MARYLAND HIGHER EDUCATION COMMMISSION
ACADEMIC PROGRAM PROPOSAL

PROPOSAL FOR:

____ NEW INSTRUCTIONAL PROGRAM

✓ SUBSTANTIAL EXPANSION/MAJOR MODIFICATION **(for online delivery)**

____ COOPERATIVE DEGREE PROGRAM

✓ WITHIN EXISTING RESOURCES or ____ REQUIRING NEW RESOURCES

(For each proposed program, attach a separate cover page. For example, two cover pages would accompany a proposal for a degree program and a certificate program.)

Johns Hopkins University
Institution Submitting Proposal

Fall 2017
Projected Implementation Date

Award to be Offered	Title of Proposed Program
M.S.	**Applied and Computational Mathematics**

Suggested HEGIS Code	Suggested CIP Code
1703-01	**27.0301**

Department of Proposed Program	Name of Department Head
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[signature] **3/24/2017**
Signature and Date — President/Chief Executive Approval

n/a
Date — Date Endorsed/Approved by Governing Board

The Johns Hopkins University
Whiting School of Engineering
Proposal for Substantial Modification to an Existing Program

Master of Science in Applied and Computational Mathematics

A. Centrality to institutional mission statement and planning priorities

1. Program description and alignment with mission

The Johns Hopkins University Whiting School of Engineering is pleased to submit a proposal for a substantial modification to its existing Master of Science in Applied and Computational Mathematics (HEGIS 1703-01, CIP code 27.0301) to offer an online option. This degree began as the Master of Science in Numerical Science Program in 1966 as part of the Johns Hopkins Evening College Center. In 1988, the name was changed to Applied Mathematics to reflect the broader educational goals of the program. In 2000, it was again renamed as the Applied and Computational Mathematics Program to reflect the critical role of computing in modern applications of mathematics.

The program provides students pursuing careers in applied and computational mathematics with a course of study that balances theory with practice, giving them the knowledge and skills necessary to enhance their effectiveness in a complex and rapidly evolving technological environment. Graduates will be prepared for specialized jobs involving all aspects of mathematical and computational techniques that are fundamentally important and practically relevant in all areas of science and engineering. To prepare our students to meet the challenges they will face, the program offers a wide variety of graduate courses in the areas of applied analysis, information technology and computation, operations research, probability and statistics, and simulation and modeling.

The mission of The Johns Hopkins University is to educate its students and cultivate their capacity for life-long learning, to foster independent and original research, and to bring the benefits of discovery to the world. In addition, the mission of the JHU Whiting School of Engineering is to provide educational programs of the highest quality that will attract the most qualified and driven students and faculty and will be a world-recognized leader in engineering education, to lead in the creation and dissemination of knowledge, and to translate those educational and research activities into solutions to important societal problems. The proposed degree program aligns with both of these missions as discussed below.

2. **Alignment with institutional strategic goals**

One of the four strategic priorities of the JHU Whiting School of Engineering is to "Educate future leaders by providing students with an innovative and distinctive education of the highest quality, both at the undergraduate and graduate level, in a diverse and inclusive environment." One of the near-term goals within that priority is to develop a comprehensive suite of contemporary master's degree offerings, for full- and part-time students, with flexible formats that respond to the needs of industry in both the domestic and international markets. It is clear that an online program offers a flexible format and enables this program to more easily reach the international markets cited in this goal.

The Johns Hopkins University professional programs in the fields of engineering and applied science are among the oldest and largest in the United States. Administered by the Whiting School of Engineering through JHU-EP, this activity seeks to meet the lifelong education needs of working professionals in engineering and applied science. JHU-EP offers state-of-the-art courses combined with the convenience, flexibility, and accessibility that make these educational opportunities feasible for working adults.

In recent years, JHU-EP has moved steadily into the field of distance education, offering more and more courses online. This development meets two needs: (1) it contributes to the convenience and flexibility of existing offerings, by allowing students to take a mix of classroom and online courses, and (2) it opens this educational opportunity to a much larger market, enabling students throughout the country and, indeed, the world to take courses at Johns Hopkins University.

The goal of this initiative is to promote and enhance the quality of education in applied and computational mathematics both nationwide and internationally through the utilization of advanced online educational technologies. The proposal is for the development of a fully online Master of Science in Applied and Computational Mathematics degree that will build and draw on the strengths of existing resources and the expert faculty within the Johns Hopkins University Whiting School of Engineering as well as the private and government sectors already involved in our classroom program. The program will provide professionals with in-depth knowledge and technical skills in the field of applied and computational mathematics and prepare students for technically significant careers within industry and governmental organizations.

B. Adequacy of curriculum design and delivery to related learning outcomes

1. **Program outline and requirements**

A full course listing with course titles and descriptions is provided in Appendix A. All courses are three (3) credits.

Admission Requirements
General admission requirements for master's degree candidates and others seeking graduate status are as follows: applicants must be in the last semester of undergraduate study or hold a bachelor's degree from a regionally accredited college or university.

In addition, applicants for the Master of Science in Applied and Computational Mathematics must have a prior educational experience that includes (1) at least one mathematics course beyond multivariate calculus (such as advanced calculus, differential equations, or linear algebra); and (2) familiarity with at least one programming language (e.g., C, C++, FORTRAN, Java, Python, or MATLAB). When reviewing an application, the candidate's academic and professional background will be considered. Routine admission decisions are made on an individual basis by JHU-EP staff acting on behalf of the ACM program committee. Non-routine admission decisions are made by the program chair in consultation with, or acting on behalf of, the ACM program committee. Some undergraduate courses are offered to provide mathematical background for the program. These 200-level courses are not for graduate credit. Some students may find one or more of these courses useful as a refresher or to fill gaps in their training. International students may have additional admission requirements.

Degree Requirements

In order to earn a Master of Science in Applied and Computational Mathematics, a total of 10 courses (30 credits) approved by an adviser must be completed within five years. The curriculum consists of four core courses (12 credits), including one two-term course (6 credits), in addition to six electives (18 credits).

The six electives must include at least four (12 credits) from the program (625.xxx), with at least two (6 credits) of the four courses at the 700-level. Students are required to take at least one 700-level course (3 credits) outside of the core sequences (625.717/718, 625.721/722, and 625.725/726). An independent study (625.800), research project (625.801–802), or thesis (625.803–804) may be substituted for one or two of the 700-level courses outside of the 700-level core sequence. A student who has taken at least one year of undergraduate statistics or one semester of graduate statistics (outside of Applied and Computational Mathematics) may substitute another 625.xxx course for 625.403 with approval of the student's advisor. Focus areas are not required for this program. Only one grade of C may count toward the master's degree. All course selections are subject to advisor approval.

Core Courses

625.403 Statistical Methods and Data Analysis
625.401 Real Analysis OR 625.409 Matrix Theory

Select <u>one</u> sequence from below:

625.717 Advanced Differential Equations: Partial Differential Equations
625.718 Advanced Differential Equations: Nonlinear Differential Equations and Dynamical Systems

625.721 Probability and Stochastic Processes I
625.722 Probability and Stochastic Processes II

625.725 Theory of Statistics I
625.726 Theory of Statistics II

Focus Areas (not required)
Applied Analysis
Information Technology and Computation
Operations Research
Probability and Statistics
Simulation and Modeling

2. Educational objectives and student learning outcomes

The educational objective of the online Applied and Computational Mathematics program is to provide students pursuing careers in applied and computational mathematics with a course of study that balances theory with practice giving them the knowledge and skills necessary to enhance their effectiveness in a complex and rapidly evolving technological and organizational environment. The program is designed not only to broaden and strengthen students' understanding of the traditional fundamentals but also to introduce them to contemporary applications and technologies. Graduates will be prepared for specialized jobs involving all aspects of applied and computational mathematics based on material from five focus areas: applied analysis, information technology and computation, operations research, probability and statistics, and simulation and modeling.

The student learning outcomes for the Master of Science in Applied and Computational Mathematics program are as follows:

- Explain the basic terms, concepts, and notation of mathematical logic and reasoning.
- Explain the distinction between axioms, definitions, and theorems.
- Construct and explain proofs of theorems at the level studied in the courses.
- Solve basic probability problems, including finding properties of distribution functions.
- Explain how to determine point and interval estimates.
- Solve for, and interpret, simple regression models.
- Employ statistical software confidently for topics addressed in the courses.
- Learn and use fundamental matrix algebra concepts.
- Explain basic notions and limitations of numerical computation (round-off error, stability of algorithms, operation counts).
- Demonstrate the ability to carry out a formal mathematical proof.

3. General education requirements

Not applicable.

4. Specialized accreditation/certification requirements

Not applicable.

5. Contract with another institution or non-collegiate organization

Not applicable.

C. Critical and compelling regional or statewide need as identified in the State Plan

1. Demand and need for program

JHU-EP has offered the Master of Science in Applied and Computational Mathematics as part of the Whiting School of Engineering since 1982 and as part of the JHU Evening College from 1958 to 1981. This long history indicates the essential importance of applied and computational mathematics as part of any engineering or applied science endeavor. Annual course enrollments have averaged 371 over the past five years. Students come primarily from throughout Maryland and northern Virginia. The demand for applied and computational mathematically educated professionals by the defense industry and the commercial sector in this region and nationwide has made the need for degree programs like this more apparent.

For busy working professionals, flexibility is very important, as is the ability to continue their education in the face of work demands. Online courses will create scheduling flexibility and increase course choices for students pursuing the onsite program. They will also accommodate students who must leave the area due to military deployment or relocation by their employer. Online offerings will give JHU-EP the opportunity to retain students with frequent business travel or job assignment outside of this region as, well as those with personal commitments requiring schedule flexibility.

