

Foreword

Industrial and Systems Engineering Body of Knowledge (ISE BoK)

Revised Edition – 2026

The Industrial and Systems Engineering Body of Knowledge (ISE BoK) serves as a foundational reference for the breadth and depth of knowledge that defines the profession of industrial and systems engineering. As the field continues to evolve in response to emerging technologies, global challenges, and interdisciplinary integration, periodic review and revision of the BoK are essential to ensure its continued relevance and rigor. Thus, ISE BoK constitutes a living document.

This revision represents a collaborative effort across the Institute of Industrial and Systems Engineers (IISE). The BoK Governing Board worked closely with designated liaisons from IISE Divisions and Societies to review, evaluate, and update each chapter. Through this structured and inclusive process, subject matter experts provided insight into advances in research, practice, education, and professional expectations within their respective domains.

Following this comprehensive review, the Governing Board examined each chapter and approved updates to reflect current practice, emerging methodologies, and the expanding impact of industrial and systems engineers across sectors. The result is a Body of Knowledge that maintains continuity with the profession's core principles while incorporating new perspectives, tools, and applications, shaping the future of ISE.

The ISE BoK serves multiple audiences:

- **Academic programs**, as a guide for curriculum development and accreditation alignment
- **Practitioners**, as a reference for professional competency and continuing development
- **Students**, as a roadmap to the knowledge domains that define the profession
- **Industry and stakeholders**, as a clear articulation of the capabilities and value of industrial and systems engineers
- **Professional licensure**, as a framework for both the Fundamentals of Engineering and Professional Engineering examinations and training

We extend our sincere appreciation to the Division and Society liaisons, chapter contributors, reviewers, and members of the BoK Governing Board whose dedication made this revision possible. Their thoughtful engagement ensures that the ISE BoK remains a living document that evolves alongside the profession it represents.

As industrial and systems engineering continues to expand its influence, this Body of Knowledge provides both a foundation and a forward-looking guide for the profession.

On behalf of the BoK Governing Board, we are pleased to present this revised edition of the Industrial and Systems Engineering Body of Knowledge.

Introduction

Industrial and Systems Engineering (ISE) is concerned with the design, improvement, and implementation of integrated systems composed of people, materials, information, equipment, and energy. The discipline draws upon specialized knowledge in the mathematical, physical, and social sciences, together with engineering analysis and design principles, to specify, predict, and evaluate the performance of complex systems.

While this foundational definition remains central to the profession, the context in which Industrial and Systems Engineers operate continues to evolve. Rapid advances in data analytics, artificial intelligence, automation, digital transformation, and intelligent systems are reshaping industries worldwide. At the same time, global challenges—such as supply chain disruption, sustainability, resilience, healthcare transformation, cybersecurity, and socio-technical integration—are expanding both the scope and impact of the profession.

The Industrial and Systems Engineering Body of Knowledge (ISE BoK) reflects both the enduring principles and the emerging competencies that define the field. Like all engineering disciplines, ISE requires a strong foundation in mathematics and science, including calculus, probability, statistics, physics, chemistry, and engineering sciences. Building upon this foundation, modern ISE increasingly integrates advanced analytics, systems modeling, human-centered design, computational tools, and interdisciplinary collaboration to address complex, data-rich, and interconnected systems.

This document serves as a structured repository of essential knowledge for Industrial and Systems Engineers. The ISE BoK defines a taxonomy of core concepts, methods, and domains that characterize the profession and provides a framework for achieving competence and mastery. It establishes a shared understanding of the knowledge areas that support education, professional development, certification, and practice.

The ISE BoK is organized into fourteen (14) knowledge areas representing fundamental domains within the discipline. Each knowledge area outlines essential topics and provides references to guide readers toward deeper study and advanced expertise. Because ISE is inherently integrative, overlap among knowledge areas is expected and intentional; cross-references acknowledge the interdisciplinary connections that are central to systems thinking.

The structure of the ISE BoK emphasizes foundational domains rather than industry-specific applications. Industrial and Systems Engineers apply these knowledge areas across manufacturing, healthcare, logistics, service systems, finance, energy, defense, technology, and emerging sectors. The BoK does not prescribe how knowledge is implemented within any particular industry; rather, it defines the essential competencies required to design, improve, and implement integrated systems in any context.

As the profession continues to evolve, the ISE BoK remains a living framework. It supports adaptation to new technologies, methodologies, and societal needs while preserving the core systems-oriented perspective that distinguishes Industrial and Systems Engineering. In doing so, it prepares current and future engineers to lead in an increasingly complex, digital, and interconnected world.

Institute of Industrial and Systems Engineers

IISE Body of Knowledge



2026



Institute of Industrial and Systems Engineers
3577 Parkway Lane, Suite 200 | Norcross, GA 30092



1 Work Design and Measurement

A Work System is a system in which a human interacts with other humans, live beings, tools, machines, information, and technology to perform processes that directly or indirectly result in products or services for internal or external customers. Work design and measurement involves understanding these processes in terms of different design variables, quantifying the inputs (e.g., time, effort, energy, and cost) and outputs (e.g., productivity) of different designs to support the creation of a work environment that maximizes worker satisfaction while creating value for stakeholders over time.

Work Measurement covers the tools and techniques used to quantify the time and effort that well-trained workers can be expected to take in carrying out a defined sequence of tasks, at a specified pace, given a set of resources laid out in a specific manner, and under specific working conditions (environmental, team configuration, and others).

Work Design involves the use of work measurements in decomposing, integrating, recombining, updating, and/or replacing work methods, equipment, technology, and work environments required to execute productive activities within an enterprise while ensuring a fair day's work.

1.1 Introduction to Work Systems

- 1.1.1 Importance and application across multiple industries and stakeholder groups (workers, management, society)
- 1.1.2 The relationship between design and measurement
- 1.1.3 History of Work Design and Measurement and their Pioneers (Frederick Taylor, Frank and Lillian Gilbreth)

1.2 Defining Work

- 1.2.1 Defining the scope of methods and standards in work design
- 1.2.2 Manual and machine systems
- 1.2.3 Job descriptions and evaluations
- 1.2.4 System performance metrics related to work
 - 1.2.4.1 Cycle time
 - 1.2.4.2 Production Rate
 - 1.2.4.3 Productivity
 - 1.2.4.4 Takt time

1.3 The Work Design Process

- 1.3.1 Methods Engineering Process
- 1.3.2 Overview of alternative approaches for process design, process improvement, and problem-solving
- 1.3.3 Examples of approaches include (not limited to):
 - 1.3.3.1 The design process (Design for X, e.g., design for Six Sigma, design for maintainability, etc.)



- 1.3.3.2 Lean/Six Sigma's Design, Measure, Analyze, Improve, Control (DMAIC)
- 1.3.3.3 Process improvement's Plan-Do-Check-Act (PDCA)
- 1.4 Defining Work Design/Improvement Goals (Exploratory Tools)
 - 1.4.1 Sources of data and initial analysis
 - 1.4.1.1 Quantitative data sources, e.g., descriptive statistics, Pareto charts
 - 1.4.1.2 Qualitative data (interviews and observations), e.g., Root Cause Analysis, Mind maps
- 1.5 Recording and Analysis Tools
 - 1.5.1 Process Maps and variations
 - 1.5.2 Multiactivity charts, e.g., worker and machine charts, Gang charts, left-hand, right-hand charts
- 1.6 Work Measurement
 - 1.6.1 Overview of work measurement goals and process
 - 1.6.1.1 Definitions: standard work, standard time
 - 1.6.1.2 Performance Ratings and Allowances
 - 1.6.1.3 Engineered vs. non-engineered techniques
 - 1.6.2 Time Study
 - 1.6.2.1 Data collection
 - 1.6.2.2 Data analysis
 - 1.6.2.3 Reporting/visualization and use in practice
 - 1.6.3 Standard Data and Formulas; Pre-Determined Time Systems
 - 1.6.3.1 MTM variations
 - 1.6.3.2 MOST
 - 1.6.3.3 MODAPTS
 - 1.6.4 Work Sampling
 - 1.6.4.1 Data collection
 - 1.6.4.2 Data analysis
 - 1.6.4.3 Reporting/visualization and use in practice.
 - 1.6.5 Analytical Tools
 - 1.6.5.1 Role of technology in collecting and analyzing data
 - 1.6.5.2 Software tools to facilitate work measurement
- 1.7 Workstation Design
 - 1.7.1 Ergonomic principles for designing and improving human work
 - 1.7.2 Ergonomic principles for the selection of equipment and tools
 - 1.7.3 Collaborative robots (cobot) work design



- 1.7.4 Human-centered systems
- 1.7.5 Analysis and improvement of machine clusters
- 1.7.6 Line balancing
- 1.7.7 Principles of Facility Layout Design

1.8 Lean Manufacturing

1.9 Work Environment Design

- 1.9.1 Cleanliness, clutter and disorder
- 1.9.2 Illumination
- 1.9.3 Noise
- 1.9.4 Temperature and humidity

1.10 Implementation

- 1.10.1 Safety assessments (e.g., Failure Modes and Effects Analysis (FMEA))
- 1.10.2 Change Management
- 1.10.3 Process governance
- 1.10.4 Motivation Theory
- 1.10.5 Wage Surveys

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2 Operations Research and Analysis

Operations Research and the Management Sciences include a variety of problem-solving techniques focused on improved efficiency of systems and support in the decision-making process. The realm of Operations Research involves the construction of mathematical models that aim to describe and/or improve real or theoretical systems and solution methodologies to gain real-time efficiency. The knowledge area of Operations Research is by its nature mathematical and computational. A fundamental basis in this knowledge area includes probability, statistics, calculus, algebra, and computing.

