AN M&S-BASED TRANSPORTATION ENGINEERING PROGRAM

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Abstract. What concepts should be covered in a Transportation Engineering program in modeling and simulation (M&S)? While many professionals and scientists agree on the need for an M&S program, there is no established program for students to learn the nuts and bolts of M&S, for educators to teach, and for employees to evaluate the graduates of the program for competency and comprehension, leaving aside, for the time being, qualification and certification requirements. This paper presents a set of courses in Transportation Engineering which will qualify students for a degree program or specialization in M&S. While students in science may also take advantage of a similar program, the course work suggested here is intended for M&S-based Transportation Engineering.

1 Introduction

Many programs established in engineering are the product of a marriage between science and mathematics. For example, the Electrical Engineering program emerged from a combination of physics and math when people found more practical ways of applying them that didn't require a detailed solution every time. The same was true for Computer Engineering which emerged from the application of math and Electrical Engineering.

Transportation Engineering is currently an area of specialization in Civil Engineering and has a good chance to be recognized as an independent field due to its need. This field concentrates in the issues involved with the design, planning, and safe operation of highways, waterways, and airways as well as the issues involved with handling traffic under normal and emergency conditions, such as the bottlenecks created during the rerouting/detouring and/or mass evacuations during emergencies. The range of applications for this field vary from bike path designs to airport runway designs to transit modes of operation from pedestrians to rail to air.

Determining the accuracy, financial viability, and utility of a new transportation project depends increasingly on computational modeling and simulation. M&S, being an inexpensive and safe method for designing for unavailable physical circumstances, is used to provide details for design issues by verifying and validating the models of the design and analyzing the results obtained from the model. No design is complete unless its accuracy has been verified by simulation.

M&S may be considered as a field in applied math using engineering and computer science concepts for development and testing of the models. Due to the vast opportunity for application areas of M&S in both science and engineering, establishment of an M&S program is needed in both areas. This program is heavily dependent on math, software engineering, and the student's field of specialization. Since M&S applications can be in any field, the program should emphasize the utilization of the concepts in the student's area of specialization [3,4].

Recognizing the importance of M&S, the 2006 NSF Blue Ribbon Panel [1] reported that continued advancement in the M&S field is critical for resolving a multitude of scientific and technological problems facing the United States. In addition, the White House American Competitive Initiative [2] report identified M&S as a key enabling technology of the 21st century. With pressure to cut costs while increasing technological development, researchers are turning more and more to M&S in order to increase the development and understanding of the systems and their interactions.

Due to many potential applications of M&S in transportation, much attention has been focused recently on what should be a proper M&S educational program in transportation engineering and what qualifications the graduates of this program should posses for a career in M&S. This has motivated the educators to focus on developing a model curriculum for Bachelor of Science (B.S.) and/or Master of Science (M.S.) degrees in M&S-based Transportation Engineering to assist engineering schools in establishing a new program in this field.

However, defining a curriculum for a degree program in computational modeling and simulation in Transportation Engineering is difficult. This is because 1) M&S is usually regarded as a fragmented subject with components in a range of disciplines but with a wide range of applications, and 2) Transportation Engineering is an area of specialization in Civil Engineering. The following is a first draft of the proposed elements for a program in M&S-based Transportation Engineering.

2 Elements of a Program

To The ABET accredited bachelor programs in engineering [5] include basic math, science, general education, communication and interpersonal skills, out-of-major area courses followed by the discipline related required and elective technical courses. The average total number of the credit hours is an engineering program is 128. In order an M&S based transportation engineering to be an accredited program, it should follow the similar number of credit hours and requirements in engineering in addition to the M&S requirements.

2.1 Basic Math Requirement

About seventeen credit hours of basic math will include analytical geometry, calculus, and differential equations. The topics covered in these courses are usually packed into four-to-five courses as calculus I, II, III, and differential equations. The concepts covered in these courses usually include:

Calculus I:

Functions of one variable, limits, differentiation, exponential, trigonometric and inverse trigonometric functions, maximum-minimum, and basic integration theory with some applications.

Calculus II:

Integration theory, application of definite integrals, basics of ordinary differential equations, series, Taylor series.

Calculus III:

Vectors and surfaces, parametric equations and motion, functions of multivariable, partial differentiation, maximum-minimum, LaGrange multipliers, multiple integration, vector fields, path integrals, Green's Theorem, and applications.

Differential Equations:

First and second order methods for ordinary differential equations including separable, linear, Laplace transform, linear systems, and some applications.

2.2 Basic Science Requirements

About 15 to 18 credit hours of fundamental science will be necessary in the curriculum. This number of credit hours will satisfy the science knowledge required by ABET. These courses are Physics and Chemistry.

