new standards
4. **Quick Wins:**
    - Some improvements cost $0 (just reorganization)
    - Early wins built momentum
    - Celebrating successes kept energy high
5. **Standard Work:**
    - Documenting new method critical
    - Prevents backsliding
    - Training tool for new employees

Challenges:

1. **Initial Skepticism:**
    - "We've always done large batches"
    - Took pilot results to convince
    - Leadership consistency essential
2. **Investment Approval:**
    - $82K seemed large (small company)
    - Had to build business case
    - Phased approach helped (prove ROI on pilot first)
3. **Time to Implement:**
    - Workshops took time (operators off floor)
    - Management had to support (short-term pain for long-term gain)
4. **Sustaining:**
    - Vigilance required (drift back to old ways)
    - Audits, visual management, reinforcement

CEO Quote: *"SMED transformed our business. We went from struggling to keep up to having capacity for growth. Best $82K we ever spent. If we had known the impact, we would have done it years ago."*

24.19.2 Case Study: Cellular Manufacturing Reduces Lead Time 90%

Company Profile

Precision Parts Inc. - Size: 50 employees - Products: Hydraulic manifolds (aluminum) - Equipment: CNC mills, drill/tap machines, deburr, wash, test - Market: OEM supplier (medium volume, some customization) - Annual Revenue: $8.5M

The Problem

Traditional Functional Layout:

```
Receiving → Raw Material Warehouse → Mill Dept →
Drill/Tap Dept → Deburr Area → Wash Station →
Test Lab → Finished Goods → Shipping
```

Symptoms: - Lead time: 21 days (customer requirement: 10 days) - Late deliveries: 40% - WIP inventory: $450K (all over the floor) - Quality issues discovered late (at test) - Complex scheduling (MRP system overwhelmed)

Analysis: - Value-stream map showed: - Value-added time: 4.5 hours - Lead time: 504 hours (21 days) - **VA ratio: 0.9%** (99.1% waste!) - Most time = waiting (batches sitting between operations)

The Solution: Product Family Cell

VSM Future State Design:

Created "Manifold Cell": - All operations for manifolds in one area - U-shaped layout - 30-foot maximum distance between any two operations - One-piece flow (no batching)

Cell Equipment: - 3 CNC mills (shared from Mill Dept) - 2 drill/tap machines (shared) - 1 deburr station (new, dedicated) - 1 wash station (dedicated) - 1 test station (dedicated)

Cell Staffing: - 4 operators cross-trained on all operations - Multi-machine handling - Variable staffing (3-5 operators based on demand)

Implementation (4 Months)

Month 1: Planning - Selected product family (hydraulic manifolds, 80% of volume) - Designed cell layout - Identified equipment moves - Planned shutdown weekend

Month 2: Move - Hired rigging company - Moved equipment over 3-day weekend - Reconnected utilities, air, coolant - Tested equipment

Month 3: Ramp-Up - Operators training (cross-training on new operations) - Process refinement (balancing, standard work) - Worked bugs out - Initially slower (learning curve)

Month 4: Stabilization - Standard work documented - Visual management installed - Achieving target performance - Continuous improvement

Results (After 6 Months)

Operational Metrics:

Metric	Before	After	Improvement
Lead Time	21 days	2 days	90% □
WIP Inventory	$450K	$75K	83% □
On-Time Delivery	60%	98%	63% □
Floor Space	18,000 sq ft	12,000 sq ft	33% □
First-Pass Yield	92%	98.5%	7% □

Metric	Before	After	Improvement
Productivity	100%	135%	35% ▯

Quality Impact: - Defects caught immediately (next operation) - No large batches scrapped (one-piece flow) - Test failures reduced 80% - Root cause analysis easier (just happened)

Financial Impact:

Annual Savings: - Inventory reduction: $375K × 25% = $93,750/yr - Floor space freed: 6,000 sq ft × $10/sq ft = $60,000/yr - Reduced scrap/rework: $85,000/yr - **Total: $238,750/year**

Investment: - Equipment moves: $35,000 - New deburr/wash equipment: $45,000 - Training time: $15,000 - **Total: $95,000**

ROI: - Payback: 4.8 months - 3-Year ROI: 654%

Revenue Impact: - Faster lead times attracted new customers - Won 3 new contracts (2-day lead time was differentiator) - **New revenue: $1.2M/year**

Lessons Learned

Critical Success Factors:

1. **Cross-Training:**
    - Took 3 months to fully cross-train
    - Time well-spent (flexibility is key)
    - Operators loved variety
2. **Pilot Family Selection:**
    - Chose family representing 80% of volume
    - High impact
    - Left low-volume products in functional area (for now)
3. **Operator Involvement:**
    - Operators designed cell layout
    - They knew best work flow
    - Ownership led to success
4. **Leadership Patience:**
    - Month 3 was rough (learning curve)
    - Management stayed the course
    - Month 4 onward: excellent
5. **Visual Management:**
    - Production board at cell entrance
    - Status obvious
    - Self-managing team

Challenges:

1. **Resistance to Change:**
    - “Operators won’t learn multiple operations”
    - Reality: Operators eager for variety
    - Underestimated their capability

2. **Equipment Availability:**
    - Sharing equipment from departments
    - Had to coordinate (some disruption)
    - Planned it carefully (minimized impact)
3. **Balancing:**
    - Not perfectly balanced initially
    - Continuous improvement refined over time
    - "Good enough to start" mindset

Plant Manager Quote: *"The cell changed everything. Lead time from 21 days to 2 days opened new markets. Operators love it–they see the product start to finish. Our customers love it–we deliver fast and on-time. Best decision we've made."*

24.19.3 Case Study: TPM Increases OEE from 52% to 83%

Company Profile

Advanced CNC Systems - Size: 28 employees - Products: Aerospace components (tight tolerances, exotic materials) - Equipment: 8 high-end 5-axis CNC machines ($500K-$1M each) - Market: Aerospace (AS9100 certified)

The Problem

Equipment Performance: - OEE averaging 52% (terrible for expensive equipment) - Frequent breakdowns - Unscheduled downtime: 12% - Quality issues: 4% scrap rate (very expensive in aerospace)

Analysis: - Availability: 75% (breakdowns, long setups) - Performance: 78% (small stops, reduced speed) - Quality: 89% (startup defects, process defects) - **OEE: 0.75 × 0.78 × 0.89 = 52%**

Business Impact: - Can't meet delivery commitments - Expensive equipment underutilized - High scrap costs ($180K/year) - Customer complaints

The Solution: Total Productive Maintenance (TPM)

TPM Implementation (12 Months)

Pillar 1: Autonomous Maintenance

Months 1-3: Initial Cleaning - Operators deep-cleaned one 5-axis machine - 40+ issues discovered (leaks, loose parts, worn components) - Tagged for maintenance to fix - Established baseline condition

Months 4-6: Preventive Maintenance - Created daily AM checklist (operators) - 10-15 minutes daily: - Clean chip trays - Check coolant level - Lubricate manual points - Inspect for leaks/wear - Log observations

Months 7-9: Training - Operators trained on machine basics (pneumatic, hydraulic, mechanical) - General inspection skills - Empowered to perform minor maintenance

Months 10-12: Autonomous Inspection - Operators conduct weekly detailed inspections - Trend critical parameters (spindle temp, hydraulic pressure) - Report anomalies to maintenance

Pillar 2: Planned Maintenance

Maintenance Department: - Preventive maintenance schedule (based on OEM + experience) - Predictive maintenance (vibration analysis, oil analysis) - Component replacement before failure - Major overhauls scheduled

Pillar 3: Focused Improvement (Kaizen)

Targeted Losses: 1. Chip birds' nests (small stops) 2. Hydraulic failures (breakdowns) 3. Startup defects (thermal growth)

Kaizen Teams: - Cross-functional (operators, maintenance, engineering) - Root cause analysis - Countermeasures implemented

Example: Chip Bird Nests - Problem: Chips jamming, stopping machine - Root cause: Inadequate chip evacuation - Countermeasure: High-pressure through-spindle coolant upgrade - Result: Chip stops reduced 85%

Results (After 12 Months)

OEE Improvement:

Component	Before	After	Improvement
Availability	75%	92%	+17 pts
Performance	78%	91%	+13 pts
Quality	89%	99%	+10 pts
OEE	**52%**	**83%**	**+31 pts**

Breakdown Analysis:

Metric	Before	After	Improvement
Unscheduled Downtime	12%	3%	75% □
MTBF (Mean Time Between Failures)	120 hrs	450 hrs	275% □
Scrap Rate	4%	0.8%	80% □
Setup Time	180 min	65 min	64% □

Financial Impact:

Increased Capacity: - OEE: 52% □ 83% = **60% more effective capacity** - Equivalent to buying 5 more machines ($3M value!) - Revenue increase: $1.8M (used freed capacity)

Cost Savings: - Scrap reduction: $180K □ $36K = $144K/year saved - Maintenance costs reduced: $82K/year (fewer emergency repairs) - **Total savings: $226K/year**

Investment: - Training: $25K - Tools/supplies (for AM): $8K - Focused improvements (coolant, etc.): $45K - **Total: $78K**

ROI: - Direct savings payback: 4.1 months - Capacity increase: Priceless (avoided $3M equipment purchase)

Lessons Learned

What Worked:

1. **Operator Ownership:**
    - Operators became equipment owners (not just users)
    - Pride in condition of "their" machine
    - Caught issues early
2. **Initial Cleaning:**
    - Discovered 40+ hidden issues
    - Established baseline
    - Operators learned machine intimately
3. **Small Daily Effort:**
    - 10-15 min/day autonomous maintenance
    - Prevented big problems
    - Consistent attention
4. **Cross-Functional Kaizen:**
    - Operators + maintenance + engineering = best solutions
    - Broke down silos
5. **Data-Driven:**
    - OEE tracking made improvement visible
    - Celebrated successes

Challenges:

1. **Cultural Shift:**
    - "Maintenance fixes, operators operate"
    - Had to break this mindset
    - Took time and leadership reinforcement
2. **Time for AM:**
    - 10-15 min/day felt like "lost production time"
    - Had to show ROI (prevented hours of downtime)
3. **Maintenance Buy-In:**
    - Some maintenance techs felt threatened
    - "Operators doing our job"
    - Reframed: Operators do routine, maintenance does skilled work
4. **Sustaining:**
    - Easy to skip AM when busy
    - Visual management, audits, leadership necessary

VP Operations Quote: *"TPM gave us the equivalent of five more $500K machines without spending $2.5M. Our operators are now machine experts–they know when something's not right and catch it early. OEE of 83% puts us in world-class territory. Customers notice–our on-time delivery is now 99%."*

24.19.4 Lessons Across All Case Studies

Common Success Factors

1. Leadership Commitment: - All three cases: Leaders walked the talk - Resources provided - Patience during ramp-up - Celebrated successes

2. Operator Involvement: - Not done TO operators, done WITH operators - Best ideas came from operators - Ownership led to sustainability

3. Pilot Approach: - Start small, prove concept - Build skills and confidence - Scale successes

4. Data-Driven: - Baseline metrics captured - Progress measured - Results communicated

5. Training Investment: - SMED workshops - Cross-training - TPM training - Paid off many times over

6. Visual Management: - Made status obvious - Self-managing teams - Problems visible (and solved)

7. Continuous Improvement Culture: - Not one-time projects - Kaizen mindset - Never done improving

Common Challenges

1. Skepticism: - “Won’t work here” - “We’re different” - Results overcome skepticism

2. Time: - Implementation takes time - Short-term disruption - Long-term gain worth it

3. Investment: - Some investment required (tools, equipment, training) - ROI proven (< 1 year payback typical)

4. Sustaining: - Easy to backslide - Requires discipline - Leadership reinforcement

ROI Summary

Case Study	Investment	Annual Savings	Payback	3-Yr ROI
SMED	$82K	$105K + revenue	9.4 mo	285%
Cellular	$95K	$239K + revenue	4.8 mo	654%
TPM	$78K	$226K + capacity	4.1 mo	769%

Average Payback: 6 months Average 3-Year ROI: 569%

Conclusion: Your Lean Journey

Getting Started

Don’t wait for perfect conditions.

Start Small: - Pick one improvement (SMED, 5S, visual management) - One area (one cell, one machine) - Prove it works - Build from there

Learn by Doing: - Don't over-analyze - Try something - Learn from results - Adjust

Involve Your People: - They know the work - Tap their knowledge - Give them authority - Celebrate their ideas

Sustaining Lean

It's a Journey, Not a Destination: - Never "done" with Lean - Continuous improvement - Always another level of excellence

Culture is Key: - Tools are easy - Culture is hard (and essential) - Leaders must model it - Everyone must live it

Stay the Course: - Results take time - Don't give up during rough patches - Long-term thinking

Final Thoughts

Quote from Taiichi Ohno: *"Having no problems is the biggest problem of all."*

Lean makes problems visible so you can solve them.

Your turn: - What will you improve first? - When will you start? - Who will you involve?

Go to Gemba. See with your own eyes. Take action. Improve every day.

Good luck on your Lean journey!

Module 24 - Complete

Congratulations! You've completed Module 24: L.E.A.N. Strategies for CNC Manufacturing.

You now have the knowledge and tools to: - Identify and eliminate the eight wastes - Map and improve value streams - Implement JIT, Kanban, and pull systems - Reduce setup times dramatically (SMED) - Improve equipment effectiveness (TPM) - Design and operate manufacturing cells - Error-proof processes (Poka-Yoke) - Lead continuous improvement (Kaizen) - Create visual, self-explaining workplaces - Standardize work for consistent quality - Apply Lean in job shop environments

The real learning begins when you apply these tools in your workplace.

Start today. Start small. Start somewhere.

Kaizen!

Module 24 - L.E.A.N. Strategies for CNC Manufacturing

24.2.1 Understanding Waste in Manufacturing

In Lean thinking, **waste** (or **muda** in Japanese) is defined as any activity that consumes resources (time, material, labor, equipment) but does not create value for the customer.

The Value Question

Would the customer pay for this activity?

- **YES** □ Value-added activity (keep and optimize)
- **NO** □ Non-value-added activity (waste–eliminate if possible)

Three Categories of Activities

Type 1: Value-Added (VA) - Transforms the product in a way customers value - Customer willing to pay for it - Examples: Cutting metal, drilling holes, welding

Type 2: Non-Value-Added but Necessary (NVAN) - Doesn't add customer value but required (for now) - Due to current technology, regulations, or methods - Examples: Inspections, setups, some material handling - **Goal**: Minimize these activities

Type 3: Pure Waste (NVA) - Adds no value and not necessary - Examples: Waiting, searching for tools, rework, excess inventory - **Goal**: Eliminate completely

The Waste Iceberg

Most companies only see obvious wastes (scrap, rework, downtime). These are like the tip of an iceberg–visible above water.

Above Water (Visible ~20%): - Scrap and rework - Machine breakdowns - Customer complaints - Obvious defects

Below Water (Hidden ~80%): - Waiting time - Excess inventory - Unnecessary motion - Over-production - Transportation - Extra processing - Underutilized talent

Lean makes the invisible waste visible.

24.2.2 Defects (D)

Definition: Production of non-conforming parts or products requiring rework or scrap.

24.2.2.1 Cost of Scrap and Rework

Defects are expensive, and the cost multiplies as they move downstream.

The 1-10-100 Rule: - Defect caught at the operation: **$1** to fix - Defect caught at final inspection: **$10** to fix - Defect reaches customer: **$100** to fix (plus reputation damage)

Real Costs of Defects:

Material Costs: - Raw material wasted - Consumables used (tooling, coolant, etc.)

Labor Costs: - Operator time on defective work - Inspector time finding defect - Rework labor (if salvageable) - Engineering time investigating

Equipment Costs: - Machine time wasted - Capacity lost to rework - Setup time for rework

Indirect Costs: - Delayed shipments - Expediting costs - Lost customer confidence - Warranty claims - Sales team time placating customers

Hidden Costs: - Future business lost - Employee morale impact - Management attention diverted

Example: CNC Scrap Part

Scenario: Aluminum part, 4 hours machining, discovered defective at final inspection

Direct Costs: - Material: \$85 - Machine time: 4 hrs × \$75/hr = \$300 - Operator labor: 4 hrs × \$35/hr = \$140 - Tooling consumed: \$25 - **Subtotal: \$550**

Indirect Costs: - Inspector time: 0.5 hr × \$40/hr = \$20 - Engineering investigation: 2 hrs × \$85/hr = \$170 - Supervisor time: 1 hr × \$60/hr = \$60 - Remake setup: 1 hr × \$75/hr = \$75 - **Subtotal: \$325**

Total Cost: \$875 (for one defective part!)

If 100 defects/year at this cost: \$87,500 annual impact

24.2.2.2 Root Causes of Defects

Understanding root causes is essential to prevention.

Process-Related Causes: - Inadequate process capability (Cpk < 1.33) - Process variation (temperature, pressure, etc.) - Tool wear not monitored - Inconsistent methods (no standard work) - Poor process design

Equipment-Related Causes: - Machine out of calibration - Worn or damaged equipment - Inadequate maintenance - Equipment not capable for tolerance required

Material-Related Causes: - Material variation (hardness, composition) - Incorrect material used - Damaged material not detected - Poor supplier quality

Method-Related Causes: - Unclear work instructions - No standard work - Outdated procedures - Missing critical steps

People-Related Causes: - Inadequate training - Fatigue or distraction - Lack of understanding requirements - No feedback on quality

Measurement-Related Causes: - Gage not calibrated - Wrong inspection method - Measurement error - Unclear specifications

Management-Related Causes: - Pressure to ship over quality - Inadequate resources for quality - No time allowed for problem-solving - Quality not valued in culture

24.2.2.3 Prevention Strategies

1. Design for Manufacturability - Eliminate tight tolerances where not needed - Design for standard processes - Reduce complexity

2. Mistake-Proofing (Poka-Yoke) - Fixtures prevent incorrect loading - Sensors detect missing operations - Automated checks verify critical dimensions - *Covered in detail in Section 24.9*

3. Standard Work - Document best method - Train everyone to same standard - Make deviations visible - *Covered in Section 24.12*

4. Process Control - Monitor critical parameters - Statistical Process Control (SPC) - Automatic adjustments where possible - Alarms for out-of-spec conditions

5. First-Off Inspection - Verify first piece after setup - Dimensional check before running quantity - Prevents batch defects

6. In-Process Inspection - Frequent checks during run - Self-inspection by operator - Catch drift before many defects

7. Problem-Solving Culture - Stop and fix problems when found - Root cause analysis (5 Whys, fishbone) - Countermeasures implemented - Follow-up to verify effectiveness

8. Supplier Quality - Certified suppliers - Incoming inspection - Partnership approach - Shared quality standards

---

Summary

The eight wastes (DOWNTIME) consume resources without adding customer value. Section 24.2 covers defects, overproduction, waiting, non-utilized talent, transportation, inventory, motion, and extra processing. Understanding and eliminating these wastes is fundamental to Lean manufacturing success.