In addition, the online Master of Science in Applied and Computational Mathematics will enable JHU to further spread its influence on the education and practice of applied and computational mathematics across the nation and around the world.

For these reasons, JHU-EP identified a need for a fully online Master of Science in Applied and Computational Mathematics and committed to the development of such a program.

2. Alignment with the <u>2013 Maryland State Plan for Postsecondary Education</u>

The proposed program is well aligned with Maryland Ready, the 2013–2017 Maryland State Plan for Postsecondary Education. The Master of Science in Applied and Computational Mathematics is intended to prepare highly trained scientists and engineers to work in organizations where they can contribute to the needs of society. The long-term success of JHU-EP programs for working professionals attests to the quality and effectiveness of these programs. This is consistent with the Goal 1 of the State Plan, "Quality and Effectiveness," which asserts that Maryland will enhance its array of postsecondary education programs to more effectively fulfill the evolving educational needs of its students, the state, and the nation.

Similarly, the proposed program is consistent with Goal 4, "Innovation," which articulates Maryland's aspiration to be "a national leader in the exploration, development, and implementation of creative and diverse education and training opportunities that will align with state goals, increase student engagement, and improve learning outcomes…" By leveraging technology in innovative ways to make JHU-EP offerings more accessible and interactive, candidates can pursue "anytime, anywhere" learning opportunities.

Candidates can undertake course-related activities at a time and a location most convenient to them, allowing students to participate in and to complete their program even if their work schedules do not permit regular class attendance or if they move away from the Maryland region, thus also supporting Goal 2, "Access, Affordability, and Completion."

The proposed program is also consistent with Goal 5, "Economic Growth and Vitality," which is centered on supporting a knowledge-based economy through increased education and training. The proposed program will prepare highly qualified local scientists and engineers to contribute to the economic growth and vitality by providing life-long learning to scientists and engineers so they can maintain the skills they need to succeed in the workforce.

D. Quantifiable and reliable evidence and documentation of market supply and demand in the region and State

1. Market demand

The Master of Science in Applied and Computational Mathematics program has seen a decline in annual course enrollments from 419 in 2011 to 339 in 2015. In spite of the economic downturn, enrollments are expected to increase again when the online program is available to students across a larger geographic region. The number of requests from students for more online courses, which would give them better access to the program, has also increased.

According to the Bureau of Labor Statistics (BLS), "Employment of mathematicians is projected to grow 23 percent from 2012 to 2022, much faster than the average for all occupations. Job prospects may be best for those who stay abreast of the most recent advances in technology." Pursuing a degree like this Master of Science in Applied and Computational Mathematics is a significant way to maintain career viability. Job opportunities for the graduates of this program include positions in corporations and government organizations.

In addition to the national employment projections made by the Bureau of Labor Statistics noted above, the State of Maryland makes projections in a more detailed way. The Classification of Instructional Program (CIP) code for this proposed Master of Science in Applied and Computational Mathematics program is 27.0301.

The Standard Occupational Codes (SOC) associated with this CIP by the Bureau of Labor Statistics are: 11-9121 Natural Sciences Managers; 15-2011 Actuaries; 15-2021 Mathematicians; 15-2041 Statiticians15-2091 Mathematical Technicians; 15-2099 Mathematical Science Occupations, All Other; 25-1022 Mathematical Science Teachers, Postsecondary. The Maryland Department of Labor Licensing and Regulation (DLLR) projects that long-term employment opportunities for these SOC codes will increase from 2012 to 2022 at an annual rate of 0.3% for Natural Sciences Managers; 0.7% for Actuaries; 2.6% for Mathematicians (Operations Research Analysis); 1.8% for

Statisticians; 1.2% for Mathematical Technicians; 2.0% for Mathematical Science Occupations, All Other; and 1.1% for Mathematical Science Teachers, Postsecondary.

Based on the projected market demand and the accessibility and convenience of an online program, we expect this degree program to be successful.

2. **Educational and training needs in the region**

Applied and computational mathematics is one of the core engineering and applied science disciplines and plays an important part in the technical workforce of defense contractors in the area and government facilities like the Goddard Space Flight Center and the Aberdeen Proving Ground. The number of job openings in Maryland, Virginia, and the District of Colombia for applied mathematicians posted on major job clearing house web sites range from 50 to 100. There is no reason to expect the number of students seeking this Master of Science in Applied and Computational Mathematics to decrease in the foreseeable future.

3. **Prospective graduates**

The following table shows the number of graduates over the last five years from Maryland universities with master's degrees for programs with the CIP code of 27.0301. This data was found in the Maryland Higher Education Commission's graduation trend data base.

Univ.	Degree	Field	2010	2011	2012	2013	2014
Bowie	Masters	Applied and Computational Mathematics	0	0	1	4	1
Towson	Masters	Applied and Industrial Mathematics	3	7	12	9	10
UMBC	Masters	Applied Mathematics	3	4	11	9	2
UMCP	Masters	Applied Mathematics & Statistics & Scientific Computation	13	7	19	10	4
UMCP	Masters	Mathematics of Advanced Industrial Technology	2	0	0	0	0
JHU	Masters	Applied and Computational Mathematics	6	17	10	42	37
JHU	Masters	Financial Mathematics	9	12	15	30	26

During the last five years there have been an average of 21 graduates per year receiving the JHU Master of Science in Applied and Computational Mathematics degree. We expect that number to increase significantly when the degree becomes available online.

E. Reasonableness of program duplication

1. Similar programs

As noted above in Section D.3 there are several other master's level degree programs with the CIP code of 27.0301offered in the state of Maryland. The first, a Master of Science in Applied and Computational Mathematics offered at Bowie State University, was approved by MHEC in 1997, well after JHU-EP began its Master of Science in Applied and Computational Mathematics program. It has not seemed to affect enrollments in the JHU-EP program adversely. While this program offers classes in the evening to make it more accessible to part-time students, it does not have an online delivery option like the proposed JHU-EP program.

The second is a Master of Science in Applied and Industrial Mathematics offered by Towson University. This degree program was also approved by MHEC in 1997. While it has more graduates than the Bowie State University program, it also does not seem to have adversely affected enrollments in the JHU-EP program. The web-site description of the degree program does not indicate that it is oriented toward the working, part-time student. This program also does not have an online delivery option.

The University of Maryland Baltimore County Campus offers a Master of Science degree in Applied Mathematics through its Department of Mathematics and Statistics. This degree does not cover all the material covered by the proposed JHU-EP degree. According to the website, this program is oriented toward full-time students and so does not provide opportunities for part-time or distance students to obtain degrees.

The University of Maryland offers a Master of Science in Applied Mathematics, a Master of Science in Scientific Computation, and a Master of Science in Applied Statistics through its Applied Mathematics & Statistics, and Scientific Computation Program. While each of these degree programs covers some of the material in the proposed JHU-EP degree none of them totally overlap with the proposed JHU-EP program. According to the website, these University of Maryland programs are oriented toward full-time students and so do not provide opportunities for part-time or distance students to obtain degrees.

2. Program justification

There is no applied and computational mathematics master's degree program offered asynchronously online in the State of Maryland. In view of the market demand for such a program, the JHU-EP Master of Science in Applied and Computational Mathematics clearly meets a currently important need in the region.

F. Relevance to Historically Black Institutions (HBIs)

1. Potential impact on implementation or maintenance of high-demand programs at HBIs

As noted in section D.3 above, there is another degree program with the same CIP and name at Bowie State University. It was approved by MHEC in 1997, well after the JHU-EP degree program was established. As can be seen in the graduation trend data in the table in section D.3, the Bowie State University program is very small. Since the Bowie State University program focuses on face-to-face learning, this new online option will likely target a different prospective student body.

2. Potential impact on the uniqueness and institutional identities and missions of HBIs

By definition, an appropriate student for the proposed Master of Science in Applied and Computational Mathematics would apply after completing a baccalaureate degree at any undergraduate institution, including any of Maryland's Historically Black Institutions. The proposed program would not directly affect the implementation, maintenance, uniqueness, identity or mission of these institutions.

G. Evidence of the <u>Principles of Good Practice</u>

See Appendix B for the evidence that this program complies with the Principles of Good Practice noted above.

The Higher Education Opportunity Act (HEOA) enacted in 2008 requires that an academic institution that offers distance education opportunities to students 1) has a process established to verify that the student who registers is the same student who participates in and completes the offering and receives academic credit for it, 2) has a process established to verify that student privacy rights are protected, and 3) has a process established that notifies the student about any additional costs or charges that are associated with verification of student identity. In this graduate program the following actions have been taken to satisfy these requirements: 1) students may only enter the academic website for the online courses they take by providing their unique student ID and password they receive when they are admitted to the program, 2) all FERPA privacy rights are preserved by limiting access very specifically in the University student information system to only those permitted by law to have access to restricted student information, and 3) there are no additional costs assessed to the student for the measures we use to verify student identity.

H. Adequacy of faculty resources

See Appendix C for a representative list of faculty who will teach in the proposed program. The program has 28 highly qualified faculty members. Each is a distinguished and experienced professional and 24 have Ph.D.'s and 2 have D.Sc.'s in their fields of expertise. Each has demonstrated a strong commitment to excellence in teaching. Most are practicing engineers or scientists in the JHU Whiting School of Engineering, the JHU Applied Physics Laboratory, and other local universities, corporations or government, and many hold influential positions in their organizations. Eleven faculty members are currently teaching or developing online courses. The JHU Engineering for Professionals program strives to provide engineering education rooted in practice, and for this, we rely heavily on the practitioner faculty members employed. While a majority of the faculty are part-time instructors, the strength of the program depends on the fact that they are full-time practitioners in their disciplines.

