DHANALAKSHMI SRINIVASAN ENGINEERING COLLEGE
(AUTONOMOUS)
(Approved by AICTE & Affiliated to Anna University, Chennai)
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Syllabus:

UNIT I/ INTRODUCTION TO LEAN MANUFACTURING	**No. of Periods:9**
Objectives of lean manufacturing-key principles and implications of lean manufacturing –traditional Vs lean manufacturing- flow-continuous improvement/Kaizen –worker involvement- 5S principles elements of JIT - uniform production rate - Kanban system - Lean implementation, Reconciling lean with other systems - lean six sigma- lean and ERP - lean with ISO 9001:2000.	
UNIT II/ AGILE MANUFACTURING	**No. of Periods: 9**
Agile Manufacturing Vs Mass Manufacturing - Agile practice for product development - Manufacturing agile practices - Implementing new technology - A checklist, technology applications that enhance agility - agile technology make or buy decisions. - Costing for Agile Manufacturing practices.	
UNIT III/ SUSTAINABLE MANUFACTURING	**No. of Periods:9**
Concepts of competitive strategy and manufacturing strategies and development of a strategic improvement programme - Manufacturing strategy in business success strategy formation and formulation - Structured strategy formulation - Sustainable manufacturing system design options - Approaches to strategy formulation - Realization of new strategies/system designs	
UNIT IV/ INTELLIGENT MANUFACTURING	**No. of Periods:9**
Introduction to intelligent manufacturing- fundamentals of artificial intelligence-AI in manufacturing processes- introduction to fuzzy logic-applications of fuzzy logic in manufacturing - case studies and practical applications	
UNIT V/ SMART MANUFACTURING	**No. of Periods:9**
Introduction to various Smart Manufacturing Techniques - Supply chain management -Block chain of inventory management - Plant digitization - Predictive maintenance-Supply chain visibility -Warehouse-Cost reduction-Waste management-Automated systems-Applications	

Objective:

- The objective of this course is to teach the lean tools to attain optimum level in quality.
- To enhance the ability to make decisions for new product development.
- Aims to develop the students to conserve energy and natural resources, and to ensure that they have minimal impact on the environment and society.
- To give students an introduction to an advanced information process technique.
- To learn about the various smart manufacturing techniques and applications.

Text Book:

T1. Lonnie Wilson, "How to Implement Lean manufacturing", McGraw-Hill Professional; 2nd edition, 2015.

T2. Ibrahim Garbie, "Sustainability in Manufacturing Enterprises Concepts, Analyses and Assessments for Industry 4.0", Springer International Publishing., United States, 2016.

T3. Kusiak, Andrew, "Intelligent Manufacturing Systems", Prentice Hall, 1st edition, 1990.

Website:

W1: https://https://nptel.ac.in/courses/112107078
W2:**http://home.iitk.ac.in/~jrkumar/download/ME761A_Lecture%201%20Introduction.pdf**

Online Mode of Study:

W1: https://www.coursera.org/specializations/digital-manufacturing-design-technology
W2: https://www.coursera.org/specializations/digital-technologies-future-of-manufacturing

Course Outcome:

At the end of course: Students should be able to do:
CO1: Demonstrate on basic lean manufacturing.
CO2: Integrate the knowledge on agile manufacturing.
CO3: Formulate strategy in sustainable manufacturing.
CO4: Apply artificial intelligence (AI) and fuzzy techniques to improve the efficiency of manufacturing systems
CO5: Exposure to smart manufacturing and its various techniques.
CO6: Integrate the knowledge Predictive maintenance and Waste management.

Course Outcome Vs Program Outcome Mapping:

COs	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
CO1	2	-	-	1	1	1	-	-	-	-	-	-	-	-
CO2	2	1	-	-	-	1	-	-	-	-	-	-	-	-
CO3	2	1	-	1	2	1	-	-	-	-	-	-	-	-
CO4	2	1	-	-	-	1	-	-	-	-	-	-	-	-

CO5	2	-	-	-	1	1	-	-	-	-	-	-	-	-
CO6	2	1	-	1	1	1	-	-	-	-	-	-	-	-
AVG	**2**	**0.67**	**-**	**0.5**	**0.83**	**1**							**-**	**-**

Content beyond Syllabus:

- Applications of Lean manufacturing
- Applications of TPS and TPM.