2.1 Operations Research

2.1.1 Modeling approaches

2.1.2 Solution approaches: heuristics and exact methods

2.2 Linear Programming (LP)

2.2.1 LP applications

2.2.1.1 Diet problem

2.2.1.2 Workforce scheduling

2.2.1.3 Capital budgeting

2.2.1.4 Blending problems

2.2.2 LP modeling techniques

2.2.3 LP assumptions

2.2.4 Simplex method

2.2.5 Degenerate and unbounded solutions

2.2.6 Post-optimality and sensitivity analysis

2.2.7 Interior-point approaches

2.2.8 Duality theory

2.2.9 Revised simplex method

2.2.10 Dual simplex method

2.2.11 Parametric programming

2.2.12 Goal programming

2.3 Transportation Problem

2.3.1 Transportation model and its variants

2.3.2 Transportation simplex method

2.3.3 Transshipment problems

2.4 Linear Assignment Problem

2.4.1 Assignment model



- 2.4.2 The Hungarian algorithm
- 2.5 Network Flows and Optimization
 - 2.5.1 Shortest path problem
 - 2.5.2 Minimum spanning tree problem
 - 2.5.3 Maximum flow problem
 - 2.5.4 Minimum cost flow problem
 - 2.5.5 CPM and PERT problems
 - 2.5.6 Network simplex method
- 2.6 Deterministic Dynamic Programming
 - 2.6.1 Applications
 - 2.6.1.1 Knapsack/fly-away/cargo-loading problems
 - 2.6.1.2 Workforce size problems
 - 2.6.1.3 Equipment replacement problems
 - 2.6.1.4 Investment problems
 - 2.6.1.5 Inventory problems (see **Error! Reference source not found.**)
 - 2.6.2 Forward and backward recursions
- 2.7 Integer Programming
 - 2.7.1 Applications and modeling techniques
 - 2.7.1.1 Capital budgeting
 - 2.7.1.2 Set-covering and set-partitioning problems
 - 2.7.1.3 Fixed-charge problem
 - 2.7.1.4 Either-or and if-then constraints
 - 2.7.2 Branch and bound algorithm
 - 2.7.3 Cutting plane algorithm
 - 2.7.4 Traveling salesperson problem and solution methods
- 2.8 Nonlinear Programming
 - 2.8.1 Unconstrained algorithms
 - 2.8.1.1 Direct search methods
 - 2.8.1.2 Gradient methods
 - 2.8.2 Constrained algorithms
 - 2.8.2.1 Separable programming
 - 2.8.2.2 Quadratic programming
 - 2.8.2.3 Linear combinations method



2.9 Optimization under Uncertainty

- 2.9.1 Two-stage and multi-stage stochastic programming
- 2.9.2 Chance-constrained stochastic programming
- 2.9.3 Robust optimization
- 2.9.4 Markov decision processes
- 2.9.5 Approximate dynamic programming
- 2.9.6 Reinforcement learning
- 2.9.7 Inventory problems

2.10 Metaheuristics

- 2.10.1 Steepest ascent and descent (Greedy algorithms)
- 2.10.2 Tabu search
- 2.10.3 Simulated annealing
- 2.10.4 Genetic algorithms
- 2.10.5 Ant colony optimization
- 2.10.6 Particle swarm techniques
- 2.10.7 Greedy Randomized Adaptive Search Procedure (GRASP)

2.11 Decision Analysis and Game Theory

- 2.11.1 Multi-criteria decision making
- 2.11.2 Decision-making under certainty
 - 2.11.2.1 Analytic Hierarchy Process (AHP)
 - 2.11.2.2 Elimination and Choice Translating Reality (ELECTRE)
- 2.11.3 Decision-making under risk and uncertainty
 - 2.11.3.1 Decision tree-based expected value criterion
 - 2.11.3.2 Utility theory
- 2.11.4 Two-person zero-sum and constant-sum games
- 2.11.5 Robust decision-making

2.12 Stochastic Modeling

- 2.12.1 Stochastic processes
- 2.12.2 Markov chains
- 2.12.3 Chapman-Kolmogorov equations
- 2.12.4 States and properties

2.13 Queuing Systems

- 2.13.1 Components of a queuing model



- 2.13.2 Relationship between the exponential and Poisson distributions
- 2.13.3 Birth-and-death process-based queuing models
- 2.13.4 Queuing models involving non-exponential distributions
- 2.13.5 Priority-discipline queuing models
- 2.13.6 Queuing networks
- 2.14 Simulation
 - 2.14.1 Simulation paradigms
 - 2.14.1.1 Discrete Event Simulation (DES)
 - 2.14.1.2 Continuous simulation
 - 2.14.1.3 Agent-based simulation
 - 2.14.1.4 Hybrid simulation
 - 2.14.1.5 Machine learning and modeling
 - 2.14.2 Simulation methodology
 - 2.14.2.1 Simulation problem definition & scope
 - 2.14.2.2 Conceptual modeling (e.g., endogenous and exogenous activities, systems dynamics, model assumptions)
 - 2.14.2.3 Data collection
 - 2.14.2.4 Generating random numbers and variates
 - 2.14.2.5 Input analysis (i.e., modeling arrival and service processes, input parameter estimation, and goodness-of-fit test)
 - 2.14.2.6 Verification
 - 2.14.2.7 Validation
 - 2.14.2.8 Statistical methods for simulation (e.g., number of replications, design of experiments)
 - 2.14.2.9 Output analysis (i.e., statistical comparison of multiple system designs, and what-if analysis)
 - 2.14.2.10 Simulation optimization
 - 2.14.2.11 Visualization and animation
 - 2.14.2.12 Digital twins
 - 2.14.3 Simulation-based training (academia and industry)
 - 2.14.4 The Practice of simulation
 - 2.14.4.1 The process of simulation
 - 2.14.4.2 The Art & science of simulation
 - 2.14.4.3 Applications



2.15 Fundamentals of systems dynamics

2.15.1 Principles of system dynamics

2.15.2 Balancing loops

2.15.3 Feedback loops

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3 Engineering Economic Analysis

Engineering Economics is a specific knowledge area of economics that applies economic principles and analytical methods to evaluate engineering projects, systems, and processes. This area focuses on financial viability, the allocation of resources, and the long-term value of engineering solutions to aid in making informed decisions. Industrial engineers play a critical role in this process; they are responsible for the economic evaluation of potential solutions to problems, cost optimization, and maximization of financial returns while considering constraints such as time, resources, and sustainability. Engineering Economics is essential for prioritizing alternatives, managing risks, and achieving efficiency in complex, real-world projects.

3.1 Value and Utility

- 3.1.1 Understand the difference between value and utility in economics
- 3.1.2 Understand the relationship between value and utility and its importance in economics

3.2 Classification of Cost

- 3.2.1 Understand costs to properly compare engineering alternatives
- 3.2.2 First (initial) cost
- 3.2.3 Fixed and variable cost
- 3.2.4 Incremental and marginal cost
- 3.2.5 Average cost
- 3.2.6 Sunk cost

3.3 Interest and Interest Formulas

- 3.3.1 Time value of money
 - 3.3.1.1 Simple interest
 - 3.3.1.2 Compound interest
 - 3.3.1.3 Nominal and effective interest rates
- 3.3.2 Equivalence calculations
- 3.3.3 Digital tools for interest calculations (e.g., spreadsheets, programming)

3.4 Cash Flow Analysis

- 3.4.1 Equivalent worth methods (i.e., Present worth, annual worth, future worth)
- 3.4.2 Benefit-cost ratio
- 3.4.3 Payback periods
 - 3.4.3.1 Simple payback period
 - 3.4.3.2 Discounted payback period
- 3.4.4 Rate of returns
 - 3.4.4.1 Internal rate of return
 - 3.4.4.2 External rate of return



- 3.4.5 Return on investment
- 3.5 Financial Decision-Making Among Alternatives
 - 3.5.1 Proposal types
 - 3.5.2 Decision criteria for alternatives
 - 3.5.3 Decision criteria under limited funds
 - 3.5.4 Methods
 - 3.5.4.1 Ranking methods (e.g., Present worth, annual worth)
 - 3.5.4.2 Incremental method (e.g., internal rate of return, benefit-cost ratio)
- 3.6 Evaluation of Public Activities
 - 3.6.1 General welfare of public interests
 - 3.6.2 Financing public activities
 - 3.6.3 Benefit-cost analysis
- 3.7 Cost Accounting and Management
 - 3.7.1 Budgeting
 - 3.7.1.1 Top-down budgeting
 - 3.7.1.2 Bottom-up budgeting
 - 3.7.1.3 Negotiated budgeting
 - 3.7.2 Financial Statements
 - 3.7.2.1 Balance sheet
 - 3.7.2.2 Income statement
 - 3.7.2.3 Cash flow statement
 - 3.7.2.4 Statement of shareholders' equity
 - 3.7.3 Cost accounting
 - 3.7.3.1 Traditional cost accounting
 - 3.7.3.2 Activity-based accounting
- 3.8 Depreciation and Depreciation Accounting
 - 3.8.1 Types of depreciation
 - 3.8.2 Consuming assets
 - 3.8.3 Depreciation methodologies
 - 3.8.4 Depletion
 - 3.8.5 Capital recovery
- 3.9 Income Taxes in Economic Analysis
 - 3.9.1 Profit and income taxes