I. Adequacy of library resources

Students have full and complete access to the Milton S. Eisenhower Library on the Homewood campus, which is ranked as one of the nation's foremost facilities for research and scholarship. Its collection of more than three million bound volumes, several million microfilms, and more than 13,000 journal subscriptions has been assembled to support the academic efforts of the University. The interlibrary loan department makes the research collection of the nation available to faculty and students. The library also provides easy access to a wide selection of electronic information resources, including the library's online catalog, and numerous electronic abstracting and indexing tools. Many of the databases are accessible remotely. Librarians help students electronically and the library maintains an extensive web site to take visitors through all of its services and materials. To this are added more than 10,000 audiovisual titles available for on-site consultation.

J. Adequacy of physical facilities, infrastructure and instructional equipment

All courses in the proposed program will be offered online. The program will have no discernible impact on the use of existing facilities and equipment beyond the standard requirements already in place; primarily, faculty office space in an existing university facility location.

In terms of technology infrastructure and support, this program will be delivered via JHU-EP's online programs infrastructure, which includes the Blackboard course management system and the Adobe Connect video conferencing system. Both of these systems are supported by the Whiting School and the university's IT infrastructure. These systems provide password-protected online course sites and community management systems that enable ongoing collaborative exchange and provide convenient channels for synchronous and asynchronous learning. Blackboard is one of the world's leading providers of e-learning systems for higher education institutions. This software focuses on educational outcomes and provides a highly flexible learning environment for students. Johns Hopkins is also outfitted with suitable technical and professional staff and a 24/7 technical help desk to provide technical assistance to the students taking online courses. All of the student services such as application processes, course registration, bookstore, ID service, and advising are currently provided online as well.

The Whiting School already successfully delivers all of its online and web-enhanced courses and programs using the above mentioned platforms. As part of the program's development, the school's technical support team and business office have determined that JHU-EP possesses the necessary technology infrastructure and resources in place to support successful delivery of this online program.

K. Adequacy of financial resources with documentation

See Appendix D for detailed financial information.

L. Adequacy of provisions for evaluation of program

Once the online Master of Science in Applied and Computational Mathematics program is launched, the program and courses will be evaluated using student surveys and program committee reviews on a regular basis. For example, feedback regarding the appropriateness of course content will be solicited from students every time a course is offered. The program committee will meet annually to assess course evaluations and other feedback provided by students, faculty and other stakeholders in the program. Based on these data, the program committee will implement changes to the program (in terms of curriculum content, course delivery mechanisms, etc.) as necessary.

M. Consistency with the State's minority student achievement goals

Any student meeting the admissions requirements can apply to the Master of Science in Applied and Computational Mathematics. The program will work to help all accepted students improve their workplace competitiveness and reach their professional goals, an aim consistent with the State's minority student achievement goals.

N. Relationship to low productivity programs identified by the Commission

Not applicable.

Appendix A

Course List and Descriptions

625.201 General Applied Mathematics (3)

This course is designed for students whose prior background does not fully satisfy the mathematics requirements for admission and/ or for students who wish to take a refresher course in applied mathematics. The course provides a review of differential and integral calculus in one or more variables. It covers elementary linear algebra and differential equations, including first- and second-order linear differential equations. Basic concepts of matrix theory are discussed (e.g., matrix multiplication, inversion, and eigenvalues/eigenvectors).

Prerequisite: Two semesters of calculus.

Course Note: Not for graduate credit.

625.250 Applied Mathematics I (3)

This course covers the fundamental mathematical tools required in applied physics and engineering. The goal is to present students with the mathematical techniques used in engineering and scientific analysis and to demonstrate these techniques by the solution of relevant problems in various disciplines. Areas include vector analysis, linear algebra, matrix theory, and complex variables.

Prerequisite: Differential and integral calculus.

Course Note: Not for graduate credit.

625.251 Applied Mathematics II (3)

This course is a companion to 625.250. Topics include ordinary differential equations, Fourier series and integrals, the Laplace transformation, Bessel functions and Legendre polynomials, and an introduction to partial differential equations.

Prerequisite: Differential and integral calculus. Students with no experience in linear algebra may find it helpful to take 625.250 Applied Mathematics I first.

Course Note: Not for graduate credit.

625.260 Introduction to Signals and Systems (3)

Linear systems that produce output signals of some type are ubiquitous in many areas of science and engineering. This course will consider such systems, with an emphasis on fundamental concepts as well as the ability to perform calculations for applications in areas such as image analysis, signal processing, computer-aided systems, and feedback control. In particular, the course will approach the topic from the perspectives of both mathematical principles and computational learning. The course will also include examples that span different real-world applications in broad areas such as engineering and medicine. The course is designed primarily for students who do not have a bachelor's degree in electrical engineering or a great deal of prior mathematical coursework. The course will be of value to those with general interests in linear systems analysis, control systems, and/or signal processing. Topics include signal representations, linearity, time-variance, convolution, and Fourier series and transforms. Coverage includes both continuous and discrete-time systems.

Prerequisite: Differential and integral calculus.

Course Note: Not for graduate credit.

625.401 Real Analysis (3)
This course presents a rigorous treatment of fundamental concepts in analysis. Emphasis is placed on careful reasoning and proofs. Topics covered include the completeness and order properties of real numbers, limits and continuity, conditions for integrability and differentiability, infinite sequences, and series. Basic notions of topology and measure are also introduced.
Prerequisite: Multivariate calculus.

625.402 Modern Algebra (3)
This course examines the structures of modern algebra, including groups, linear spaces, rings, polynomials, and fields, and some of their applications to such areas as cryptography, primality testing and the factorization of composite numbers, efficient algorithm design in computing, circuit design, and signal processing. It will include an introduction to quantum information processing. Grading is based on weekly problem sets, a midterm, and a final.
Prerequisite: Multivariate calculus and linear algebra.

625.403 Statistical Methods and Data Analysis (3)
This course introduces commonly used statistical methods. The intent of this course is to provide an understanding of statistical techniques and guidance on the appropriate use of methodologies. The course covers the mathematical foundations of common methods as an aid toward understanding both the types of applications that are appropriate and the limits of the methods. MATLAB and statistical software are used so students can apply statistical methodology to practical problems in the workplace. Topics include the basic laws of probability and descriptive statistics, conditional probability, random variables, expectation and variance, discrete and continuous probability models, bivariate distributions and covariance, sampling distributions, hypothesis testing, method of moments and maximum likelihood point (MLE) estimation, confidence intervals, contingency tables, analysis of variance (ANOVA), and linear regression modeling.
Prerequisite: Multivariate calculus.

625.404 Ordinary Differential Equations (3)
This course provides an introduction to the theory, solution, and application of ordinary differential equations. Topics discussed in the course include methods of solving first-order differential equations, existence and uniqueness theorems, second-order linear equations, power series solutions, higher-order linear equations, systems of equations, nonlinear equations, Sturm–Liouville theory, and applications. The relationship between differential equations and linear algebra is emphasized in this course. An introduction to numerical solutions is also provided. Applications of differential equations in physics, engineering, biology, and economics are presented. This course covers more material in greater depth than the standard undergraduate-level ODE course.
Prerequisites: Two or more terms of calculus are required. Course in linear algebra is helpful.

625.409 Matrix Theory (3)
In this course, topics include the methods of solving linear equations, Gaussian elimination, triangular factors and row exchanges, vector spaces (linear independence, basis, dimension, and linear transformations), orthogonality (inner products, projections, and Gram–Schmidt process), determinants, eigenvalues and eigenvectors (diagonal form of a matrix, similarity

transformations, and matrix exponential), singular value decomposition, and the pseudo-inverse. The course also covers applications to statistics (least squares fitting to linear models, covariance matrices) and to vector calculus (gradient operations and Jacobian and Hessian matrices). MATLAB software will be used in some class exercises.

625.411 Computational Methods (3)

As the need to increase the understanding of real-world phenomena grows rapidly, computer-based simulations and modeling tools are increasingly being accepted as viable means to study such problems. In this course, students are introduced to some of the key computational techniques used in modeling and simulation of real-world phenomena. The course begins with coverage of fundamental concepts in computational methods including error analysis, matrices and linear systems, convergence, and stability. It proceeds to curve fitting, least squares, and iterative techniques for practical applications, including methods for solving ordinary differential equations and simple optimization problems. Elements of computer visualization and Monte Carlo simulation will be discussed as appropriate. The emphasis here is not so much on programming technique but rather on understanding basic concepts and principles. Employment of higher-level programming and visualization tools, such as MATLAB, reduces burdens on programming and introduces a powerful tool set commonly used by industry and academia. A consistent theme throughout the course is the linkage between the techniques covered and their applications to real-world problems.

Prerequisites: Multivariate calculus and ability to program in MATLAB, FORTRAN, C++, Java, or other language. Courses in matrix theory or linear algebra as well as in differential equations would be helpful but are not required.

625.415 Introduction to Optimization (3)

A number of applications (inverse problems, machine learning, computer vision, data analysis, scheduling, etc.) require optimization problems to be solved. The objective of this course is to introduce the student to computational methods for linear, network, integer, and nonlinear optimization. Topics include traditional algorithms (e.g., Newtonian methods, interior-point methods, dynamic programming) as well as heuristics. Students will formulate real-world problems as optimization models and be exposed to the theoretical foundations for developing algorithms used for large scale problems.

Prerequisites: Multivariate calculus, linear algebra. Some real analysis is helpful but is not required; 625.414 Linear Optimization is not required.

625.416 Optimization in Finance (3)

Optimization models play an increasingly important role in financial decisions. This course introduces the student to financial optimization models and methods. We will specifically discuss linear, integer, quadratic, and general nonlinear programming. If time permits, we will also cover dynamic and stochastic programming. The main theoretical features of these optimization methods will be studied as well as a variety of algorithms used in practice.

Prerequisites: Multivariate calculus and linear algebra.