UNIT I/ INTRODUCTION TO LEAN MANUFACTURING

Two Marks

1. **What are the main objectives of lean manufacturing?**
   The primary objectives include eliminating all forms of waste (muda), reducing production costs through streamlined processes, enhancing product quality by minimizing defects, shortening lead times, and maximizing customer value delivery. This is achieved by focusing on value-adding activities while ensuring flexibility and responsiveness in manufacturing operations.
2. **List and explain the five key principles of lean manufacturing.**
   The five principles are: (1) Identify value from the customer's perspective; (2) Map the value stream to visualize all steps; (3) Create continuous flow by removing bottlenecks; (4) Establish pull systems based on actual demand; (5) Pursue perfection through Kaizen. These principles guide systematic waste reduction and process optimization.
3. **What is the implication of 'create flow' in lean manufacturing?**
   'Create flow' implies designing processes for smooth, uninterrupted movement of materials and products, often via one-piece flow or cellular layouts, which reduces cycle times, inventory buildup, waiting periods, and transportation waste. It contrasts batch production by minimizing handoffs and enabling quick problem detection.
4. **Define Kaizen and its role in continuous improvement.**
   Kaizen refers to ongoing, incremental improvements involving every employee, from shop floor to management, through small daily changes rather than radical overhauls. It fosters a culture of problem-solving, empowers workers, and sustains long-term gains in efficiency, quality, and morale.
5. **How does lean manufacturing emphasize worker involvement?**
   Lean promotes worker involvement by training operators as problem-solvers using tools like Andon for stopping lines on issues, suggestion systems, and cross-training for multi-skilling. This shifts from top-down control to bottom-up

empowerment, leveraging frontline knowledge to identify and eliminate waste effectively.

6. **Explain the 5S principles with their elements.**

   5S comprises Sort (remove unnecessary items), Set in order (organize tools for easy access), Shine (clean workplace daily), Standardize (create visual standards), and Sustain (audit and maintain discipline). These create an organized, safe, efficient workspace that supports visual management and quick setups.

7. **State and describe the key elements of Just-In-Time (JIT).**

   JIT elements include takt time alignment (production rate matching demand), minimal inventory via pull signals, quick changeovers (SMED), and reliable suppliers. It ensures parts arrive exactly when needed, preventing overproduction and stock-related costs while improving cash flow.

8. **What is uniform production rate in JIT and its benefits?**

   Uniform production rate (Heijunka) levels production volumes and mixes to match customer demand steadily, avoiding peaks/troughs. Benefits include stable workflows, reduced overtime/inventory, easier forecasting, and smoother supplier coordination.

9. **Explain the Kanban system in detail.**

   Kanban employs visual cards, bins, or electronic signals to authorize production or withdrawal only when downstream processes signal need, enforcing pull. Types include production Kanban (authorizes making) and withdrawal Kanban (moves materials); it limits work-in-progress (WIP) to expose issues.

10. **Compare traditional vs. lean manufacturing approaches.**

    Traditional manufacturing relies on push scheduling, large batches, high inventory buffers, and functional layouts causing transport waste. Lean uses pull systems, small lots, minimal stock, and cellular layouts for flow, emphasizing waste elimination, flexibility, and customer focus over mass efficiency.

11. Differentiate push and pull systems in manufacturing.

Push systems forecast demand and produce in batches, leading to overproduction/inventory risks. Pull systems wait for actual consumption signals (e.g., Kanban) before producing, aligning output precisely with demand, reducing waste, and enhancing responsiveness.

12. What are the seven (or eight) wastes (Muda) in lean?

Wastes are overproduction, waiting, transportation, overprocessing, excess inventory, unnecessary motion, defects, and unused employee creativity (non-utilized talent). Identifying and eliminating these via tools like value stream mapping drives lean success.

13. Define value stream and its mapping process.

A value stream encompasses all actions (value-adding and non-adding) from raw material to customer delivery. Mapping involves current-state (as-is) analysis to highlight waste, then future-state design for ideal flow, guiding kaizen events.

14. How does lean promote continuous flow production?

Lean achieves flow by reducing setup times, balancing lines (Takt time), U-shaped cells, and eliminating queues/batch mentality. This enables one-piece flow, shortens lead times, improves quality via quick feedback, and cuts costs.