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- 3.9.2 Individual income taxes
 - 3.9.3 Corporate income taxes
 - 3.9.4 Depreciation and income taxes
 - 3.9.5 Depletion and income taxes
 - 3.9.6 Tax credit
 - 3.10 Estimating Economic Elements
 - 3.10.1 Cost estimating methods
 - 3.10.2 Cost elements
 - 3.10.3 Project, product, operations, system, and processes cost estimation
 - 3.10.4 Job cost estimation
 - 3.10.5 Service life estimation
 - 3.10.6 Judgment in cost estimation
 - 3.10.7 Ethics in cost estimation
 - 3.11 Estimates and Decision Making
 - 3.11.1 Estimating economic benefits
 - 3.11.2 Judgments in estimating
 - 3.12 Decision Making Under Risk and Uncertainty
 - 3.12.1 Probabilistic methods related to decision making
 - 3.12.2 Methods related to decision-making in the absence of meaningful data
 - 3.12.3 Payoff matrix
 - 3.12.4 Laplace rule
 - 3.12.5 Maximin and maximax rules
 - 3.12.6 Hurwicz rule
 - 3.12.7 Minimax regret rule
 - 3.12.8 Simulation analysis (e.g., Monte Carlo Simulation)
 - 3.12.9 Decision trees (e.g., abandonment, replacement analysis)
 - 3.12.10 Break-even analysis
 - 3.12.11 Sensitivity analysis
 - 3.13 Analysis of Construction and Production Operations
 - 3.13.1 Critical path
 - 3.13.2 Geographic location
 - 3.13.3 Economic operation of equipment
 - 3.13.4 Variable demand



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4 Facilities Engineering and Energy Management

Facilities Engineering is concerned with the arrangement of physical resources to support the optimal production and distribution of goods and services. Energy Management includes the planning and operation of energy required in facilities to support the production and distribution of goods and services. Their close interrelationship accounts for their knowledge topic described in a common section.

4.1 Facilities Location

- 4.1.1 Single-facility placement
- 4.1.2 Multiple-facility placement and tradeoffs with a single facility
- 4.1.3 Location-allocation problems
- 4.1.4 Global facilities, geopolitical risks, and reshoring/offshoring
- 4.1.5 Social and environmental impact of facility locations

4.2 Facilities Sizing

- 4.2.1 Customer demand, market analysis, and inventory implications
- 4.2.2 Product, process, and schedule analysis
- 4.2.3 Equipment selection and personnel requirements analysis
- 4.2.4 Space and code requirements analysis
 - 4.2.4.1 Workstations
 - 4.2.4.2 Storage
 - 4.2.4.3 Departments
 - 4.2.4.4 Aisles
 - 4.2.4.5 Offices
 - 4.2.4.6 Green buildings
 - 4.2.4.7 Scalability and flexibility
- 4.2.5 Environmental footprint of facility size

4.3 Facilities Layout

- 4.3.1.1 Basic layout types
- 4.3.1.2 Applications
- 4.3.1.3 Advantages
- 4.3.1.4 Disadvantages
- 4.3.2 Data requirements
- 4.3.3 Traditional approaches
 - 4.3.3.1 Systematic layout planning
 - 4.3.3.2 Flow process chart



- 4.3.3.3 Activity relationship chart
- 4.3.3.4 From-to chart
- 4.3.3.5 Distance measures
- 4.3.4 Basic algorithms
 - 4.3.4.1 Construction
 - 4.3.4.2 Improvement
 - 4.3.4.3 Hybrid
- 4.3.5 Accessibility and universal design considerations
- 4.3.6 Evaluation of alternative layouts
- 4.4 Material Handling
 - 4.4.1 Material handling principles
 - 4.4.2 Unit of measure
 - 4.4.3 Equipment types and selection
 - 4.4.4 Models for material handling system design
 - 4.4.5 Smart material handling systems (e.g., Automated Guided Vehicles (AGVs), Autonomous Mobile Robots (AMRs))
 - 4.4.6 Storage, Warehousing, and Distribution
 - 4.4.7 Storage/warehouse/distribution functions
 - 4.4.8 Storage policies
 - 4.4.9 Order picking methods and design principles
 - 4.4.10 Analytical models of order picking functions
 - 4.4.11 Storage/retrieval equipment and systems
 - 4.4.12 Location and layout of docks
 - 4.4.13 Design for racks and block stacking
 - 4.4.14 Warehouse layout models
 - 4.4.15 Automation in storage/retrieval
 - 4.4.16 Social and environmental impact of warehouse and distribution centers
- 4.5 Plant and Facilities Engineering
 - 4.5.1 Building codes compliance and use of standards
 - 4.5.2 Structural systems
 - 4.5.3 Atmospheric systems
 - 4.5.4 Enclosure systems
 - 4.5.5 Lighting and electrical systems
 - 4.5.6 Life safety systems



- 4.5.7 Security and loss control systems
- 4.5.8 Sanitation systems
- 4.5.9 Building automation systems
- 4.5.10 Facilities maintenance management systems
- 4.5.11 Sustainable building and energy-efficient systems (e.g., solar, geothermal, net zero)
- 4.5.12 Building energy management systems and international standards (ISO 50001)
- 4.5.13 Smart building integration
- 4.5.14 Predictive maintenance

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5 Quality & Reliability Engineering

Quality Engineering covers the tools and techniques employed in manufacturing and service industries. In product manufacturing, these techniques help prevent mistakes or defects in products. In service processes, these tools are used to avoid problems when delivering solutions or services to customers. A closely related knowledge area is Reliability Engineering. These concepts are used to determine the ability of a system or component to function under stated conditions for a specified period.

5.1 Quality Definition and Fundamentals

5.1.1 Quality Concepts

- 5.1.1.1 Design for quality
- 5.1.1.2 Manufacturing quality
- 5.1.1.3 Marketing/service quality

5.1.2 Fundamentals

- 5.1.2.1 Probability
- 5.1.2.2 Sample data
- 5.1.2.3 Distributions
- 5.1.2.4 Basic statistics
- 5.1.2.5 Hypothesis testing
- 5.1.2.6 Analysis of variance
- 5.1.2.7 Regression analysis
- 5.1.2.8 Histogram, box plot and probability plot

5.2 On-line Quality Engineering Methods

5.2.1 Control Charts and Process Capability

- 5.2.1.1 Variable control charts (e.g., \bar{X} -chart, R-chart, S-chart, S^2 -chart, exponentially weighted moving average (EWMA) chart, cumulative sum control (CUSUM) chart, moving range (MR) chart, multivariate control chart, single stage production processes, multi-stage production processes)
- 5.2.1.2 Attribute control charts (e.g., Fraction defective (p-chart, np-chart), number of defects per unit (c-chart, u-chart), CUSUM chart, EWMA chart)

5.2.2 Lot Acceptance Sampling

- 5.2.2.1 Attributes (e.g., Single-sample plans, double and sequential fraction-defective sampling, multiple fraction-defective, DoD sampling plans)
- 5.2.2.2 Variables (e.g., Fraction defective)
- 5.2.2.3 Process/lot fraction defective
- 5.2.2.4 Mean or standard deviation of a process/lot

5.2.3 Rectifying inspection/auditing

- 5.2.3.1 Lot-by-lot sampling



- 5.2.3.2 Continuous production
- 5.2.3.3 Toward eliminating inspection
- 5.2.3.4 Mistake proofing
- 5.2.3.5 Gauge repeatability and reproducibility (R&R)
- 5.2.4 Quality Control in Cyber-Physical and IoTs-based Smart Systems
 - 5.2.4.1 Industry 4.0: Cyber-physical systems and IoT Network
 - 5.2.4.2 Quality assessment in IoT systems
 - 5.2.4.3 Digital Twins
- 5.3 Off-Line Quality Engineering Methods
 - 5.3.1 Design of Experiments
 - 5.3.1.1 Strategy of experimentation
 - 5.3.1.2 Basic analysis techniques, analysis of variance (ANOVA)
 - 5.3.1.3 Experimental principles: replication, randomization, and blocking
 - 5.3.1.4 Factorial designs
 - 5.3.1.5 Two-level factorial designs, blocking, and confounding
 - 5.3.1.6 Fractional factorial designs
 - 5.3.1.7 Random factors in experiments
 - 5.3.1.8 Nested and split-plot designs
 - 5.3.2 Regression
 - 5.3.2.1 Simple linear regression models
 - 5.3.2.2 Inference in simple linear regression
 - 5.3.2.3 Residual analysis and model adequacy checking
 - 5.3.2.4 Multiple linear regression model fitting
 - 5.3.2.5 Inference in multiple regression
 - 5.3.2.6 Model adequacy checking
 - 5.3.2.7 Variable selection techniques, stepwise regression, and related methods
 - 5.3.3 Response Surface Methodology
 - 5.3.3.1 One factor at a time
 - 5.3.3.2 Central composite design
 - 5.3.3.3 Robust design
 - 5.3.3.4 Control factor and noise factor
 - 5.3.3.5 Cross array design
 - 5.3.3.6 Taguchi method



5.4 Quality Management and Training

5.4.1 Lean Six Sigma

- 5.4.1.1 Customer focused quality
- 5.4.1.2 Defects per million opportunities (DPMO)
- 5.4.1.3 Process capability
- 5.4.1.4 Value stream mapping
- 5.4.1.5 Types of wastes
- 5.4.1.6 Business diagnostic
- 5.4.1.7 Decision making based on data
- 5.4.1.8 DMAIC
- 5.4.1.9 DMADV

