Office of the Registrar
FORM 40G REV. 11/09
0

PURDUE UNIVERSITY

REQUEST FOR ADDITION, EXPIRATION,
OR REVISION OF A GRADUATE COURSE
(50000-60000 LEVEL)

Print Form

EFD 30-09
Graduate Council Doc. No. 10-22a

DEPARTMENT School of Aeronautics and Astronautics
EFFECTIVE SESSION Spring 2011

INSTRUCTIONS: Please check the items below which describe the purpose of this request.

- [X] 1. New course with supporting documents (complete proposal form)
- [ ] 2. Add existing course offered at another campus
- [ ] 3. Expiration of a course
- [ ] 4. Change in course number
- [ ] 5. Change in course title
- [ ] 6. Change in course credit/type
- [ ] 7. Change in course attributes
- [ ] 8. Change in instructional hours
- [ ] 9. Change in course description
- [ ] 10. Change in course requisites
- [ ] 11. Change in semesters offered
- [ ] 12. Transfer from one department to another

PROPOSED:		EXISTING:	
Subject Abbreviation	AAE	Subject Abbreviation	
Course Number	56000	Course Number	
Long Title	System-of-Systems Modeling and Analysis		
Short Title	System-of-Sys. Modeling & ~~Analy~~ Anlys		

Abbreviated title will be entered by the Office of the Registrar if omitted. (30 CHARACTERS ONLY)

TERMS OFFERED
Check All That Apply:
[ ] Summer [ ] Fall [X] Spring

CAMPUS(ES) INVOLVED
[ ] Calumet [ ] N. Central
[ ] Cont Ed [ ] Tech Statewide
[ ] Ft. Wayne [X] W. Lafayette
[ ] Indianapolis

CREDIT TYPE
1. Fixed Credit: Cr. Hrs. 3
2. Variable Credit Range:
Minimum Cr. Hrs
(Check One) To [ ] Or [ ]
Maximum Cr. Hrs.
3. Equivalent Credit: Yes [ ] No [X]
4. Thesis Credit: Yes [ ] No [X]

COURSE ATTRIBUTES: Check All That Apply
1. Pass/Not Pass Only [ ]
2. Satisfactory/Unsatisfactory Only [ ]
3. Repeatable [ ]
Maximum Repeatable Credit: [ ]
4. Credit by Examination [ ]
5. Special Fees [ ]
6. Registration Approval Type
Department [ ] Instructor [ ]
7. Variable Title [ ]
8. Honors [ ]
9. Full Time Privilege [ ]
10. Off Campus Experience [ ]

Schedule Type	Minutes Per Mtg	Meetings Per Week	Weeks Offered	% of Credit Allocated
Lecture	75	2	15	
·itation				
·sentation				
Laboratory				
Lab Prep				
Studio				
Distance				
Clinic				
Experiential				
Research				
Ind. Study				
Pract/Observ				

Cross-Listed Courses

COURSE DESCRIPTION (INCLUDE REQUISITES/RESTRICTIONS):

Prerequisite: Graduate or senior-level undergraduate standing.
Introduction to features of system-of-systems problems; problem definition tools; role of complexity; network topology analysis and agent-based simulation models; architecture analysis; metrics for multi-stakeholder problems; semester team projects allow students to exercise and critique such methods for analyzing system-of-systems problems. Some background in probability and statistics (e.g. random variables, probability density and distributions, sampling methods) is expected.

Professor DeLaurentis.

Calumet Department Head	Date	Calumet School Dean	Date	Calumet Undergrad Curriculum Committee	Date
Fort Wayne Department Head	Date	Fort Wayne School Dean	Date	Fort Wayne Chancellor	Date
Indianapolis Department Head	Date	Indianapolis School Dean	Date	V R Cipra Undergrad Curriculum Committee	2/16/2010 Date
North Central School Dean	Date	North Central Vice Chancellor for Academic Affairs	Date	APPROVED 10/21/10 Date Approved by Graduate Council	
West Lafayette Department Head 4/6/10	Date	West Lafayette College/School Dean 2/22/2010	Date	Graduate Council Secretary Susan R. Hayne 10/25/10	Date
Graduate Area Committee Convener 10/24/10	Date	Graduate Dean	Date	West Lafayette Registrar 11/29/10	Date

OFFICE OF THE REGISTRAR

11/23/10

Office of the Registrar
FORM 40G REV. 11/09

PURDUE UNIVERSITY

REQUEST FOR ADDITION, EXPIRATION,
OR REVISION OF A GRADUATE COURSE
(50000-60000 LEVEL)

Print Form

EFD 30-09

DEPARTMENT School of Aeronautics and Astronautics

EFFECTIVE SESSION Spring 2011

INSTRUCTIONS: Please check the items below which describe the purpose of this request.