15. What is the role of standard work in lean manufacturing?

Standard work documents the safest, most efficient sequence, timing, and layout for tasks using visual charts/job instructions. It reduces variation, serves as baseline for kaizen, trains new hires, and stabilizes processes before improvements.

16. Outline the steps for lean implementation.

Steps: Assess current state via gemba walks/value stream maps; prioritize waste; pilot kaizen events for flow/pull; standardize gains; expand enterprise-wide; sustain via policy deployment (Hoshin Kanri) and audits.

17.What is Lean Six Sigma and its integration?

Lean Six Sigma merges Lean's speed/waste focus with Six Sigma's statistical defect reduction (DMAIC: Define-Measure-Analyze-Improve-Control). It targets 3.4 DPMO while streamlining flows, ideal for complex processes.

18.How does lean reconcile with ERP systems?

ERP handles forecasting/planning/master data; lean overlays real-time pull (Kanban digitally in ERP), CONWIP for capacity, and visual scheduling. Integration avoids ERP's batch rigidity, using it for stability while lean drives execution.

19.Describe lean integration with ISO 9001:2000.

ISO 9001 emphasizes process approach, continual improvement, and customer focus, aligning with lean tools (5S for housekeeping, Kaizen for PDCA). Lean provides practical mechanisms for ISO audits, documentation, and corrective actions.

20.What is cellular manufacturing in lean and its advantages?

Cellular manufacturing groups machines into compact cells by product family for sequential one-piece flow, inverting traditional job shops. Advantages: reduced lead times (50-90%), lower WIP/transport, easier supervision, and built-in flexibility/poka-yoke.

UNIT II/ AGILE MANUFACTURING

Two Marks

1. **What is Agile Manufacturing?**
   Agile Manufacturing is a production strategy emphasizing rapid adaptability to changing customer demands, market volatility, and technological shifts through flexible processes, modular systems, and collaborative networks, enabling quick customization without sacrificing efficiency.
2. **Compare Agile vs. Mass Manufacturing.**
   Mass Manufacturing produces standardized high-volume products via fixed lines and economies of scale; Agile Manufacturing delivers customized, low-volume products rapidly using flexible cells, modular tooling, and dynamic reconfiguration to handle variety and short lifecycles.
3. **List key attributes of Mass Manufacturing.**
   Mass attributes include produce-to-forecast, long market life, standardized products, high inventory buffers, pricing by cost, and rigid Taylorist hierarchies, optimized for stable demand but vulnerable to disruptions.
4. **List key attributes of Agile Manufacturing.**
   Agile attributes feature produce-to-order, short market life, customized products, minimal finished goods inventory, pricing by customer value, and networked teams leveraging information for responsiveness.
5. **What are Agile practices for product development?**
   Agile product development uses iterative cycles, cross-functional teams, rapid prototyping, customer feedback loops, and concurrent engineering to shorten time-to-market, incorporating changes dynamically unlike sequential mass development.
6. **Describe manufacturing agile practices.**
   Practices include flexible manufacturing systems (FMS), cellular layouts, quick changeovers (SMED), programmable automation, and pull-based scheduling to enable seamless switches between product variants and volumes.

7. **What is involved in implementing new technology in Agile Manufacturing?**
   Implementation requires assessing fit for agility, pilot testing in cells, employee training, modular integration, and scalability planning to ensure technology enhances flexibility rather than creating rigidity.
8. **Provide a checklist for Agile technology implementation.**
   Checklist: Evaluate modularity/scalability; test interoperability; train workforce; measure ROI on responsiveness; ensure cyber-physical integration; pilot with real demand; audit post-implementation agility metrics like setup time reduction.
9. **Name technology applications enhancing agility.**
   Key applications: CNC with quick tooling, robotics for reconfiguration, IoT sensors for real-time monitoring, AI-driven predictive maintenance, 3D printing for prototyping, and cloud-based MES for dynamic scheduling.
10. **How do agile technologies influence make-or-buy decisions?**
    Agile tech favors insourcing modular/core competencies via flexible in-house cells; outsourcing non-core via agile supplier networks with rapid integration, decided by total agility cost (speed, quality, responsiveness) over pure unit cost.
11. **What factors drive make-or-buy in Agile Manufacturing?**
    Factors: Strategic control of IP/processes (make), supplier agility/reliability (buy), capacity flexibility, total ownership cost including reconfiguration time, and network compressibility for end-to-end responsiveness.
12. **Explain costing for Agile Manufacturing practices.**
    Agile costing uses activity-based costing (ABC) for flexibility overheads, target costing by customer value, lifecycle costing including reconfiguration, and throughput accounting prioritizing speed over traditional absorption costing.
13. **What is customer collaboration in Agile Manufacturing?**
    It involves real-time co-design, direct feedback integration, mass customization platforms, and long-term relationships to align products precisely with evolving needs, creating value through responsiveness.