5.4.2 Change Management

- 5.4.2.1 Building Support

5.4.3 Sustainability and Environmental Considerations in Quality Engineering

- 5.4.3.1 Sustainability metrics in quality evaluation
- 5.4.3.2 Life cycle assessment in design for quality and sustainability

5.5 Reliability Engineering

5.5.1 Fundamentals

- 5.5.1.1 Definition: reliability, availability, maintainability
- 5.5.1.2 Failure time distributions
- 5.5.1.3 Basic system configurations (e.g., Series systems, parallel systems, K-out-of-n systems, network systems)

5.5.2 Reliability Testing

- 5.5.2.1 Burn-in testing
- 5.5.2.2 Demonstration testing
- 5.5.2.3 Acceptance testing
- 5.5.2.4 Accelerated testing
- 5.5.2.5 Degradation testing

5.5.3 Failure Analysis

- 5.5.3.1 Failure modes
- 5.5.3.2 Failure mechanisms
- 5.5.3.3 Fault tree analysis
- 5.5.3.4 Failure modes and effects analysis (FMEA)

5.5.4 Maintenance



- 5.5.4.1 Sensors and applications in maintenance
 - 5.5.4.2 Preventative maintenance
 - 5.5.4.3 Failure replacement
 - 5.5.4.4 Condition-based maintenance
 - 5.5.4.5 Group replacement
 - 5.5.4.6 Maintenance and warranty
- 5.6 Quality Control and Reliability Engineering in Emerging Fields
- 5.6.1 Biotechnology and Healthcare Systems
 - 5.6.2 Renewable Energy Systems
 - 5.6.3 Electric and Autonomous Vehicles
 - 5.6.4 Aerospace and Aviation Systems

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6 Ergonomics and Human Factors

Ergonomics and Human Factors as a field of research and practice is concerned with the design and analysis of equipment and devices that fit the human body and its cognitive abilities. The knowledge area includes contributions from anthropometry, psychology, physiology, biomechanics, industrial and graphic design, operations research, safety, and other disciplines. Areas of Practice include: Physical Ergonomics, Cognitive Ergonomics, and Organizational Ergonomics.

6.1 Ergonomic Basics

6.1.1 Focuses of Ergonomics

6.1.2 Ergonomics and work systems

6.1.3 Suggesting, implementing, and managing ergonomic interventions

6.1.4 Effectiveness and cost-effectiveness of ergonomics

6.2 Organizational and Social Aspects of System Design

6.2.1 Systems design methods for ergonomics (see **Error! Reference source not found.**)

6.2.2 Organizational aspects

6.2.3 Individual and organizational psychosocial factors

6.2.4 Litigation

6.2.5 Cross-cultural considerations

6.3 Anthropometric Principles in Workspace and Equipment Design

6.3.1 Basic body mechanics

6.3.2 Risk factors for musculoskeletal disorders

6.3.3 Designing for a population of users

6.3.4 Sources of human variability

6.3.5 Principles of applied anthropometry in ergonomics

6.3.6 Application of anthropometry in design

6.3.7 Designing for everyone

6.4 Work Capacity and Fatigue

6.4.1 Muscles, structure, function, and capacity

6.4.2 Occupational biomechanics

6.4.3 Cardiovascular system

6.4.4 Respiratory system

6.4.5 Physical work capacity

6.4.6 Applied physiology in designing the workplace

6.4.7 Fitness for work/fit for duty/return to work



- 6.5 Design of the Thermal Environment
 - 6.5.1 Fundamentals of human thermoregulation
 - 6.5.2 Thermoregulatory mechanisms
 - 6.5.3 Measuring the thermal environment
 - 6.5.4 Work in hot climates
 - 6.5.5 Work in cold climates
- 6.6 Design of Repetitive Tasks
 - 6.6.1 Introduction to work-related musculoskeletal disorders
 - 6.6.2 Injuries to the body at work
 - 6.6.3 Tissue pathomechanics
 - 6.6.4 Redesign of work to limit repetition
- 6.7 Design of Manual Handling Tasks
 - 6.7.1 Anatomy and biomechanics of manual handling
 - 6.7.2 Prevention of manual handling injuries in the workplace
 - 6.7.3 Design of manual handling tasks
 - 6.7.4 Lifting, carrying, and pushing
- 6.8 Design for Standing and Sitting
 - 6.8.1 Ergonomic approach to workstation design, including movement
 - 6.8.2 Design for standing posture
 - 6.8.3 Design for seated posture
 - 6.8.4 Design for other postures
 - 6.8.5 Work surface design
 - 6.8.6 Visual displays
- 6.9 Vision, Light, and Lighting
 - 6.9.1 Vision and the eye
 - 6.9.2 Measurement of light
 - 6.9.3 Lighting design considerations
 - 6.9.4 Visual fatigue, eyestrain, and near work
 - 6.9.5 Psychological aspects of indoor lighting
- 6.10 Hearing, Sound, Noise, and Vibration
 - 6.10.1 Sound and the ear
 - 6.10.2 Measurement of sound
 - 6.10.3 Hearing protection



- 6.10.4 Design of the acoustic environment
- 6.10.5 Noise control
- 6.10.6 Effects of noise on task performance
- 6.10.7 Non-auditory effects of noise on health
- 6.10.8 Vibration
- 6.11 Human Information Processing, Skill, and Performance
 - 6.11.1 Information processing models
 - 6.11.2 Cognitive systems
 - 6.11.3 Problem solving
- 6.12 Displays and Controls
 - 6.12.1 Human-centered design processes for interactive systems
 - 6.12.2 Principles for the design of visual displays
 - 6.12.3 Auditory, tactile, and vibratory displays
 - 6.12.4 Design of controls
 - 6.12.5 Combining displays and controls
- 6.13 Human-machine interaction, human error, and safety
 - 6.13.1 Human error and machine/equipment design and interaction
 - 6.13.2 Mental workload in human-machine interaction
 - 6.13.3 Psychological aspects of human error
 - 6.13.4 Prevention of error in human-machine interaction
 - 6.13.5 Accidents and safety

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7 Operations Engineering & Management

Operations Engineering and Management is an area of technical management dealing with the design and analysis of production and service processes. From an industrial engineering viewpoint this knowledge area employs tools and techniques to ensure business operations function efficiently, using as few resources as needed, and effectively in meeting customer requirements.

7.1 Operations Planning

7.1.1 Life cycles

7.1.1.1 Product

7.1.1.2 Service

7.1.1.3 Process

7.1.2 Forecasting

7.1.2.1 Methods/models

7.1.2.2 Trend-based

7.1.2.3 Seasonal series

7.1.2.4 Machine learning-based

7.1.3 Aggregate planning

7.1.4 Market analysis

7.2 Project Management

7.2.1 Network analysis (Critical Path Analysis (CPA), PERT)

7.2.2 Managing multiple projects with constrained resources

7.2.3 Agile project management

7.3 Production and Operations Planning and Control

7.3.1 Scheduling

7.3.1.1 Master scheduling

7.3.1.2 Capacity

7.3.1.3 Leveling load demand

7.3.2 Sequencing

7.4 Production Scheduling

7.4.1 Job shops

7.4.2 Continuous flow

7.4.3 Just-in-time/Kanban

7.4.4 Level loading

7.4.5 Work schedules/personnel scheduling



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- 7.5 Inventory Management & Control
 - 7.5.1 Known demand
 - 7.5.2 Uncertain demand
 - 7.5.3 Make to order
 - 7.5.4 Make to assembly
 - 7.5.5 Make to stock
 - 7.6 Capacity Management
 - 7.6.1 Labor
 - 7.6.2 Equipment
 - 7.6.3 Materials
 - 7.6.4 Demand management (voice of customer)
 - 7.6.5 Throughput
 - 7.7 Enterprise Systems
 - 7.7.1 Materials Requirements Planning (MRP)
 - 7.7.2 Enterprise Resource Planning (ERP)
 - 7.7.3 Manufacturing Execution Systems (MES)
 - 7.7.4 Explosion calculus and lot sizing
 - 7.8 Purchasing/Supply Chain
 - 7.8.1 (See **Error! Reference source not found.**)
 - 7.9 Maintenance Management & Control
 - 7.9.1 Maintenance models
 - 7.9.2 Total Productive Maintenance (TPM)
 - 7.9.3 Overall Equipment Effectiveness (OEE)
 - 7.10 Organizational Issues (See **Error! Reference source not found.**)
 - 7.11 Sustainable and Lifecycle-Oriented Operations
 - 7.11.1 Product Lifecycle Management
 - 7.11.1.1 Aftermarket services and support
 - 7.11.1.2 Spare parts planning
 - 7.11.1.3 Repair and refurbishment systems
 - 7.11.1.4 Warranty/non-warranty/good-will support
 - 7.11.1.5 End-of-life product recovery
 - 7.11.2 Green manufacturing and circular economy



7.12 Operational Performance Metrics

- 7.12.1 Cost
- 7.12.2 Quality
- 7.12.3 Service level
- 7.12.4 Delivery
- 7.12.5 Productivity
- 7.12.6 Throughput
- 7.12.7 Plan effectiveness
- 7.12.8 Cycle time
- 7.12.9 Inventory turnover
- 7.12.10 JIT ratios
- 7.12.11 Efficiency
- 7.12.12 Overall Equipment Effectiveness (OEE)
- 7.12.13 Work in process (WIP)

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- *Production and Operations Analysis*. Nahmias, S. and T. Lennon Olsen. Waveland Press, Inc., 8th Edition. 2020.
- *Operations and Supply Chain Management*. Russell, Roberta S. and Taylor, Bernard W. John Wiley & Sons, 11th Edition. 2023.
- *Product Lifecycle Management (Volume 1): 21st Century Paradigm for Product Realisation*. Stark, John. Springer, 5th Edition. 2022.