625.417 Applied Combinatorics and Discrete Mathematics (3)

Combinatorics and discrete mathematics are increasingly important fields of mathematics because of their extensive applications in computer science, statistics, operations research, and engineering. The purpose of this course is to teach students to model, analyze, and solve combinatorial and discrete mathematical problems. Topics include elements of graph theory, graph coloring and covering circuits, the pigeonhole principle, counting methods, generating functions, recurrence relations and their solution, and the inclusion-exclusion formula. Emphasis is on the application of the methods to problem solving.

Course Note: This course is the same as 605.423 Applied Combinatorics and Discrete Mathematics.

625.420 Mathematical Methods for Signal Processing (3)

This course familiarizes the student with modern techniques of digital signal processing and spectral estimation of discrete-time or discrete-space sequences derived by the sampling of continuous-time or continuous-space signals. The class covers the mathematical foundation needed to understand the various signal processing techniques as well as the techniques themselves. Topics include the discrete Fourier transform, the discrete Hilbert transform, the singular-value decomposition, the wavelet transform, classical spectral estimates (periodogram and correlogram), autoregressive and autoregressive-moving average spectral estimates, and Burg maximum entropy method.

Prerequisites: Mathematics through calculus, matrix theory, or linear algebra, and introductory probability theory and/or statistics. Students are encouraged to refer any questions to the instructor.

625.423 Introduction to Operations Research: Probabilistic Models (3)

This course investigates several probability models that are important to operations research applications. Models covered include Markov chains, Markov processes, renewal theory, queueing theory, scheduling theory, reliability theory, Bayesian networks, random graphs, and simulation. The course emphasizes both the theoretical development of these models and the application of the models to areas such as engineering, computer science, and management science.

Prerequisites: Multivariate calculus and a course in probability and statistics (such as 625.403 Statistical Methods and Data Analysis)

625.433 Monte Carlo Methods (3)

This course is an introduction to fundamental tools in designing, conducting, and interpreting Monte Carlo simulations. Emphasis is on generic principles that are widely applicable in simulation, as opposed to detailed discussion of specific applications and/or software packages. At the completion of this course, it is expected that students will have the insight and understanding to critically evaluate or use many state-of-the-art methods in simulation. Topics covered include random number generation, simulation of Brownian motion and stochastic differential equations, output analysis for Monte Carlo simulations, variance reduction, Markov chain Monte Carlo, simulation-based estimation for dynamical (state-space) models, and, time permitting, sensitivity analysis and simulation-based optimization.

Prerequisites: Multivariate calculus and a course in probability and statistics (such as 625.403 Statistical Methods and Data Analysis).

625.436Graph Theory (3)

This course focuses on the mathematical theory of graphs; a few applications and algorithms will be discussed. Topics include trees, connectivity, Eulerian and Hamiltonian graphs, matchings, edge and vertex colorings, independent sets and cliques, planar graphs, and directed graphs. An advanced topic completes the course.

Prerequisite: Familiarity with linear algebra and basic counting methods such as binomial coefficients is assumed. Comfort with reading and writing mathematical proofs is required.

625.438 Neural Networks (3)

This course provides an introduction to concepts in neural networks and connectionist models. Topics include parallel distributed processing, learning algorithms, and applications. Specific networks discussed include Hopfield networks, bidirectional associative memories, perceptrons, feedforward networks with back propagation, and competitive learning networks, including self-organizing and Grossberg networks. Software for some networks is provided.

Prerequisites: Multivariate calculus and linear algebra

Course Note: This course is the same as 605.447 Neural Networks.

625.441 Mathematics of Finance: Investment Science (3)

This course offers a rigorous treatment of the subject of investment as a scientific discipline. Mathematics is employed as the main tool to convey the principles of investment science and their use to make investment calculations for good decision making. Topics covered in the course include the basic theory of interest and its applications to fixed-income securities, cash flow analysis and capital budgeting, mean-variance portfolio theory and the associated capital asset pricing model, utility function theory and risk analysis, derivative securities and basic option theory, and portfolio evaluation.

Prerequisites: Multivariate calculus and an introductory course in probability and statistics (such as 625.403 Statistical Methods and Data Analysis). Some familiarity with optimization is desirable but not necessary.

625.442 Mathematics of Risk, Options, and Financial Derivatives (3)

The concept of options stems from the inherent human desire and need to reduce risks. This course starts with a rigorous mathematical treatment of options pricing, credit default swaps, and related areas by developing a powerful mathematical tool known as Ito calculus. We introduce and use the well-known field of stochastic differential equations to develop various techniques as needed, as well as discuss the theory of martingales. The mathematics will be applied to the arbitrage pricing of financial derivatives, which is the main topic of the course. We treat the Black–Scholes theory in detail and use it to understand how to price various options and other quantitative financial instruments. We also discuss interest rate theory. We further apply these techniques to investigate stochastic differential games, which can be used to model various financial and economic situations including the stock market. Time permitting, we discuss related topics in mechanism designs, a subfield of game theory that is concerned about designing economic games with desired outcome.

Course Notes: This class is distinguished from 625.441 Mathematics of Finance (formerly 625.439) and 625.714 Introductory Stochastic Differential Equations with Applications, as follows: 625.441 Mathematics of Finance: Investment Science gives a broader and more general treatment of financial mathematics, and 625.714 Introductory Stochastic Differential Equations *with Applications provides a deeper (more advanced) mathematical understanding of stochastic differential equations, with applications in both finance and non-finance areas. No one of the classes 625.441 Mathematics of Finance: Investment Science, 625.442 Mathematics of Risk, Options, and Financial Derivatives, and 625.714 Introductory Stochastic Differential Equations with Applications is a prerequisite or co-requisite for the other classes; the classes are intended to be complementary. Feel free to contact the instructor(s) should you have any questions about these courses.*

Prerequisites: Multivariate calculus, linear algebra and matrix theory (e.g., 625.409 Matrix Theory), and a graduate-level course in probability and statistics (such as 625.403 Statistical Methods and Data Analysis).

625.461 Statistical Models and Regression (3)

Introduction to regression and linear models including least squares estimation, maximum likelihood estimation, the Gauss-Markov theorem, and the fundamental theorem of least squares. Topics include estimation, hypothesis testing, simultaneous inference, model diagnostics, transformations, multicollinearity, influence, model building, and variable selection. Advanced topics include nonlinear regression, robust regression, and generalized linear models including logistic and Poisson regression.

Prerequisites: One semester of statistics (such as 625.403 Statistical Methods of Data Analysis), multivariate calculus, and linear algebra.

625.462 Design and Analysis of Experiments (3)

Statistically designed experiments are the efficient allocation of resources to maximize the amount of information obtained with a minimum expenditure of time and effort. Design of experiments is applicable to both physical experimentation and computer simulation models. This course covers the principles of experimental design, the analysis of variance method, the differences between fixed and random effects and between nested and crossed effects, and the concept of confounded effects. The designs covered include completely random, randomized block, Latin squares, split-plot, factorial, fractional factorial, nested treatments and variance component analysis, response surface, optimal, Latin hypercube, and Taguchi. Any experiment can correctly be analyzed by learning how to construct the applicable design structure diagram (Hasse diagrams).

Prerequisites: Multivariate calculus, linear algebra, and one semester of graduate probability and statistics (e.g., 625.403 Statistical Methods and Data Analysis). Some computer-based homework assignments will be given.

625.463 Multivariate Statistics and Stochastic Analysis (3)

Multivariate analysis arises with observations of more than one variable when there is some probabilistic linkage between the variables. In practice, most data collected by researchers in virtually all disciplines are multivariate in nature. In some cases, it might make sense to isolate each variable and study it separately. In most cases, however, the variables are interrelated in such a way that analyzing the variables in isolation may result in failure to uncover critical patterns in the data. Multivariate data analysis consists of methods that can be used to study several variables at the same time so that the full structure of the data can be observed and key properties can be identified. This course covers estimation, hypothesis tests, and distributions for multivariate mean vectors and covariance matrices. We also cover popular multivariate data analysis methods including multivariate data visualization, maximum likelihood, principal components analysis, multiple comparisons tests, multi-dimensional scaling, cluster analysis, discriminant analysis and multivariate analysis of variance, multiple regression and canonical correlation, and analysis of repeated measures data. Course work will include computer assignments.

Prerequisites: Linear algebra, multivariate calculus, and one semester of graduate probability and statistics (e.g., 625.403 Statistical Methods of Data Analysis).

625.464 Computational Statistics (3)

Computational statistics is a branch of mathematical sciences concerned with efficient methods for obtaining numerical solutions to statistically formulated problems. This course will introduce students to a variety of computationally intensive statistical techniques and the role of computation as a tool of discovery. Topics include numerical optimization in statistical inference [expectation-maximization (EM) algorithm, Fisher scoring, etc.], random number generation, Monte Carlo methods, randomization methods, jackknife methods, bootstrap methods, tools for identification of structure in data, estimation of functions (orthogonal polynomials, splines, etc.), and graphical methods. Additional topics may vary. Course work will include computer assignments.

Prerequisites: Multivariate calculus, familiarity with basic matrix algebra, graduate course in probability and statistics (such as 625.403 Statistical Methods of Data Analysis)

625.480 Cryptography (3)

An important concern in the information age is the security, protection, and integrity of electronic information, including communications, electronic funds transfer, power system control, transportation systems, and military and law enforcement information. Modern cryptography, in applied mathematics, is concerned not only with the design and exploration of encryption schemes (classical cryptography) but also with the rigorous analysis of any system that is designed to withstand malicious attempts to tamper with, disturb, or destroy it. This course introduces and surveys the field of modern cryptography. After mathematical preliminaries from probability theory, algebra, computational complexity, and number theory, we will explore the following topics in the field: foundations of cryptography, public key cryptography, probabilistic proof systems, pseudorandom generators, elliptic curve cryptography, and fundamental limits to information operations.