The breakdown is usually about 12 credit hours of general physics and 4 to 6 credit hours of general chemistry. This number of credit hours may be packaged into three to four physics courses and one or two chemistry courses. The topics in the physics courses will include mechanics, fluids, wave motion, heat, electricity, magnetism, optics, relativity, quantum mechanics, atoms, and nuclei. A one credit hour lab course will accompany the physics courses to reinforce the theoretical concepts learned in those courses.

The topics in chemistry may include state of matter and kinetic molecular theory, atomic theory and structure, chemical bonding and molecular structure, kinetics and equilibrium, acid-base and oxidation-reduction reactions.

2.3 Basic Computer Science Requirement

In order to design a model for a project, simulate and analyze the results successfully, and plan adequately for its execution, basic knowledge of computer programming, data representation, and data analysis are required.

2.3.1 Computer Programming

M&S relies heavily on computer processing and analysis. Therefore, it is highly recommended that students take at least one course in programming using a high level programming language, one course in numerical analysis, and one course in data structure. The contents of the programming course may include introduction to a programming language, problem solving and problem analysis using computers, specification and development of an algorithm, program design and implementation, data type and data representation, and processing of the algorithms in a computer system. A brief introduction to computer architecture and peripheral devices will also be helpful.

2.3.2 Numerical Analysis
Simulation is performed as an algorithm on a hardware platform. All the operations described in an algorithm are processed by the arithmetic and logic unit (ALU). Therefore, it is important that students have good knowledge of the concepts such as computer arithmetic, solution of a set of linear equations, interpolations and approximation using polynomial functions, extrapolations, and numerical differentiations and integrations. The basic integration algorithms may include Euler, Runge-Kutta, and multistep methods for ordinary differential equations (ODE) and initial value problems. The course may be taken from the Computer Science department or the Math department. Mathlab is currently the language of choice for programming of these concepts even though C and C++ programming languages are also in use for some time.

2.3.3 Data Structure
A basic course for representation, processing, and analysis of data is recommended. This course will cover concepts such as arrays, stacks, queues, and linked lists, enumerations, iterations, efficient use of memory, recursion, specification of lists, sorting algorithms, tree structures, binary search, trees and heaps, tables and graphs, graph algorithms, and execution time of algorithms.

3 Upper Level Math Courses

Based Five upper level math courses are recommended as the core math requirement in the curriculum. They should be taken from the following courses with recommendation of the student's academic advisor. The courses are: *Probability Theory*, *Linear System Analysis and Design*, *Applied Linear Algebra*, *Introduction to Statistics for Engineers*, *Statistical Methods for Transportation Analysis*, *Stochastic and Random Processes,* and *Operation Research.* Some of the courses may be combined. For example the contents of *Probability Theory*, *Introduction to* S*tatistics for Engineers*, *Statistical Methods for Transportation Analysis*, *Stochastic and Random Processes,* and *Operation Research* may be packed into three courses.

3.1 Linear System Analysis and Design
The content of this course provides an in-depth introduction to the theory of linear systems. Major topics will include the concept of state-variable models of both time-varying and time-invariant continuous and discrete-time systems, linear state feedback, controllability and pole placement design, observability and observer design, and stability and realization theory**.** The objectives here are:

- To determine the controllability, observability, and stability of state variable systems.
- To use state variable feedback to place systems poles.
- To design state variable observers and controllers.
- To set up and solve least squares problems.
- To simulate state variable systems using computer-based tools.

3.2 Applied Linear Algebra
This course is to provide a high level of knowledge on linear system analysis and design. Depending on the level of offering of the course, the following topics may be taught more in-depth:

- Matrices and vectors
- Gaussian elimination
- Matrix inverse (Gauss Jordan elimination)
- Superposition Principle, Fundamental Theorem of Linear Algebra, Graphs and Incidence Matrices, Inner Products
- Inner Products on Function Spaces, Orthogonal Vectors
- Complex Numbers
- Complex Vector Spaces and Inner Products
- Minimization and Least Squares Approximation
- Polynomial Approximation and Interpolation
- Least Squares Approximation in Function Spaces
- Linearity (Linear Functions, Linear Operators)
- Space of Linear Functions
- Eigenvalues and Eigenvectors
- Diagonalization

- Optimization, Singular Values
- Linear Dynamical Systems
- Iteration of Linear Systems and Stability

3.4 Probability and Statistics for Engineers

Three courses from the following courses in probability and statistics are recommended. These courses cover fundamental and advanced concepts appropriate for the degree in M&S-based Transportation Engineering. To cover the broad topics in probability and statistics, it is suggested that the contents of the following five course to be packed into three courses.

3.4.1 Probability Theory and Introduction to Random Processes

This course provides knowledge on random experiment models, random variables, functions of random variables, and introduction to random processes. The objectives for the students in this course are to be able to describe:

- The elements of the random experiment model
- Nondeterministic phenomena using the random experiment model.
- The concept of random variable and to use the probability distribution and density function associated with the random variable in calculating probabilities of events.
- The concept of a random variable to that of a random process as an indexed set of random variables.