8 Supply Chain Management

Supply Chain Management (SCM) covers the movement, production, and storage of raw materials, work-in-process inventory, finished goods, and services from the point of origin to the point of consumption or use. Suppliers, manufacturers, intermediaries, retailers, and service providers are involved in delivering products and services to end customers within a supply chain. In the circular economy, the SCM also covers the reuse, repurpose, recycling, disposal, and reverse logistics.

8.1 Supply Chain Management Fundamentals

- 8.1.1 Supply chain management processes
- 8.1.2 Make/buy analysis
- 8.1.3 Adding value to organizations
- 8.1.4 Importance of aligning supply chain strategy with corporate strategy
- 8.1.5 Supply chain risk management strategies
- 8.1.6 Assessment and measurement of the effectiveness of supply chains
- 8.1.7 The environmental footprint and social impact of supply chain
- 8.1.8 Supply chain resilience
- 8.1.9 Digital and decentralized supply chain capabilities (e.g., IoT, cloud platforms, blockchains, digital twin)

8.2 Building Competitive Operations, Planning, and Logistics

- 8.2.1 Dynamics within the supply chain to optimize performance and increase profitability
- 8.2.2 Designing agility into a supply chain
- 8.2.3 Lean principles in a supply chain
- 8.2.4 Assessing the value of demand
- 8.2.5 Reducing complexity in demand planning
- 8.2.6 Establishing collaborations to replace or improve demand estimates
- 8.2.7 Including supply chain factors in product design
 - 8.2.7.1 Cost
 - 8.2.7.2 Packaging
 - 8.2.7.3 Environmental footprint in product design
- 8.2.8 Aligning distribution and transportation options with supply chain strategy
- 8.2.9 3PL and 4PL service providers
- 8.2.10 Supply chain network design
 - 8.2.10.1 Tiers
 - 8.2.10.2 Number, size, and location of facilities



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- 8.3 Circular Supply Chain in the Circular Economy
 - 8.3.1 Circular economy and its characteristics in the supply circle
 - 8.3.2 Reverse logistics for reuse, repurpose, remanufacturing, recycle, and disposal
 - 8.4 Managing Product Flow
 - 8.4.1 Inventory control methodologies (see **Error! Reference source not found.**)
 - 8.4.2 Material handling systems
 - 8.4.3 Work sourcing management
 - 8.4.4 Transportation management
 - 8.4.4.1 Mode/multi-mode/carrier selection
 - 8.4.4.2 Consolidation
 - 8.4.4.3 Vehicle routing
 - 8.4.4.4 Last-mile problem
 - 8.5 Warehouse Systems
 - 8.5.1 Order picking strategies
 - 8.5.2 Cross-docking
 - 8.5.3 Kitting
 - 8.5.4 Sortation
 - 8.5.5 Warehouse management systems
 - 8.6 Managing Customer Relationships
 - 8.6.1 Customer stratification based on their profiles and needs
 - 8.6.2 Understanding customer loyalty and lifetime value of a customer
 - 8.6.3 Establishing measures of customer satisfaction
 - 8.6.4 Managing Supplier Relationships
 - 8.6.5 Insourcing vs. outsourcing decisions
 - 8.6.5.1 On-shore
 - 8.6.5.2 Off-shore
 - 8.6.6 Strategic importance of purchasing and supplier relationships
 - 8.6.7 Supplier scorecard systems
 - 8.6.8 Managing the supplier lifecycle
 - 8.6.8.1 Supplier selections
 - 8.6.8.2 Contracting
 - 8.6.8.3 Onboarding
 - 8.6.8.4 Order-to-cash



- 8.6.8.5 Decommissioning a supplier
- 8.6.9 Customer data
 - 8.6.9.1 Service performance
 - 8.6.9.2 Increasing value to suppliers and customers
- 8.6.10 Personalized service strategies using AI
- 8.6.11 Selection of and understanding Tier 2,3, etc. suppliers
- 8.6.12 Supplier risk management

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9 Engineering Management

Engineering Management is a focused area of management dealing with the application of engineering principles to business practice. Whereas Operations Engineering and Management focuses on the design and analysis of production and service processes, Engineering Management deals with the technical business side of the organization.

9.1 Stakeholder Focus

9.1.1 Needs identification

- 9.1.1.1 Stakeholder analysis
- 9.1.1.2 Stakeholder relationship management
- 9.1.1.3 Stakeholder Elicitation
- 9.1.1.4 Stakeholder Conflict
- 9.1.1.5 Stakeholder Negation
- 9.1.1.6 Stakeholder Agreement

9.1.2 Market product strategy

- 9.1.2.1 Market analysis
- 9.1.2.2 SWOT, PESTEL

9.1.3 Voice of Customer

- 9.1.3.1 Quality Function Deployment

9.2 Organizational Management

9.2.1 Leadership

9.2.2 Organizational structure and development

9.2.3 Teamwork

- 9.2.3.1 Conflict resolution
- 9.2.3.2 Team stages

9.2.4 Communication

9.2.5 Internal corporate culture and external global culture

9.2.6 Management

9.2.7 Resource allocation

9.2.8 Organizational responsibilities

9.2.9 Change (culture) management

9.3 Knowledge Management

9.3.1 Systems planning, design, and justification



- 9.3.2 Systems development
- 9.3.3 Infrastructure of a shared knowledge system
- 9.3.4 Systems Thinking
- 9.3.5 Systems Design Life Cycle (VEE model)
- 9.3.6 Systems costing

9.4 Business Process and Technology Management

- 9.4.1 Business Processes
- 9.4.2 Process Design
- 9.4.3 Business Process Reengineering
- 9.4.4 Business Process Improvement
- 9.4.5 Business Process Management Systems
- 9.4.6 Production Overhead Processes
- 9.4.7 Production Processes
- 9.4.8 Service processes
- 9.4.9 Technology Integration
- 9.4.10 Business Process Simulation
- 9.4.11 Product/process development
- 9.4.12 Process management and improvement
- 9.4.13 Research and development
- 9.4.14 Transactional business processes
- 9.4.15 Customer support
- 9.4.16 Data analytics and statistical analysis
- 9.4.17 Enterprise and Business Architecture (e.g., SysML and Model-based Systems Engineering)
 - 9.4.17.1 Information systems and architectures
- 9.4.18 Socio technical systems
- 9.4.19 Human factors engineering
- 9.4.20 Quality management

9.5 Strategic Management

- 9.5.1 Vision and mission
- 9.5.2 Environmental scanning
- 9.5.3 Organizational assessment
- 9.5.4 The planning processes



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- 9.5.5 Goals, objectives, targets, and measures
 - 9.5.6 Strategic planning
 - 9.5.7 Plan implementation
 - 9.5.8 Monitoring and evaluating progress
- 9.6 Human Resource Management
- 9.6.1 Human capital and technical competency management
 - 9.6.2 Motivation theory and practice
 - 9.6.3 Learning, education, training, and development
 - 9.6.4 Performance management
 - 9.6.5 Compensation management
 - 9.6.5.1 Elements of Compensation
 - 9.6.5.2 Job analysis
 - 9.6.5.3 Job evaluation
 - 9.6.5.4 Incentive systems
 - 9.6.5.5 Labor contracts
 - 9.6.5.6 Collective bargaining
- 9.7 American Labor Unions – provenance and history
- 9.7.1 Unions and Democratic Relations Between Unions and Members
 - 9.7.2 Union governance
 - 9.7.3 Employer-Employee-Union Relations: Collective Bargaining
 - 9.7.4 The Law on Collective Bargaining
 - 9.7.5 Collective Bargaining as a process
 - 9.7.6 Negotiating Labor-Management Agreements
 - 9.7.7 Settling Labor Relations Problems through Arbitration
 - 9.7.8 Grievances and Discipline
- 9.8 Project Management
- 9.8.1 Project Life Cycle
 - 9.8.1.1 Gates & Decision Points
 - 9.8.2 Prerequisites for formalizing project management
 - 9.8.2.1 Organization
 - 9.8.2.2 Systems & Continuous Improvement alignment
 - 9.8.3 Integrated Project Management Processes



- 9.8.3.1 Initiating
- 9.8.3.2 Oversight
- 9.8.3.3 Directing
- 9.8.3.4 Controlling
- 9.8.3.5 Managing Delivery & Closing

9.8.4 Management Practices for Projects

- 9.8.4.1 Planning
- 9.8.4.2 Benefits
- 9.8.4.3 Resources
- 9.8.4.4 Schedule
- 9.8.4.5 Costs
- 9.8.4.6 Risks
- 9.8.4.7 Issues
- 9.8.4.8 Change Control
- 9.8.4.9 Quality
- 9.8.4.10 Stakeholders
- 9.8.4.11 Communication
- 9.8.4.12 Managing Organization & Society Change
- 9.8.4.13 Reporting
- 9.8.4.14 Information & Document Management
- 9.8.4.15 Procurement
- 9.8.4.16 Lessons Learned

