Proposed Curriculum
Master of Science in Systems Engineering
for
The MITRE Corporation

Core Requirements: (9 Credits)
SYS 501 Concepts of Systems Engineering
SYS 510 Systems Architecture and Design
SYS 511 Systems Integration, Verification & Validation

Management Requirements: (6 credits)
OIE 541 Operations Risk Management
SD 550 System Dynamics: Managing Complexity

SE Depth Requirements: (6 credits)
SYS 540 Introduction to Systems Thinking
SYS 579D Engineering Dependable and Secure Systems

Electives: (6 Credits)
SYS 520 System Optimization
SYS 521 Model-Based Systems Engineering

Capstone: (3 Credits)
SYS 585 Systems Engineering Capstone Experience
Course Descriptions and Learning Outcomes

Core Requirements: (9 Credits)

SYS 501   Concepts of Systems Engineering

In this course, students will learn how to:

✓ Appreciate and apply the fundamental principles of systems engineering.
✓ Holistically apply systems engineering processes to effectively define, develop, and deploy complex systems.
✓ Apply the various systems engineering methods and techniques as appropriate across all phases of a system’s life cycle.
✓ Improve the performance of large, complex defense and information processing systems for the DoD, Intelligence Community, Homeland Security and other sponsors.

Systems Engineering is a multifaceted discipline, involving human, organizational, and various technical variables that work together to create complex systems. This course is an introduction and overview of the methods and disciplines that systems engineers use to define, develop, and deploy systems. It includes specific integrated examples, projects, and team building exercises to aid in understanding and appreciating fundamental principles. Topics covered include; Introduction to Systems Engineering; Requirements Development; Functional Analysis and Requirements Allocation; System Architecture and System Design; Integration, Verification and Validation; Trade Studies; Systems Analysis, Modeling and Simulation; Specialty Engineering; Risk Management; and Technical Planning and Management.

SYS 510   Systems Architecture and Design

In this course, students will learn how to:

✓ Appreciate and apply the principles of architecture frameworks by exploring various framework representations, tools, and methodologies.
✓ Work in depth with one particular architecture framework tool and system.
✓ Implement architecture and design methodologies to develop enterprise-level systems and system of systems solutions.
✓ Utilize design and architectural trends and techniques to help achieve multilevel and multilateral security.
✓ Identify both risks and opportunities associated with architectural choices to design and deliver the best system solution to the sponsor.

This course will study and contrast various important architectural frameworks, representations, tools, and methodologies in order to provide scalable and flexible approaches for enterprises operating in dynamic and complex environments. Enterprise-level system architecting tools will be discussed and demonstrated. At a minimum, the DoDAF, FEAF, Zachman, and TOGAF architectural frameworks will be discussed in depth. Other topics will include analysis of architectural alternatives to meet physical and logical objectives and providing information and systems assurance in an environment that takes people, processes, and technology into account. Modeling tools such as UML/SysML and the use of model-driven architectures will be presented. Validation of the architecture with stakeholders will be discussed. Methods of
identifying risks and opportunities associated with the architectural choice will be explored. Practical examples will be included for illustration.

**SYS 511 Systems Integration, Verification & Validation**

In this course, students will learn how to:

- Properly plan for and implement the appropriate Integration, Verification and Validation (IV&V) methodologies at each phase across a system’s life cycle.
- Develop an agile and executable IV&V plan early in the life cycle with traceability back to requirements and user needs.
- Work with users and systems developers to define appropriate acceptance criteria for agile systems.
- Plan for and conduct agile IV&V activities for critical and complex systems.

This course examines the use of Systems Engineering principles and best practices with respect to systems and systems-of-systems verification and validation (V&V). V&V processes, activities and methods as they apply across the product lifecycle will be examined. Case studies, papers and exercises will be used to examine the success and failure of verification, validation and test processes. Course topics include 1) How early systems engineering activities and solution sets affect integration, verification, validation and test; 2) V&V activities relative to product development phases; 3) Modeling quality, cost, time and risk; 4) Testing and non-testing methods; 5) V&V planning, execution and reporting; 6) Systems integration; and 7) V&V of critical and complex systems.

**Management Requirements:** (6 credits)

**OIE 541 Operations Risk Management**

In this course, students will learn how to:

- Make sound decisions when faced with uncertainty.
- Integrate subjective and objective information to model and evaluate risk.
- Determine risk, develop mitigation strategies and effectively report risk to the sponsor.

Operations risk management deals with decision making under uncertainty. It is interdisciplinary, drawing upon management science and managerial decision-making, along with material from negotiation and cognitive psychology. Classic methods from decision analysis are first covered and then applied, from the perspective of business process improvement, to a broad set of applications in operations risk management and design including: quality assurance, supply chains, information security, fire protection engineering, environmental management, projects and new products. A course project is required (and chosen by the student according to his/her interest) to develop skills in integrating subjective and objective information in modeling and evaluating risk. (An introductory understanding of statistics is assumed.)

**SD 550 System Dynamics: Managing Complexity**

In this course, students will learn how to:

- Examine the feedback concept in complex systems.
✓ Construct and execute models to simulate human behavior changes due to feedback.
✓ Adjust organization structure to change behavior and results.
✓ Use system dynamics concepts to better assure success in complex projects and businesses.
✓ Utilize the dynamics of complex organizations to determine the difference between failure and success and facilitate accomplishing the goals.