Key Takeaways

1. **Waste (muda)** is any activity consuming resources without creating customer value
2. **DOWNTIME** acronym represents the eight wastes
3. **The 1-10-100 rule** shows defect costs multiply downstream
4. **Three activity types**: Value-added, non-value-added but necessary, pure waste
5. **Most waste is hidden** like an iceberg below the waterline

---

Review Questions

1. Define "waste" in Lean terms
2. List the eight wastes represented by DOWNTIME
3. Explain the 1-10-100 rule for defects
4. What are the three categories of activities?
5. Why is most waste invisible to management?

Module 24 - L.E.A.N. Strategies for CNC Manufacturing

24.3.1 What is Value Stream Mapping?

Value Stream Mapping (VSM) is a Lean tool used to visualize the complete flow of materials and information required to bring a product from order to delivery.

Definition

Value Stream: All activities (both value-added and non-value-added) required to bring a product through the main flows: 1. **Production flow:** From raw material to customer 2. **Design flow:** From concept to launch 3. **Order flow:** From order entry to delivery

Value Stream Map: Visual representation showing every process step, with data on cycle times, changeover times, uptime, number of operators, WIP inventory, and information flows.

Purpose of VSM

See the Whole: - Not just individual processes, but the entire flow - Identify where value is created vs. waste occurs - Understand the system, not just the parts

Common Language: - Cross-functional teams see the same picture - Production, engineering, quality, materials all aligned - Eliminates finger-pointing ("it's their fault")

Foundation for Improvement: - Current state map shows reality - Future state map shows vision - Implementation plan bridges the gap

Quote from Mike Rother & John Shook: *"Value stream mapping is a pencil and paper tool that helps you see and understand the flow of material and information as a product makes its way through the value stream."*

When to Use VSM

Ideal Applications: - Beginning a Lean transformation - Chronic delivery or quality problems - Excessive inventory or long lead times - Poor communication between departments - Before major capital investments - Product family rationalization

Less Suitable: - Very low volume (one-off custom engineering) - Highly variable processes (R&D, creative work) - When quick action needed (use Kaizen event instead)

24.3.2 VSM Symbols and Conventions

Value stream maps use standard symbols for consistency and communication.

Process Symbols

Process Box:

```
+-----------------+
|   MACHINING     |
|   C/T = 45 sec  |
|   C/O = 30 min  |
|   Uptime = 85%  |
|   1 operator    |
+-----------------+
```

Represents a process step where material is transformed.

Data Box (below process): - **C/T** = Cycle Time (time to complete one piece) - **C/O** = Changeover Time (setup time) - **Uptime** = Percentage of available time - **EPE** = Every Part Every (production frequency) - **Batch** = Typical batch size

Shared Process (Multiple Value Streams):

```
+-----------------+
|   HEAT TREAT    |
|   (SHARED)      |
+-----------------+
```

Inventory Symbols

Inventory Triangle:

```
    △
   / \
  /   \
 /  I  \
/_______\
```

Shows inventory between processes. Number inside = quantity or time.

Safety Stock:

```
    ⚠
   / \
  / S \
 /_____\
```

Material Flow Symbols

Push Arrow (thick):

```
━━━━━━━━►
```

Material pushed from one process to next (scheduled production).

Supermarket:

```
╔═══════╗
║ SUPER ║
║ MKT   ║
╚═══════╝
```

Controlled inventory; pull replenishment.

Pull Arrow (thin):

```
– – – – – – ►
```

Material pulled from downstream customer.

FIFO Lane:

```
+---------+
| FIFO: 5 |
+---------+
```

First-in-first-out queue with maximum quantity.

Kanban Post:

```
   ║
  ╠╣
  ╠╣
   ║
```

Physical location for Kanban cards.

Kanban Movement:

```
--▷--
```

Movement of Kanban signal.

Information Flow Symbols

Manual Information:

```
     ___
    /   \
   |  i  |
    \___/
```

Paper, verbal, or manual signal.

Electronic Information:

```
   /\___/\
  |  ⚡  |
   \_____/
```

EDI, email, ERP, MES systems.

Production Control Box:

```
╔══════════════╗
║  PRODUCTION  ║
║   CONTROL    ║
╚══════════════╝
```

Centralized scheduling function.

Schedule Arrow:

Production schedule/instruction.

Other Symbols

Operator:

```
   O
  /|\
  / \
```

Person icon with number of operators.

Shipment:

```
+---------+
| TRUCK   |
+---------+
```

External shipments (supplier or customer).

Go See:

```
   ☼
```

Visual check or inspection required.

Kaizen Burst:

```
     /\
    /  \
   / ⚡ \
  /______\
```

Improvement opportunity identified.

Timeline

Value-Added Time (bottom):

```
---------------------
  VA: 2 min  5 min
```

Non-Value-Added Time (top):

```
 NVA: 2 days  1 day
---------------------
```

Total Lead Time calculated at end.

24.3.3 Creating a Current State Map

The current state map documents how things actually work today–not how they should work, not how the procedures say, but reality.

24.3.3.1 Selecting the Product Family

Product Family: Group of products that pass through similar processing steps using common equipment.

Why Start with One Family? - Manageable scope - Faster results - Learn by doing - Prove the concept - Build capability

Selection Criteria:

High Business Impact: - High revenue product - Problem product (late deliveries, quality issues) - Strategic customer - High volume

Representative: - Typical of other products - Success can be replicated

Achievable: - Not too complex for first VSM - Team has authority to change

Example: CNC Job Shop Product Families

Family	Description	Common Routing
Shaft Family	Round parts, 0.5-3” dia	Lathe → Grind → Inspect
Housing Family	Aluminum housings	Mill → Drill → Tap → Inspect
Bracket Family	Small steel brackets	Laser Cut → Bend → Weld
Plate Family	Large aluminum plates	Mill (roughing) → Mill (finishing)

Choose ONE family to start.

24.3.3.2 Walking the Process

“Go to Gemba” - See the actual process with your own eyes.

Team Composition: - Value stream manager (leads the map) - Representatives from each process step - Support functions (quality, maintenance, materials) - Someone who knows VSM methodology - **5-8 people ideal**

Walking the Process:

1. Start at Shipping (Work Backwards): - How do finished goods get to customer? - What triggers shipment? - How much inventory is here?

2. Walk Upstream to Each Process: - Follow the physical flow - Observe actual work - Talk to operators (they know reality) - Don’t skip steps

3. Note Everything: - Process steps - Inventory piles - Information flows - Quality checks - Material handling - Wait times

4. End at Receiving: - How do materials arrive? - What triggers orders? - Supplier performance

Tips: - Take photos (with permission) - Use stopwatch for cycle times - Count inventory physically - Get actual data, not estimates - 2-4 hours for first walk

24.3.3.3 Collecting Data

Data Needed for Each Process:

Time Data: - **Cycle Time (C/T):** Time to complete one piece (seconds or minutes) - Measure actual, not theoretical - Include load/unload, not just machine time - Average over multiple cycles - **Changeover Time (C/O):** Time from last good part of previous job to first good part of new job - Include all setup activities - Important for batch sizing - **Available Time:** Hours per shift × shifts × days - Minus breaks, meetings, planned downtime

Reliability Data: - **Uptime %:** Actual run time ÷ available time - Track breakdowns, unplanned stops - 85% uptime = 15% loss to breakdowns

Staffing: - **Number of Operators:** People required to run process - Full-time equivalent - Per shift

Batch & Inventory: - **Batch Size:** Typical production quantity - **EPE (Every Part Every):** How often each part runs - Daily? Weekly? Monthly? - **WIP Inventory:** Count pieces between operations - Convert to days or hours of demand

Quality: - **First Time Through (FTT) %:** Percent of parts passing without rework - **Scrap %:** Percent scrapped

How to Collect: - **Stopwatch studies** for cycle times - **Maintenance logs** for uptime - **Production records** for batch sizes - **Physical count** for inventory - **Ask operators** - they know!

24.3.3.4 Drawing the Current State

Tools Needed: - Large paper (36" × 48" or bigger) or whiteboard - Sticky notes (for easy changes) - Pencils, markers - VSM symbol stencil (or draw freehand)

Drawing Steps:

1. **Customer & Supplier (Top Corners):**

```
+---------+                                  +---------+
|SUPPLIER |                                  |CUSTOMER |
+---------+                                  +---------+
```

2. **Production Control (Top Center):**

```
             ╔══════════╗
             ║PRODUCTION║
             ║ CONTROL  ║
             ╚══════════╝
```

3. **Process Boxes (Center, Left to Right):** Draw each process step across the page in sequence.
4. **Data Boxes Below Each Process:** Fill in C/T, C/O, uptime, etc.
5. **Inventory Triangles Between Processes:** Show WIP with quantity/days.

6. **Material Flow Arrows:** Connect processes with push or pull arrows.

7. **Information Flows (Top Half):** - Customer orders to production control - Production control schedules to each process - Forecasts, MRP, manual instructions

8. **Shipment Frequency:** - To customer (daily? weekly?) - From supplier

9. **Timeline (Bottom):** - Value-added time under each process - Lead time (inventory time) between processes - Total at bottom right

10. **Summary Metrics (Bottom Right):**

```
Total Lead Time: 20 days
Total Value-Added Time: 2.5 hours
VA Ratio: 0.5%
```

Example Current State (Simplified):

```
Supplier          Production Control        Customer
  |                      |                      |
  |     Weekly           |         Daily        |
  |     Forecast         |        Orders        |
  ▼                      ▼                      ▼
+---+   ▲   +-----+   ▲   +-----+   ▲   +-----+
|RCV|-►|  |-►|MILL|-►|  |-►|ASSY|-►|  |-►|SHIP|
+---+  10d  +-----+  5d   +-----+  3d   +-----+
        -     VA:5m  -    VA:3m   -
```

24.3.4 Analyzing the Current State

Once the current state map is complete, analyze it to understand problems and opportunities.

24.3.4.1 Process Time vs. Lead Time

Process Time (Value-Added Time): - Sum of all cycle times - Time actually transforming the product - What customer pays for

Lead Time (Total Time): - Time from order to delivery - Includes all waiting, queuing, batching - What customer experiences

The Gap is Opportunity:

Example: - Process Time: 2 hours - Lead Time: 15 days = 360 hours - **Gap: 358 hours (99.4% waste!)**

Where is the gap? - Inventory wait time - Batching delays - Transportation - Rework loops - Waiting for approvals

Goal: Reduce gap by eliminating waste.

24.3.4.2 Value-Added vs. Non-Value-Added

Calculate VA Ratio:

VA Ratio = Total Value-Added Time ÷ Total Lead Time

Example: - VA Time: 2.5 hours - Lead Time: 20 days × 8 hrs = 160 hours - **VA Ratio = 2.5 ÷ 160 = 1.56%**

Only 1.56% of time adds value!

Industry Benchmarks: - **Traditional manufacturing:** 1-5% VA ratio - **Lean manufacturing:** 10-30% VA ratio - **World-class:** 30%+ VA ratio

Where's the other 98.44%? - Waiting (inventory between operations) - Batching (parts sit while batch completes) - Transportation - Inspection delays - Rework

24.3.4.3 Identifying Bottlenecks

Bottleneck: Process step with longest cycle time or lowest capacity.

Bottleneck determines system capacity (Theory of Constraints).

How to Identify:

1. **Compare Cycle Times:** - Process A: 30 sec/pc - Process B: 60 sec/pc □ **Bottleneck** - Process C: 45 sec/pc

2. **Look for Inventory Build-Up:** - Large WIP queue before a process = bottleneck - Starved process (no WIP) after bottleneck

3. **Calculate Capacity:** - Available time ÷ cycle time = capacity - Lowest capacity = bottleneck

Example:

Process	C/T	Available Time	Capacity (pcs/day)
Lathe	2 min	450 min/day	225
Mill	5 min	450 min/day	**90** □ Bottleneck
Grind	3 min	450 min/day	150

System capacity limited to 90 pcs/day (bottleneck).

Implications: - Don't overproduce at lathe (creates excess WIP) - Focus improvement on mill (biggest impact) - Offload mill work if possible

Elevate the Constraint: - Add capacity at bottleneck - Reduce cycle time at bottleneck - Offload work to non-bottlenecks - Ensure bottleneck never starved or blocked

---

24.3.5 Designing the Future State

The future state map is your vision of how the value stream should operate after Lean improvements.

24.3.5.1 Applying L.E.A.N. Principles

Future State Questions (from Rother & Shook):

1. **What is takt time?** - Available time ÷ customer demand - Pace of production to match demand - *Covered in Section 24.4.2*

2. **Will you build to a finished goods supermarket or directly to shipping?** - Make-to-stock supermarket - Make-to-order direct shipping

3. **Where can you use continuous flow?** - Eliminate batches - One-piece flow wherever possible - Group operations into cells

4. **Where will you need pull systems?** - Can't flow everything - Use pull/Kanban for disconnected processes

5. **What single point will you use to schedule production?** - Pacemaker process - Only one point receives schedule - Upstream pulled, downstream flows

6. **How will you level the production mix?** - Smooth demand variation - Produce small batches of each product regularly - Avoid large batches and long changeovers

7. **What increment of work will you consistently release?** - Pitch: Consistent work unit - Example: One container every 20 minutes

8. **What process improvements are necessary?** - Kaizen bursts on current state - What must change to enable future state?

24.3.5.2 Continuous Flow Opportunities

Continuous Flow (One-Piece Flow): - Parts move one at a time from process to process - No batching, no queuing - Immediate quality feedback - Shortest lead time

Where to Apply Flow:

Good Candidates: - Processes physically close (or can be) - Similar cycle times (balanced) - Reliable processes (high uptime) - Stable demand - Common product family

Create Cells: - Group operations together - U-shaped layout - Operator moves with part - Cross-training enables flexibility

Benefits: - Lead time: days hours or minutes - WIP inventory: eliminated - Floor space: 30-50% reduction - Quality: defects caught immediately

Example:

Before (Batch):

```
Lathe (batch 50) → [10 days WIP] → Mill (batch 50) → [5 days WIP] → Grind (batch 50)
Lead time: 15+ days
```

After (Flow Cell):

```
Lathe → Mill → Grind (one-piece flow in U-cell)
Lead time: 10 minutes
```

24.3.5.3 Pull System Implementation

Where Flow Not Possible: - Shared resources (heat treat, painting) - Vastly different cycle times - Geographical separation - Supplier relationships

Use Pull (Kanban): - Downstream consumes inventory - Signal sent upstream to replenish - Inventory limited to Kanban quantity

Supermarket: - Small, controlled inventory - Each SKU has location - Visual min/max levels - Pull replenishment

Benefits: - Eliminate overproduction - Right-size inventory - Visual control - Self-regulating

Kanban covered in detail in Section 24.5

24.3.6 Implementation Planning

The value stream map identifies what to improve. The implementation plan determines how and when.

Value Stream Plan

Kaizen Bursts on Map: - Each burst = improvement needed - Number them - Prioritize

Implementation Loop:

Annual Improvement: - Big changes (layout, equipment) - Requires capital, planning

Kaizen Events (Weeks): - Quick improvement bursts - Cross-functional team - 3-5 days intense focus - *Covered in Section 24.10*

Point Kaizen (Daily/Weekly): - Small improvements - Operator-led - Continuous

Create Value Stream Plan:

#	Improvement	Type	Responsibility	Start	Complete	Metrics
1	SMED on Mill	Kaizen	John S.	Week 2	Week 3	C/O: 60□ 15 min
2	Create Assembly Cell	Annual	Engineering	Month 2	Month 4	LT: 5d□ 4hr
3	Kanban for Hardware	Kaizen	Mary T.	Week 5	Week 6	Inv: 30d□ 5d

Review Cadence: - Monthly value stream review - Track progress - Adjust plan - Celebrate wins

Communication: - Share maps with all stakeholders - Visual display in Gemba - Update as changes implemented

---

24.3.7 VSM for CNC Job Shops vs. High-Volume

High-Volume (Repetitive Manufacturing)

Characteristics: - Limited product variety - High volume per product - Dedicated lines/equipment - Stable, predictable demand

VSM Approach: - Map one product (representative) - Design continuous flow cells - Takt time drives balancing - Kanban for purchased parts - Pacemaker sets rhythm

Example: Automotive stamping, consumer electronics assembly

CNC Job Shops (High-Mix, Low-Volume)

Characteristics: - Wide product variety - Low volume per product - Shared equipment - Variable, unpredictable demand

VSM Challenges: - Can't map every product - Flow difficult with shared resources - Demand variability

Adapted Approach:

1. **Product Families:** - Group by similar routing - Map the family, not individual products

2. **Flexible Cells:** - Cell can handle family variations - Quick changeover critical (SMED) - Cross-trained operators

3. **Shared Resources:** - Supermarket before/after shared process - Pull system manages flow - Visual scheduling

4. **Focus on Lead Time:** - Reduce batch sizes (via SMED) - Eliminate queue time - Better scheduling

5. **Capacity Management:** - Load leveling - Mixed-model scheduling - Manage bottlenecks actively

Job shop Lean strategies covered in Section 24.18

Summary

Value Stream Mapping is a pencil-and-paper tool that makes the entire product flow visible, from raw material to customer delivery. The current state map documents reality, revealing waste and opportunities. The future state map designs the Lean vision using continuous flow, pull systems, and other Lean principles. The implementation plan bridges current and future states through Kaizen events, annual improvements, and daily continuous improvement.

VSM provides a common language for cross-functional teams and creates the blueprint for Lean transformation. It's especially powerful because it shows the system, not just individual processes, enabling systemic improvements rather than local optimizations.

Key Takeaways

1. **VSM visualizes** the complete flow of material and information
2. **Current state** documents reality through Gemba walks and data collection
3. **Standard symbols** provide common language across organizations
4. **VA ratio** (value-added time ÷ lead time) typically 1-5% in traditional manufacturing
5. **Bottlenecks** limit system capacity–identify and elevate constraints
6. **Future state** applies Lean principles: flow, pull, level, and continuous improvement
7. **Implementation plan** with Kaizen bursts translates map to action
8. **Job shops** adapt VSM using product families and flexible cells
9. **Go to Gemba**–see reality, not assumptions or procedures
10. **Team activity**–cross-functional participation essential

---

Review Questions

1. What is a value stream? What are the three main flows?
2. Why walk the process backwards from shipping to receiving?
3. List 5 standard VSM symbols and their meanings
4. Calculate VA ratio: Process time = 3 hours, Lead time = 12 days. What's the VA ratio?
5. What is a bottleneck and why is it important?
6. List the 8 future state questions from Rother & Shook
7. When should you use continuous flow vs. pull systems?
8. What is the pacemaker process?
9. How do job shops adapt VSM for high-mix, low-volume?
10. What are Kaizen bursts on a VSM?