- [X] 1. New course with supporting documents (complete proposal form)
- [ ] 2. Add existing course offered at another campus
- [ ] 3. Expiration of a course
- [ ] 4. Change in course number
- [ ] 5. Change in course title
- [ ] 6. Change in course credit/type
- [ ] 7. Change in course attributes
- [ ] 8. Change in instructional hours
- [ ] 9. Change in course description
- [ ] 10. Change in course requisites
- [ ] 11. Change in semesters offered
- [ ] 12. Transfer from one department to another

PROPOSED:

Subject Abbreviation AAE

Course Number 56000

Long Title System-of-Systems Modeling and Analysis

Short Title System-of-Sys. Model. & Analy.

Abbreviated title will be entered by the Office of the Registrar if omitted. (30 CHARACTERS ONLY)

EXISTING:

Subject Abbreviation

Course Number

TERMS OFFERED
Check All That Apply:
[ ] Summer [ ] Fall [X] Spring

CAMPUS(ES) INVOLVED
[ ] Calumet [ ] N. Central
[ ] Cont Ed [ ] Tech Statewide
[ ] Ft. Wayne [X] W. Lafayette
[ ] Indianapolis

CREDIT TYPE
1. Fixed Credit: Cr. Hrs. 3
2. Variable Credit Range:
Minimum Cr. Hrs
(Check One) To [ ] Or [ ]
Maximum Cr. Hrs.
3. Equivalent Credit: Yes [ ] No [ ]
4. Thesis Credit: Yes [ ] No [ ]

COURSE ATTRIBUTES: Check All That Apply
1. Pass/Not Pass Only [X]
2. Satisfactory/Unsatisfactory Only [ ]
3. Repeatable [ ]
Maximum Repeatable Credit: [ ]
4. Credit by Examination [ ]
5. Special Fees [ ]
6. Registration Approval Type
Department [ ] Instructor [ ]
7. Variable Title [ ]
8. Honors [ ]
9. Full Time Privilege [ ]
10. Off Campus Experience [ ]

Schedule Type	Minutes Per Mtg	Meetings Per Week	Weeks Offered	% of Credit Allocated
Lecture	75	2	15	
itation				
sentation				
Laboratory				
Lab Prep				
Studio				
Distance				
Clinic				
Experiential				
Research				
Ind. Study				
Pract/Observ				

Cross-Listed Courses

COURSE DESCRIPTION (INCLUDE REQUISITES/RESTRICTIONS):

Prerequisite: Graduate or senior-level undergraduate standing
Introduction to features of system-of-systems problems; problem definition tools; role of complexity; network topology analysis and agent-based simulation models; architecture analysis; metrics for multi-stakeholder problems; semester team projects allow students to exercise and critique such methods for analyzing system-of-systems problems. Some background in probability and statistics (e.g. random variables, probability density and distributions, sampling methods) is expected.

Calumet Department Head	Date	Calumet School Dean	Date	Calumet Undergrad Curriculum Committee	Date
Fort Wayne Department Head	Date	Fort Wayne School Dean	Date	Fort Wayne Chancellor	Date
Indianapolis Department Head	Date	Indianapolis School Dean	Date	V R Cipra Undergrad Curriculum Committee	2/16/2010 Date
North Central School Dean	Date	North Central Vice Chancellor for Academic Affairs	Date	Date Approved by Graduate Council	
West Lafayette Department Head	4/6/10 Date	West Lafayette College/School Dean	2/22/2010 Date	Graduate Council Secretary	Date
Graduate Area Committee Convener	Date	Graduate Dean	Date	West Lafayette Registrar	Date

OFFICE OF THE REGISTRAR

Engineering Faculty Document 30-09
Date: December 3, 2008

TO: Faculty of the College of Engineering
FROM: Faculty of the School of Aeronautics and Astronautics
SUBJECT: New Graduate Course, AAE 56000 System of Systems Modeling and Analysis

The Faculty of the School of Aeronautics and Astronautics has approved the new course listed below. This action is now submitted to the Engineering Faculty with a recommendation for approval.

AAE 56000 System-of-Systems Modeling and Analysis
Sem. 2, Class 3, cr. 3.
Prerequisite: Graduate or senior-level undergraduate standing;

Course Description:
Introduction to features of system-of-systems problems; problem definition tools; role of complexity; network topology analysis and agent-based simulation models; architecture analysis; metrics for multi-stakeholder problems; semester team projects allow students to exercise and critique such methods for analyzing system-of-systems problems. Some background in probability and statistics (e.g. random variables, probability density and distributions, sampling methods) is expected.