9.8.5 Delivery Approaches

- 9.8.5.1 Predictive
- 9.8.5.2 Iterative
- 9.8.5.3 Incremental
- 9.8.5.4 Hybrid

9.9 Organization system engineering and design

- 9.9.1 Relevant systems science principles (LORV, Conant-Ashby)
- 9.9.2 Representations for form, fit, function, control
- 9.9.3 Architectures and reference models (IDEF0, SM-BSC, LOC, Viable System Model, MC Packages)
- 9.9.4 Analysis and Design principles for Organization design



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- 9.9.5 Organization Control
 - 9.9.6 Socio technical systems (STS)
 - 9.9.7 High reliability organizations (HRO)
 - 9.9.8 Resilience (systems) engineering (RE)
 - 9.9.9 Balanced scorecard
 - 9.9.10 Productivity
 - 9.9.11 Quality
 - 9.9.12 Efficiency
 - 9.9.13 Effectiveness
 - 9.9.14 Safety Engineering
 - 9.9.15 Customer satisfaction
 - 9.9.16 Financial
 - 9.9.17 Cost benefit analysis
 - 9.9.18 Return on Investment
 - 9.9.19 Time Value of Money
 - 9.9.20 Personnel (human capital) development
 - 9.10 Ethics in Engineering Management
 - 9.10.1 Values and Value Judgements
 - 9.10.2 Ethics and Ethical Justification
 - 9.10.3 Interests and Consequences
 - 9.10.4 Moral Obligations and Rules in Engineering
 - 9.10.5 Categories of Moral, Legal, and Institutional Rights
 - 9.10.6 Rights of Privacy and Confidentiality
 - 9.10.7 Intellectual Property Rights
 - 9.11 Legal Issues in Engineering Management
 - 9.11.1 Contracts
 - 9.11.2 Regulatory Compliance
 - 9.11.3 Environmental Management
 - 9.11.4 Warranties
 - 9.11.5 Liability
 - 9.11.6 Licenses
 - 9.11.7 Patents
 - 9.12 Infrastructure Management
 - 9.12.1 Establish Infrastructure



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- 9.12.2 Maintain Infrastructure
 - 9.12.3 Manage Infrastructure
 - 9.13 Portfolio Management
 - 9.13.1 Portfolio Project Definition
 - 9.13.2 Portfolio Project Authorization
 - 9.13.3 Portfolio Project Evaluation
 - 9.13.4 Portfolio Project Termination
 - 9.14 Configuration Management
 - 9.14.1 Configuration Identification
 - 9.14.2 Configuration Change Management
 - 9.14.3 Configuration Status Accounting
 - 9.14.4 Configuration Verification and Auditing
 - 9.14.5 Configuration Documentation
 - 9.15 Information Management
 - 9.15.1 Information Generation
 - 9.15.2 Information Engineering
 - 9.15.3 Information Collection
 - 9.15.4 Information Confirmation
 - 9.15.5 Information Transformation
 - 9.15.6 Information Retention
 - 9.15.7 Information Retrieval
 - 9.15.8 Information Dissemination
 - 9.15.9 Information Disposition
 - 9.16 Risk Analysis
 - 9.16.1 Risk Assessment
 - 9.16.1.1 Methods
 - 9.16.1.2 Tools
 - 9.16.2 Risk Management
 - 9.16.2.1 Risk Profile
 - 9.16.2.2 Risk Treatment
 - 9.16.3 Risk Communications
 - 9.16.4 Business Continuity Planning
 - 9.16.5 Risk mitigation and costing
 - 9.16.6 Risk tracking



9.17 Leadership

- 9.17.1 Leadership principles
- 9.17.2 Leadership styles
- 9.17.3 Leadership competencies

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10 Safety

Safety Engineering addresses the origins of workplace accidents, regulations, and management practices towards mitigating hazard exposures, preventing harm, and reducing liability. Safety engineering also addresses methods and measures for recognizing and controlling workplace physical hazards, as well as approaches for dealing with accidents and facilitating recovery.

10.1 Perspective and Overview

10.1.1 History of safety and health movement

10.1.2 Definition of hazards and accident statistics

10.1.3 Theories of accident causation

10.1.3.1 Accident analysis methods and techniques (e.g., AcciMap, TRIPOD, STAMP, FRAM)

10.1.4 Effects on global competition on safety and health practice and regulations

10.2 USA Laws and Regulations

10.2.1 Product safety and liability (safety in the courtroom)

10.2.2 Consumer product safety commission

10.2.3 Workers' compensation

10.2.4 OSHA standards and liability

10.2.5 OSHA record keeping system

10.2.6 Hazard communication standard (DOT regulations)

10.2.7 Environmental Protection Agency (EPA)

10.2.8 Clean Air Act

10.2.9 Toxic Substances Control Act (TSCA)

10.2.10 Resource Conservation and Recovery Act (RCRA)

10.2.11 Mine Safety and Health Administration (MSHA)

10.3 Hazard Recognition, Evaluation, and Control

10.3.1 Mechanical hazards and machine safeguarding

10.3.2 Fall hazards, acceleration, and impacts

10.3.3 Thermal stress

10.3.4 Noise and vibration hazards

10.3.5 Electrical hazards

10.3.6 Fire hazards

10.3.7 Radiation and Biological Hazards

10.3.8 Nanotechnology

10.3.9 Emerging technologies (e.g., Cobots, remote controls, computers, artificial intelligence)



10.3.10 Industrial hygiene

10.3.10.1 Introduction to toxicology

10.3.10.2 Introduction to epidemiology

10.4 Fire Protection

10.4.1 Fire protection analysis

10.4.2 Fire dynamics fundamentals

10.4.3 Active and passive systems

10.4.4 Egress and occupant movement

10.4.5 Fire protection codes and standards

10.4.6 Confined spaces

10.4.7 Mobile equipment

10.4.8 Ergonomics and Human Factors

10.5 Safety and Health Management

10.5.1 Ethics and safety

10.5.2 Emergency planning

10.5.3 Accident investigation and reporting

10.5.4 Corporate safety culture

10.5.5 Risk assessment/hazard analysis (Examples include: preliminary hazard analysis, Failure Modes and Effects Analysis, Fault Tree Analysis)

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11 Information Engineering

Information Engineering is an approach to planning, generating, distributing, analyzing, and using collections of data in systems to facilitate decision making and business communication.

11.1 Differentiating Data and Information

11.1.1 Data types

11.1.2 Types of data structures: lists, dictionaries, queues, stacks, hash tables

11.2 Systems Concepts

11.2.1 Number systems/codes

11.2.2 Computer organization

11.2.3 Servers and virtual machines (VM)

11.2.4 Data centers

11.2.5 Network basics

11.2.6 ERP architectures

11.2.7 Workflow management systems

11.2.8 Web and mobile applications

11.2.9 Content management systems (CMS)

11.2.10 N-tier architectures

11.2.11 Web service architectures

11.2.12 Cloud computing and service architectures

11.2.13 Ecommerce system architectures

11.2.14 Systems integration concepts

11.3 Information Requirements for Organizations

11.3.1 Classification of information

11.3.2 Management requirements

11.3.3 Data definitions and governance

11.3.4 Decision making requirements

11.3.5 Operations requirements

11.3.6 Eliciting and gathering requirements

11.3.7 Usability and accessibility requirements (e.g., functional and non-functional performance)



11.4 Designing Information Outputs

11.4.1 Filtering

11.4.2 Key variable reporting/key performance measures (KPIs)/metrics

11.4.3 Monitoring

11.4.4 Modeling

11.4.5 Interrogative

11.4.6 Strategic decision center

11.4.7 Usability/user interface concepts

11.4.8 Data visualization concepts

11.4.9 Designing dashboards

11.5 Data Processing Overview

11.5.1 Data processing resources used in information systems

11.5.2 Data Preprocessing and cleaning

11.5.3 Understanding the data Exploring patterns in data and pattern mining

11.5.4 Anomaly and change point detection

11.5.5 Data Reduction methods

11.5.6 Organizing data processing resources

11.5.7 Cloud and data center processing concepts

11.5.8 Big data processing concepts

11.6 Database Concepts

11.6.1 Application vs. data base processing

11.6.2 Data base management systems

11.6.3 SQL – language, joins, filters, sorting, aggregating, grouping, union/intersection/difference, ranking

11.6.4 Open source (MySQL, PGAdmin,) tools

11.7 Logical Data Organization

11.7.1 Extract, transform, load (ETL), structured, and non-structured data

11.7.2 Data warehousing and storage

11.7.3 Trees

11.7.4 Relational and other database structures

11.7.5 Star schema/data cube/ multidimensional model

11.7.6 NoSQL models



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- 11.7.7 Natural language processing (NLP) (e.g., regular expressions)
 - 11.7.8 Data sharing models - CSV, XML, JSON
 - 11.8 Storage and Processing
 - 11.8.1 Sequential data organization
 - 11.8.2 Direct data organization
 - 11.8.3 Data file classification
 - 11.8.4 File media and file organization
 - 11.8.5 File design
 - 11.8.6 Replication and distribution
 - 11.8.7 Backup and recovery
 - 11.9 System Analysis
 - 11.9.1 Systems development methodology for information systems
 - 11.9.2 Determining the information system demand
 - 11.9.3 Requirements modeling
 - 11.9.4 Data and process modeling
 - 11.9.5 Object modeling
 - 11.9.6 Development strategies
 - 11.9.7 UML and other common diagramming tools in analysis
 - 11.10 System Design
 - 11.10.1 Development of specifications to meet demand
 - 11.10.2 Design process
 - 11.10.3 Data design
 - 11.10.4 System architecture design
 - 11.10.5 UML and other common diagramming tools in design
 - 11.10.6 Communication standards (e.g., fast healthcare interoperability resources (FHIR), application programming interface (API))
 - 11.11 System Evaluation and Justification
 - 11.11.1 Obtaining equipment proposals
 - 11.11.2 Obtaining software proposals
 - 11.11.3 Evaluation of proposals
 - 11.11.4 Acquisition considerations