14. **Describe cross-functional teams in Agile practices.**
    Teams break silos uniting design, production, suppliers, and sales for concurrent decisions, rapid iterations, and holistic problem-solving, accelerating development cycles and innovation.
15. **What role does rapid iteration play in Agile Manufacturing?**
    Rapid iterations deliver incremental value via short sprints, data-driven refinements, and version control, enabling quick pivots to market shifts while building on validated learnings unlike mass's big-bang launches.
16. **How does Agile Manufacturing leverage information technology?**
    IT enables real-time data sharing via ERP/MES integration, predictive analytics, digital twins for simulation, and collaborative platforms, turning information into agility advantage.
17. **What is flexible production systems (FPS) in Agile?**
    FPS uses reconfigurable machines, universal fixtures, and software-defined controls to switch products/volumes instantly, supporting high variety at mass efficiency levels.
18. **Explain Leagile (Lean-Agile hybrid) systems.**
    Leagile combines Lean's waste elimination in stable base processes with Agile's flexibility for variants, decoupling points (e.g., postponement) balance efficiency and responsiveness.
19. **What are enablers of Agile Manufacturing competitiveness?**
    Enablers: Organizing for change, human/IT leverage, supplier partnerships, knowledge-based enrichment, and virtual enterprises for temporary alliances exploiting transient opportunities.
20. **Discuss challenges in transitioning to Agile Manufacturing.**
    Challenges include cultural shift from stability, high initial tech investment, skill upskilling, supply chain reconfiguration, and measuring non-traditional KPIs like response time over volume output.

UNIT III: SUSTAINABLE MANUFACTURING

Two Marks

1. Define competitive strategy in manufacturing context

Competitive strategy refers to how a manufacturing firm positions itself against rivals to achieve superior performance, using approaches like cost leadership, differentiation, or focus. In sustainable manufacturing, it integrates environmental goals such as resource efficiency and emission reduction alongside economic priorities. This alignment ensures long-term viability while meeting market demands.

2. What are the core elements of manufacturing strategy?

Manufacturing strategy comprises structural decisions (capacity, technology, facilities) and infrastructural decisions (workforce, quality systems, planning). It translates business objectives into operational capabilities supporting competitive priorities like cost, quality, delivery, flexibility, and sustainability. The goal is to create aligned production systems that drive business success.

3. List three competitive priorities in sustainable manufacturing.

Key priorities include cost (via waste reduction), quality (lifecycle durability), and sustainability (emission minimization). Delivery focuses on resilient green supply chains, while flexibility emphasizes modular designs for adaptability. These priorities balance economic, environmental, and social performance under the triple bottom line framework.

4. What is a strategic improvement programme?

A strategic improvement programme is a structured initiative to enhance manufacturing performance toward sustainability targets through gap analysis, goal setting, and continuous monitoring. It involves phases like assessment, planning, implementation, and review using tools such as Kaizen and KPIs. The aim is operational excellence with measurable environmental gains.

5. Explain the role of manufacturing strategy in business success.

Manufacturing strategy contributes to business success by aligning operations with market needs, fostering innovation, and ensuring resilience. It drives profitability through efficiency, enhances market share via eco-differentiation, and attracts stakeholders with strong ESG performance. Examples include Toyota's evolution to sustainable lean practices yielding cost leadership.

6. Differentiate strategy formation from strategy formulation.

Strategy formation is an emergent, organic process shaped by leadership vision and culture, while strategy formulation is deliberate and analytical, following structured steps like situational analysis and objective setting. Formation evolves informally; formulation uses tools like SWOT and PESTEL systematically. Both are essential for sustainable manufacturing alignment.

7. What is structured strategy formulation?

Structured strategy formulation employs frameworks like maturity assessments, roadmaps, and decision matrices to ensure comprehensive coverage and alignment. It involves phased diagnosis, design, and deployment using tools such as QFD and Hoshin Kanri. This approach suits SMEs transitioning to sustainable systems with traceability.