Prerequisites: Linear algebra and an introductory course in probability and statistics such as 625.403 Statistical Methods and Data Analysis.

625.485 Number Theory (3)

This course covers principal ideas of classical number theory, including the fundamental theorem of arithmetic and its consequences, congruences, cryptography and the RSA method, polynomial congruences, primitive roots, residues, multiplicative functions, and special topics.

Prerequisites: Multivariate calculus and linear algebra.

625.487 Applied Topology (3)

The course is both an introduction to topology and an investigation of various applications of topology in science and engineering. Topology, simply put, is a mathematical study of shapes, and it often turns out that just knowing a rough shape of an object (whether that object is as concrete as platonic solids or as abstract as the space of all paths in large complex networks) can enhance one's understanding of the object. We will start with a few key theoretical concepts from point-set topology with proofs, while letting breadth take precedence over depth, and then introduce key concepts from algebraic topology, which attempts to use algebraic concepts, mostly group theory, to develop ideas of homotopy, homology, and cohomology, which render topology "computable." Finally, we discuss a few key examples of real-world applications of computational topology, an emerging field devoted to the study of efficient algorithms for topological problems, especially those arising in science and engineering, which builds on classical results from algebraic topology as well as algorithmic tools from computational geometry and other areas of computer science. The questions we like to ask are: Do I know the topology of my network? What is a rough shape of the large data set that I am working with (is there a logical gap?) Will the local picture of a part of the sensor field I am looking at give rise to a consistent global common picture?

Prerequisites: Multivariate calculus, linear algebra and matrix theory (e.g., 625.409 Matrix Theory), and an undergraduate-level course in probability and statistics.

Course Note: This course is the same as 605.428 Applied Topology.

625.490 Computational Complexity and Approximation (3)

This course will cover the theory of computational complexity, with a focus on popular approximation and optimization problems and algorithms. It begins with important complexity concepts including Turing machines, Karp and Turing reducibility, basic complexity classes, and the theory of NP-completeness. It then discusses the complexity of well-known approximation and optimization algorithms and introduces approximability properties, with special focus on approximation algorithm and heuristic design. The impact of emerging computing techniques, such as massive parallelism and quantum computing, will also be discussed. The course will specifically target algorithms with practical significance and techniques that can improve performance in real-world implementations.

Prerequisites: Introductory probability theory and/or statistics (such as 625.403 Statistical Methods of Data Analysis) and undergraduate-level exposure to algorithms and matrix algebra. Some familiarity with optimization and computing architectures is desirable but not necessary.

625.492 Probabilistic Graphical Models (3)

This course introduces the fundamentals behind the mathematical and logical framework of graphical models. These models are used in many areas of machine learning and arise in numerous challenging and intriguing problems in data analysis, mathematics, and computer science. For example, the "big data" world frequently uses graphical models to solve problems. While the framework introduced in this course will be largely mathematical, we will also present algorithms and connections to problem domains. The course will begin with the fundamentals of probability theory and will then move into Bayesian networks, undirected graphical models, template-based models, and Gaussian networks. The nature of inference and learning on the graphical structures will be covered, with explorations of complexity, conditioning, clique trees, and optimization. The course will use weekly problem sets and a term project to encourage mastery of the fundamentals of this emerging area.

Prerequisites: Graduate course in probability and statistics (such as 625.403 Statistical Methods of Data Analysis).

Course Note: This course is the same as 605.425 Probabilistic Graphical Models.

625.495 Time Series Analysis and Dynamic Modeling (3)
This course will be a rigorous and extensive introduction to modern methods of time series analysis and dynamic modeling. Topics to be covered include elementary time series models, trend and seasonality, stationary processes, Hilbert space techniques, the spectral distribution function, autoregressive/integrated/moving average (ARIMA) processes, fitting ARIMA models, forecasting, spectral analysis, the periodogram, spectral estimation techniques, multivariate time series, linear systems and optimal control, state-space models, and Kalman filtering and prediction. Additional topics may be covered if time permits. Some applications will be provided to illustrate the usefulness of the techniques.
Prerequisites: Graduate course in probability and statistics (such as 625.403 Statistical Methods of Data Analysis) and familiarity with matrix theory and linear algebra.
Course Note: This course is also offered in the full-time Department of Applied Mathematics & Statistics (Homewood campus).

625.703 Functions of a Complex Variable (3)
Topics include properties of complex numbers, analytic functions, Cauchy's theorem and integral formulas, Taylor and Laurent series, singularities, contour integration and residues, and conformal mapping.
Prerequisites: 625.401 Real Analysis, or 625.404 Ordinary Differential Equations, or permission of the instructor.

625.710 Fourier Analysis with Applications to Signal Processing and Differential Equations (3)
This applied course covers the theory and application of Fourier analysis, including the Fourier transform, the Fourier series, and the discrete Fourier transform. Motivation will be provided by the theory of partial differential equations arising in physics and engineering. We will also cover Fourier analysis in the more general setting of orthogonal function theory. Applications in signal processing will be discussed, including the sampling theorem and aliasing, convolution theorems, and spectral analysis. Finally, we will discuss the Laplace transform, again with applications to differential equations.
Prerequisites: Familiarity with differential equations, linear algebra, and real analysis.

625.714 Introductory Stochastic Differential Equations with Applications (3)
The goal of this course is to give basic knowledge of stochastic differential equations useful for scientific and engineering modeling, guided by some problems in applications. The course treats basic theory of stochastic differential equations, including weak and strong approximation, efficient numerical methods and error estimates, the relation between stochastic differential equations and partial differential equations, Monte Carlo simulations with applications in financial mathematics, population growth models, parameter estimation, and filtering and optimal control problems.
Prerequisites: Multivariate calculus and a graduate course in probability and statistics, as well as exposure to ordinary differential equations.

625.717 Advanced Differential Equations: Partial Differential Equations (3)
This course presents practical methods for solving partial differential equations (PDEs). The course covers solutions of hyperbolic, parabolic, and elliptic equations in two or more

independent variables. Topics include Fourier series, separation of variables, existence and uniqueness theory for general higher-order equations, eigenfunction expansions, finite difference and finite element numerical methods, Green's functions, and transform methods. MATLAB, a high-level computing language, is used throughout the course to complement the analytical approach and to introduce numerical methods.

Prerequisites: 625.404 Ordinary Differential Equations or equivalent graduate-level ordinary differential equations class and knowledge of eigenvalues and eigenvectors from matrix theory. (Note: The standard undergraduate-level ordinary differential equations class alone is not sufficient to meet the prerequisites for this class.)

625.718 Advanced Differential Equations: Nonlinear Differential Equations and Dynamical Systems (3)

This course examines ordinary differential equations from a geometric point of view and involves significant use of phase-plane diagrams and associated concepts, including equilibrium points, orbits, limit cycles, and domains of attraction. Various methods are discussed to determine existence and stability of equilibrium points and closed orbits. Methods are discussed for analyzing nonlinear differential equations (e.g., linearization, direct, perturbation, and bifurcation analysis). An introduction to chaos theory and Hamiltonian systems is also presented. The techniques learned will be applied to equations from physics, engineering, biology, ecology, and neural networks (as time permits).

Prerequisites: 625.404 Ordinary Differential Equations or equivalent graduate-level ordinary differential equations class and knowledge of eigenvalues and eigenvectors from matrix theory. (Note: The standard undergraduate-level ordinary differential equations class alone is not sufficient to meet the prerequisites for this class.) 625.717 Advanced Differential Equations: Partial Differential Equations is not required.

625.721 Probability and Stochastic Process I (3)

This rigorous course in probability covers probability space, random variables, functions of random variables, independence and conditional probabilities, moments, joint distributions, multivariate random variables, conditional expectation and variance, distributions with random parameters, posterior distributions, probability generating function, moment generating function, characteristic function, random sum, types of convergence and relation between convergence concepts, law of large numbers and central limit theorem (i.i.d. and non- i.i.d. cases), Borel-Cantelli Lemmas, well known discrete and continuous distributions, homogenous Poisson process (HPP), non-homogenous Poisson process (NHPP), and compound Poisson process. This course is proof oriented. The primary purpose of this course is to lay the foundation for the second course, 625.722 Probability and Stochastic Process II, and other specialized courses in probability. Note that, in contrast to 625.728 Theory of Probability, this course is largely a non-measure theoretic approach to probability.

Prerequisites: Multivariate calculus and 625.403 Statistical Methods and Data Analysis or equivalent.

625.722 Probability and Stochastic Process II (3)

This course is an introduction to theory and applications of stochastic processes. The course starts with a brief review of conditional probability, conditional expectation, conditional variance, central limit theorems, and Poisson Process. The topics covered include: Gaussian random vectors and processes, renewal processes, renewal reward process, discrete-time Markov chains, classification of states, birth-death process, reversible Markov chains, branching process, continuous-time Markov chains, limiting probabilities, Kolmogorov differential equations, approximation methods for transition probabilities, random walks, and martingales. This course is proof oriented.

Prerequisites: Differential equations and 625.721 Probability and Stochastic Process I or equivalent.

625.725 Theory of Statistics I (3)

This course covers mathematical statistics and probability. Topics covered include discrete and continuous probability distributions, expected values, moment-generating functions, sampling theory, convergence concepts, and the central limit theorem. This course is a rigorous treatment of statistics that lays the foundation for 625.726 Theory of Statistics II and other advanced courses in statistics.

Prerequisites: Multivariate calculus and 625.403 Statistical Methods and Data Analysis or equivalent.