Why do some businesses grow while others stagnate or decline? What causes oscillation and amplification (the so called bull whip) in supply chains? Why do large scale projects so commonly over overrun their budgets and schedules? This course explores the counter-intuitive dynamics of complex organizations and how managers can make the difference between success and failure. Students learn how even small changes in organizational structure can produce dramatic changes in organizational behavior. Real cases and computer simulation modeling combine for an in-depth examination of the feedback concept in complex systems. Topics include: supply chain dynamics, project dynamics, commodity cycles, new product diffusion, and business growth and decline. The emphasis throughout is on the unifying concepts of system dynamics.

**SE Depth Requirements:** (6 credits)

**SYS 540  Introduction to Systems Thinking**

In this course, students will learn how to:

✓ Effectively and efficiently apply systems thinking tools and techniques to improve the performance of complex and agile developed systems.
✓ Provide impartial and independent systems thinking and technical expertise to assist sponsors in making key decisions with scientific, engineering, and analytical rigor.
✓ Holistically consider all aspects of a system to ensure consistent functionality as needed in the intended operational environment.

Systems Thinking provides an arsenal of tools that enable program managers and systems engineers to better identify, understand, and control systems, and to improve their performance. In this course, we will study system identification and delineation, causal loops and feedback, system leverage points, delays and oscillations, mental models and unintended consequences, emergent properties, patterns, events, and self- organization, and use these tools to improve the performance of engineering, biological, business, and complex social systems. We will explore great system failures, how they might have been avoided, and how we can learn from them in developing and participating in current systems. Finally, we will learn how systems thinking explains the conflicting behavior of individuals, departments, businesses, and countries.

**SYS 579D  Engineering Dependable and Secure Systems**

In this course, students will learn how to:

✓ Design and develop dependable system architectures with resilience.
✓ Design for and assess software reliability.
✓ Build in dependability, reliability and security up front in the requirements and architecture design of the system.
This course considers all facets of engineering dependable and secure systems, i.e., systems that are reliable, available, secure, and can be depended upon to deliver their intended capabilities despite hardware failures, software failures, network failures, external attack, and unexpected behavior. Topics include building dependable system architectures; resilience; security and quality of service of networks; dependability assessment; and software reliability. The class will consist of lectures, case studies, and a class project. (Prerequisite: SYS 501.)

**Electives: (6 Credits)**

**SYS 520 System Optimization**

In this course, students will learn how to:

- Properly optimize any systems solutions though practical hands-on qualitative and quantitative approaches.
- Identify system optimization opportunities in a business/engineering environment.
- Apply rigorous mathematical tools and models to solve multi-objective optimization problems.
- Use linear programming, non-linear programming, integer programming, and stochastic techniques to solve simple system optimization problems such as blending, set covering, networking, pricing, location, and economic order quantity problems.

This course covers both the principles and practices of system optimization. The course includes both traditional mathematical treatments of optimization (including linear programming, non-linear programming, integer programming, stochastic methods such as Monte-Carlo methods, multi-objective system optimization, data envelope analysis) and practical, hands-on application with many real-world examples and student projects/exercises. Qualitative as well as quantitative approaches will be discussed. Course content is not specific to any particular manufacturer’s equipment.

The course begins with an introduction and definitions of system, optimization, and system optimization. It then proceeds to explain the traditional mathematical tools and models used in system optimization including location, allocation, scheduling, and blending models as well as sensitivity analysis and network models. Optimized design is covered next. The course will conclude with several multi-objective optimization problems. Student projects and real-world examples will be heavily emphasized. Projects may include optimization of military vehicles (tanks, helicopters, fighter jets); optimization of riding lawnmowers, construction equipment, home theater systems, and pumping/filtration systems; project or investment portfolio optimization; optimization of professional sports team rosters; and optimization of corporate organizational structures. (Prerequisite: SYS 501.)

**SYS 521 Model-Based Systems Engineering**

In this course, students will learn how to:

- Formalize the practice of systems engineering through the use of models.
- Work in depth with modeling languages, tools and methods through a hands-on project that includes construction of an executable model.
- Integrate multiple modeling domains across the life cycle from system of systems to component level.
✓ Implement MBSE to achieve quality/productivity improvements, lower risk through rigor and precision, increase critical communications among system/project stakeholders and manage complexity.

Model-based systems engineering (MBSE) formalizes the practice of systems engineering through the use of models. This course is intended to answer the why, what and how of MBSE. The course provides background and motivation for transitioning to MBSE from a document centric approach. The course provides a foundation for MBSE by introducing SysML as a descriptive language for modeling systems, and the Object-Oriented Systems Engineering Method (OOSEM) as a method for applying SysML to support the specification, architecture design, and analysis of complex systems. The course also introduces other important aspects of implementing MBSE, including organizational and project planning considerations.

The course includes a combination of slide presentations to introduce the fundamentals, coupled with class exercises and a class project (to be confirmed) to help the student grasp the fundamentals. A modeling tool is expected to be used for the class project. (Prerequisite: SYS 501.)

**Capstone: (3 Credits)**

**SYS 585 Systems Engineering Capstone Experience**

In this course, students will learn how to:

✓ Effectively integrate and apply academic knowledge and skills learned previously in the systems engineering graduate program courses to a real-world problem.
✓ Work effectively in a team environment on a complex project of interest to the sponsoring organization.
✓ Effectively communicate through writing about and briefing various aspects of the project.
✓ Practice effective leadership skills to accomplish the goals of the project.

One of the central priorities in WPI's educational philosophy is the application of academic skills and knowledge to real-world problems. The capstone project represents a substantive evaluation and application of coursework covered in the program. Students are encouraged to select projects with practical significance for the advancement of their company's competitive position as well as their own personal development. The project is administered, advised, and evaluated by WPI as part of the learning experience, but students are encouraged to seek mentorship from experienced colleagues in the Systems Engineering profession. The presence of or degree of participation from a mentor is made at the discretion of the student or the organization sponsoring the program.