Reason:
Over the last decade there has been substantial growth in the recognition of system-of-systems (SoS) as a distinctive class of design problems. Many civil and defense applications are being developed (either implicitly or explicitly) using the SoS framework. The technical background required for research or development in these areas spans several traditional fields, including systems engineering, complexity science, network theory, agent-base simulations, robust control, and optimization. This course introduces students to the integration of these different areas into a cohesive approach for tackling SoS problems. This course was taught as AAE590K for three terms in Spring 06, 07, and 08 with enrollments of between 27, 27, and 32 respectively (the most recent term's number including 10 EPE distance students). Though a majority of the enrollment has come from AAE, a substantial portion has consisted of students outside of AAE (primarily from other engineering disciplines).

Kathleen C. Howell

Kathleen C. Howell, Interim Head
Hsu Lo Professor of Aeronautical and Astronautical Engineering
School of Aeronautics and Astronautics

APPROVED FOR THE FACULTY
OF THE SCHOOLS OF ENGINEERING
BY THE ENGINEERING
CURRICULUM COMMITTEE
ECC Minutes #10
Date 12/7/09
Chairman ECC R. Cipra

AAE 560 System-of-Systems Modeling and Analysis

- **Course Instructor:** Daniel DeLaurentis

- **Course Description:**

This course is an introduction to modeling and analysis techniques for system-of-systems (SoS) problems in engineering. The primary focus is on generating in students the ability for understanding, modeling, and analyzing SoS problems, which consist of multiple, heterogeneous, distributed systems embedded in networks at multiple levels that evolve over time. These problems are often large-scale and interdisciplinary, involving systems and behaviors found in diverse fields such as engineering, economics, social science, policy, etc. The course presents recent developments in addressing system-of-systems problems, describes criteria, lexicon, and analysis methodology for their study, and, through semester-long team projects, allows students to explore the many unknowns that persist in this emerging field. The major subjects covered are: distinguishing traits of and behaviors of SoS problems, complexity and complex adaptive systems, agent-based modeling, modern network theory and analysis tools, modeling for decision-making, and exploratory modeling. Applications for projects typically include national transportation systems, space exploration endeavors, and defense challenges, though others are possible in consultation with instructor. The audiences for this course are beginning graduate students or advanced undergraduates from any School of Engineering, other technical disciplines (especially Physics and Mathematics), or certain students in Management. Some background in probability and statistics (e.g. random variables, probability density and distributions, sampling methods) is expected.

- **Course outline:**

Introduction and Overview What does the literature say about distinct features of SoS problems; Distinguishing traits and examples; Outline of the remainder of the course. [1 week]

Backdrop: Systems Engineering Basic goals and processes for systems engineering; new challenges brought by SoS problems, and the need for a system-of-systems engineering (SoSE). [1 week]

Lineage: Modeling for Complex Adaptive Systems Definitions for complexity; Review of major threads of complex systems modeling; Basics of chaotic systems, adaptive systems, nonlinear systems; Role of observer perspectives in designing actions. [1 week]

A Model for SoSE A three-phase framework, including definition phase, abstraction phase, and implementation phase is introduced and discussed. [2 weeks]

Background Material: Probability & Statistics Probability density and distributions; Expected value and moments; Use of random variables for uncertainty analysis; Power laws. [1 week]

Agent-Based Modeling Goals, objectives, applications, history, and limitations of ABM; Definitions of agents; Agent logic, starting from simple finite state machine; advanced agent models, including learning [3 weeks]

Network Theory Elementary definitions and constructs from graph theory; The standard random graph model and the failure of this model to capture real world networks; network measures (degree, clustering coefficient, centrality, assortativity); degree distributions and power law vs. exponential distributions. Tools for network analysis [3 weeks]

Exploratory Modeling Pitfalls in direct modeling of uncertainty; the use of a plausible ensemble of scenarios to generate outcomes; measures of regret and confidence; computational modeling under deep uncertainty. [1 week]

Validation and Verification Definitions, approaches, and tools for verification and validation in modeling & simulation of complex adaptive systems and SoS problems. [1 week]

Advanced Topics Dynamic-decision making algorithms, motivated by models such as Boyd's OODA loop and Hofstadter's Strange Loops; the challenges of multi-stakeholder optimization and the role of game theory models. [1 week]

Total = 15 weeks

- **Text:** *None.* However, key technical papers are assigned reading throughout the semester. An extensive set of lecture slides are also made available to students.