Practical Exercise

Create a Value Stream Map for a product in your facility:

1. **Select product family** (high volume or problem product)
2. **Assemble team** (5-8 people cross-functional)
3. **Walk the process** (shipping backwards to receiving)
4. **Collect data:**
    - Cycle times
    - Changeover times
    - Uptime %
    - Inventory quantities
    - Batch sizes
5. **Draw current state map**
    - Use standard symbols
    - Include timeline
    - Calculate lead time and VA ratio
6. **Analyze:**
    - Identify bottleneck

    - Mark improvement opportunities with Kaizen bursts
7. **Sketch future state** (apply Lean principles)
8. **Create implementation plan** (top 3-5 improvements)

Deliverable: Current state map, future state sketch, implementation plan with timeline and owners.

Module 24 - L.E.A.N. Strategies for CNC Manufacturing

24.4.1 JIT Principles and Philosophy

Just-In-Time (JIT) is a production strategy that strives to produce the right part, in the right quantity, at the right time.

Core Principle

"Nothing is produced until it is needed."

The Three Elements of JIT

1. Just-In-Time Delivery: - Parts arrive exactly when needed - No early (creates inventory) - No late (creates shortages) - Frequent small deliveries vs. large batches

2. Just-In-Time Production: - Make only what's needed - Match customer demand rate (takt time) - Eliminate overproduction waste

3. Just-In-Time Information: - Information flows at right time - Pull signals trigger production - Real-time visibility

JIT vs. "Just-In-Case"

Traditional "Just-In-Case" Thinking: - Build inventory buffers everywhere - "Better safe than sorry" - Protect against problems - Result: High inventory, slow response, hidden problems

JIT Thinking: - Minimal inventory - Expose problems - Fix root causes - Result: Low inventory, fast response, continuous improvement

Analogy: Water and Rocks - Inventory = water level in river - Problems = rocks hidden underwater - **Just-In-Case:** Raise water level (hide rocks) - **JIT:** Lower water level (expose rocks), remove rocks

JIT Requirements

For JIT to work, you need:

1. Stable, Capable Processes: - High equipment uptime - Consistent quality - Low variation - TPM (Total Productive Maintenance)

2. Quick Changeovers: - Short setup times - Small batch flexibility - SMED (Single Minute Exchange of Dies)

3. **Balanced Operations:** - Smooth flow - Minimal bottlenecks - Takt time alignment
4. **Visual Management:** - Pull signals - Kanban cards - Andons
5. **Supplier Partnerships:** - Reliable deliveries - Quality at source - Frequent small shipments
6. **Quality at Source:** - Build quality in - Immediate problem solving - Poka-yoke (error proofing)

24.4.2 Takt Time

Takt is German for "beat" or "pulse" (like a metronome marking musical time).

Takt Time is the rate at which customers demand products.

24.4.2.1 Calculating Takt Time

Formula:

Takt Time = Available Production Time ÷ Customer Demand

Example 1: CNC Machine Shop

Given: - Customer demand: 400 parts per day - Shift: 8 hours (480 minutes) - Breaks: 2 × 15 min = 30 minutes - Available time: 480 - 30 = 450 minutes/day

Takt Time Calculation: - Takt = 450 min ÷ 400 parts - **Takt = 1.125 minutes per part** - **= 67.5 seconds per part**

Interpretation: Need to complete one part every 67.5 seconds to meet customer demand.

Example 2: Variable Demand

Monthly demand: - Week 1: 100 parts - Week 2: 120 parts - Week 3: 110 parts - Week 4: 90 parts - **Average: 105 parts/week**

Takt Time (based on average): - Available time: 5 days × 450 min = 2,250 min/week - Takt = 2,250 ÷ 105 = **21.4 minutes per part**

24.4.2.2 Balancing to Takt

Goal: Adjust process capacity to match takt time.

Process Cycle Time vs. Takt Time:

If Cycle Time < Takt Time: - Process capacity exceeds demand - Potential overproduction - **Solution:** Slow down, redeploy operator time, reduce staffing

If Cycle Time > Takt Time: - Process can't meet demand - Bottleneck - **Solution:** Add capacity, reduce cycle time, add shifts/overtime

If Cycle Time ≈ Takt Time: - Balanced - Match demand perfectly - **Ideal state**

Example: Balancing a Cell

Takt Time: 60 seconds

Operation	Current C/T	Status	Action
Load part	15 sec	OK	None
Machine op 1	45 sec	OK	None
Machine op 2	75 sec	**Over takt!**	Reduce C/T or add capacity
Inspect	20 sec	OK	None
Unload	10 sec	OK	None

Operation 2 is bottleneck (75 sec > 60 sec takt).

Options: 1. Reduce cycle time (better tooling, feeds/speeds) 2. Offload some work to another operation 3. Add second machine for operation 2 4. Run operation 2 on overtime/extra shift

24.4.2.3 Takt Time in Job Shop Environments

Challenge: Job shops have high mix, variable demand per product.

Approaches:

1. Family Takt Time: - Calculate takt for product family - Balance cell to family average - Mix products within family

Example: - Product A: 50/week - Product B: 30/week - Product C: 20/week - **Family demand: 100/week** - Takt = 2,250 min ÷ 100 = **22.5 min**

2. Adjust Staffing: - Flexible labor - Cross-trained operators - Add/remove operators as demand changes

3. Running Takt: - Calculate takt based on current orders - Re-evaluate weekly or monthly - Adapt capacity

4. Focus on Cycle Time Reduction: - Even with variable takt, reducing cycle time helps - Increases flexibility - Enables faster response

---

24.4.3 Continuous Flow Manufacturing

Continuous Flow: Products move through operations without interruption, one piece at a time.

24.4.3.1 One-Piece Flow

Definition: Each part completes all operations before the next part starts.

Contrast with Batch:

Batch Processing:

```
Operation 1: Make 100 pieces (100 min)
↓ [Wait: 1 day]
Operation 2: Process 100 pieces (150 min)
↓ [Wait: 1 day]
Operation 3: Finish 100 pieces (80 min)
```

```
Lead time: ~2 days
```

One-Piece Flow:

```
Part 1: Op1 (1 min) → Op2 (1.5 min) → Op3 (0.8 min)
Part 2: Op1 (1 min) → Op2 (1.5 min) → Op3 (0.8 min)
...

Lead time per part: 3.3 minutes
```

Benefits of One-Piece Flow:

1. Shortest Lead Time: - Part 1 complete in 3.3 minutes (not 2 days!) - Customer sees fast delivery

2. Minimal WIP: - Only parts currently being processed - No batches waiting - Reduced inventory cost

3. Immediate Quality Feedback: - Defect discovered at next operation (seconds away) - Not days later - Small impact (one part, not batch of 100)

4. Flexible: - Can switch products easily - No large batches to complete first

5. Less Space: - No WIP storage areas - Compact cell layout

6. Simpler Scheduling: - No complex batch sequencing - Just release parts at takt time

24.4.3.2 Cell Design for Flow

Manufacturing Cell: Group of operations arranged in process sequence for one-piece flow.

U-Shaped Cell (Most Common):

```
Inlet ↓            ↑ Outlet
     +-----------+
     |           |
Op1  |           |  Op5
     |           |
Op2  |   Work    |  Op4
     |   Area    |
Op3  +-----------+

Operator walks inside U
Tends multiple machines
Inlet/Outlet close together
```

Cell Design Principles:

1. Sequence by Process: - Operations in production sequence - Minimize backtracking - Logical flow

2. Compact Layout: - Machines close together - Walking minimized - Hand-off between operations

3. U-Shape Benefits: - Operator in center - Can see all machines - Inlet/outlet close (easy communication) - Compact footprint

4. Multi-Process Handling: - One operator runs multiple machines - Walk loop through cell - Tends machine while previous operation runs

5. Built-In Quality: - Inspection integrated - Immediate feedback - Defects don't propagate

24.4.3.3 Flow in CNC Operations

Challenge: CNC machines have long cycle times.

Strategies:

1. Multi-Machine Cells: - Operator tends 3-5 CNC machines - While one runs, operator loads/unloads others - Walking path through cell

Example: - Takt time: 5 minutes - CNC cycle time: 15 minutes each - **Solution:** 3 CNCs in cell, 1 operator - Load machine 1, start cycle - Load machine 2, start cycle - Load machine 3, start cycle - Unload machine 1 (cycle complete), reload - Continuous loop

2. Mixed Manual/Automated: - CNC for long operations - Manual for quick operations - Operator does manual work while CNC runs

3. Right-Size Equipment: - Smaller machines (faster cycle) - Multiple smaller vs. one large - Dedicated to cell, not shared

4. Quick Changeover (SMED): - Enable small batches - Mix products in cell - Flexibility

5. Standardize Work: - Consistent method - Predictable timing - Smooth flow

---

24.4.4 Pull Systems

Pull Production: Downstream customer signals upstream to produce.

Contrast with Push:

Push System: - Forecast demand - Schedule each operation independently - Push work through - Result: Overproduction, excess WIP

Pull System: - Actual consumption triggers production - Produce only to replace what was used - Signal upstream (Kanban) - Result: Right-sized inventory, no overproduction

24.4.4.1 Pull vs. Push Production

Push Example (Traditional MRP):

```
Forecast: 1000 parts needed next month

MRP Schedule:
- Release 1000 blanks to Lathe
- Release 1000 to Mill (after lathe)
- Release 1000 to Assembly
```

```
Reality:
- Demand changes to 800
- WIP: 200 extra parts throughout system
```

Pull Example (Kanban):

```
Customer takes 100 parts from supermarket
↓ [Empty Kanban signals]
Assembly produces 100 to refill
↓ [Assembly Kanban signals]
Mill produces 100 to refill assembly
↓ [Mill Kanban signals]
Lathe produces 100 to refill mill

Result: Only 100 produced (what was consumed)
```

Pull Benefits: - Produce exactly what's needed - Self-regulating (demand changes automatically adjust production) - Minimal inventory - Simple visual signals

24.4.4.2 Supermarket Systems

Supermarket: Controlled inventory location with specific quantity of each item.

Like a Grocery Store: - Each product has shelf location - Quantity limits (min/max) - When customer takes item, store restocks - Visual signals

Manufacturing Supermarket: - Finished goods or WIP storage - Each SKU has defined location - Visual min/max levels - Pull replenishment when stock taken

Design: - Flow racks or shelving - FIFO (first-in-first-out) - Clear labels - Color-coded - Kanban cards

Sizing: - Buffer for demand variation - Lead time to replenish - Not excess "just in case"

Example:

Hardware Supermarket: - Bolts, nuts, screws for assembly - Each SKU in labeled bin - Min/max marked visually - When quantity reaches min, Kanban triggers reorder - Supplier delivers to supermarket

24.4.4.3 Kanban Cards and Signals

Kanban: Japanese for "signal" or "card."

Kanban Card: - Authorization to produce or move - Contains: Part number, quantity, location - Attached to container

How It Works:

Production Kanban: 1. Downstream customer takes parts from supermarket 2. Production Kanban card removed 3. Card goes to upstream process 4. Card authorizes production of one container quantity 5. Parts produced, card attached to container 6. Container delivered to supermarket 7. Cycle repeats

Withdrawal Kanban: - Authorization to move parts - Material handler sees card - Moves container from upstream to downstream

Signal Kanban: - Batch production situations - Accumulate cards until batch size reached - Produce batch to replenish

Visual Signals (Alternative to Cards): - **Two-bin system:** Empty bin signals reorder - **Andon lights:** Light color indicates status - **Floor markings:** Empty space = produce to fill - **Ball/flag:** Physical signal at machine

Detailed Kanban covered in Section 24.5

24.4.5 Leveling Production (Heijunka)

Heijunka: Japanese for "leveling" or "smoothing."

Goal: Produce products in small batches at a steady, predictable rate.

24.4.5.1 Production Smoothing

Problem: Lumpy Demand

Customer orders (monthly): - Week 1: 200 Product A - Week 2: 0 - Week 3: 150 Product A - Week 4: 50 Product A

Traditional Response (Chase Demand): - Week 1: Build 200 A (surge capacity, overtime) - Week 2: Idle or build other products - Week 3: Build 150 A - Week 4: Build 50 A

Problems: - Variable workload (overload then underload) - Overtime costs - Quality suffers (rushing) - Supplier whipsaw effect

Heijunka Approach (Level): - Average demand: 400/month = 100/week - **Build 100 per week every week** - Smooth, predictable

Benefits: - Stable workforce (no overtime surges) - Consistent quality - Supplier stability - Can respond to actual demand changes faster

24.4.5.2 Mixed Model Scheduling

Mixed Model: Produce multiple products in same period (day/shift) in small batches.

Example:

Traditional (Large Batches): - Monday-Tuesday: Product A (200 pcs) - Wednesday: Product B (50 pcs) - Thursday-Friday: Product C (150 pcs)

Problem: - Long wait for Product C customer - Large batch WIP - Inflexible

Heijunka (Mixed Model): - Daily production: - Product A: 40 pcs - Product B: 10 pcs - Product C: 30 pcs - **Every day, all products**

Benefits: - All products available daily - Shorter lead time - Can respond to changes - Smaller batches (less WIP)

Requires: - Quick changeover (SMED) - Flexible workers - Balanced operations

24.4.5.3 Heijunka Boxes

Heijunka Box: Visual scheduling tool for leveled production.

Design: - Grid: Rows = products, Columns = time intervals - Kanban cards placed in slots - Workers take cards in sequence

Example Box:

Product	8:00	8:30	9:00	9:30	10:00	…
A	[K]	[K]		[K]		…
B			[K]		[K]	…
C	[K]			[K]		…

- [K] = Kanban card
- Every 30 minutes (pitch), worker takes next card
- Card signals what to produce

Benefits: - Visual schedule - Level mix - Easy to adjust - Pitch-based production

---

24.4.6 JIT Implementation Challenges

JIT is simple in concept, difficult in practice.

Common Challenges

1. Resistance to Change: - "We've always done large batches" - Fear of running out - Comfort with inventory buffers

Solution: - Education on JIT benefits - Start small (pilot area) - Show results

2. Equipment Reliability: - JIT exposes breakdowns immediately - No inventory buffer to hide problems

Solution: - TPM (Total Productive Maintenance) - Preventive maintenance - Operator care

3. Long Setup Times: - Can't run small batches economically - Forces large batches (anti-JIT)

Solution: - SMED (Single Minute Exchange of Dies) - Target: < 10 minute setups - *Section 24.6*

4. Supplier Issues: - Unreliable deliveries - Poor quality - Long lead times

Solution: - Supplier development - Partnerships vs. adversarial - Frequent small deliveries - Quality agreements

5. Demand Variation: - Takt time changes - Difficult to level completely

Solution: - Flexible capacity (cross-training) - Heijunka to smooth what you can - Strategic buffers for extreme variation

6. Quality Problems: - Can't afford defects (no buffer inventory) - Pressure to ship bad parts

Solution: - Build quality in (Poka-Yoke) - Stop and fix (andon) - Root cause problem solving

7. Organizational Silos: - Departments optimize locally - Conflict with JIT system optimization

Solution: - Value stream management - Cross-functional teams - Aligned metrics

8. Metrics Conflict: - Traditional metrics (efficiency, utilization) conflict with JIT - Pressure to "keep machines running"

Solution: - Change metrics: lead time, inventory turns, on-time delivery - Education on Lean metrics

Implementation Tips

Start Small: - Pilot cell or product family - Prove concept - Build capability - Scale successes

Fix the Basics First: - 5S (workplace organization) - Standard work - TPM (equipment reliability) - Setup reduction - **Then** implement JIT

Support from Top: - Leadership commitment - Resources for improvement - Patience (takes time) - Celebrate progress

Train Everyone: - JIT principles - Why change is necessary - New roles and responsibilities - Problem-solving skills

Measure Results: - Inventory reduction - Lead time improvement - Quality improvement - On-time delivery - **Show the wins**

Summary

Just-In-Time (JIT) manufacturing produces the right part, in the right quantity, at the right time. JIT eliminates waste by producing only to customer demand (takt time), using continuous flow where possible and pull systems where flow isn't feasible. Production leveling (heijunka) smooths demand variation, enabling stable operations.

JIT requires quick changeovers, reliable equipment, capable processes, and supplier partnerships. While challenging to implement, JIT delivers significant benefits: reduced inventory, shorter lead times, improved quality, and increased flexibility.

Key Takeaways

1. **JIT philosophy:** Produce only what's needed, when needed
2. **Takt time** = Available time ÷ Customer demand (pace of production)
3. **Balance operations** to takt time for smooth flow
4. **One-piece flow** minimizes lead time and WIP
5. **Pull systems** (Kanban) prevent overproduction
6. **Supermarkets** provide controlled inventory with pull replenishment
7. **Heijunka** levels production mix and volume

8. **Mixed-model** scheduling produces all products frequently in small batches
9. **JIT prerequisites:** Quick changeover, reliable equipment, quality at source
10. **Implementation:** Start small, fix basics first, measure results

---

Review Questions

1. What is the core principle of JIT?
2. Calculate takt time: 480 min available, 240 parts demanded per day
3. What's the difference between push and pull production?
4. Explain one-piece flow vs. batch production
5. What is a supermarket in Lean manufacturing?
6. What is Heijunka and why is it important?
7. List 5 prerequisites for successful JIT implementation
8. Why is equipment reliability critical for JIT?
9. How does mixed-model scheduling differ from batch production?
10. What are the benefits of one-piece flow?