11.12 Controls

11.12.1 Control points for reliable data processing

11.12.2 Security controls

11.12.3 Encryption

11.13 Forms, Programs, and Procedures

11.13.1 Forms/reports design

11.13.2 Program specifications

11.13.3 Programming techniques

11.14 System Implementation

11.14.1 Training and education

11.14.2 System testing

11.14.3 System conversion

11.14.4 Implementation follow-up

11.15 Management Considerations for the Information System

11.15.1 Maintenance

11.15.2 Auditing

11.15.3 Project management of information systems and software projects

11.15.4 Change management

11.15.5 I.T. governance

11.16 Data Analytics and Machine Learning

11.16.1 Data preparation

11.16.2 Feature identification and evaluation

11.16.3 Model evaluation

11.16.4 Descriptive analytics

11.16.5 Clustering models

11.16.6 Classification models

11.16.7 Predictive analytics

11.16.8 Prescriptive analytics

11.16.9 Statistical inference

11.16.10 Model generalizability

11.16.11 Model Complexity, bias, fairness, variance

11.16.12 Model explainability and interpretability



11.16.13 Programming tools (e.g., R, Python)

11.16.14 Business intelligence tools (e.g., Tableau, MS Power BI, Cognos))

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12 Design and Manufacturing Engineering

Design and Manufacturing Engineering focuses on tools and techniques to conceptualize, engineer, produce, and qualify physical products across feature-scales, production quantities, and application domains. From an industrial engineering viewpoint, this knowledge area is concerned with the development, optimization, and standardization of methods to transform raw materials into functional products to satisfy human long-term well-being and stakeholders' requirements in the most time and cost-efficient manner.

12.1 Engineering Design

12.1.1 Product design methodology (see Product Design and Development knowledge area)

12.1.2 Dimensions, tolerances, limits, and fits

12.1.3 Computer aided design (CAD)

12.1.4 Physical modeling and prototyping

12.1.5 Design for X methodologies (design for machining, design for additive manufacturing, design for assembly, design for quality, etc.)

12.1.6 Other important considerations in product, process, and systems design – sustainability, legal, social, economic, and ethical issues

12.2 Fundamentals of Materials

12.2.1 Types of engineering materials: metals, polymers, ceramics, and composites

12.2.2 Atomic and crystalline structure

12.2.3 Mechanical properties of materials

12.2.4 Physical properties of materials: thermal, electrical, and biological

12.2.5 Environmental sustainability of materials, environmental, toxicity, health, etc.

12.3 Solidification-based Manufacturing Processes

12.3.1 Metal solidification, fluid flow, and heat transfer

12.3.2 Metal casting: expendable and permanent mold processes

12.3.3 Design for metal casting

12.3.4 Casting quality and inspection methods

12.3.5 Environmental sustainability of materials, energy, emissions, water use, etc.

12.3.6 Polymer processing: thermoplastics, thermosets, and polymer-matrix composites processing

12.3.7 Design for polymer processing

12.3.8 Quality considerations for processed polymer parts

12.4 Material Removal Processes

12.4.1 Theory of metal cutting



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- 12.4.2 Conventional machining processes: turning, milling, drilling, and related operations and tools
 - 12.4.3 Abrasive machining processes
 - 12.4.4 Non-traditional machining processes
 - 12.4.5 Machinability and quality considerations
 - 12.4.6 Design for machining
 - 12.5 Forming-based Processes
 - 12.5.1 Fundamentals of metal forming
 - 12.5.2 Bulk deformation processes: rolling, forging, extrusion, and related operations
 - 12.5.3 Sheet metal working processes
 - 12.5.4 Design for metal forming
 - 12.5.5 Quality considerations
 - 12.6 Particulate Processing
 - 12.6.1 Characterization of engineering powders
 - 12.6.2 Powder metallurgy
 - 12.6.3 Ceramics processing
 - 12.6.4 Design and quality considerations
 - 12.7 Joining Processes
 - 12.7.1 Welding: fusion and solid-state processes
 - 12.7.2 Brazing, soldering, adhesive bonding, and related operations
 - 12.7.3 Design and quality considerations
 - 12.8 Additive Manufacturing (AM)
 - 12.8.1 Fundamentals of AM
 - 12.8.2 Categories and principles of AM processes
 - 12.8.3 Design and material considerations in AM
 - 12.8.4 Design and quality considerations in AM
 - 12.8.5 Economics of AM
 - 12.8.6 Hybrid AM: integration with traditional manufacturing processes
 - 12.9 Biomedical Manufacturing (BM)
 - 12.9.1 Fundamentals and categories of BM
 - 12.9.2 Design and material considerations in BM
 - 12.9.3 Principles of BM processes for polymer devices



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- 12.9.4 Principles of BM processes for metal implants
 - 12.9.5 Principles of BM processes for polymer scaffolds
 - 12.9.6 Principles of BM processes for bioink constructs
 - 12.9.7 Regulatory and economic considerations in BM
 - 12.10 Micro and Nano-scale Manufacturing
 - 12.10.1 Fundamentals of scaling
 - 12.10.2 Deposition processes
 - 12.10.3 Etching processes
 - 12.10.4 Doping and surface modification
 - 12.10.5 Lithography processes
 - 12.10.6 Surface and wet bulk micromachining
 - 12.10.7 LIGA
 - 12.10.8 Scanning probe-based processes
 - 12.10.9 Self-assembly processes
 - 12.10.10 Economic considerations
 - 12.11 Manufacturing Planning
 - 12.11.1 Process planning
 - 12.11.2 Group technology and product families
 - 12.11.3 Computer-aided manufacturing (CAM)
 - 12.11.4 Concurrent engineering
 - 12.11.5 Metrology: measurement and inspection
 - 12.11.6 Quality control and assurance
 - 12.11.7 Lean manufacturing and Six Sigma
 - 12.11.8 Cost estimation and economics of manufacturing
 - 12.12 Manufacturing Systems
 - 12.12.1 Automation and systems integration
 - 12.12.2 Numerical control
 - 12.12.3 Robotics
 - 12.12.4 Production and assembly lines
 - 12.12.5 Production systems, planning, and control
 - 12.12.6 Flexible manufacturing systems
 - 12.12.7 Computer-integrated manufacturing (CIM)



12.12.8 Cellular manufacturing

12.12.9 Industry 4.0: digital and smart manufacturing

12.12.9.1 Analytics in manufacturing

12.12.9.2 Sensing and process monitoring

12.12.9.3 Artificial intelligence (AI) application in manufacturing

12.12.9.4 Security

12.12.9.5 Integration of operational and informational technology

12.13 Industry 5.0: Industry 4.0 plus consideration of human well-being

12.13.1 Worker health and safety

12.13.2 Environmental sustainability

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13 Product Design & Development

Product Design and Development is the efficient and effective generation and development of ideas through a process that leads to new products that serve people, the planet, and the circular economy. From an industrial engineering perspective, the processes and analyses employed support efficient decision-making during Product Design and Development.

13.1 Design Process

- 13.1.1 State of the art
- 13.1.2 Identify need
- 13.1.3 Conceptualization
- 13.1.4 Feasibility analysis
- 13.1.5 Production
- 13.1.6 Product life cycle

13.2 Design Process Steps

- 13.2.1 Business strategy
- 13.2.2 Identification of need
 - 13.2.2.1 Technology development
 - 13.2.2.2 Proposal
 - 13.2.2.3 Capture
- 13.2.3 Definition of a problem
 - 13.2.3.1 Statement of requirements
 - 13.2.3.2 Jobs-to-be-done statements
- 13.2.4 Gathering of information and data
- 13.2.5 Benchmarking
 - 13.2.5.1 Competitive intelligence
 - 13.2.5.2 Intellectual property
 - 13.2.5.3 Hands-on interaction documentation
- 13.2.6 Conceptualization
- 13.2.7 Evaluation
 - 13.2.7.1 Analysis of design
 - 13.2.7.2 Decision making
 - 13.2.7.3 Trade studies
 - 13.2.7.4 Weighing and judging



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- 13.2.7.5 Quality function deployment (QFD)
 - 13.2.8 Communication of the design
 - 13.3 Design Project
 - 13.3.1 Gating process
 - 13.3.2 Feasibility study
 - 13.3.3 Preliminary design
 - 13.3.3.1 Internal interfaces
 - 13.3.3.2 External interfaces
 - 13.3.4 Detailed design
 - 13.3.5 Verification and Test
 - 13.3.5.1 Demonstration builds
 - 13.3.5.2 Systems test
 - 13.3.5.3 Operational test
 - 13.3.5.4 Audits
 - 13.3.6 Planning for manufacture/production
 - 13.3.6.1 Factory planning
 - 13.3.6.2 Supply chain
 - 13.3.7 Planning for distribution
 - 13.3.8 Planning for use
 - 13.3.9 Operations and support
 - 13.3.10 Planning for retirement
 - 13.4 Product Evaluation for People, Planet, and Profit
 - 13.4.1 Life cycle economic analysis
 - 13.4.2 Product analysis and usability testing for human well-being
 - 13.4.3 Product analysis for the planet with life cycle assessment (LCA)
 - 13.4.4 Design for circular economy
 - 13.5 Planning and Scheduling
 - 13.5.1 Planning for manufacturing
 - 13.5.2 Project planning