- **Grading:** Homework 35%; Exams 25%; Project 40%

Supporting Document for a New Graduate Course

To: Purdue University Graduate Council

From:
Faculty Member: Daniel DeLaurentis
Department: School of Aeronautics & Astronautics
Campus: West Lafayette, IN

Date: 11/16/2009

Subject: Proposal for New Graduate Course-Documentation Required by the Graduate Council to Accompany Registrar's Form 40G

For Reviewer's comments only (Select One)

Reviewer:

Comments:

Contact for information if questions arise:
Name: Terri Moore
Phone Number: 43006
E-mail: terri@purdue.edu
Campus Address: Armstrong Hall Rm #3315

Course Subject Abbreviation and Number: AAE 56000

Course Title: System-of-Systems Modeling and Analysis

A. Justification for the Course:

- Provide a complete and detailed explanation of the need for the course (e. g., in the preparation of students, in providing new knowledge/training in one or more topics, in meeting degree requirements, etc.), how the course contributes to existing fields of study and/or areas of specialization, and how the course relates to other graduate courses offered by the department, other departments, or interdisciplinary programs.

- Justify the level of the proposed graduate course (50000- or 60000-level) including statements on, but not limited to: (1) the target audience, including the anticipated number of undergraduate and graduate students who will enroll in the course; and (2) the rigor of the course.

B. Learning Outcomes and Method of Evaluation or Assessment:

- Describe the course objectives and student learning outcomes that address the objectives (i.e., knowledge, communication, critical thinking, ethical research, etc.).

- Describe the methods of evaluation or assessment of student learning outcomes. (Include evidence for both direct and indirect methods.)

- Grading criteria (select from dropdown box); include a statement describing the criteria that will be used to assess students and how the final grade will be determined.

Criteria

- Identify the method(s) of instruction (select from dropdown box) and describe how the methods promote the likely success of the desired student learning outcomes.

Method of Instruction [ ]

C. Prerequisite(s):

- List prerequisite courses by subject abbreviation, number, and title.
- List other prerequisites and/or experiences/background required. If no prerequisites are indicated, provide an explanation for their absence.

D. Course Instructor(s):

- Provide the name, rank, and department/program affiliation of the instructor(s).
- Is the instructor currently a member of the Graduate Faculty? ___ Yes ___ No
  (If the answer is no, indicate when it is expected that a request will be submitted.)

E. Course Outline:

- Provide an outline of topics to be covered and indicate the relative amount of time or emphasis devoted to each topic. If laboratory or field experiences are used to supplement a lecture course, explain the value of the experience(s) to enhance the quality of the course and student learning. For special topics courses, include a sample outline of a course that would be offered under the proposed course.

F. Reading List (including course text):

- A primary reading list or bibliography should be limited to material the students will be required to read in order to successfully complete the course. It should not be a compilation of general reference material.
- A secondary reading list or bibliography should include material students may use as background information.

G. Library Resources

- Describe the library resources that are currently available or the resources needed to support this proposed course.

H. Example of a Course Syllabus (While not a necessary component of this supporting document, an example of a course syllabus is available, for information, by clicking on the link below, which goes to the *Graduate School's Policies and Procedures Manual for Administering Graduate Student Programs*. See Appendix K.)

http://www.gradschool.purdue.edu/downloads/Graduate_School_Policies_and_Procedures_Manual.pdf

AAE 56000 System-of-Systems Modeling and Analysis

A. Justification for the Course:

Over the last decade there has been substantial growth in the recognition of system-of-systems (SoS) as a distinctive class of design problems. Many civil and defense applications are being developed (either implicitly or explicitly) using the SoS framework. The technical background required for research or development in these areas spans several traditional fields, including systems engineering, complexity science, network theory, agent-base simulations, robust control, and optimization. This course introduces students to the integration of these different areas into a cohesive approach for tackling SoS problems using a systems approach. This course was taught as AAE590K/AAE590 for five terms in Spring 06, 07, 08, 09, 10 with enrollments ranging between 27 and 47 (the most recent term's number including 16 EPE distance students).

The rigor of the course is modulate such that the target audiences for this course are beginning graduate students or advanced undergraduates from any School of Engineering, other technical disciplines (especially Physics and Mathematics), or certain students in Management. The goal has been for 75% of enrollees or greater to be graduate level. Though a majority of the enrollment may come from AAE, a substantial portion will likely consist of students outside of AAE (primarily from other engineering disciplines).