8. Name two sustainable manufacturing system design options.

Key options include eco-design with lifecycle assessment (LCA) for material optimization and benign factory layouts for energy/material flow efficiency. Remanufacturing and closed-loop supply chains enable resource recovery. These reduce waste and emissions across product lifecycles.

9. List steps in developing a strategic improvement programme.

Steps include current-state assessment (waste audits), future-state planning (SMART goals), implementation (pilots and training), review (KPI monitoring), and sustainment (policy deployment). Tools like value stream mapping and Gemba walks ensure continuous progress. Focus is on quick wins leading to systemic change.

10. What are Porter's generic competitive strategies?

Porter's strategies are cost leadership (lowest costs), differentiation (unique value), and focus (niche targeting). In sustainability, cost leadership uses circular economy efficiencies, differentiation leverages green innovation, and focus targets eco-conscious segments. Alignment with manufacturing capabilities is crucial.

11. Explain order winners and qualifiers.

Order qualifiers are minimum requirements for market consideration (e.g., basic compliance), while order winners are differentiators driving customer choice (e.g., superior sustainability). Analysis prioritizes investments in winners like green flexibility. This guides manufacturing strategy formulation.

12. What is triple bottom line in sustainable manufacturing?

Triple bottom line measures economic (profit), environmental (planet), and social (people) performance. Manufacturing strategies balance these through resource efficiency, emission cuts, and fair labor. It ensures holistic success beyond traditional financial metrics.

13. Describe Hoshin Kanri.

Hoshin Kanri is policy deployment aligning organizational goals from top to bottom via cascading objectives and reviews. In manufacturing, it ensures strategic priorities like sustainability permeate all levels. Visual management and audits sustain implementation.

14. What is value stream mapping?

Value stream mapping visualizes material, information, and energy flows to identify wastes in manufacturing processes. It supports strategic improvements by highlighting non-value-adding activities for elimination. Sustainable applications target energy and emission wastes.

15. List approaches to strategy formulation.

Approaches include top-down (leadership-driven), bottom-up (employee input), and interactive hybrids. Manufacturing-specific ones are market requirements, capabilities-based, and scenario planning. Sustainable adaptations incorporate backcasting from eco-futures.

16. Explain LCA in system design.

Life Cycle Assessment evaluates environmental impacts from cradle-to-grave, guiding sustainable design by optimizing materials, processes, and end-of-life. Unit process LCA refines manufacturing choices for lower emissions. It informs strategy realization.

17. What are structural decisions in manufacturing strategy?

Structural decisions include capacity planning, facility location, process technology, and vertical integration. For sustainability, they emphasize clean tech, local sourcing, and flexible capacity. These form the physical backbone supporting competitive priorities.

18. Describe strategy realization phases.

Phases are preparation (change management), pilot implementation (quick wins), scale-up (standardization), integration (supplier alignment), and sustainment (culture embedding). Monitoring via KPIs like OEE and carbon metrics ensures success. Phased roadmaps mitigate risks.

19. What is the sandcone model?

The sandcone model posits sequential capability building: quality first, then cost, delivery, flexibility. It counters trade-off thinking in manufacturing strategy. Sustainable extensions prioritize environmental quality cumulatively.

20. Define backcasting in sustainable strategy.

Backcasting starts from a desired sustainable future (e.g., zero emissions) and works backward to identify necessary steps. Unlike forecasting, it challenges status quo assumptions. It's ideal for realizing ambitious green manufacturing systems.

UNIT IV: INTELLIGENT MANUFACTURING

TWO MARKS

1. Define intelligent manufacturing.

Intelligent manufacturing integrates AI, IoT, and CPS to create adaptive factories that self-optimize production in real-time. It evolves from rigid assembly lines to flexible systems enabling mass customization and predictive maintenance, as in Industry 4.0 smart factories like Siemens Amberg (99.99885% defect-free). Key benefits include 20-50% efficiency gains and sustainability through data-driven decisions.

2. List core components of intelligent manufacturing.

Core components are IoT sensors for data collection, big data analytics for insights, cloud/edge computing for low-latency processing, digital twins for simulations, and blockchain for traceability. These enable autonomy and resilience, e.g., edge devices achieving <10ms response in dynamic lines.