Practical Exercises

Exercise 1: Calculate and Balance to Takt

Your cell produces product X with the following data: - Demand: 160 parts per day - Shift: 8 hours (480 min) - Breaks: 30 min total - Current process cycle times: - Operation 1: 1.5 min - Operation 2: 3.2 min - Operation 3: 2.0 min - Operation 4: 1.8 min

Tasks: 1. Calculate takt time 2. Identify bottleneck operation(s) 3. Determine if cell is balanced 4. Recommend actions to balance to takt

Exercise 2: Batch vs. Flow Comparison

Compare batch processing vs. one-piece flow:

Scenario: - 3 operations: A (2 min), B (3 min), C (1 min) - Batch size: 10 pieces - Transportation time between ops: 10 min

Calculate: 1. Lead time for first piece (batch method) 2. Lead time for last piece (batch method) 3. Lead time per piece (one-piece flow) 4. Total WIP inventory (batch vs. flow)

Exercise 3: Design a Pull System

Design a simple pull system for an assembly operation: - Consumes 100 parts per day of Component X - Replenishment lead time: 1 day - Desired safety stock: 20% - Container size: 25 parts

Determine: 1. How many Kanban cards needed? 2. Draw the pull loop (sketch) 3. When does production signal trigger?

Module 24 - L.E.A.N. Strategies for CNC Manufacturing

24.5.1 Introduction to Kanban

Kanban (Japanese: □ □) literally means "signboard" or "visual card."

In Lean manufacturing, **Kanban is a pull system tool that uses visual signals to trigger production or movement of materials.**

Origin

Taiichi Ohno developed Kanban at Toyota in the 1950s, inspired by American supermarkets:

Observation: - Supermarket shelves stocked with products - Customers take what they need - Store restocks based on what was consumed - No overproduction, minimal inventory

Application to Manufacturing: - "Supermarket" of parts between operations - Downstream "customer" takes what's needed - Kanban signal triggers upstream to replenish - Self-regulating inventory system

Core Principles

1. Visual Management: - Status visible at a glance - No need to check computer systems - Anyone can understand

2. Pull Production: - Actual consumption authorizes production - No production without signal - Prevents overproduction

3. Inventory Control: - Limits WIP to Kanban quantity - Can't produce more than authorized - Right-sized inventory

4. Continuous Flow: - Smooth replenishment - No large batches - Responsive to demand

5. Continuous Improvement: - Reduce Kanban quantity over time - Expose problems - Drive improvement

---

24.5.2 Types of Kanban

24.5.2.1 Production Kanban

Production Kanban (P-Kanban): Signal authorizing production of parts.

Function: - Instructs upstream process to produce - Specifies what, how many, when - Attached to container of parts

Information on Card: - Part number and description - Quantity per container - Producing work center - Storage location - Card number (e.g., 3 of 5)

Example Production Kanban:

```
+---------------------------------+
|  PRODUCTION KANBAN              |
```

```
|                                 |
|  Part No: 12345-B               |
|  Description: Shaft, Steel      |
|                                 |
|  Quantity: 25 pcs               |
|                                 |
|  Produce At: CNC Cell 3         |
|  Store At: Rack A-12            |
|                                 |
|  Card: 2 of 4                   |
+---------------------------------+
```

Flow: 1. Downstream consumes parts from supermarket 2. Production Kanban removed, goes to producing cell 3. Cell produces one container (25 pcs) 4. Kanban attached to full container 5. Container returned to supermarket 6. Cycle repeats

24.5.2.2 Withdrawal Kanban

Withdrawal Kanban (W-Kanban): Signal authorizing movement of parts.

Function: - Authorizes material handler to move parts - From one location to another - Specifies what, how many, from where, to where

Information on Card: - Part number and description - Quantity - Supplying location - Consuming location - Delivery frequency

Example Withdrawal Kanban:

```
+---------------------------------+
|  WITHDRAWAL KANBAN              |
|                                 |
|  Part No: 12345-B               |
|  Description: Shaft, Steel      |
|                                 |
|  Quantity: 25 pcs               |
|                                 |
|  From: CNC Cell 3, Rack A-12    |
|  To: Assembly Cell 2            |
|                                 |
|  Delivery: Every 2 hours        |
+---------------------------------+
```

Flow: 1. Assembly consumes parts 2. Withdrawal Kanban goes to material handler 3. Material handler takes card to CNC supermarket 4. Exchanges withdrawal Kanban for production Kanban 5. Takes full container to assembly 6. Returns production Kanban to CNC cell

24.5.2.3 Supplier Kanban

Supplier Kanban: Signal for external supplier to deliver parts.

Function: - Extends pull system to suppliers - Frequent small deliveries - Eliminates large inventory

Information on Card: - Part number - Quantity per delivery - Delivery frequency - Supplier contact - Delivery location

Example: - 500 bolts per day consumption - Kanban quantity: 100 bolts - **5 Kanban cards circulating** - Supplier delivers 100 when receives Kanban (daily)

Benefits: - Reduced raw material inventory - Supplier visibility to consumption - Smooth, predictable deliveries - Partnership vs. adversarial

---

24.5.3 Kanban Card Design

Effective Kanban cards are:

Visual and Clear

Color Coding: - Different colors for different product families - Red = urgent/priority - Yellow = standard - Green = low priority

Size: - Large enough to read from distance - Durable (laminated, heavy card stock) - Standardized dimensions

Information Hierarchy: - Most important info largest (part number) - Organized logically - Icons/symbols where possible

Essential Information Only

Must Have: - Part number - Description (brief) - Quantity - Location (from/to)

Nice to Have: - Barcode (for scanning) - Photo of part - Container type - Lead time

Avoid: - Excessive detail - Instructions (should be in standard work) - Clutter

Durable

Materials: - Heavy card stock - Laminated - Magnetic backing (for metal boards) - Plastic holders

Attachment: - Clip to container - Magnetic - Pocket on container - Hook/ring

---

24.5.4 Calculating Kanban Quantities

How many Kanban cards are needed?

Formula

Number of Kanbans = (Demand During Lead Time + Safety Stock) ÷ Container Quantity

Where: - **Demand During Lead Time** = Daily demand × Lead time (days) - **Safety Stock** = Buffer for variation (typically 10-20% of demand during lead time) - **Container Quantity** = Standard container size

Example Calculation

Given: - Daily demand: 200 parts - Replenishment lead time: 0.5 days (4 hours) - Safety stock: 20% (to handle variation) - Container capacity: 25 parts

Calculate:

Demand During Lead Time: - 200 parts/day × 0.5 days = 100 parts

Safety Stock: - 100 parts × 20% = 20 parts

Total Inventory Needed: - 100 + 20 = 120 parts

Number of Kanbans: - 120 parts ÷ 25 parts/container = 4.8 - **Round up to 5 Kanbans**

Inventory Level: - 5 Kanbans × 25 parts = **125 parts maximum**

Factors Affecting Quantity

Lead Time: - Longer lead time = more Kanbans - **Reduce lead time to reduce inventory**

Demand Variation: - High variation = more safety stock - **Level demand (heijunka) to reduce Kanbans**

Container Size: - Larger containers = fewer Kanbans - But less frequent replenishment - **Right-size containers**

Reliability: - Unreliable processes = more safety stock - **Improve reliability to reduce Kanbans**

Continuous Improvement

Start Conservative: - Calculate Kanbans with 20% safety stock - Ensure system works smoothly

Gradually Reduce: - After system stable, reduce to 4 Kanbans - Observe for stockouts - If OK, reduce to 3 - **Expose problems, solve them, reduce again**

Goal: - Minimize inventory - Maintain flow - Never stop reducing

---

24.5.5 Two-Bin Kanban Systems

Simplest Kanban implementation: Two bins for each part.

How It Works

Setup: - Two identical containers (bins) per part - Each bin holds enough for lead time + safety stock - When bin empty, triggers reorder

Operation:

Bin 1 (In Use): - Consume parts from Bin 1 - Bin 2 sits full (inventory)

Bin 1 Empty: - Trigger: Empty bin signals replenishment needed - Action: Send Bin 1 to be refilled (or place reorder card) - Switch to Bin 2

While Using Bin 2: - Bin 1 being refilled - Must fill Bin 1 before Bin 2 empty - If Bin 2 empties before Bin 1 refilled = stockout (problem!)

Bin 1 Refilled: - Return to use, Bin 2 becomes inventory - Cycle repeats

Benefits

Simple: - No cards needed - Easy to understand - Self-evident

Visual: - Empty bin obvious - No tracking required

Effective: - Prevents stockouts (if sized correctly) - Limits inventory (only 2 bins worth)

Sizing Two-Bin

Bin Capacity: - Must hold demand during replenishment lead time + safety stock - Same calculation as Kanban

Example: - Daily usage: 50 bolts - Lead time: 2 days (to reorder and receive) - Safety stock: 20% - **Bin size: (50 × 2) × 1.2 = 120 bolts** - **Two bins = 240 bolts maximum inventory**

Best Applications

Two-Bin Ideal For: - Small, inexpensive parts (fasteners, consumables) - Stable demand - Simple replenishment (supplier or internal) - Limited SKUs

Not Ideal For: - Large, expensive parts - Complex manufacturing - Many SKUs (racks of bins needed) - Tight space constraints

---

24.5.6 Electronic Kanban (e-Kanban)

e-Kanban: Electronic signals replace physical cards.

Technology

Systems: - Barcode scanning - RFID tags - MES/ERP integration - Visual displays - Email/text alerts

Example Flow: 1. Operator scans empty container barcode 2. System sends signal to upstream cell 3. Upstream cell receives production order on screen 4. Produces parts 5. Scans completed 6. System updates inventory

Benefits

Real-Time Visibility: - Instant signal transmission - No lost cards - System-wide visibility

Data Collection: - Automatic tracking - Lead time measurement - Consumption patterns - Analytics for improvement

Scalability: - Hundreds of parts manageable - Multiple locations - Supplier integration

Flexibility: - Easy to adjust quantities - Add/remove SKUs - Route changes

Drawbacks

Complexity: - Requires IT infrastructure - Training needed - System maintenance

Cost: - Software licenses - Scanners/devices - Implementation time

Less Visual: - Signals hidden in system - Not as obvious as cards - Requires discipline to check screens

Failure Risk: - System down = no signals - Requires backup plan

When to Use e-Kanban

Good Fit: - Large number of SKUs - Multiple locations - Mature Lean organization - Existing IT infrastructure - Need for data analytics

Not Good Fit: - Beginning Lean journey (start with cards!) - Simple operations - Limited resources - Visual management priority

Best Practice: - **Start with card Kanban** - Master the principles - Transition to e-Kanban when needed - Maintain visual elements (boards, lights)

24.5.7 Kanban for Raw Materials

Applying Kanban to supplier deliveries.

Internal Raw Material Kanban

Setup: - Supermarket at receiving or point-of-use - Kanban for each raw material SKU - Min/max levels marked

Operation: 1. Production consumes raw material 2. Kanban removed when reaching min level 3. Kanban goes to purchasing/receiving 4. Triggers reorder or delivery from supplier 5. Material delivered, replenishes supermarket 6. Kanban returns to supermarket

Benefits: - Right-sized raw material inventory - No excess “just in case” stock - Automatic reordering

Supplier Integration

Kanban with Suppliers:

Option 1: Kanban-Triggered Orders - Send Kanban to supplier (fax, email, EDI) - Supplier delivers one Kanban quantity - Frequent small deliveries

Option 2: Supplier-Managed Inventory - Supplier owns inventory on your floor - Supplier monitors levels - Replenishes as needed - You pay as consumed

Option 3: Milk Runs - Regular supplier pickup route - Collects Kanbans, delivers parts - Daily or multiple times per day - Mixed loads from multiple suppliers

Requirements:

Supplier Partnership: - Trust and commitment - Quality at source (no incoming inspection) - Reliable delivery - Proximity helps (but not required)

Stable Demand: - Predictable consumption - Level scheduling (heijunka) - Advance visibility to changes

Flexible Delivery: - Small quantities - Frequent deliveries - Standard containers

Example: CNC Shop Raw Materials

Aluminum Bar Stock: - Consumption: 10 bars/week - Lead time: 1 week - Safety stock: 20% - **Kanban quantity: (10 × 1) × 1.2 = 12 bars** - **2 Kanbans (minimum) = 24 bars max inventory**

Before Kanban: - Ordered monthly: 40 bars - "Just in case" buffer: 10 bars - **Total: 50 bars inventory** - **Carrying cost: 50 bars × $100 × 25% = $1,250/year**

After Kanban: - Weekly deliveries: 12 bars - **Max: 24 bars inventory** - **Carrying cost: 24 bars × $100 × 25% = $600/year** - **Savings: $650/year per SKU**

24.5.8 Kanban for Tools and Consumables

Extend Kanban to tooling, supplies, consumables.

Tool Crib Kanban

Problem: - Stockouts delay production - Excess inventory ties up cash - No visibility to usage

Solution: Kanban for Tools

Setup: - Two-bin system for each tool/consumable - Bins at point-of-use (not central crib) - Empty bin triggers reorder

Example: Cutting Inserts - Consumption: 20 inserts/week - Lead time: 1 week (internal stock or supplier) - Bin size: 25 inserts - **Two bins per machine = 50 inserts max**

Benefits: - Tools at point-of-use (no walking to crib) - Automatic replenishment - Reduced inventory - No stockouts

Consumables Kanban

Examples: - Coolant - Shop rags - Abrasives - Gloves - Cutting oil

Two-Bin for Consumables: - Works perfectly - Simple, visual - Self-managing

Supplier Kanban for Consumables: - Vendor-managed inventory - Supplier monitors levels - Automatic restocking - Pay as consumed

---

24.5.9 Kanban Rules and Discipline

Kanban only works with discipline. Breaking rules breaks the system.

The Six Rules of Kanban (Toyota)

Rule 1: Never Pass Defective Products - Downstream process inspects - Rejects defects immediately - Stops flow, signals problem - Root cause addressed

Rule 2: Downstream Process Withdraws Only What's Needed - Pull, not push - Take only Kanban quantity - At specified time/frequency - No "borrowing" ahead

Rule 3: Produce Only Exact Quantity Withdrawn - No overproduction - One Kanban = one container - No producing "extra just in case"

Rule 4: Level the Production (Heijunka) - Smooth demand variation - Small batches frequently - Avoid lumpy schedules - Enables small Kanban quantities

Rule 5: Kanban is a Fine-Tuning Tool - Small adjustments to demand - Not for large changes or new products - Gradual reduction of Kanban quantity - Continuous improvement tool

Rule 6: Stabilize and Rationalize the Process - Reliable equipment (TPM) - Standard work - Quality at source - **Foundation before Kanban**

Common Discipline Failures

"Borrowing" from Next Kanban: - "We're almost out, I'll just take from the next bin" - **Breaks the signal** - Hides true demand - Causes shortages

Overproducing: - "I have time, I'll make extras" - Defeats Kanban purpose - Creates excess inventory - No authorization

Ignoring Signals: - Cards pile up, not acted on - "I'll get to it later" - Breaks pull system - Stock-outs result

Not Following Min/Max: - Overfilling supermarkets - "More is safer" - Defeats inventory control

Bypassing System: - Emergency orders outside Kanban - "Just this once" - Becomes habitual - System credibility lost

Enforcing Discipline

Visual Management: - Kanban status boards - Red flags for violations - Public metrics

Leadership: - Follow rules consistently - No exceptions - Gemba walks to verify - Address violations immediately

Training: - Everyone understands why rules matter - Consequences of breaking rules - System logic

Continuous Improvement: - Problems exposed by Kanban - Solve root causes - Make system easier to follow

---

Summary

Kanban is a visual pull system that controls inventory and production through signals. Production Kanbans authorize manufacturing, withdrawal Kanbans authorize movement, and supplier Kanbans trigger deliveries. The number of Kanbans is calculated based on demand, lead time, and safety stock. Simple two-bin systems work well for small consumables, while electronic Kanban scales for complex operations.

Kanban requires discipline: produce only to Kanban authorization, never pass defects, withdraw only what's needed. When rules are followed, Kanban prevents overproduction, limits WIP, and creates self-regulating flow. Continuous improvement reduces Kanban quantities over time, exposing and eliminating waste.

Key Takeaways

1. **Kanban** = visual signal triggering production or movement
2. **Three types**: Production, Withdrawal, Supplier Kanban
3. **Number of Kanbans** = (Demand during lead time + safety stock) ÷ container quantity
4. **Two-bin system**: Simplest Kanban for consumables
5. **e-Kanban**: Electronic signals for complex operations
6. **Six Kanban rules**: Discipline essential for success
7. **Pull system**: Downstream consumption authorizes upstream production
8. **Continuous improvement**: Gradually reduce Kanban quantity
9. **Visual management**: Status obvious at a glance
10. **Foundation required**: Stable processes, quality, reliable equipment

---

Review Questions

1. What does "Kanban" mean and what inspired its development?
2. Explain the difference between Production and Withdrawal Kanban
3. Calculate number of Kanbans: Demand = 300/day, Lead time = 0.25 days, Safety stock = 10%, Container = 20 pcs

4. How does a two-bin system work?
5. What are the six rules of Kanban?
6. When should you use e-Kanban vs. card Kanban?
7. Why is discipline critical for Kanban success?
8. How does Kanban prevent overproduction?
9. What information must be on a Kanban card?
10. How do you continuously improve a Kanban system?

Practical Exercises

Exercise 1: Design a Kanban System

Your assembly area uses Component XYZ: - Consumption: 150 pcs/day - Replenishment lead time: 4 hours (0.5 days) - Desired safety stock: 15% - Standard container: 30 pcs

Tasks: 1. Calculate number of Kanbans needed 2. Calculate maximum inventory level 3. Design a Kanban card (sketch with all info) 4. Describe the pull loop (upstream to downstream) 5. After 3 months, system is stable. How would you improve (reduce Kanbans)?

Exercise 2: Two-Bin System

Implement two-bin for cutting inserts: - Daily usage: 12 inserts - Supplier lead time: 3 days - Safety factor: 20%

Determine: 1. Bin capacity (pcs per bin) 2. Total inventory (both bins) 3. When does reorder trigger? 4. What happens if bin capacity too small?

Exercise 3: Kanban Discipline Scenario

Scenario: You're a CNC operator. Your Kanban bin is empty but no new Kanban has arrived. You have 2 hours of work left. You notice the next workstation has 3 full Kanban bins.

Questions: 1. What should you do according to Kanban rules? 2. What should you NOT do? 3. What does empty bin with no Kanban signal? 4. How should this problem be addressed?

Module 24 - L.E.A.N. Strategies for CNC Manufacturing

24.6.1 The Importance of Quick Changeovers

Setup time (changeover time) is one of the biggest barriers to Lean manufacturing.