625.726 Theory of Statistics II (3)

This course is the continuation of 625.725. It covers method of moments estimation, maximum likelihood estimation, the Cramér–Rao inequality, sufficiency and completeness of statistics, uniformly minimum variance unbiased estimators, the Neyman–Pearson Lemma, the likelihood ratio test, goodness-of-fit tests, confidence intervals, selected non-parametric methods, and decision theory.

Prerequisite: 625.725 Theory of Statistics I or equivalent.

625.728 Theory of Probability (3)

This course provides a rigorous, measure-theoretic introduction to probability theory. It begins with the notion of fields, sigma-fields, and measurable spaces and also surveys elements from integration theory and introduces random variables as measurable functions. It then examines the axioms of probability theory and fundamental concepts including conditioning, conditional probability and expectation, independence, and modes of convergence. Other topics covered include characteristic functions, basic limit theorems (including the weak and strong laws of large numbers), and the central limit theorem.

Prerequisites: 625.401 Real Analysis and 625.403 Statistical Methods and Data Analysis.

625.734 Queuing Theory with Applications to Computer Science (3)

Queues are a ubiquitous part of everyday life; common examples are supermarket checkout stations, help desk call centers, manufacturing assembly lines, wireless communication networks, and multi-tasking computers. Queuing theory provides a rich and useful set of mathematical models for the analysis and design of service process for which there is contention for shared resources. This course explores both theory and application of fundamental and advanced models in this field. Fundamental models include single and multiple server Markov queues, bulk arrival and bulk service processes, and priority queues. Applications emphasize communication networks and computer operations but may include examples from transportation, manufacturing, and the service industry. Advanced topics may vary.

Prerequisites: Multivariate calculus and a graduate course in probability and statistics such as

625.403 Statistical Methods and Data Analysis.
Course Note: This course is the same as 605.725 Queuing Theory with Applications to Computer Science.

625.740 Data Mining (3)
The field of data science is emerging to make sense of the growing availability and exponential increase in size of typical data sets. Central to this unfolding field is the area of data mining, an interdisciplinary subject incorporating elements of statistics, machine learning, artificial intelligence and data processing. In this course, we will explore methods for preprocessing, visualizing and making sense of data, focusing not only on the methods, but also on the mathematical foundations of many of the algorithms of statistics and machine learning. We will learn about approaches to classification, including traditional methods such as Bayes Decision Theory and more modern approaches such as Support Vector Machines and unsupervised learning techniques that encompass clustering algorithms applicable when labels of the training data are not provided or are unknown. We will introduce and use open-source statistics and data mining software such as R and Weka. Students will have an opportunity to see how data mining algorithms work together by reviewing case studies and exploring a topic of choice in more detail by completing a project over the course of the semester.
Prerequisites: Multivariate calculus, linear algebra, and matrix theory (e.g., 625.409 Matrix Theory), and a course in probability and statistics (such as 625.403 Statistical Methods and Data Analysis). This course will also assume familiarity with multiple linear regression and basic ability to program.

625.741 Game Theory (3)
Game theory is a field of applied mathematics that describes and analyzes interactive decision making when two or more parties are involved. Since finding a firm mathematical footing in 1928, it has been applied to many fields, including economics, political science, foreign policy, and engineering. This course will serve both as an introduction to and a survey of applications of game theory. Therefore, after covering the mathematical foundational work with some measure of mathematical rigor, we will examine many real-world situations, both historical and current. Topics include two-person/N-person game, cooperative/noncooperative game, static/dynamic game, and combinatorial/strategic/coalitional game, as well as their respective examples and applications. Further attention will be given to the meaning and the computational complexity of finding of Nash equilibrium.
Prerequisites: Multivariate calculus, linear algebra and matrix theory (e.g., 625.409 Matrix Theory), and a course in probability and statistics (such as 625.403 Statistical Methods and Data Analysis).
Course Note: This course is the same as 605.726 Game Theory.

625.743 Stochastic Optimization and Control (3)
Stochastic optimization plays an increasing role in the analysis and control of modern systems. This course introduces the fundamental issues in stochastic search and optimization, with special emphasis on cases where classical deterministic search techniques (steepest descent, Newton–Raphson, linear and nonlinear programming, etc.) do not readily apply. These cases include many important practical problems, which will be briefly discussed throughout the course (e.g., neural network training, nonlinear control, experimental design, simulation-based optimization,

sensor configuration, image processing, discrete-event systems, etc.). Both global and local optimization problems will be considered. Techniques such as random search, least mean squares (LMS), stochastic approximation, simulated annealing, evolutionary computation (including genetic algorithms), and machine learning will be discussed.

Prerequisites: Multivariate calculus, linear algebra, and one semester of graduate probability and statistics (e.g., 625.403 Statistical Methods and Data Analysis). Some computer-based homework assignments will be given. It is recommended that this course be taken only in the last half of a student's degree program.

625.744 Modeling, Simulation, and Monte Carlo (3)

Computer simulation and related Monte Carlo methods are widely used in engineering, scientific, and other work. Simulation provides a powerful tool for the analysis of real-world systems when the system is not amenable to traditional analytical approaches. In fact, recent advances in hardware, software, and user interfaces have made simulation a "first-line" method of attack for a growing number of problems. Areas in which simulation-based approaches have emerged as indispensable include decision aiding, prototype development, performance prediction, scheduling, and computer-based personnel training. This course introduces concepts and statistical techniques that are critical to constructing and analyzing effective simulations and discusses certain applications for simulation and Monte Carlo methods. Topics include random number generation, simulation-based optimization, model building, bias-variance trade-off, input selection using experimental design, Markov chain Monte Carlo (MCMC), and numerical integration.

Prerequisites: Multivariate calculus, familiarity with basic matrix algebra, graduate course in probability and statistics (such as 625.403 Statistical Methods and Data Analysis). Some computer-based homework assignments will be given. It is recommended that this course be taken only in the last half of a student's degree program.

625.800 Independent Study in Applied and Computational Mathematics (3)

An individually tailored, supervised project on a subject related to applied and computational mathematics. A maximum of one independent study course may be applied toward the Master of Science degree or post-master's certificate. This course may only be taken in the second half of a student's degree program. All independent studies must be supervised by an ACM instructor and must rely on material from prior ACM courses. The independent study project proposal form must be approved prior to registration.

625.801/802 Applied and Computational Mathematics Master's Research (3)

This course sequence is designed for students in the master's program who wish to work with a faculty advisor to conduct significant, original independent research in the field of applied and computational mathematics (each course is one semester). A sequence may be used to fulfill two courses within the 700-level course requirements for the master's degree; only one sequence may count towards the degree. For sequence 625.801–802, the student will produce a technical paper for submission to a journal or to a conference with accompanied refereed proceedings. The intent of the research is to expand the body of knowledge in the broad area of applied mathematics, with the research leading to professional-quality documentation. Students with a potential interest in pursuing a doctoral degree at JHU, or another university, should consider enrolling in either this sequence or 625.803–625.804 to gain familiarity with the research process (doctoral intentions are not a requirement for enrollment).

Prerequisites: Completion of at least six courses towards the Master of Science, including 625.401 Real Analysis and/or 625.409 Matrix Theory, 625.403 (Statistical Methods and Data Analysis), and at least one of the following three two-semester sequences: 625.717–718 Advanced Differential Equations: Partial Differential Equations and Nonlinear Differential Equations and Dynamical Systems, 625.721–722 Probability and Stochastic Processes I and II, or 625.725–726 Theory of Statistics I and II). It is recommended that the sequence represent the final two courses of the degree.

Course Note: The student must identify a potential research advisor from the Applied and Computational Mathematics Research Faculty (ep.jhu.edu/acm-research) to initiate the approval procedure prior to enrollment in the chosen course sequence; enrollment may only occur after approval. A full description of the process and requirements can be found at ep.jhu.edu/acm-process.

625.803/804 Applied and Computational Mathematics Master's Thesis (3)

This course sequence is designed for students in the master's program who wish to work with a faculty advisor to conduct significant, original independent research in the field of applied and computational mathematics (each course is one semester). A sequence may be used to fulfill two courses within the 700-level course requirements for the master's degree; only one sequence may count towards the degree. For sequence 625.803–804, the student is to produce a bound hard-copy thesis for submission to the JHU library and an electronic version of the thesis based on standards posted at guides.library.jhu.edu/etd (the student is also encouraged to write a technical paper for publication based on the thesis). The intent of the research is to expand the body of knowledge in the broad area of applied mathematics, with the research leading to professional-quality documentation. Students with a potential interest in pursuing a doctoral degree at JHU, or another university, should consider enrolling in either this sequence or 625.801–802 to gain familiarity with the research process (doctoral intentions are not a requirement for enrollment).

Prerequisites: Completion of at least six courses towards the Master of Science, including 625.401 Real Analysis and/or 625.409 Matrix Theory, 625.403 (Statistical Methods and Data Analysis), and at least one of the following three two-semester sequences: 625.717–718 Advanced Differential Equations: Partial Differential Equations and Nonlinear Differential Equations and Dynamical Systems, 625.721–722 Probability and Stochastic Processes I and II, or 625.725–726 Theory of Statistics I and II). It is recommended that the sequence represent the final two courses of the degree.

Course Note: The student must identify a potential research advisor from the Applied and Computational Mathematics Research Faculty (ep.jhu.edu/acm-research) to initiate the approval procedure prior to enrollment in the chosen course sequence; enrollment may only occur after approval. A full description of the process and requirements for 625.803–804 can be found at ep.jhu.edu/acm-process.