B. Learning Outcomes and Method of Evaluation or Assessment

This course objective is an introduction to modeling and analysis techniques for system-of-systems (SoS) problems in engineering. The learning objectives center on students' ability for understanding, modeling, and analyzing SoS problems, which consist of multiple, heterogeneous, distributed systems embedded in networks at multiple levels that evolve over time. These problems are often large-scale and interdisciplinary, involving systems and behaviors found in diverse fields such as engineering, economics, social science, policy, etc. The course presents recent developments in addressing system-of-systems problems, describes criteria, lexicon, and analysis methodology for their study, and, through semester-long team projects, allows students to explore the many unknowns that persist in this emerging field. The major subjects covered are: distinguishing traits of and behaviors of SoS problems, complexity and complex adaptive systems, agent-based modeling, modern network theory and analysis tools, modeling for decision-making, and exploratory modeling.

Student learning outcomes are assessed via class participation, homework, exams, and team-based projects. Applications for projects typically include national transportation systems, space exploration endeavors, and defense challenges, though others are possible in consultation with instructor.

Grading Criteria: Homework 30%; Mid-term Exam 25%; Class Project 40%

The method of instruction is lecture-based.

C. Prerequisites

Graduate or senior-level undergraduate standing; Some background in probability and statistics (e.g., random variables, probability density and distributions, sampling methods) is expected.

D. Course Instructor

Daniel DeLaurentis, Assistant professor, Aeronautics and Astronautics
Is the instructor a member of the Graduate faculty? YES

E. Course Outline

Introduction and Overview What does the literature say about distinct features of SoS problems; Distinguishing traits and examples; Outline of the remainder of the course. [3 hours]

Backdrop: Systems Engineering Basic goals and processes for systems engineering; new challenges brought by SoS problems, and the need for a system-of-systems engineering (SoSE). [3 hours]

Lineage: Modeling for Complex Adaptive Systems Definitions for complexity; Review of major threads of complex systems modeling; Basics of chaotic systems, adaptive systems, nonlinear systems; Role of observer perspectives in designing actions. [3 hours]

A Model for SoSE A three-phase framework, including definition phase, abstraction phase, and implementation phase is introduced, discussed, and debated. [6 hours]

Background Material: Probability & Statistics Probability density and distributions; Expected value and moments; Use of random variables for uncertainty analysis; Power laws. [3 hours]

Agent-Based Modeling Goals, objectives, applications, history, and limitations of ABM; Definitions of agents; Agent logic, starting from simple finite state machine; advanced agent models, including learning [9 hours]

Network Theory Elementary definitions and constructs from graph theory; The standard random graph model and the failure of this model to capture real world networks; network measures (degree, clustering coefficient, centrality, assortativity); degree distributions and power law vs. exponential distributions. Tools for network analysis [9 hours]

Exploratory Modeling Pitfalls in direct modeling of uncertainty; the use of a plausible ensemble of scenarios to generate outcomes; measures of regret and confidence; computational modeling under deep uncertainty. [3 hours]

Validation and Verification Definitions, approaches, and tools for verification and validation in modeling & simulation of complex adaptive systems and SoS problems. [3 hours]

Advanced Topics Dynamic-decision making algorithms, motivated by models such as Boyd's OODA loop and Hofstadter's Strange Loops; the challenges of multi-stakeholder optimization and the role of game theory models. [3 hours]

F. Reading List

Primary:

- Newman, M., "The structure and function of complex networks," *SIAM Review*, Vol. 45, 2003, pp. 167-256.

- DeLaurentis, D. A., and Callaway, R. K., "A System-of-Systems Perspective for Public Policy Decision," *Review of Policy Research*, Vol. 21, Issue 6, November 2004, pp. 829-837.
- Bonabeau, E., "Agent-based Modeling: Methods and Techniques for Simulating Human Systems," *Proceeding of the National Academy of Sciences (PNAS) of the Unites States of America*, Vol. 99, Suppl. 2, 14 May 2002, pp. 7280-7287.
- Sage, A. P. and Cuppan, C. D. "On the Systems Engineering and Management of Systems of Systems and Federations of Systems," *Information, Knowledge, and Systems Management*, Vol. 2, No. 4, 2001, pp. 325-345
- Saunders, T., et al.: System-of-Systems Engineering for Air Force Capability Development. United States Air Force Scientific Advisory Board, Report SAB-TR-05-04, Washington, DC, July 2005.
- Keating, C., et al, "System of Systems Engineering," *Engineering Management J.*, Sep. 2003, vol.15, no. 3, pp. 36 – 45.
- Maier, M. "Architecting principles for system-of-systems", *Systems Engineering* Vol. 1, No. 4, 1998, pp. 267-284

G. Library Resources
None

H. Syllabus (not required)