The Setup Time Problem

Traditional Thinking: - Long setups are "necessary" - Run large batches to "absorb" setup cost - Result: Excess inventory, long lead times, inflexibility

Example: - Setup time: 2 hours (120 minutes) - Run time: 1 minute/part - Economic batch: 200+ parts (to make setup % small) - Lead time: Days or weeks of WIP

Problems from Long Setups:

1. Large Batch Sizes - Must run many parts to justify setup - Creates WIP inventory - Long lead times

2. Inflexibility - Can't respond quickly to demand changes - Committed to large batches - Mix flexibility limited

3. Quality Issues - Large batch means many defects before detection - Setup errors affect entire batch - Scrap costs multiplied

4. Schedule Complexity - Minimize setups by batching - Complex scheduling logic - Late orders wait for batch completion

The SMED Revolution

SMED: Single Minute Exchange of Dies

Goal: Reduce setup time to single digits (< 10 minutes)

Not literally "one minute" but less than 10 minutes (single-digit minutes).

Developed by Shigeo Shingo at Toyota in 1950s-1970s.

SMED Benefits:

1. Small Batch Capability - Setup time negligible vs. run time - Economic to run one piece - Enables one-piece flow

2. Flexibility - Quick response to demand changes - Mix model scheduling - Competitive advantage

3. Reduced Inventory - No need for large batches - Lower WIP - Cash freed up

4. Shorter Lead Times - Small batches flow faster - Customer satisfaction

5. Better Quality - Small batches = quick feedback - Setup errors caught early - Less scrap risk

Example SMED Impact:

Before: - Setup: 120 minutes - Batch: 200 parts - Setups/day: 1 (max) - WIP: 1,000+ parts - Lead time: 10 days

After SMED: - Setup: 9 minutes (93% reduction!) - Batch: 20 parts - Setups/day: 10+ possible - WIP: 100 parts - Lead time: 1 day

---

24.6.2 SMED Methodology

Three-Step Process for Setup Reduction

24.6.2.1 Separate Internal and External Setup

Internal Setup: Activities that MUST be done while machine is stopped.

Examples: - Remove old fixture, install new fixture - Adjust tool positions - Load first part - Make first part, inspect

External Setup: Activities that CAN be done while machine is running.

Examples: - Get tools, fixtures, programs - Pre-set tool lengths - Gather materials - Stage next job

Key Insight: 30-50% of "setup time" is actually external work done while machine is idle!

Step 1: Identify What's Internal vs. External

Current state: Everything done after machine stops.

Example Traditional Setup: 1. Stop machine (last part of previous job) 2. Walk to tool crib, get fixtures (5 min) 3. Walk to office, get program (3 min) 4. Remove old fixture (10 min) 5. Find new fixture (wasn't staged) (5 min) 6. Install new fixture (15 min) 7. Load program (2 min) 8. Find tools (3 min) 9. Adjust tool positions (20 min) 10. Run first part (5 min) 11. Inspect, adjust (15 min) 12. Run good part

Total: 83 minutes (all internal)

Separate Internal/External:

External (Do BEFORE machine stops): - Get fixtures (5 min) - Get program (3 min) - Stage tools (3 min) - Pre-set tools (can be done offline)

Internal (MUST do while stopped): - Remove old fixture (10 min) - Install new fixture (15 min) - Load program (2 min) - Adjust tool positions (20 min) - First part/inspect (20 min)

New Internal Time: 67 minutes (16 min saved just by separating!)

24.6.2.2 Convert Internal to External

Goal: Move as much internal work as possible to external.

Strategies:

1. Standardize Components - Standard fixture base (quick-change top plate) - Standard tool holders - Standard collets - Reduces adjustment time

2. Pre-Setting - Pre-set tool lengths offline - Pre-heat dies/fixtures - Pre-load programs - Pre-position adjustments

3. Parallel Operations - Two operators work simultaneously - One inside machine, one outside - Team setup vs. individual

4. Function Clamps - Quick-clamp systems replace bolts - Toggle clamps, cam locks - One motion vs. multiple turns

5. Eliminate Adjustments - Fixed positions (repeatability) - Hard stops, locating pins - Eliminate trial-and-error

Example Conversion:

Internal to External: - Tool pre-setting: 20 min internal → 0 min internal (done offline before) - Program loading: Use USB drive staged at machine (no walking)

Internal Simplified: - Quick-change fixture base: 15 min □ 3 min - Adjustments eliminated (preset): 20 min □ 2 min (verify only)

New Internal Time: 35 minutes (67 □ 35, another 32 min saved!)

24.6.2.3 Streamline All Setup Activities

Refine both internal and external to be faster.

Internal Streamlining:

1. **Organize Work** - Sequence for efficiency - Minimize movement - Batch similar tasks

2. **Improve Methods** - Better tools (power vs. manual) - Ergonomic positioning - Two-hand economy

3. **Visual Aids** - Color coding - Directional arrows - Instruction photos at machine

4. **Standard Work** - Document best method - Train everyone the same - Continuous improvement platform

External Streamlining:

1. **Kitting** - All tools/fixtures/programs in one kit - Staged at machine before changeover - No searching

2. **Point-of-Use Storage** - Fixtures stored at machine - Tools in shadow board - Programs on USB at machine

3. **Visual Management** - Labeled locations - Shadow boards - Checklists

Example Final State:

Streamlined Setup (All Steps):

External (Before Stop): - Kit staged: fixtures, tools, program (2 min prep)

Internal (Machine Stopped): 1. Remove old fixture (quick-change): 1 min 2. Install new fixture (quick-change): 1 min 3. Load program (USB at machine): 0.5 min 4. Install pre-set tools: 1 min 5. Run first part (pre-set, no adjustment): 3 min 6. Quick verify (should be good): 1 min

Total Internal: 7.5 minutes (83 □ 7.5 min = **91% reduction!**)

SMED achieved: Single-digit setup time!

24.6.3 Setup Time Analysis

Before improving, you must understand current state.

24.6.3.1 Current State Documentation

Select Representative Setup: - Common product change - Typical, not easiest or hardest - Perform actual setup (not from memory)

Data to Collect: - Total setup time (start to finish) - Each step (description, duration) - Who performs (number of people) - Tools/equipment used - Problems encountered

Setup Time Definition:

Start: Last good part of previous job

End: First good part of new job

Include ALL time: - Getting ready - Actual changeover - Adjustments - First-off inspection - Rework first parts if needed

24.6.3.2 Video Analysis

Most powerful SMED tool: Video the setup.

Benefits:

1. **Objective Reality** - Not what you think happens - What actually happens - Surprises guaranteed!

2. **Detailed Analysis** - Frame-by-frame if needed - Exact times - Multiple reviewers

3. **Before/After Comparison** - Powerful visual - Proves improvement - Training tool

4. **Waste Identification** - Walking - Searching - Waiting - Rework

How to Video:

Equipment: - Simple camera or smartphone - Tripod (stable view) - Wide angle (capture whole area)

Setup: - Position to see operator and machine - Include clock in frame (timestamp) - Audio helpful (hear problems)

Recording: - Start before setup begins - Record continuously - Don't stop for "boring parts" (wait time is data!) - End with first good part

Analysis: - Watch with team - Note every activity (timestamp start/end) - Classify: internal/external, value-added/waste - Brainstorm improvements

24.6.3.3 Waste Identification

Wastes in Setup:

1. **Searching** - Looking for tools - Looking for fixtures - Looking for programs - Looking for parts/materials

Solution: Point-of-use storage, kitting, shadow boards

2. **Walking** - To tool crib - To office for program - To get materials - Back and forth

Solution: Stage everything before setup, point-of-use storage

3. **Waiting** - For crane/forklift - For other person - For approval - For first part to run

Solution: Scheduling, parallel operations, pre-planning

4. Adjustments - Trial and error positioning - “Run a part, measure, adjust, repeat” - 10+ cycles sometimes

Solution: Preset tools, fixed positions, standardization

5. Rework - First part(s) scrap - Have to adjust and remake - Learning curve each setup

Solution: Standard work, better training, pre-setting

Typical Waste in Traditional Setup: - **Searching/Walking: 20-30%** - **Adjustments: 30-40%** - **Actual changeover work: 30-40%**

Huge opportunity!

24.6.4 SMED Improvement Techniques

24.6.4.1 Standardize Tooling and Fixtures

Problem: Every fixture different, every setup unique.

Solution: Standardization

Fixture Standardization:

1. Standard Base Plate - Same bolt pattern - Same height - Same locating features - Quick-change top plates

2. Fixture Families - Similar parts use similar fixtures - Modular components - Mix and match

3. Standard Clamping - Same clamps across fixtures - Same torque requirements - Same tools to operate

Tooling Standardization:

1. Tool Holders - Standardize on one system (CAT40, HSK, etc.) - Standard pull studs - Standard lengths where possible

2. Cutting Tools - Limit variety - Standard inserts - Standard tool assemblies

3. Gaging - Standard inspection tools - Stored at machine - Quick access

Benefits: - Faster changeover (familiarity) - Fewer mistakes (consistency) - Cross-training easier - Spare parts simpler

24.6.4.2 Quick-Change Systems

Replace Slow Methods with Fast Methods

Bolted Connections □ Quick-Change:

Traditional: - 4 bolts holding fixture - Each bolt: loosen 10 turns, remove, replace, tighten 10 turns - 4 bolts × 20 turns = 80 turns - Time: 5-10 minutes

Quick-Change: - Cam-lock or toggle clamp - 1/4 turn to lock/unlock - 4 clamps × 1/4 turn = 1 turn - Time: 30 seconds

90% time reduction!

Options:

1. **Cam Locks** - Rotate 90° to lock - High clamping force - Repeatable
2. **Toggle Clamps** - Flip lever - Visual locked/unlocked - Many styles
3. **Hydraulic/Pneumatic** - Push button - Consistent clamping force - Fastest
4. **Magnetic Chucks** - Instant on/off - No clamping mechanism - Limited applications

Vise Jaws: - Quick-change jaws (dovetail, serrated) - Pre-set jaw pairs - Master jaws + soft jaws

Pallets: - Standard pallet system - Fixtures mounted on pallets - Pallet change seconds - Setup done offline on spare pallet

24.6.4.3 Visual Aids and Checklists

Reduce Thinking and Errors

Setup Checklists: - Step-by-step sequence - Checkboxes for each step - Prevents skipped steps - Training tool

Visual Work Instructions: - Photos of correct setup - Color-coded connections - Arrows showing direction - At point of use (laminated at machine)

Color Coding: - Red fixture goes in red position - Green tool in green holder - Obvious matching

Directional Indicators: - "This side up" labels - Arrows for rotation direction - Markings for alignment

Shadow Boards: - Tool outline on board - Missing tool obvious - Return tools to correct spot

Measurement Standards: - Go/no-go gages - Pre-set measuring tools - Eliminate thinking "what dimension?"

24.6.4.4 Parallel Operations

Two or More People Working Simultaneously

When to Use: - Internal time > 10 minutes after other improvements - Complex setups (many steps) - Heavy fixtures (safety) - Opportunities for simultaneous work

Example:

Single Person Setup: 1. Remove old fixture (5 min) 2. Install new fixture (5 min) 3. Change tools (8 min) 4. Load program, set offsets (4 min) 5. First part, inspect (5 min) **Total: 27 minutes**

Two-Person Setup (Parallel):

Person A	Person B	Time
Remove old fixture	Get new fixture, tools	5 min
Install new fixture	Change tools	5 min
Load program, offsets	Stage material	4 min
First part (both inspect)		5 min

Person A	Person B	Time

Total: 19 minutes (30% faster)

Requirements: - Coordination (practiced) - Safety (clear communication) - Standard work (each knows their role) - Cost/benefit (labor cost vs. machine time value)

24.6.4.5 Eliminate Adjustments

Adjustments are HUGE Time Wasters

Typical Adjustment Cycle: 1. Run part 2. Measure 3. Adjust tool offset 4. Run another 5. Measure 6. Adjust again 7. Repeat 5-10 times until good

Time: 20-30 minutes often!

Elimination Strategies:

1. Pre-Setting - Tool pre-setter machine offline - Set all tool lengths before setup - Load into machine with known offsets - First part should be good

2. Fixed Positions - Hard stops for fixtures - Locating pins (poka-yoke) - Repeatability = no adjustment - Reference surfaces

3. Standardized Fixtures - Fixture mounted same place every time - Work offsets stored in control - Recall program with offsets

4. Proven Programs - Programs verified on first use - No changes needed after - Stored with correct offsets

5. First-Off Verification (Not Adjustment) - Run first part - Should be within tolerance (if not, something wrong–investigate) - Verify, not adjust

Goal: Zero adjustments during setup

Reality: May need 1-2 minor tweaks, but not 10+ iteration loops

---

24.6.5 SMED for CNC Machines

CNC-Specific Setup Reduction

24.6.5.1 Workholding Optimization

Fixture Changeover Often the Longest Step

Quick-Change Fixture Plates:

System: - Master plate bolted to table (permanent) - Grid of holes or slots - Subplates attach quickly (pins + clamps) - Fixtures mounted on subplates

Setup: - Fixtures pre-mounted on subplates offline - Subplate + fixture as unit - Quick-change to table master plate - **Changeover: 1-2 minutes**

Common Systems: - Erowa - System 3R - Chick - Lang - 5th Axis

Tombstone Fixtures: - Multiple setups on one tombstone - Rotate to different faces - Pre-load all faces - Run continuously, minimal changeover

Hydraulic/Pneumatic Workholding: - Push-button clamping - Consistent force - Fast - Integrate with machine control

24.6.5.2 Tool Presetting

Tool Length Presetting Eliminates Adjustment

Tool Presetter Machine: - Optical or contact measurement - Set tool lengths offline - Record in tool library - Transfer to CNC control

Workflow:

External (Offline): 1. Assemble tools per setup sheet 2. Measure each tool on presetter 3. Record lengths and diameters 4. Kit tools in holder/tray 5. Generate tool list for CNC

Internal (At Machine): 1. Load tools from kit into magazine 2. Load tool list into control 3. Tools ready, no touching off 4. Run part (should be good!)

Time Savings: - Traditional touch-off: 15-30 min - Presetter method: 2 min (load tools) - **Saves 13-28 minutes per setup**

Quality Improvement: - Accurate measurement - First part right - Consistent

Investment: - Tool presetter: $5,000-$50,000 - ROI usually < 1 year

24.6.5.3 Program Standardization

Program Management for Quick Setups

Standardize Formats: - Common structure across programs - Standard sub-routines - Consistent naming - Templates for new programs

Offsets and Work Coordinates: - Fixture in standard position - Work offset (G54, etc.) predefined - Recall program, offsets already set

Program Storage: - USB drive at each machine - Network folder access - Cloud storage - Organized by part number

Program Verification: - Simulate before first use - Verify offsets - Proven programs don't change - Version control

Quick Loading: - Copy from USB (seconds) - Network transfer - DNC (Direct Numerical Control) - No typing code at machine

24.6.5.4 First-Off Inspection Strategies

First Part Inspection Can Take 10-20 Minutes

Optimize:

1. In-Process Inspection: - Critical dimensions checked during run - Catch errors early - Less to measure at end

2. Inspection at Machine: - Gages stored at machine - Operator does inspection - No wait for QC

3. Reduced Inspection: - Proven setups = sample only - Not every dimension every time - Risk-based inspection

4. Go/No-Go Gages: - Faster than measurement - Pass/fail decision - Eliminate recording

5. Automated Inspection: - Probe in machine - Automatic measurement - Immediate feedback

6. Standard Work for Inspection: - Checklist of critical dimensions - Documented method - Consistent

---

24.6.6 Measuring and Sustaining SMED Results

Measurement

Track Setup Times: - Before SMED (baseline) - After each improvement - Ongoing (sustain)

Metrics:

Setup Time: - Minutes per changeover - Trend over time - Target: < 10 minutes

Setup Efficiency: - Setup time as % of available time - Lower = more production time

Batch Size: - Parts per run (should decrease) - As setup time drops, batch size can drop

Inventory: - WIP levels (should decrease) - Result of smaller batches

Lead Time: - Order to delivery (should decrease) - Smaller batches flow faster

Sustaining

Challenges: - Drift back to old ways - New employees not trained - Changes not documented

Sustain Strategies:

1. Standard Work: - Document improved setup method - Photos, checklists - Training material - Update as improved further

2. Training: - Train all operators - Practice setups - Certify competency

3. Visual Management: - Setup time displayed - Target vs. actual - Trend chart

4. Audits: - Periodically observe setups - Verify standard work followed - Identify drift

5. Continuous Improvement: - Setup time in Kaizen events - Operator ideas - Incremental improvements - Never stop reducing

Example: Setup Time Board

```
+----------------------------------+
|  CNC CELL 3 - SETUP TIMES        |
|                                  |
|  Target: < 8 minutes             |
|                                  |
|  This Week:                      |
|  Mon: 7.5 min  [check]                |
|  Tue: 9.2 min  ✗ (Why?)          |
|  Wed: 7.0 min  [check]                |
|  Thu: 6.8 min  [check]                |
|  Fri: 7.3 min  [check]                |
|                                  |
|  Average: 7.6 min  [check]            |
|                                  |
|  Ideas for Improvement:          |
|  - Pre-kit all setups            |
|  - Add second presetter          |
+----------------------------------+
```

Summary

Single Minute Exchange of Dies (SMED) reduces setup time to single digits (< 10 minutes), enabling small batches, flexibility, and reduced inventory. The three-step methodology–separate internal/external setup, convert internal to external, streamline all activities–achieves dramatic reductions (50-95% common).

CNC-specific SMED techniques include quick-change fixtures, tool presetting, program standardization, and optimized first-off inspection. SMED requires discipline to sustain: standard work, training, visual management, and continuous improvement.

Quick changeovers are foundational to Lean manufacturing, enabling pull systems, heijunka, and one-piece flow.

Key Takeaways

1. **SMED goal**: Setup time < 10 minutes (single-digit)
2. **Three steps**: Separate internal/external, convert internal to external, streamline all
3. **Internal setup**: Must be done while machine stopped
4. **External setup**: Can be done while machine running
5. **30-50% of setup** is typically external but done as internal
6. **Quick-change fixtures** reduce bolt-changing from minutes to seconds
7. **Tool presetting** eliminates adjustment time (15-30 min savings)
8. **Eliminate adjustments** through pre-setting, fixed positions, standardization
9. **Video analysis** is most powerful SMED tool
10. **Small batches** enabled by SMED reduce inventory, lead time, improve flexibility

---

Review Questions

1. What does SMED stand for and what is the goal?
2. Explain the difference between internal and external setup
3. What are the three steps of SMED methodology?
4. Why are adjustments such a big time waster in setups?
5. How does tool presetting reduce setup time?
6. What is a quick-change fixture system?
7. List 5 wastes commonly found in traditional setups
8. Why is video analysis valuable for SMED?
9. How does SMED enable small batch sizes?
10. What metrics should you track to measure SMED success?