625.805/806 Applied and Computational Mathematics Post-Master's Research (3)

This course sequence is designed for students in the post-master's certificate (PMC) program who wish to work with a faculty advisor to conduct significant, original independent research in the field of applied and computational mathematics (each course is one semester). A sequence may be used to fulfill two courses within the course requirements for the PMC; only one sequence may count towards the certificate. For sequence 625.805–806, the student is to produce

a technical paper for submission to a journal or to a conference with accompanied refereed proceedings. The intent of the research is to expand the body of knowledge in the broad area of applied mathematics, with the research leading to professional-quality documentation. Students with a potential interest in pursuing a doctoral degree at JHU, or another university, should consider enrolling in one of these sequences to gain familiarity with the research process (doctoral intentions are not a requirement for enrollment).
Prerequisites: At least three courses (four are recommended) towards the post-master's certificate. It is recommended that the sequence represent the final two courses in the post-master's certificate program.
Course Note: The student must identify a potential research advisor from the Applied and Computational Mathematics Research Faculty (ep.jhu.edu/acm-research) to initiate the approval procedure prior to enrollment in the chosen course sequence; enrollment may only occur after approval. A full description of the process and requirements can be found at ep.jhu.edu/acm-process.

625.807/808 Applied and Computational Mathematics Post-Master's Thesis (3)
This course sequences is designed for students in the post-master's certificate (PMC) program who wish to work with a faculty advisor to conduct significant, original independent research in the field of applied and computational mathematics (each course is one semester). A sequence may be used to fulfill two courses within the course requirements for the PMC; only one sequence may count towards the certificate. For sequence 625.807–808, the student is to produce a bound hard-copy thesis for submission to the JHU library and an electronic version of the thesis based on standards posted at guides.library.jhu.edu/etd (the student is also encouraged to write a technical paper for publication based on the thesis). The intent of the research is to expand the body of knowledge in the broad area of applied mathematics, with the research leading to professional-quality documentation. Students with a potential interest in pursuing a doctoral degree at JHU, or another university, should consider enrolling in one of these sequences to gain familiarity with the research process (doctoral intentions are not a requirement for enrollment).
Prerequisites: At least three courses (four are recommended) towards the post-master's certificate. It is recommended that the sequence represent the final two courses in the post-master's certificate program.
Course Note: The student must identify a potential research advisor from the Applied and Computational Mathematics Research Faculty (ep.jhu.edu/acm-research) to initiate the approval procedure prior to enrollment in the chosen course sequence; enrollment may only occur after approval. A full description of the process and requirements can be found at ep.jhu.edu/acm-process.

Appendix B
Evidence of Compliance with the Principles of Good Practice
(as outlined in COMAR 13B02.03.22C)

(a) Curriculum and Instruction

(i) A distance education program shall be established and overseen by qualified faculty.

This is already a well-established site-based program; many of the faculty teaching in the on-site program also serve as online instructors. Any new instructor recruited to teach online would be required to meet the same qualifications as those teaching in the traditional site-based program.

(ii) A program's curriculum shall be coherent, cohesive, and comparable in academic rigor to programs offered in traditional instructional formats.

All the courses in the online program have been and/or are offered in the traditional, site-based program. Prior to a course being converted for online delivery, the course must be taught minimally twice in-class. A formal online course development process is used to support the course conversion from in-class to online. The online course development process incorporates the Quality Matters™ research-based set of eight standards for quality online course design to ensure the academic rigor of the online course is comparable or better to the traditionally offered course.

(iii) A program shall result in learning outcomes appropriate to the rigor and breadth of the program.

The program learning outcomes for the distance education program are identical to the traditional on-site program (please see section B.2). The program learning outcomes are derived from input from professionals within the discipline, the program instructors, program leadership and other program stakeholders.

(iv) A program shall provide for appropriate real-time or delayed interaction between faculty and students.

The Master of Science in Applied and Computational Mathematics will be delivered via Blackboard, JHU's course management system. This platform supports asynchronous interaction between faculty and students. Students and faculty also have the option to participate in optional 'real-time' interaction through weekly web-conference office hours, supported by Adobe Connect.

(v) Faculty members in appropriate disciplines in collaboration with other institutional personnel shall participate in the design of courses offered through a distance education program.

The program has established a process for identifying the appropriate faculty to design an online course. All faculty members are selected based on domain expertise, program-related teaching experience and completion of a required online course development training course.

(b) Role and Mission

(i) A distance education program shall be consistent with the institution's mission.

Refer to Section A.1 in the main body of the proposal.

(ii) Review and approval processes shall ensure the appropriateness of the technology being used to meet a program's objectives.

The development of online courses is supported by JHU-EP's Center for Learning Design and Technology (CLDT) professional staff, which includes instructional designers, instructional support specialists and other supporting staff. Each online course development is assigned an instructional designer. The course instructor(s) consults with the instructional designer during the course design process to determine the most effective learning technologies and strategies needed to meet the course learning objectives. The course design goes through multiple reviews by the instructional designer and program chairs. The program chairs are responsible for making sure the course design meets the program's expectations for online courses and that the course learning objectives reflect what your program expects students to achieve after completing this course. Once the online course launches, the assigned instructional designer continually monitors the courses, and consults with the instructor(s) to make adjustments to the course, if needed. All new online courses participate in a mid-term and end-of-term course evaluation process. The mid-term feedback is used to determine if any mid-point term corrections are needed. The end-of-term feedback is used to assess whether further course refinements are needed prior to the next time the course is offered.

(c) Faculty Support

(i) An institution shall provide for training for faculty who teach with the use of technology in a distance education format, including training in the learning management system and the pedagogy of distance education.

Faculty support for the development of online courses is provided by JHU-EP's CLDT professional staff. Faculty have multiple opportunities to receive training in the learning management system, and pedagogy of online learning – these opportunities are presented at various times throughout the year at events such as fall/spring annual faculty meetings, Brown Bag workshops, webinars, and scheduled training sessions. Once an instructor has been identified to develop an online course, they are given access to a set of web-based resources that cover a broad range of topics on online pedagogy, use of instructional technologies and learning management system tutorials. Throughout the online course development, the instructor receives direct support and guidance from their assigned instructional designer on variety of online learning related topics.

(ii) Principles of best practice for teaching in a distance education format shall be developed and maintained by the faculty.

The JHU-EP CLDT has created a series of online teaching strategies resources. These resources are based on best practices from research and other related sources. All new online course instructors are encouraged to review these resources prior to teaching their first online course. New online instructors also receive one-on-one coaching from instructional designers and peer mentors.

(iii) An institution shall provide faculty support services specifically related to teaching through a distance education format.

The JHU-EP CLDT provides a wide range of faculty support services for instructors engaged in online instruction. Instructors have access to multi-media specialists, instructional technologists, instructional designers, a training specialist and other institutional support staff to assist them in their role as online instructors. Some of the services provided include instructional technology training, course design support, learning management system training, course production support (i.e., recording studio), video production, and a faculty support help line and email.

(d) An institution shall ensure that appropriate learning resources are available to students including appropriate and adequate library services and resources.

The students will have online access to the Milton S. Eisenhower Library on the Homewood campus, which is ranked as one of the nation's foremost facilities for research and scholarship. Its collection of more than three million bound volumes, several million microfilms, and more than 13,000 journal subscriptions has been assembled to support the academic efforts of the University. The interlibrary loan department makes the research collection of the nation available to faculty and students. The library also provides easy access to a wide selection of electronic information resources, including the library's online catalog, and numerous electronic abstracting and indexing tools. Many of the databases are accessible remotely. Librarians help students electronically and the library maintains an extensive web site to take visitors through all of its services and materials.

(e) Students and Student Services

(i) A distance education program shall provide students with clear, complete, and timely information on the curriculum, course and degree requirements, nature of faculty/student interaction, assumptions about technology competence and skills, technical equipment requirements, learning management system, availability of academic support services and financial aid resources, and costs and payment policies.

JHU-EP maintains numerous web-based resources to inform prospective students on the information they may need as an online student. These resources include: JHU-EP main website (http://ep.jhu.edu); JHU-EP online catalog, which includes detailed programmatic information, academic support services, financial aid, costs, policies, etc. and specific information for online learning (refer to https://ep.jhu.edu/files/2015-2016-catalog.pdf). As new online students are admitted and enrolled, they receive timely emails with important information to help them prepare to become an online student. These emails include information on how to create their JHU login account for the course management systems, technical requirements, and available academic support services. JHU-EP also offers a New Online Student Orientation course.

(ii) Enrolled students shall have reasonable and adequate access to the range of student services to support their distance education activities.

JHU-EP online students have access to the following academic support services:

Academic Advising. Students are assigned an advisor when accepted. Students in most master's degree programs are requested to submit a program planning form for their advisor's approval. Students work individually with the advisor to develop a course of study that meets the requirements of the program and the career goals of the student. Courses that deviate from the program plan and have not been approved by an adviser may not count toward degree requirements.

Library Services. Students have online access to the Milton S. Eisenhower Library on the Homewood campus, ranked as one of the nation's foremost facilities for research and scholarship. The interlibrary loan department allows students access to resources at any other university in the nation. The library also provides easy access to a wide selection of electronic information resources, including the library's online catalog, and numerous electronic abstracting and indexing tools. Many of the databases are accessible remotely. Librarians are available to assist students remotely and the library maintains an extensive web site to take visitors through all its services and materials.

Services with Students with Disabilities. The Johns Hopkins University is committed to making all academic programs, support services, and facilities accessible to qualified individuals. Students with disabilities who require reasonable accommodations can contact the JHU-EP Disability Services Administrator.

Johns Hopkins Student Assistance Program. The Johns Hopkins Student Assistance Program (JHSAP) is a professional counseling service that can assist students with managing problems of daily living. Stress, personal problems, family conflict, and life challenges can affect the academic progress of students. JHSAP focuses on problem solving through short-term counseling. Accessing the service is a simple matter of a phone call to arrange an appointment with a counselor. Online students may call a phone number for consultation and will be directed to the appropriate resource or office. JHSAP services are completely confidential. The program operates under State and Federal confidentiality legislation and is HIPAA compliant.