- 13.6 Risk and Opportunity Management
- 13.7 Metrics for Design and Development
- 13.8 Program Leadership, Management, and Control
 - 13.8.1 Project start-up
 - 13.8.2 Plans/schedules
- 13.9 Design for Manufacturability
 - 13.9.1 How manufacturability can influence design
 - 13.9.2 Methods and procedures for production activity
 - 13.9.3 Work instruction/documentation for production
 - 13.9.4 Manufacturing process optimization
- 13.10 Design for Cost
- 13.11 Design for Six Sigma
 - 13.11.1 I2DOV process
 - 13.11.1.1 Invent
 - 13.11.1.2 Innovate
 - 13.11.1.3 Develop
 - 13.11.1.4 Optimize
 - 13.11.1.5 Verify
 - 13.11.2 CDOV process
 - 13.11.2.1 Concept design
 - 13.11.2.2 Design development
 - 13.11.2.3 Optimize
 - 13.11.2.4 Verify

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14 Systems Design & Engineering

Systems Design and Engineering involves the structured development and integration of complex systems, leveraging lifecycle thinking, digital tools, and interdisciplinary coordination to deliver effective and sustainable solutions. This area closely aligns with systems thinking, model-based systems engineering (MBSE), and human-centered design. Systems Design and Engineering integrates aspects of other engineering disciplines, ensuring that all likely aspects of a project or system are considered and integrated efficiently. This area exhibits strong cross-coupling with industrial engineering. Refer to the Systems Engineering Body of Knowledge (SEBoK) for additional details.

14.1 Mission Engineering

14.1.1 Stakeholder Needs and Use Cases

14.1.2 Articulation and analysis of purpose for the system

14.2 Requirements Analysis and Allocation

14.2.1 Requirements elicitation and documentation

14.2.2 Obtaining requirements

14.2.3 Derived and allocated requirements

14.2.4 Requirements analysis

14.2.5 System specification

14.2.6 Interface (e.g., Internal, external, customer, interface control documents (ICDs))

14.2.7 Value engineering

14.2.8 Sensitivity analysis

14.2.9 Trade studies

14.2.10 Ethics, policy, legal (e.g., data)

14.2.11 Sustainability and resiliency

14.3 System Architecting

14.3.1 Architecture framework (e.g., Zachman, DoDAF)

14.3.2 Architecture descriptions

14.3.3 Steps in system architecting

14.3.4 Fundamental design choices in constructing a system

14.3.4.1 Component Lifecycle Analysis and Planning

14.3.4.2 Component and System Integration Feasibility and Analysis

14.3.4.3 Physical System Definition

14.3.4.4 Digital System Definition

14.3.5 80-20 rule

14.3.6 Scalability and feasibility



14.4 Subsystem Design

14.4.1 Detailed design of elements

14.4.2 Interface control

14.5 System Construction

14.5.1 Components

14.5.1.1 Hardware and physical components

14.5.1.2 Software

14.5.1.3 Security

14.5.1.4 Connectivity

14.5.1.5 Manageability

14.5.1.6 Data

14.5.2 Hardware, software, human components

14.5.3 Integration

14.5.4 Release management

14.6 Verifying and Validating Requirements

14.6.1 Verification program components

14.6.2 Requirements

14.6.3 Planning

14.6.4 Success criteria

14.6.5 Reports

14.6.6 Compliance

14.6.7 Test and evaluation

14.6.8 Design of experiments (DOE)

14.6.9 Satisfaction of all user and customer requirements

14.7 Design Iteration

14.7.1 Refinement

14.7.2 Convergence

14.7.3 Robust systems

14.7.4 Asset / Lifecycle Management (e.g., Future proofing, effectivity, expiration, vaulting, retention)

14.8 Product and Services Design

14.9 Role of Models in Systems Design Process

14.9.1 Model vs. actual system

14.9.2 System objectives/user input



14.9.3 Analyzing model output for system design decisions

14.10 Completing the Systems Engineering Process

14.10.1 Establishing a systematic and repeatable process

14.10.1.1 Total cost of ownership

14.10.1.2 End of system life plan

14.10.1.3 Technical performance measures

14.10.1.4 Technical data management

14.10.1.5 Configuration management (i.e., Identification, auditing, management and delivery, and tools)

14.10.2 Life cycle costing

14.10.2.1 Cost estimation models and techniques

14.10.2.2 Design, development, manufacturing, operations, and supportability

14.10.2.3 Cost effective trade-offs to customer problems (see Engineering Economic Analysis knowledge area)

14.10.2.4 Activity-based costing

14.10.2.5 Customer and solution value

14.10.3 Human factors: Human and system interaction

14.10.4 Risk analysis

14.10.4.1 Cost, schedule, and performance risk

14.10.5 Concurrent engineering

14.10.6 Integrated logistics support

14.10.6.1 Interoperability and harmonious system operation

14.10.7 Reliability, maintainability, availability (see Quality and Reliability Engineering knowledge area)

14.10.8 Quality assurance and management (see Quality and Reliability Engineering knowledge area)

14.10.9 Specialty engineering

14.10.10 Preplanned product improvement

14.10.11 Training

14.10.12 Documentation

14.10.13 Production

14.10.14 Installation

14.10.15 Operations and maintenance

14.10.16 Operations evaluation/reengineering

14.10.17 Systems engineering management



14.10.17.1 Planning

14.10.17.2 Organizing

14.10.17.3 Directing

14.10.18 Monitoring

14.11 Systems Engineering Structures, Behaviors, and Dynamics

14.12 Integrated Model-Based System Engineering

14.13 Digital and Physical Systems Engineering and Management

14.14 AI for Systems

14.15 Systems using AI

14.16 Systems Thinking Methods and Tools

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Contributors (alphabetically)

- Magdy Akladios, Professor of Occupational Safety and Health with specializations in industrial hygiene or safety, University of Houston-Clear Lake
- Ben Amaba, Senior Strategic Advisor and Board Member for Perfect Planner
- Philip Appiah-Kubi, Associate Professor, Department of Engineering Management, Systems, and Technology, University of Dayton
- Omar Ashour, 2022–2024, GB Co-Chair; 2024–2025, GB Chair; Associate Director for Research; Professor of Industrial Engineering, School of Engineering, Penn State University, The Behrend College
- Fazleena Badurdeen, 2022–2025, GB Chair, Professor of Mechanical Engineering, Director of Graduate Studies, University of Kentucky
- Shelia Barnett, Research Engineer, US Army Corps of Engineers
- Dean Bartles, CEO, Manufacturing Technology Deployment Group
- Barrett Caldwell, Professor, Edwardson School of Industrial Engineering, Purdue University
- David Claudio, Associate Professor, Industrial Engineering Program Director, Mechanical and Industrial Engineering, UMass Lowell
- Beth Cudney, Professor of Data Analytics, Maryville University
- Laila Cure, Associate Professor, Industrial, Systems and Manufacturing Engineering, Wichita State University
- Syed Hasib Akhter Faruqui, Assistant Professor, Department of Engineering Technology, Sam Houston State University
- Sandy Furterer, Professor of Practice, The Ohio State University
- Michael Graul, PE - Professor of Practice, Department of Industrial and Systems Engineering, Texas A&M University, Sr. Director of Professional and Continuing Education
- Jon Grooms, Manager, West Monroe Partners
- Dave Hampton, Retired, Frito Lay
- Dave Harry, 2022–2024, GB Member, President & CEO, Process Whisperer® Consultants LLC
- Mindy Holmes, Supply Chain Strategist, Intel Corporation
- Guiping Hu, Professor and Department Chair, Systems Engineering & Operations Research, George Mason University
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- Steven J. Kiester, 2023–2025, GM Member, Sr. Integrated Program Scheduling Specialist | EVMS Administration, Bell-Textron
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- Asela Kulatunga, 2023–2025, GB Member, Lecturer in Industrial Systems, University of Exeter, UK
- Chad Laux, Associate Professor, Institute for a Sustainable Future, Purdue University
- Henry Lester, Associate Professor, Department of Engineering Management, Systems, and Technology, University of Dayton
- Cameron MacKenzie, Associate Professor, Department of Industrial and Manufacturing Systems Engineering, Iowa State University
- Azad Madni, 2021–2023, GB Member, Professor of Astronautics and Aerospace and Mechanical Engineering, University of Southern California

- Yariela Mejia, Industrial Engineering Functional Leader, W. L. Gore & Associates
- Leon McGinnis, Professor Emeritus, Georgia Tech
- Becca Mercer, Industrial Engineering Functional Leader, W. L. Gore & Associates
- Joseph Michels, Executive Managing Director, Solomon Bruce Consulting
- Russell Milam, Project Manager, Fluor Corporation
- Isaac Mitchell, Strategy Deployment Leader, Ballad Health
- Amirmasoud Momenipour, Assistant Professor, Rose-Hulman Institute of Technology
- Ikechukwu Ohu, Associate Professor and Program Director, Industrial and Robotics Engineering Program, Gannon University
- Martha Parker, Project Manager, Texas A&M Center for Worker Health, Texas A&M University
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- Yongjia Song, Associate Professor, Department of Industrial Engineering, Clemson University
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- Jun Zhuang, Professor, Department of Industrial and Systems Engineering, SUNY Buffalo