Practical Exercise: SMED Project

Conduct a SMED improvement project on a CNC machine:

Phase 1: Current State 1. Select a common setup (typical product change) 2. Video record the complete setup (start = last good part previous job, end = first good part new job) 3. Document each step with timestamp and description 4. Calculate total setup time

Phase 2: Analysis 5. Watch video with team, identify: - Internal vs. external activities - Waste (searching, walking, waiting, adjusting) - Improvement opportunities 6. Create list of improvements (brainstorm) 7. Classify improvements by impact/effort

Phase 3: Implementation 8. Implement quick wins first (external work, kitting, etc.) 9. Implement quick-change solutions (fixture, tools) 10. Develop standard work for new method 11. Train operators

Phase 4: Validation 12. Video record improved setup 13. Compare times (before/after) 14. Calculate % reduction 15. Identify next improvements (continuous)

Deliverables: - Before/after videos - Setup time comparison (steps and total) - Standard work document for new setup - Visual aids created (checklists, photos, labels) - Savings calculation (time × machine rate)

Module 24 - L.E.A.N. Strategies for CNC Manufacturing

24.7.1 TPM Philosophy and Objectives

Total Productive Maintenance (TPM) is a holistic approach to equipment maintenance that strives to achieve perfect production with no breakdowns, defects, or accidents.

Philosophy

Core Belief: Equipment operators are the first line of defense for equipment health.

Traditional Maintenance: - Operators operate, maintenance fixes - "Not my job to maintain equipment" - Reactive: fix when broken - Maintenance department owns all maintenance

TPM Philosophy: - Operators perform daily maintenance - Everyone responsible for equipment health - Proactive: prevent breakdowns - Shared ownership: operators + maintenance

Quote from Japan Institute of Plant Maintenance: *"TPM involves everyone in the company, from top management to front-line operators, in equipment improvement. It creates a culture where all employees take pride in maintaining their workplace and equipment."*

Objectives

Perfect Production:

Zero Breakdowns: - Equipment runs reliably - No unplanned downtime - Predictable production

Zero Defects: - Equipment produces quality parts - No equipment-related defects - Process capability maintained

Zero Accidents: - Safe equipment operation - No injuries from equipment - Hazards eliminated

Zero Waste: - No scrap from equipment issues - Efficient operation - Minimal energy, materials waste

Maximize OEE (Overall Equipment Effectiveness): - World-class goal: 85%+ OEE - Focus on the "Six Big Losses" - Continuous improvement

---

24.7.2 The Six Big Losses

Equipment losses that reduce OEE:

Loss Categories

1. Downtime Losses (Availability):

1. Breakdowns (Equipment Failure): - Unplanned stops - Equipment malfunction - Component failure - Result: No production

Example: Spindle bearing failure stops CNC machine for 8 hours

2. Setup and Adjustments: - Changeover time - Warmup time - Calibration - Result: Planned downtime

Example: 45-minute setup between jobs

2. Speed Losses (Performance):

3. Small Stops and Idling: - Minor stoppages < 5 minutes - Jams, misfeeds - Sensor trips - Clearing chips - Result: Frequent interruptions

Example: Chip bird nest stops machine 3 min, happens 10× per shift

4. Reduced Speed: - Running slower than design speed - Not optimal parameters - Wear/aging equipment - Result: Lower output

Example: CNC capable of 200 IPM rapids but running at 150 IPM due to vibration

3. Quality Losses (Quality):

5. Startup Defects (Process Defects): - Defects during startup/warmup - Setup-related defects - First-off scrap - Result: Scrap + rework time

Example: First 3 parts after setup out of tolerance

6. Production Defects: - Defects during normal operation - Equipment-caused defects (not design) - Tool wear, calibration drift - Result: Scrap + rework time

Example: Part dimension drift due to spindle thermal growth

Impact

Six Big Losses typically account for: - 5-20% for breakdowns - 1-10% for setup/adjustments - 2-10% for small stops - 2-15% for reduced speed - 1-5% for startup defects - 1-5% for production defects

Total Loss: 15-50% of potential production!

TPM Goal: Eliminate or minimize all six losses.

24.7.3 Overall Equipment Effectiveness (OEE)

OEE is the metric for TPM success.

Definition

OEE = Availability × Performance × Quality

OEE measures how effectively equipment is utilized when scheduled to run.

24.7.3.1 Availability

Availability: Percentage of scheduled time equipment actually runs.

Formula:

Availability = Operating Time ÷ Planned Production Time

Where: - **Planned Production Time** = Available time - planned downtime (breaks, meetings) - **Operating Time** = Planned time - downtime (breakdowns, setups)

Example: - Shift: 8 hours = 480 minutes - Breaks: 30 minutes (planned) - **Planned Production Time: 450 minutes** - Breakdown: 45 minutes - Setup: 30 minutes - **Operating Time: 450 - 45 - 30 = 375 minutes**

Availability = 375 ÷ 450 = 83.3%

Losses affecting Availability: - Breakdowns - Setups/changeovers

24.7.3.2 Performance

Performance: Speed efficiency–running at design cycle time.

Formula:

Performance = (Ideal Cycle Time × Parts Produced) ÷ Operating Time

Where: - **Ideal Cycle Time** = Design/nameplate speed - **Parts Produced** = Total output - **Operating Time** = From availability calc

Example: - Ideal cycle time: 1.5 minutes/part - Parts produced: 200 - Operating time: 375 minutes

Performance = (1.5 × 200) ÷ 375 = 300 ÷ 375 = 80%

Losses affecting Performance: - Small stops (reduce effective time) - Reduced speed (longer cycle time)

24.7.3.3 Quality

Quality: Percentage of good parts (no defects, no rework).

Formula:

Quality = Good Parts ÷ Total Parts Produced

Example: - Total parts produced: 200 - Scrap: 5 parts - Rework: 3 parts - Good parts: 200 - 5 - 3 = 192

Quality = 192 ÷ 200 = 96%

Losses affecting Quality: - Startup defects - Production defects

24.7.3.4 Calculating OEE

OEE = Availability × Performance × Quality

Example (continuing from above): - Availability = 83.3% - Performance = 80% - Quality = 96%

OEE = 0.833 × 0.80 × 0.96 = 0.64 = 64%

Interpretation: Equipment produces 64% of its theoretical maximum.

36% is lost to the six big losses!

24.7.3.5 Using OEE for Improvement

OEE Benchmarks: - **< 65%:** Uncompetitive, major improvement needed - **65-75%:** Typical for many manufacturers - **75-85%:** Good, approaching world-class - **85%+:** World-class performance - **100%:** Theoretical maximum (impossible in reality)

Using OEE:

1. Baseline Measurement: - Calculate current OEE - Understand which losses largest - Prioritize improvements

2. Track Trends: - Weekly or monthly OEE - Is it improving? - Identify regression

3. Diagnose Issues:

Low Availability (Breakdowns, Setups): - Focus: Autonomous maintenance, preventive maintenance, SMED

Low Performance (Small Stops, Speed): - Focus: Root cause analysis of stops, equipment optimization

Low Quality (Defects): - Focus: Process capability, calibration, tooling

4. Set Targets: - Realistic improvement goals - Example: 64% → 70% in 6 months → 75% in 1 year

5. Drive Continuous Improvement: - Small improvements in all three areas compound - Example: 83% Avail → 90% (+7%), 80% Perf → 85% (+5%), 96% Qual → 98% (+2%) - **OEE: 64% → 75%** (17% improvement)

OEE Loss Tree Analysis:

Identify exactly where losses occur:

```
OEE: 64%
|- Availability: 83.3%
|  |- Breakdowns: 10%
|  +- Setups: 6.7%
|- Performance: 80%
|  |- Small stops: 12%
|  +- Reduced speed: 8%
+- Quality: 96%
   |- Startup defects: 2%
   +- Production defects: 2%
```

Biggest loss: Small stops (12%) → Focus here first

24.7.4 Eight Pillars of TPM

Comprehensive framework for TPM implementation:

24.7.4.1 Autonomous Maintenance

Operators take ownership of routine maintenance.

Activities: - Daily cleaning and inspection - Minor adjustments - Lubrication - Simple repairs - Problem reporting

Benefits: - Immediate response to abnormalities - Prevents deterioration - Frees maintenance for complex work - Operator engagement

Detailed in Section 24.7.5

24.7.4.2 Planned Maintenance

Maintenance department focuses on preventing failures.

Activities: - Preventive maintenance schedules - Predictive maintenance (vibration, oil analysis) - Component replacement before failure - Equipment records and history - Major overhauls

Benefits: - Fewer breakdowns - Predictable downtime (scheduled) - Longer equipment life

24.7.4.3 Quality Maintenance

Eliminate defects at the source.

Activities: - Identify equipment conditions causing defects - Set standards for those conditions - Monitor and control - Equipment-focused Kaizen

Example: - Defect: Part taper due to spindle thermal growth - Solution: Spindle warmup routine, coolant temperature control - Result: Defects eliminated

24.7.4.4 Focused Improvement

Kaizen teams tackle chronic losses.

Activities: - Cross-functional teams - Target specific losses (small stops, defects) - Root cause analysis - Implement countermeasures - Measure results

Example: - Target: Chip bird nests causing small stops - Team: Operator, maintenance, engineering - Countermeasure: High-pressure coolant, chip conveyor improvement - Result: Small stops reduced 80%

24.7.4.5 Early Equipment Management

Design maintainability into new equipment.

Activities: - Involve operators/maintenance in equipment selection - Specify maintainability requirements - Learn from existing equipment issues - Commission new equipment properly

Benefits: - Avoid repeating past mistakes - Faster ramp-up - Lower lifecycle cost

24.7.4.6 Training and Education

Develop skills for TPM.

Activities: - Operator training (autonomous maintenance skills) - Maintenance training (advanced diagnostics) - Problem-solving training (PDCA, root cause) - Cross-training

Benefits: - Competent workforce - Self-reliance - Continuous improvement capability

24.7.4.7 Safety, Health, and Environment

Integrate safety into TPM.

Activities: - Identify safety hazards - Eliminate unsafe conditions - Environmental compliance - 5S for safety

Benefits: - Zero accidents goal - Regulatory compliance - Employee well-being

24.7.4.8 TPM in Administration

Extend TPM beyond manufacturing.

Activities: - Office equipment maintenance (computers, printers) - Process efficiency (paperwork flow) - Eliminate administrative waste

Benefits: - Support manufacturing TPM - Overall organizational efficiency

---

24.7.5 Implementing Autonomous Maintenance

Seven-step process for operator-led maintenance:

Step 1: Initial Cleaning and Inspection

Goal: Clean equipment thoroughly, discover abnormalities.

Activities: - Deep clean entire machine - Remove dirt, grime, chips - Inspect while cleaning (discover hidden issues) - Tag problems (leaks, loose bolts, worn parts)

Benefits: - Baseline condition established - Hidden problems revealed (often many!) - Operators learn their equipment intimately

Time: 1-2 weeks (thorough)

Step 2: Countermeasures for Contamination Sources

Goal: Make equipment easy to clean and inspect.

Activities: - Identify contamination sources (where does dirt come from?) - Eliminate sources or contain them - Improve access for cleaning - Reduce cleaning time

Examples: - Chip shielding to contain chips - Covers over gearboxes to prevent contamination - Quick-release panels for access

Benefits: - Less contamination = less cleaning - Faster cleaning - Equipment stays cleaner longer

Step 3: Lubrication and Cleaning Standards

Goal: Document and standardize routine maintenance.

Activities: - Create cleaning standards (what, when, how) - Create lubrication standards (points, frequency, type) - Visual aids (photos, diagrams, labels) - Tools and supplies at point-of-use

Deliverable: Autonomous Maintenance Checklist

Example (daily): - [ ] Clean chip trays (5 min) - [ ] Wipe ways (3 min) - [ ] Check coolant level (1 min) - [ ] Grease X-axis slide (5 pumps) - [ ] Inspect for leaks - [ ] Check for unusual sounds/vibration

Time per day: 10-15 minutes

Step 4: General Inspection Training

Goal: Train operators to inspect equipment.**

Activities: - Classroom training (mechanical, hydraulic, pneumatic, electrical basics) - Hands-on practice on equipment - Certification

Inspections: - Visual inspection for wear, damage - Auditory (unusual sounds) - Vibration, temperature - Leaks

Benefits: - Operators detect issues early - Problems fixed before failures - Operators understand how equipment works

Step 5: Autonomous Inspection

Goal: Operators conduct regular inspections.**

Activities: - Weekly or monthly inspection checklists - More detailed than daily cleaning - Trending measurements (temperatures, pressures) - Report issues to maintenance

Example monthly inspection: - [ ] Measure backlash (max 0.002”) - [ ] Check spindle drawbar pressure (200 psi) - [ ] Inspect tool changer for wear - [ ] Coolant concentration (8-10%) - [ ] Filter conditions

Step 6: Organization and Tidiness

Goal: Standardize workplace for TPM.**

Activities: - 5S implementation - Shadow boards for tools - Labeled storage - Visual controls

Benefits: - Support autonomous maintenance - Easy to find supplies - Workplace pride

Step 7: Full Autonomous Maintenance

Goal: Continuous improvement of maintenance.**

Activities: - Operators fully self-reliant for routine maintenance - Continuous improvement of standards - Sharing best practices - Innovation

Characteristics: - Equipment always clean - Standards always followed - Problems solved immediately - Operators take pride in equipment

Result: Cultural Change

Operators see themselves as equipment owners, not just users.

24.7.6 TPM for CNC Machines

CNC-Specific TPM Considerations:

Daily Autonomous Maintenance

Cleaning: - Chip removal from work area - Clean windows, covers - Wipe coolant spills - Clean chip conveyor

Inspection: - Visual check for leaks (hydraulic, coolant, lube oil) - Listen for unusual sounds - Check coolant level and concentration - Check tool changer operation

Lubrication: - Automatic systems: Check reservoir levels - Manual points: Grease slides, ways per schedule

Time: 10-15 minutes daily

Weekly Autonomous Maintenance

Deeper Cleaning: - Clean coolant tank, remove settled chips - Wash chip conveyor - Clean machine exterior

Inspection: - Check accuracy (test cut or touch-off) - Tool holder tapers (clean and inspect) - Drawbar force (if measurable) - Air pressure

Time: 30-60 minutes weekly

Monthly Maintenance

Operator-Performed: - Filter changes (coolant, air) - Coolant concentration adjustment - Lubrication system check - Backup battery check

Maintenance Department: - Detailed inspection per OEM schedule - Calibration checks - Preventive part replacement (belts, filters, seals) - Software updates

Common CNC Issues Prevented by TPM

Chip Buildup: - Autonomous cleaning prevents accumulation - Improves cooling, prevents jams

Coolant Issues: - Regular maintenance prevents bacteria, foam - Maintains concentration (tool life, finish)

Lubrication Failures: - Prevents way wear, backlash - Extends machine life

Hydraulic Leaks: - Early detection prevents major failures - Cleaner workplace

Spindle Issues: - Proper warmup reduces thermal drift - Monitoring prevents catastrophic failure

Tool Changer: - Cleaning prevents stuck tools - Inspection catches wear before failure

OEE for CNC

Typical CNC OEE (without TPM): 40-60%

Availability losses: - Breakdowns: Hydraulic failures, electronics, spindle - Setups: Can be significant (SMED helps)

Performance losses: - Small stops: Chip bird nests, tool magazine issues - Reduced speed: Fear of vibration, crashes

Quality losses: - Startup defects: Thermal growth, setup errors - Production defects: Tool wear, machine drift

With TPM + SMED: 75-85% OEE achievable

Summary

Total Productive Maintenance (TPM) maximizes equipment effectiveness through operator-involved maintenance, eliminating the Six Big Losses. OEE (Overall Equipment Effectiveness) measures success: Availability × Performance × Quality. World-class OEE is 85%+.

The Eight Pillars of TPM provide a comprehensive framework, with Autonomous Maintenance as the foundation. Operators perform daily cleaning, inspection, and minor maintenance, preventing failures and defect deterioration. The seven steps develop operator capabilities progressively, from initial cleaning to full autonomous maintenance.

For CNC machines, TPM focuses on chip management, coolant maintenance, lubrication, and early detection of wear. Combined with SMED, TPM dramatically improves OEE from typical 40-60% to world-class 75-85%.

Key Takeaways

1. **TPM philosophy**: Operators own routine maintenance, maintenance owns complex work
2. **Six Big Losses**: Breakdowns, setups, small stops, reduced speed, startup defects, production defects
3. **OEE** = Availability × Performance × Quality (world-class: 85%+)
4. **Eight Pillars** provide comprehensive TPM framework
5. **Autonomous Maintenance**: Seven-step implementation from cleaning to full self-reliance
6. **Daily maintenance**: 10-15 minutes by operator prevents breakdowns
7. **Early detection** of issues prevents catastrophic failures
8. **Clean equipment** = healthy equipment = better performance
9. **CNC TPM** focuses on chips, coolant, lubrication, accuracy
10. **Cultural change**: Operators become equipment owners, not just users

---

Review Questions

1. What is the TPM philosophy regarding operators and maintenance?

2. List the Six Big Losses and categorize by Availability, Performance, Quality
3. Calculate OEE: Availability = 88%, Performance = 82%, Quality = 97%
4. What are the Eight Pillars of TPM?
5. Describe the seven steps of Autonomous Maintenance implementation
6. Why is initial cleaning important in TPM?
7. What daily autonomous maintenance should a CNC operator perform?
8. How does TPM differ from traditional "fix when broken" maintenance?
9. What is considered world-class OEE?
10. How does TPM support Lean manufacturing (JIT, pull systems)?

Practical Exercise: CNC TPM Implementation

Implement autonomous maintenance for one CNC machine:

Phase 1: Baseline (Week 1) 1. Calculate current OEE (1 week of data) - Track all downtime (breakdown, setup, small stops) - Track parts produced, cycle time - Track quality (scrap, rework) 2. Calculate Availability, Performance, Quality, OEE

Phase 2: Initial Cleaning (Week 2) 3. Perform deep cleaning with operator - Remove all chips, dirt, coolant residue - Clean every accessible surface 4. Tag all abnormalities found - Leaks, loose parts, wear, damage 5. Create list of issues to address

Phase 3: Standards (Week 3-4) 6. Develop daily autonomous maintenance checklist - Cleaning tasks (specific, with time estimates) - Inspection points - Lubrication points 7. Create visual aids - Photos of correct condition - Labeled lubrication points - Laminated checklist at machine

Phase 4: Training (Week 5) 8. Train operator on checklist - Demonstrate each task - Operator practice under supervision - Certify competency

Phase 5: Sustain (Ongoing) 9. Operator performs daily autonomous maintenance 10. Audit weekly (verify checklist followed) 11. Track OEE (compare to baseline) 12. Continuous improvement (update standards)

Deliverables: - Before/after OEE comparison - Autonomous maintenance checklist (laminated at machine) - Visual aids (photos, labels) - List of issues found during initial cleaning - Training record - 3-month OEE trend

---

Module 24 - L.E.A.N. Strategies for CNC Manufacturing

24.8.1 Cell Design Principles

Manufacturing Cell: A group of workstations, machines, or processes arranged in a sequence to produce a product or family of products with minimal material handling and waiting.