Transcript Access. Official transcripts will be mailed upon written request of the student at no charge.

Student ID JCard. The JCard serves as the student's University identification card. This card is mailed to the home address of every registered student. The JCard acts as the university library card, which enables students to check out books from the Homewood Eisenhower Library or at any of the campus center libraries, and provides access to many computer laboratories.

(iii) Accepted students shall have the background, knowledge, and technical skills needed to undertake a distance education program.

All accepted online students are required to have met the admission requirements stated for the degree program. New online students are strongly encouraged to complete the "New Online Student Orientation" course prior to beginning their first online course. This course covers a broad range of topics on how to be a successful online student such as: online student learning expectations, how to access the library, how to conduct online research, and how to participate in online discussions.

(iv.) Advertising, recruiting, and admissions materials shall clearly and accurately represent the program and the services available.

All relevant program information is keep up to date on the JHU-EP web site (http://ep.jhu.edu).

(f). Commitment to Support

(i) Policies for faculty evaluation shall include appropriate consideration of teaching and scholarly activities related to distance education programs.

Faculty teaching online courses are strongly encouraged to participate in, minimally, one to two professional development opportunities annually to improve their online teaching skills.

(ii) An institution shall demonstrate a commitment to ongoing support, both financial and technical, and to continuation of a program for a period sufficient to enable students to complete a degree or certificate.

Please see sections J and K of the proposal.

(g) Evaluation and Assessment

(i) An institution shall evaluate a distance education program's educational effectiveness, including assessments of student learning outcomes, student retention, student and faculty satisfaction, and cost-effectiveness.

Please see Section L of the main body of the proposal.

(ii) An institution shall demonstrate an evidence-based approach to best online teaching practices.

The JHU-EP CLDT instructional design and faculty support staff continually participates in professional development activities to keep abreast of evidence-based approaches to online teaching practices. These online teaching practices are then incorporated into the new online instructor training sessions.

(iii) An institution shall provide for assessment and documentation of student achievement of learning outcomes in a distance education program.

As part of the online course design process, course assessments are required to be aligned with stated course learning outcomes. The JHU-EP program, where appropriate, incorporates authentic-based learning assessments that demonstrate student's application of learned concepts.

Appendix C
Faculty

First Name	Last Name	Terminal Degree	Field	Academic Title/Rank	Status	Courses taught
Jacqueline	Akinpelu	PhD	Mathematical Sciences	APL Staff	Part-time	625.423, 625.721, 625.722
Mostafa	Aminzadeh	PhD	Statistics	Professor, Towson U.	Part-time	625.725, 625.726
Barry	Bodt	PhD	Statistics	U.S. Army Research Lab	Part-time	625.403, 625.462
Raouf	Boules	PhD	Mathematics	Professor, Towson U.	Part-time	625.420
Beryl	Castello	PhD	Applied Mathematics and Statistics	Senior Lecturer, JHU WSE	Full-time	625.414, 625.415, 625.416
James	D'Archangelo	PhD	Mathematics	Professor, US Naval Academy	Part-time	625.250, 625.251
Cleon	Davis	PhD	Electrical and Computer Eng	APL Staff	Part-time	625.201, 625.490
Jason	Devinney	PhD	Mathematical Sciences	Center for Computing Sciences	Part-time	625.436
Ronald	Farris	MS	Applied Physics	APL Staff (ret.)	Part-time	625.404, 625.717, 625.718
Mark	Fleischer	PhD	Operations Research	U.S. Patent and Trademark Office	Part-time	625.438
Matthew	Henry	PhD	Systems and Information Engineering	APL Staff	Part-time	625.741
Stacy	Hill	DSc	Systems Science	APL Staff	Part-time	625.401, 625.728, 625.744
Hsien Ming	Hung	PhD	Statistics	U.S. FDA Staff	Part-time	625.461, 625.463
James	Kuttler	PhD	Applied Mathematics	APL Staff (ret.)	Part-time	625.710

First Name	Last Name	Terminal Degree	Field	Academic Title/Rank	Status	Courses taught
Paul	Massell	PhD	Mathematics	U.S. Census Bureau	Part-time	625.468
Christine	Nickel	PhD	Applied Mathematics and Statistics	Instructor	Part-time	625.464, 625.480, 625.734
Moustapha	Pemy	PhD	Mathematics	Professor, Towson U.	Part-time	625.441, 625.495, 625.714
Daniel	Rio	PhD	Biomedical Engineering & Medical Physics	U.S. NIH	Part-time	625.409
Cetin	Savkli	PhD	Theoretical Physics	APL Staff	Part-time	625.403
David	Schug	PhD	Applied Mathematics	Patuxent River Naval Air Station	Part-time	625.403
Tatyana	Sorokina	PhD	Mathematics	Assoc. Professor, Towson U.	Part-time	625.411, 625.487
James	Spall	PhD	Systems Engineering	Chair of ACM; APL Staff; Research Professor, JHU	Part-time	625.743
Leonid	Stern	DSc	Mathematics	Professor, Towson U.	Part-time	625.402, 625.485
Treven	Wall	PhD	Mathematics	APL Staff	Part-time	625.409
Sue Jane	Wang	PhD	Biometry	U.S. FDA Staff	Part-time	625.403
Michael	Weisman	PhD	Applied Mathematics	APL Staff	Part-time	625.740
James M.	Whisnant	MS	Applied Mathematics	APL Staff	Part-time	625.417, 625.703, 625.718
Thomas	Woolf	PhD	Biophysics	Professor, JHU SOM	Part-time	625.260. 625.492

Appendix D
Financial Information

TABLE 1: RESOURCES	2016-17	2017-18	2018-19	2019-20	2019-21
1. Reallocated Funds	$0	$0	$0	$0	$0
2. Tuition/Fee Revenue (c + g below)	$1,384,803	$1,528,190	$1,639,318	$1,757,354	$1,836,435
a. Number of F/T Students	0	0	0	0	0
b. Annual Tuition/Fee Rate	NA	NA	NA	NA	NA
c. Total F/T Revenue (a x b)	$0	$0	$0	$0	$0
d. Number of P/T Student Enrollments	357	377	387	397	397
e. Credit Hour Rate	$1,293	$1,351	$1,412	$1,476	$1,542
f. Credits Per Course	3	3	3	3	3
g. Total P/T Revenue (d x e x f)	$1,384,803	$1,528,190	$1,639,318	$1,757,354	$1,836,435
3. Grants, Contracts & Other Ext Sources	$0	$0	$0	$0	$0
4. Other Sources	$0	$0	$0	$0	$0
TOTAL (Add 1 – 4)	**$1,384,803**	**$1,528,190**	**$1,639,318**	**$1,757,354**	**$1,836,435**

Resources Narrative

1. Reallocated Funds: The proposed program will be funded by tuition revenue, and will make no use of reallocated funds.
2. Tuition and Fee Revenue: The enrollment projections in Table 1 are a reasonable estimate based on growth of other JHU-EP master's degree programs when moved online. The Master of Science in Applied and Computational Mathematics is a part-time degree program, so no full-time students are expected. JHU-EP students take, on average, three 3-credit courses per year, which is reflected in the "Annual Credit Hour Rate."
3. Grants and Contracts: No grants or contacts are required for the successful implementation of the program.
4. Other Sources: The program does not expect any funding from other source.

***NOTE**: The resources and expenditures data for the Master of Science in Applied and Computational Mathematics is combined with those for the Post-Master's Certificate in Applied and Computational Mathematics, as they share the same courses, and all resources and expenditures in these programs are course-based.*

TABLE 2: EXPENDITURES	2016-17	2017-18	2018-19	2019-20	2019-21
1. Faculty (b + c below)	$314,986	$350,494	$367,434	$384,912	$392,611
a. # Sections offered	31	34	35	36	36
b. Total Salary	$291,654	$324,531	$340,217	$356,400	$363,528
c. Total Benefits	$23,332	$25,963	$27,217	$28,512	$29,082
2. Admin. Staff (b + c below)	$52,380	$52,787	$53,203	$53,627	$54,060
a. # FTE	0.75	0.75	0.75	0.75	0.75
b. Total Salary	$50,870	$51,247	$51,632	$52,025	$52,425
c. Total Benefits	$1,510	$1,540	$1,571	$1,602	$1,634
3. Support Staff (b + c below)	$19,691	$20,085	$20,486	$20,896	$21,314
a. # FTE	0.25	0.25	0.25	0.25	0.25
b. Total Salary	$14,640	$14,933	$15,231	$15,536	$15,847
c. Total Benefits	$5,051	$5,152	$5,255	$5,360	$5,467
4. Equipment	$0	$0	$0	$0	$0
5. Library	$0	$0	$0	$0	$0
6. New or Renovated Space	$0	$0	$0	$0	$0
7. Other Expenses	$364,747	$396,736	$419,478	$443,226	$456,523
TOTAL (Add 1 – 7)	**$751,804**	**$820,102**	**$860,601**	**$902,662**	**$924,507**

Expenditures Narrative

1. Faculty: The Engineering for Professionals lecturers are paid $8,495 (for FY15) per course taught or developed. This was used as the base rate. For years 1 – 5, an additional 2% was added to the salary rate. The fringe rate is estimated at 8%.
2. Administrative Staff: Includes pro-rated salary for high-level program managerial support.
3. Support Staff: Includes pro-rated salaries for F/T Instructional Designers to assist in developing online courses.
4. Equipment: No direct equipment costs are identified.
5. Library: Existing library facilities are sufficient to meet the needs of the program.
6. New or Renovated Space: No new or renovated space will be needed.
7. Other Expenses: Indirect program costs (per enrollment) are provided here.