3. Explain Industry 4.0 evolution briefly.

Industry 4.0 builds on mechanization (1.0), electrification (2.0), and automation (3.0) by adding CPS and AI for connected factories. Originating from Germany's 2011 initiative, it supports agile production amid volatile demands, exemplified by Tesla's AI-orchestrated Gigafactories.

4. What are AI fundamentals in brief?

AI fundamentals include machine learning (supervised/unsupervised/reinforcement), deep learning (neural networks), and expert systems for perception and decision-making. ML algorithms like regression minimize errors via gradient descent, crucial for manufacturing pattern recognition from sensor data.

5. Differentiate supervised and unsupervised learning.

Supervised learning uses labeled data for prediction (e.g., defect classification), while unsupervised finds patterns in unlabeled data (e.g., clustering anomalies). Supervised employs regression/classification; unsupervised uses K-means for grouping, vital for unlabeled factory sensor streams.

6. Describe predictive maintenance using AI.

AI predictive maintenance analyzes sensor data (vibration, temp) with ML models like LSTM to forecast failures, reducing downtime 30-50%. Workflow: feature extraction → anomaly detection → RUL estimation via Weibull distribution, preventing costly breakdowns.

7. How does AI aid quality inspection?

AI uses computer vision (CNNs/YOLO) for real-time defect detection at 99% accuracy, surpassing manual checks. It processes hyperspectral images for subsurface flaws in assembly lines, minimizing scrap by 20-30%.

8. Explain AI workflow in manufacturing.

AI workflow: data collection → preprocessing (normalization) → model training/validation (70/30 split) → deployment (MLOps) → monitoring for drift. Evaluation metrics: F1-score, ROC-AUC ensure reliability in processes like CNC optimization.

9. What is fuzzy logic?

Fuzzy logic handles uncertainty with membership functions (0-1 truth values), unlike binary logic. It processes linguistic variables (e.g., "high temp") via fuzzification, rules, and defuzzification, mimicking human reasoning for imprecise systems.

10. Differentiate Mamdani and Sugeno inference.

Mamdani produces fuzzy outputs aggregated then defuzzified (intuitive rules), while Sugeno uses linear equations (y=ax+b) for crisp weighted averages (faster computation). Mamdani suits control; Sugeno optimization in manufacturing scheduling.

11. Describe fuzzification process.

Fuzzification converts crisp inputs (e.g., 75°C) to fuzzy memberships using triangular/Gaussian functions (μ=0.5 for medium). It maps to linguistic sets (low/med/high), enabling rule handling of vagueness in processes like oven control.

13. State advantages of fuzzy logic over PID.

Fuzzy logic needs no precise models, handles nonlinearity/noise, and uses intuitive rules (e.g., 49 for kilns). It reduces overshoot 70% in variable-fuel systems, unlike PID's tuning sensitivity.

14. Name three fuzzy logic applications in manufacturing.

Applications: sintering oven control (fuel adaptation), tool wear monitoring (vibration fuzzy sets), and FMS scheduling (fuzzy due dates). They yield 8-20% savings in energy/throughput.

15. Explain fuzzy logic in process control.

Fuzzy controllers manage nonlinear processes like cement kilns with inputs (error, rate) and rules (IF high error THEN boost fuel). Hybrid fuzzy-PID ensures ±2°C stability amid variations.

16. Describe Boulos tricycle assembly case.

Fuzzy goal programming balanced 8-station line, modeling task uncertainties with triangular MFs. Efficiency rose 88.1% to 92.4%, idle time -56.5% via MATLAB optimization.

17. Outline sintering oven fuzzy control case.

Hierarchical fuzzy-PID used 49 rules for 2000°C oven with 6 fuels. Overshoot -70%, fuel savings 8%, settling 20s faster; PLC-embedded for real-time adaptation.

18. Explain melt pool control in AM case.

Mamdani FLC regulated SLM parameters (power/speed) with 81 rules, reducing porosity <1% vs. 5%. Gaussian MFs and camera feedback ensured 99% density.

19. What is FMS scheduling fuzzy case?

Takagi-Sugeno models optimized 5-machine FMS with fuzzy due dates/loads. Tardiness -22%, throughput +16% via GA-tuned rules.

20. List steps for fuzzy system implementation.

Steps: 1) Define inputs/outputs/MFs; 2) Build rule base; 3) Simulate (MATLAB); 4) Integrate PLC; 5) Tune/validate (ITAE metric). Prototyping takes 1-3 months for manufacturing.