Core Concept

Traditional Layout (Functional/Process):

```
All Lathes    All Mills    All Grinders    Assembly
[L][L][L]     [M][M][M]    [G][G][G]      [A][A][A]
    ↓              ↓             ↓              ↓
 Parts travel long distances between departments
 Large batches, high WIP, complex scheduling
```

Cellular Layout (Product/Flow):

```
Cell 1 (Shaft Family):        Cell 2 (Housing Family):
L → M → G → A                  M → D → T → A
(Lathe, Mill, Grind, Assy)    (Mill, Drill, Tap, Assy)
    ↓                              ↓
 Parts flow through cell with minimal movement
 Small batches or one-piece flow, low WIP
```

Key Principles

1. Product Family Focus: - Cell dedicated to specific product family - Similar processing requirements - Common routing sequence

2. Process Completeness: - All operations needed for product family - Minimal handoffs to other areas - "One-stop shop" for that family

3. Spatial Proximity: - Machines close together (feet, not yards) - Minimize walking and material handling - Facilitates communication

4. Flow Orientation: - Equipment arranged in processing sequence - Linear or U-shaped flow - No backtracking

5. Operator Flexibility: - Multi-process handling (one operator, multiple machines) - Cross-trained workers - Variable staffing based on demand

6. Built-In Quality: - Inspection integrated into cell - Immediate feedback on defects - Self-inspection by operator

7. Visual Management: - Status visible at a glance - Kanban signals - Performance metrics displayed

---

24.8.2 Benefits of Manufacturing Cells

Lead Time Reduction

Before Cells (Functional Layout): - Part travels between departments - Queue time at each operation - Typical lead time: Days to weeks

After Cells: - Part flows through cell continuously - Minimal queue time - Lead time: Hours to days (or minutes!)

Example: - Functional layout lead time: 12 days - Cellular layout lead time: 1 day - **92% reduction!**

Inventory Reduction

Before Cells: - Large batches (justify setup, transportation) - WIP everywhere (between operations, departments) - High inventory carrying costs

After Cells: - Small batches or one-piece flow - Minimal WIP (only what's in process) - Low inventory

Example: - Functional WIP: 500 pieces - Cellular WIP: 20 pieces - **96% reduction!**

Quality Improvement

Before Cells: - Defects discovered days after creation - Large batch affected - Difficult to determine root cause (time lag)

After Cells: - Defects discovered immediately (next operation) - Small quantity affected - Easy root cause analysis (just happened) - Quick corrective action

Example: - Functional defect rate: 3% - Cellular defect rate: 0.5% - **83% improvement!**

Flexibility

Before Cells: - Large batches = committed to product for long time - Changeovers complex (entire department) - Slow response to customer changes

After Cells: - Small batches = quick product changes - Changeovers localized (one cell) - Fast response to demand

Space Utilization

Before Cells: - Equipment spread across facility - Wide aisles for material handling - Storage areas for WIP

After Cells: - Compact footprint (operations close) - Minimal aisles (hand-off vs. forklift) - Little WIP storage needed

Typical space reduction: 30-50%

Employee Engagement

Before Cells: - Single-task jobs (boring, repetitive) - No ownership (just one step of many) - Disconnect from final product

After Cells: - Multi-tasking (variety, interesting) - Cell ownership (team responsible for output) - See complete product (satisfaction)

Result: Higher morale, lower turnover

Simplified Scheduling

Before Cells: - Schedule each operation independently - Complex MRP/ERP - Expediting common

After Cells: - Schedule cell (one point) - Simple pull system - Self-regulating flow

---

24.8.3 Cell Layout Options

24.8.3.1 U-Shaped Cells

Most common and versatile cell design.

Configuration:

```
 Inlet ↓                    ↑ Outlet
     +-------------------+
     |                   |
Op1  |                   |  Op5
     |    Operator       |
Op2  |    walks in       |  Op4
     |    center         |
Op3  +-------------------+
```

Characteristics:

Inlet/Outlet Close Together: - Easy material delivery - Easy finished goods pickup - Communication with upstream/downstream - Supervisor visibility

Operator in Center: - Short walking distances - Can see all machines - Hear problems (audio feedback) - Efficient movement

Compact Footprint: - Minimal space - All operations visible - Team communication easy

Flexibility: - Add/remove operators based on demand - 1 operator for low volume - 2-3 operators for high volume

Benefits: - Shortest walking distance - Best communication - Most flexible staffing - Highest quality (visibility)

When to Use: - Most applications - 3-8 operations - Multi-process handling - Variable demand

24.8.3.2 L-Shaped Cells

Variation when space or operations dictate.

Configuration:

```
 Inlet ↓
     +-----------+
Op1  |           |
     |           |
Op2  |           |
     |           |
Op3  |           +------------+
     |                        |
     |  Operator              |  Op5
```

```
|  workspace            |
|                       |  Op4
|                       |
+-----------------------+
                    ↑ Outlet
```

When to Use: - Space constraints (corner location) - Fewer operations (3-5) - Operations physically separate naturally - Existing building limitations

Trade-offs: - Longer walking than U - Inlet/outlet not as close - Still better than straight line

24.8.3.3 Straight-Line Cells

Linear arrangement of operations.

Configuration:

```
Inlet → [Op1] → [Op2] → [Op3] → [Op4] → [Op5] → Outlet

         Operator walks linear path
```

When to Use: - Large parts (not easily turned) - Heavy parts (crane/conveyor moves) - Very few operations (2-3) - Paced line (automotive-style)

Benefits: - Simple flow (easy to understand) - Good for large/heavy parts - Can use conveyors

Drawbacks: - Longest walking distance - Inlet/outlet far apart - Less flexible staffing - More space required

Variations:

Serpentine (Folded Straight):

```
Inlet → [Op1] → [Op2] → [Op3]
                          ↓
               [Op6] ← [Op5] ← [Op4]
                 ↓
               Outlet
```

- Saves space vs. pure straight
- Inlet/outlet closer

24.8.4 Multi-Process Handling

One operator managing multiple machines/processes.

Concept

Traditional (One Operator, One Machine): - Operator loads part - Waits while machine runs - Unloads part - **Operator utilization: 30-40%** (rest is waiting)

Multi-Process Handling: - Operator loads machine 1, starts cycle - While machine 1 runs, operator works on machine 2 - While machine 2 runs, operator works on machine 3 - Returns to machine 1 (cycle complete), unloads - Continuous loop

Operator utilization: 80-90%

Walking Pattern

U-Cell Example (3 machines):

```
Material In
     ↓
[Machine 1]
     ↓ (operator walks)
[Machine 2]
     ↓ (operator walks)
[Machine 3]
     ↓ (operator walks back to Machine 1)
[Machine 1] (cycle complete, unload/reload)
     ↓
Parts Out
```

Operator Loop Time = Sum of manual work at each machine

Balancing Multi-Process

Goal: Operator loop time <= Longest machine cycle time

Example:

Machine	Cycle Time	Manual Work (Load/Unload)
Lathe	5 min	0.5 min
Mill	7 min	1.0 min
Grind	4 min	0.5 min

Operator loop time: 0.5 + 1.0 + 0.5 + walking (0.5 min) = **2.5 min**

Longest cycle: Mill = 7 min

Result: Operator can manage 3 machines - Start lathe, walk to mill (lathe running) - Start mill, walk to grind (lathe + mill running) - Start grind, walk to lathe (all running) - Lathe done (5 min), unload/reload (lathe still has 2 min before mill done) - Mill done (7 min), unload/reload - Grind done, unload/reload - Return to lathe

Continuous flow with one operator!

When Multi-Process Doesn't Work

Operator loop time > machine cycle time: - Machines sit idle waiting for operator - Need to reduce manual work or add operator

Safety concerns: - Can't leave machines unattended - Regulatory requirements - Requires automation/guards

High-attention processes: - Manual welding, inspection - Can't multi-task

---

24.8.5 Cell Balancing and Staffing

Takt Time Balancing

Goal: Cell output matches customer demand (takt time).

Takt Time = Available time ÷ Customer demand

Example: - Available time: 450 min/day - Demand: 150 parts/day - **Takt time: 3 minutes per part**

Cell must output one part every 3 minutes.

Balancing Operations

Cell Operations:

Operation	Cycle Time	Status vs. Takt (3 min)
Op 1	2.5 min	OK (< takt)
Op 2	4.0 min	**Over takt** (bottleneck)
Op 3	1.5 min	OK
Op 4	2.0 min	OK

Op 2 is bottleneck (can't keep up with takt).

Balancing Options:

1. Improve Bottleneck: - Better tooling (reduce cycle time to 3 min or less) - Split operation (part of work to Op 1 or 3)

2. Add Capacity: - Second machine for Op 2 - Two machines feed one Op 3

3. Offload Work: - Can some of Op 2 work move to another operation?

Balanced Cell:

Operation	Revised Cycle Time
Op 1	2.8 min (added work from Op 2)
Op 2	2.9 min (improved + offloaded)
Op 3	2.2 min (added work from Op 2)
Op 4	2.0 min

All operations <= takt time = balanced

Variable Staffing

Adjust operators based on demand.

Low Demand (Takt = 6 min): - 1 operator runs entire cell - Multi-process handling - Slower pace acceptable

Medium Demand (Takt = 3 min): - 2 operators - Each handles 2-3 machines - Medium pace

High Demand (Takt = 1.5 min): - 4 operators - One per operation - Fast pace

Requires: - Cross-training (all operators can do all jobs) - Flexible workforce - Standard work for each configuration

---

24.8.6 Designing CNC Machining Cells

24.8.6.1 Equipment Selection for Cells

Right-Size Equipment:

Traditional Thinking: - Buy largest, fastest machine possible - Maximize capability - Share across many products

Cellular Thinking: - Buy machine sized for product family - Dedicated to cell - Maximize flow, not capability

Example:

Product Family: Small shafts (1-3" diameter)

Traditional: Buy large lathe (12" capacity) - Can handle anything (over-capable for shafts) - Expensive - Large footprint - Shared resource (scheduling complexity)

Cellular: Buy small lathe (4" capacity) - Right-sized for shaft family - Less expensive - Compact (fits in cell) - Dedicated (no scheduling conflict) - Faster setup (simpler)

Benefits of Right-Sizing: - Lower cost (can afford multiple smaller machines) - Smaller footprint (fits in cell) - Faster setup (simpler machines) - Dedicated (no sharing) - Easier to move (layout flexibility)

24.8.6.2 Automation in Cells

Goal: Automation supports flow, not replaces operators.

Appropriate Automation:

1. Part Loading/Unloading: - Robotic load/unload if consistent family - Frees operator for next operation - Enables multi-process handling

2. In-Process Measurement: - Probes, gages in machine - Immediate feedback - Prevents defects

3. Material Handling Between Operations: - Conveyors, chutes, gravity feed - Minimal operator effort - Continuous flow

4. Tool Changing: - Automatic tool changers (standard on CNC) - Minimizes manual tool handling

Avoid Over-Automation: - Lights-out manufacturing in cell (usually wrong) - Flexibility lost (can't handle family variation) - Very expensive - Reliability issues (complex) - Operator disengagement

Right Balance: - Automate repetitive, non-value tasks - Operator focuses on quality, problem-solving, improvement - Flexible automation (handles family variations)

24.8.6.3 Quality at the Source

Build Quality into Cell:

Poka-Yoke (Error Proofing): - Fixtures prevent incorrect loading - Sensors detect missing operations - Go/no-go gages at each operation - *Detailed in Section 24.9*

Self-Inspection: - Operator inspects own work - Gages at point-of-use - Standard work includes inspection

Immediate Feedback: - Next operation checks previous operation - Defects caught within minutes - Stop and fix immediately

Andon (Visual Alert): - Operator signals for help - Light or buzzer - Response within minutes

Statistical Process Control (SPC): - Monitor critical dimensions - Control charts at machine - Operator adjusts before drift

Result: Quality Built In, Not Inspected In

24.8.7 Cell Performance Metrics

Measure What Matters:

Cell-Level Metrics

1. Cycle Time: - Time to complete one part through entire cell - Target: <= Takt time - Daily tracking

2. Lead Time: - Time from material arrival to part completion - Target: Minimize (hours, not days) - Weekly tracking

3. WIP Inventory: - Number of pieces in cell - Target: < 1 day of production - Visual (count daily)

4. First Time Through (FTT): - Percentage passing all operations without rework - Target: 99%+ - Daily tracking

5. OEE (Overall Equipment Effectiveness): - Cell OEE (not just machine OEE) - Target: 85%+ - Weekly tracking

6. Cell Output: - Parts per day/shift - vs. Target (based on takt time) - Daily tracking

7. Changeover Time: - Cell setup time (entire cell, not just one machine) - Target: < 10 minutes (SMED) - Track each changeover

8. Safety: - Days without incident - Near-miss reporting - Continuous target: zero

Visual Performance Board

Display at Cell:

```
+---------------------------------------+
|   CELL 3 PERFORMANCE (Shaft Family)   |
|                                       |
| Target: 150 parts/day  Takt: 3 min  |
|                                       |
| Today's Output: 142 parts  (95%) [check]  |
|                                       |
| Quality (FTT): 98%  [check]                 |
| WIP: 12 pcs  [check]                        |
| OEE: 82%  (↓ from 85% - investigate) |
|                                       |
| Issues Today:                         |
| - Coolant pump failure (20 min)     |
| - Waiting for material (15 min)     |
|                                       |
| Kaizen Ideas:                         |
| - Pre-stage next job (save 5 min)   |
|                                       |
| Safety: 45 days without incident    |
+---------------------------------------+
```

Update: Hourly or by shift

24.8.8 Transitioning from Batch to Cells

Challenge: Moving from functional layout to cells is disruptive.

Implementation Approach

Phase 1: Pilot Cell (Weeks 1-8)

Select Product Family: - High volume or problem product - Manageable scope (3-5 operations) - Team capability

Design Cell: - Map current state (functional layout) - Design future state (cell layout) - Simulate/test on paper

Implement: - Move equipment (might be weekend) - Connect utilities - Test operation

Prove Concept: - Run for 4-8 weeks - Measure results vs. functional - Refine

Phase 2: Expand (Months 3-6)

Document Success: - Lead time reduction - Inventory reduction - Quality improvement - Use data to build support

Second Cell: - Another product family - Apply lessons learned - Faster implementation

Third Cell: - Continue expansion - Build momentum

Phase 3: Full Implementation (Months 6-18)

Multiple Cells Operating: - Most product families in cells - Remaining equipment in functional area (shared resources) - Organization transformed

Common Challenges

Resistance to Change: - "We've always done it this way" - Fear of job loss - Comfort with current state

Solution: Involve operators early, communicate benefits, no-layoff commitment

Equipment Moving Costs: - Rigging, electrical, install - Can be expensive

Solution: Start with pilot (prove ROI first), phase approach

Shared Resources: - Some equipment serves multiple families (heat treat, painting) - Can't dedicate to one cell

Solution: Supermarket before/after shared process, pull system

Balancing: - Difficult to balance all operations perfectly - Some operations slower/faster

Solution: Continuous improvement, flexibility, accept imperfection initially

Training: - Operators need multi-skilling - Takes time to cross-train

Solution: Training plan, pair experienced with new, patience

Typical Results

Pilot Cell (4-8 weeks): - Lead time: 50-70% reduction - WIP: 60-80% reduction - Quality: 30-50% improvement - Space: 20-40% reduction

Full Implementation (12-18 months): - Lead time: 70-90% reduction - Inventory: 50-75% reduction - Quality: 50-80% improvement - Productivity: 20-40% improvement

ROI: Typically < 12 months

Summary

Cellular manufacturing groups operations by product family in close proximity for continuous flow. U-shaped cells are most common, enabling short walking distances and flexible staffing. Multi-process handling allows one operator to manage multiple machines efficiently.

Cells deliver dramatic improvements: 50-90% lead time reduction, 60-80% inventory reduction, 30-50% quality improvement. Cell performance metrics focus on flow (cycle time, WIP) rather than traditional efficiency. Transitioning from functional layout to cells should be phased: pilot cell first, prove results, then expand.

CNC machining cells use right-sized equipment, appropriate automation, and built-in quality. The result is faster response, lower inventory, better quality, and higher employee engagement.

Key Takeaways

1. **Cells** group operations by product family for flow vs. functional layout by process type
2. **U-shaped cells** offer shortest walking, best communication, most flexible staffing
3. **Multi-process handling** enables one operator to manage multiple machines (80-90% utilization)
4. **Lead time reduction** of 50-90% typical when transitioning to cells
5. **Balance to takt time** ensures cell meets customer demand
6. **Right-size equipment** for product family, not maximum capability
7. **Quality built in** through poka-yoke, self-inspection, immediate feedback
8. **Visual metrics** displayed at cell (output, quality, WIP, OEE)
9. **Pilot approach** proves concept before full implementation
10. **Employee engagement** increases with multi-tasking and cell ownership

---

Review Questions

1. What is a manufacturing cell and how does it differ from functional layout?
2. Draw a U-shaped cell and explain why inlet/outlet are close together
3. Explain multi-process handling with an example
4. How do you balance a cell to takt time?
5. What are the benefits of right-sizing equipment for cells?
6. Why is U-shaped preferred over straight-line for most cells?
7. Calculate: Takt time = 4 min, operations are 3.5, 5, 2, 3 min. Is the cell balanced?
8. What metrics should be displayed at a cell?
9. What is the recommended approach for transitioning to cells (pilot vs. all at once)?
10. List 5 benefits of cellular manufacturing

Practical Exercise: Design a CNC Cell

Design a manufacturing cell for a product family:

Given Product Family: Small Housings - Demand: 120 parts/day - Available time: 450 min/day - Operations: Mill roughing (4 min), Mill finishing (3 min), Drill (2 min), Tap (2 min), Deburr (1.5 min)

Tasks:

1. **Calculate Takt Time**
    - Show calculation
    - Interpret (what does it mean?)
2. **Evaluate Balance**
    - Is each operation <= takt time?
    - Identify bottleneck if any
    - Propose solutions for bottleneck
3. **Design Cell Layout**

    - Sketch U-shaped cell
    - Show equipment positions
    - Show material flow (inlet to outlet)
    - Indicate operator walking path
4. **Multi-Process Analysis**
    - Can one operator manage all operations?
    - Calculate operator loop time (manual work + walking)
    - Compare to longest cycle time
5. **Metrics**
    - What metrics will you track?
    - Design visual performance board (sketch)
6. **Implementation Plan**
    - List equipment needed
    - Estimate space requirements
    - Identify training needed
    - Estimate implementation time

Deliverables: - Takt time calculation - Cell layout sketch - Operator work analysis - Performance board design - Implementation plan

---

Module 24 - L.E.A.N. Strategies for CNC Manufacturing

24.9.1 Principles of Error Proofing

Poka-Yoke (Japanese: □ □ □ □) means "mistake-proofing" or "inadvertent error prevention."

Literal translation: - **Poka** = inadvertent mistake - **Yoke** = prevention

Philosophy

Developed by Shigeo Shingo at Toyota in the 1960s.

Core Principle: Humans make mistakes. Rather than blame people, design processes and equipment to prevent mistakes or detect them immediately.

Traditional Approach: - Train operators to be careful - Inspect to catch errors - Blame people when errors occur - "Pay more attention!"

Poka-Yoke Approach: - Assume mistakes will happen - Design to prevent mistakes - Or detect immediately (100% automatic inspection) - Blame the process, not the person

Shingo's Insight: *"Inspection finds defects. Poka-yoke prevents defects."*

The Goal

Zero Defects through defect prevention, not defect detection.

Hierarchy of Effectiveness:

Level 1: Eliminate (Best): - Design out the possibility of error - Error cannot physically occur - **Example:** Part can only fit in fixture one way (incorrect orientation impossible)

Level 2: Prevent (Better): - Detect condition leading to error - Stop process before error occurs - **Example:** Sensor ensures blank is present before machining starts

Level 3: Detect (Good): - Detect error immediately after it occurs - Prevent error from moving downstream - **Example:** Go/no-go gage after operation rejects out-of-spec parts

Level 4: Inspect (Least Effective): - Traditional inspection - Finds errors but doesn't prevent them - Waste (cost of inspection + cost of defects)

Goal: Levels 1-2 (Eliminate or Prevent)

Key Characteristics

Simple: - Low-cost solutions - Mechanical, not complex electronics - Easy to understand and maintain

Reliable: - Works every time - Fail-safe design - Doesn't depend on human memory

Immediate: - Feedback instantaneous - No delay between error and detection - Prevents propagation

100% Inspection: - Checks every part, every time - Not sampling - Automatic (no human effort)

24.9.2 Types of Poka-Yoke

24.9.2.1 Prevention (Control)

Control Poka-Yoke: Makes error impossible.

Mechanism: - Physical design prevents incorrect action - Error cannot occur - Most effective type

Examples:

1. Asymmetric Design: - USB connector (only inserts one way) - Automotive gas cap (diesel nozzle won't fit gas tank) - Electrical plugs (3-prong polarized)

Manufacturing Example: - Fixture with asymmetric locating pins - Part can only be loaded one orientation - Loading backwards physically impossible

2. Guide Pins/Locating Features: - Large pin and small pin (different diameters) - Part has matching holes - Prevents incorrect part installation

3. Interlock: - Machine won't start unless guards closed - CNC door interlock (spindle stops if door opens) - Prevents unsafe operation

4. Limit Switches: - Detect presence/absence before proceeding - Part present? Proceed. Part absent? Stop. - Prevents machining air

5. Sequencing: - Steps must occur in order - Can't skip a step - **Example:** Program requires tool change sequence (can't run Op 2 tools without Op 1 completion)

24.9.2.2 Detection (Warning)

Warning Poka-Yoke: Detects error and alerts operator.

Mechanism: - Error detected after occurrence - Signal (light, buzzer) alerts operator - Operator must respond

Less Effective than Control: - Error has occurred (though detected quickly) - Relies on operator response - But still valuable when prevention not feasible

Examples:

1. Sensors with Alarms: - Part dimensionally out of spec detected by gage - Red light and buzzer - Operator stops, investigates

2. Count Verification: - Operation requires 4 bolts - Counter ensures 4 bolt-tightening cycles - Alarm if count != 4

3. Andon (Signal Lights): - Green = normal - Yellow = attention needed - Red = stop/problem - Visual status at a glance

4. Inspection Stations: - Automated 100% inspection after operation - Rejects defects immediately - Prevents defects going downstream

5. Checklists with Verification: - Setup checklist requires sign-off - Each item verified before proceeding - Ensures no steps skipped

---

24.9.3 Poka-Yoke Methods

24.9.3.1 Contact Methods

Physical contact or measurement detects error.

Techniques:

1. Presence/Absence Detection: - Sensor detects if part present - Photoelectric, proximity, limit switch - **Example:** Photoelectric beam across fixture–if unbroken (no part), machine won’t start

2. Dimension Detection: - Gage measures critical dimension - In-tolerance: proceed. Out-of-tolerance: stop. - **Example:** Post-process gage rejects parts >0.505” diameter

3. Position Detection: - Sensor confirms correct position - **Example:** Limit switch confirms vise fully closed before machining

4. Shape/Feature Detection: - Sensor verifies feature presence - **Example:** Vision system confirms hole drilled

Examples in CNC:

Tool Presence Detection: - Spindle tool sensor confirms tool loaded - Prevents running program with missing tool - Avoids crash

Part Loaded Detection: - Pressure switch in vise/clamp - Confirms part clamped before machining - Prevents machining air or loose part

Workpiece Material Verification: - RFID tag on material - Scanner confirms correct material before machining - Prevents wrong material errors

24.9.3.2 Fixed-Value Methods

Specific count or fixed quantity prevents error.

Techniques:

1. **Counting:** - Process requires fixed number of actions - Counter ensures correct quantity - **Example:** Assembly requires 6 screws; counter ensures 6 tightening cycles

2. **Checklists:** - Fixed number of items - All must be checked - **Example:** Setup checklist with 10 items; can't start until all 10 checked

3. **Kitting:** - Exact quantity of components in kit - Empty kit = all used correctly - Extra parts = error (missing installation)

4. **Part Dispensers:** - Dispenses exact quantity needed - One part per button press - **Example:** Fastener dispenser gives exactly 4 bolts (for 4-bolt assembly)

Examples in CNC:

Tool Kitting: - Pre-staged tool kit for job - Exact tools needed, no more - Kit empty at end = all tools used

Operations Counter: - Program cycles counter - Requires specific number of tool changes - Mismatch = error (skipped operation or extra)

Parts per Kanban: - Container holds exact quantity (25 parts) - Full container = 25 parts (no more, no less) - Over/under fill obvious

24.9.3.3 Motion-Step Methods

Correct motion or sequence required.

Techniques:

1. **Sequence Enforcement:** - Steps must occur in order - Can't skip or reverse - **Example:** Fixture requires base clamped before top clamp can engage

2. **Motion Detection:** - Sensor confirms motion occurred - **Example:** Rotation sensor confirms part rotated for second-side machining

3. **Path Verification:** - Ensures correct path taken - **Example:** Guide rails force part along correct path through cell

4. **Standard Work Enforcement:** - Visual or physical cues ensure correct sequence - **Example:** Color-coded steps (do red, then yellow, then green)

Examples in CNC:

Sequential Operations: - Fixture interlock requires Op 1 locator removed before Op 2 locator installed - Prevents attempting Op 2 in Op 1 position

Two-Hand Controls: - Require both hands to start cycle - Prevents hands in danger zone

Probe Cycle Verification: - Program requires probe cycle before machining - Confirms work offset set - Prevents incorrect Z-height machining

---

24.9.4 Poka-Yoke in CNC Manufacturing

24.9.4.1 Fixture Error Proofing

Most Common CNC Errors: Part Loaded Incorrectly

Solutions:

1. Asymmetric Locating: - Locating pins of different sizes - Part has matching holes - Can only load one way - **Eliminates orientation errors**

Example:

```
Fixture Base:     Part:
  ●                 ○ (fits large pin)
    ○                 ○ (fits small pin)
```

Part can only fit with large hole over large pin.

2. Nesting (Enveloping): - Fixture closely matches part shape - Part nests into fixture - Incorrect part won't fit - **Eliminates wrong part errors**

Example: Housing fixture shaped exactly like housing exterior. Similar part (wrong p/n) won't nest correctly.

3. Positive Stops: - Hard stops for part positioning - Repeatable location - No adjustment needed - **Eliminates position errors**

4. Clamp Interlock: - Clamp can only close if part present and correct - Pressure switch confirms clamping force - **Prevents machining unclamped part**

5. Color Coding: - Part family color matched to fixture color - Visual confirmation (red part □ red fixture) - **Reduces wrong part selection**

24.9.4.2 Tool Loading Error Proofing

Error: Wrong Tool in Wrong Position

Solutions:

1. Tool Identification: - RFID chips in tool holders - CNC reads chip, verifies correct tool in position - **Prevents tool mix-ups**

2. Tool Length Verification: - Tool setter or probe measures length - Compares to expected length - Alarm if mismatch - **Catches wrong tool or broken tool**

3. Visual Tool Management: - Shadow board for tool staging - Each tool position labeled (T1, T2, etc.) - Missing tool obvious - **Prevents loading errors**

4. Pre-Set Tool Kits: - All tools for job in labeled tray - Load from tray in sequence - Empty tray = complete - **Prevents missing tools**

5. Spindle Probe Routine: - Program probes tool before using - Verifies length and diameter - Out-of-spec = alarm - **Catches errors before cutting**

24.9.4.3 Part Orientation Devices

Error: Part Loaded Upside-Down or Rotated

Solutions:

1. Mechanical Keying: - Asymmetric features prevent incorrect orientation - Flat, chamfer, notch - **Impossible to load wrong**

2. Vision System: - Camera verifies part orientation - Compares to reference image - Wrong orientation = reject/alarm

3. Probing: - Touch probe finds features - Compares to expected locations - Orientation error detected - **Before machining starts**

4. Gravity/Natural Orientation: - Part design uses gravity - Part naturally settles to correct orientation - **Example:** V-block for round parts (doesn't matter rotation)

5. Labels/Marking: - "This Side Up" on part (temporary marking) - Operator visual confirmation - Least robust (relies on human)

24.9.4.4 Process Sequence Control

Error: Operations Performed Out of Sequence

Solutions:

1. Separate Fixtures: - Op 1 fixture different from Op 2 fixture - Can't accidentally do Op 2 first - Physical prevention

2. Barcode/RFID Tracking: - Part tagged at each operation - Next operation scans tag - Verifies previous operations complete - **Prevents skipping operations**

3. Kanban with Sequence: - Kanban cards color-coded by operation - Next operation only accepts correct color card - Visual sequence control

4. Inspection Checkpoints: - Feature inspection after each operation - Next operation verifies previous features present - **Example:** Op 2 requires drilled holes; checks for holes before proceeding

5. Program Sequencing: - CNC program embedded checks - Probe cycles verify previous operation features - Won't proceed if features missing

24.9.4.5 Inspection Error Proofing

Error: Incorrect Measurement or Gage

Solutions:

1. Go/No-Go Gages: - No interpretation needed - Part fits or doesn't fit - **Eliminates measurement error**

2. Gage R&R: - Gages calibrated and verified - Measurement system capable - Reduces gage variation

3. Digital Gages with Limits: - Set upper/lower limits - Green light = pass, Red = fail - No interpretation

4. Automated Inspection: - CMM, vision system, in-machine probing - Eliminates human error - 100% inspection possible

5. Dedicated Gages: - One gage per feature (can't use wrong gage) - Labeled clearly - Shadow board at station

6. SPC with Alarms: - Automatic plotting - Out-of-control alarm - Prevents shipping trend defects

---

24.9.5 Low-Cost Error Proofing Solutions

Poka-Yoke doesn't have to be expensive.

Simple, Effective Examples

1. Paint Dots: - Cost: $2 (paint marker) - Use: Color-code parts, fixtures, tools - Prevents mix-ups

2. Locating Pins: - Cost: $10-50 (dowel pins) - Use: Asymmetric part location - Prevents orientation errors

3. Limit Switches: - Cost: $20-100 each - Use: Presence detection, position verification - Prevents missing part, incorrect position

4. Photoelectric Sensors: - Cost: $50-200 - Use: Detect part presence across beam - Prevents machining air

5. Templates: - Cost: $0 (make from scrap) - Use: Visual check of hole patterns, dimensions - Quick pass/fail check

6. Counters: - Cost: $30-100 - Use: Count operations (drilling, tapping) - Ensures correct quantity

7. Shadow Boards: - Cost: $20-50 (board + paint/foam) - Use: Tool organization, missing tool obvious - Prevents missing tools

8. Laser Pointers: - Cost: $15 - Use: Project alignment lines on part - Visual alignment check

9. Magnets: - Cost: $5-20 - Use: Hold gages, checklists at point-of-use - Prevents missing gage

10. 3D Printed Fixtures: - Cost: $10-100 (material) - Use: Custom nest for part orientation - Rapid prototyping of poka-yoke

ROI of Simple Poka-Yoke

Example: Prevent One Scrap Part per Month

Without Poka-Yoke: - Scrap: 1 part/month = 12 parts/year - Part cost: $150 - Annual scrap cost: $1,800

With Poka-Yoke (Limit Switch): - Cost: $75 (switch + installation) - Scrap eliminated: $1,800/year - **Payback: 15 days** - **ROI: 2,300% (year 1)**

And eliminates hassle, delays, customer complaints!

24.9.6 Implementing Poka-Yoke

Step-by-Step Process

Step 1: Identify Error-Prone Operations

Sources: - Scrap/rework data (where do defects occur?) - Operator input (what mistakes happen?) - Customer complaints - Near-miss reports

Prioritize by: - Frequency (how often?) - Severity (cost of error) - Detectability (how soon detected?)

Step 2: Root Cause Analysis

Why does the error occur? - Lack of information? (unclear instructions) - Physically difficult? (hard to see, reach) - Reliance on memory? (too many steps) - Similar parts/tools? (easy to confuse) - Fatigue? (repetitive, boring)

Use 5 Whys: - Defect: Part loaded backwards - Why? Operator didn't check orientation - Why? Part looks similar both ways - Why? No obvious front/back indicator - Why? Not designed with orientation feature - **Root cause:** Design lacks orientation feature

Step 3: Design Poka-Yoke

Brainstorm Solutions: - How to eliminate error? (Level 1) - How to prevent error? (Level 2) - How to detect immediately? (Level 3)

Select Best Solution: - Effectiveness (prevents error?) - Cost (simple, low-cost preferred) - Reliability (works every time?) - Ease of implementation

Step 4: Implement

Prototype if Possible: - Test solution before full implementation - Verify effectiveness - Refine

Install: - Integrate into process - Minimal disruption

Document: - Update standard work - Include poka-yoke in training

Step 5: Verify

Test: - Intentionally try to make error (safely!) - Does poka-yoke prevent/detect?

Monitor: - Track defects after implementation - Did they eliminate? - Sustain improvement

Step 6: Standardize and Replicate

Share Success: - Document the solution - Photos, drawings, description

Replicate: - Apply to similar operations - Other machines, products, areas

Culture: - Encourage operator ideas - Reward poka-yoke suggestions - Make it a habit

Summary

Poka-Yoke (mistake-proofing) prevents errors by designing processes and equipment to eliminate, prevent, or immediately detect mistakes. Developed by Shigeo Shingo, poka-yoke shifts from blaming people to improving processes. The most effective poka-yoke eliminates the possibility of error entirely through clever design.

In CNC manufacturing, poka-yoke prevents common errors: incorrect part orientation, wrong tools, skipped operations, and measurement mistakes. Simple, low-cost solutions (locating pins, limit switches, color-coding) often provide dramatic ROI by eliminating scrap and rework.

The key is systematic implementation: identify error-prone operations, determine root causes, design simple solutions, verify effectiveness, and replicate successes. When combined with other Lean tools, poka-yoke builds quality into processes and supports zero-defect goals.

Key Takeaways

1. **Poka-yoke** means mistake-proofing; prevents errors rather than detecting them
2. **Three levels**: Eliminate (best), Prevent (better), Detect (good)
3. **Two types**: Control (prevents error) and Warning (detects and alerts)
4. **Three methods**: Contact, Fixed-value, Motion-step
5. **CNC applications**: Fixture asymmetry, tool verification, sequence control
6. **Simple solutions** often most effective (pins, switches, color-coding)
7. **Low cost** with high ROI (often payback in weeks)
8. **Blame the process**, not the person (humans will make mistakes)
9. **100% inspection** automated (every part, every time)
10. **Continuous improvement**: Identify errors, design poka-yoke, verify, replicate

Review Questions

1. What does poka-yoke mean and who developed it?
2. Explain the three levels of poka-yoke effectiveness
3. What's the difference between Control and Warning poka-yoke?
4. Describe the three poka-yoke methods with examples
5. How does asymmetric fixturing prevent errors?
6. Give 3 examples of low-cost poka-yoke devices
7. Calculate ROI: Poka-yoke costs $100, prevents 1 scrap/month at $200/part. What's payback period?
8. Why is "eliminate" better than "detect" for error-proofing?
9. How does poka-yoke support zero-defect goals?
10. What's the implementation process for poka-yoke?

Practical Exercise: Design a Poka-Yoke

Design error-proofing for a CNC operation:

Scenario: You have a CNC mill operation making aluminum brackets. Common errors: - Wrong bracket orientation (30% of scrap) - Missing deburr operation (20% of rework) - Wrong material used (10% of scrap)

Tasks:

1. **Root Cause Analysis**
   - For each error, ask "5 Whys"
   - Identify root causes
2. **Design Poka-Yoke Solutions**
   - For each error, design a poka-yoke
   - Sketch or describe each solution
   - Classify: Eliminate, Prevent, or Detect?
   - Classify: Control or Warning?
3. **Cost-Benefit Analysis**
   - Estimate cost of each poka-yoke
   - Calculate current cost of errors (assume 100 parts/month, $50 material cost, $30 rework cost)
   - Calculate payback period
4. **Implementation Plan**
   - Which poka-yoke to implement first? (prioritize)
   - How to test effectiveness?
   - How to verify it works?
5. **Documentation**
   - Create one-page poka-yoke description
   - Include: problem, solution, sketch, cost, benefit

Deliverables: - 5 Whys analysis (each error) - Three poka-yoke designs (sketches + descriptions) - Cost-benefit calculations - Prioritization matrix - Implementation plan

---