3.4.2 Introductory Statistics Course

This course provides the fundamental concepts of data analysis required to prepare students for advanced topics like acceptance sampling, statistical process control, reliability, and design of experiments. The materials covered in the introductory course include probability distributions (mean; variance; discrete and continuous normal, Poisson, and Binomial; Hypothesis testing (confidence intervals, student's t-distribution, difference between two means); Goodness of Fit Tests (Chi-square test); regression analysis (least squares, multiple linear and nonlinear, analysis of errors, and use of statistical software: SPSS.

3.4.3 Statistical Methods for Transportation Analysis

The topics covered in this course include statistical inference, random variables and vectors, estimation of distribution parameters, uncertainty propagation, conditional distributions, second-moment analysis, system reliability, Poisson and Markov processes, population comparisons, quantitative analysis of uncertainty and risk for engineering applications, decision analysis, and risk-based decisions. Examples are taken from real-world applications in transportation engineering.

3.4.4 Stochastic and Random Processes

In simulation studies, inferences or predictions concerning the behavior of the system under study are to be made based on experimental results obtained from the simulation. The following topics will be appropriate in this respect for the students: probability space, multivariate distributions, conditional expectations. discrete and continuous time random processes, decision analysis and stochastic models, risk and uncertainty in decision making, queuing theory, Markov processes, dynamic programming, Monte Carlo simulation of dynamic systems, applications of linear and non-linear optimization techniques in some real application, sensitivity analysis, multicriteria optimization, and search techniques.

3.4.5 Introduction to Operation Research

The operation research (OR) course is to provide an introduction to some of the more useful OR models that exploit basic concepts and principles of probability and statistics. Although the course is organized around mathematical models and methods, the focus is on practical solutions to real operational problems; sufficient theory is provided to develop understanding of fundamental results. Topics may vary. They may be selected from the fields of Markov chains, queuing theory, decision theory, Bayesian networks, reliability and maintenance, activity networks, Markov decision processes, and inventory theory. In addition, the course will include applications of deterministic operations research techniques, linear programming, transportation problems, assignment problems, integer programming, model formulation, and problem solving using computer tools.

4 Out of Department Courses

These courses will include *Engineering Economy for Transportation Engineers* and two or three courses from other departments. The idea behind the first course is to provide the students with methods of economic comparisons of engineering alternatives. These are concepts and techniques of analysis useful in evaluating the worth of systems, products, and services in relation to their costs. This course will enable students to answer questions such as:

- Which transportation projects are worthwhile?
- Which projects should have a higher priority?
- How should the project be designed?

Students specializing in M&S-based Transportation Engineering need to have a breadth of knowledge on other disciplines in order to apply their expertise. At least nine credit hours should be taken from other departments to build the basic foundation in various application areas. A student, with the help of his/her advisor, may select these courses from the following areas: Electrical Engineering, Industrial Engineering, Mechanical Engineering, Civil Engineering, Chemical Engineering, and Engineering Mechanics. The foundation courses that are specially recommended are from the Civil and Industrial Engineering departments.

5 M&S Courses

Students specializing in M&S-based Transportation Engineering are recommended to take at least two courses in M&S and its applications in Transportation Engineering. These course are continuous time system simulation, discrete time system simulation, and advanced topics in M&S.

5.1 Continuous Time System Simulation

The contents of continuous time simulation usually cover advanced numerical techniques for solving ordinary differential equations, truncation errors, stability including absolute stability, estimation and control of error, stiff problems, numerical methods for partial differential equations, classification (parabolic, elliptic, and hyperbolic Crank-Nicolson and backward differences), treatment of boundary conditions, material discontinuities, nonlinear equations, coupled systems of equations, stability method of lines, numerical dispersion, Poisson's equation and numerical methods, constructing difference formulas and other approximation methods, characteristics and hyperbolic considerations, and solving the resulting system of equations.

5.2 Discrete System Simulation

Analysis and design of many complex systems requires knowledge of discrete event modeling and simulation. The goal here is to reproduce the activities that entities engage in and, thereby, learn something about the behavior and performance potential of the system. This is achieved by defining the states of the system and constructing activities that move it from one state to another. The following topics are suggested for the contents of this course: modeling and simulation principles and concepts, approaches to computer simulation models with special emphasis on discrete event simulation, discrete system model building, model verification and validation, data integration, modeling methodologies, advances and practices, and their applications to engineering problems

6 General Education

The General Education (GenEd) requirements describe the core courses all students must take in order to graduate. They are an important component of students' education at any institution. Besides specializing in a major and training for a career, students should become familiar with some of the many rapidly changing disciplines. Through these requirements, the students:

- Expand their historical, aesthetic, cultural, literary, scientific, and philosophical perspectives.
- Improve critical and analytical thinking.
- Learn skills in finding, managing, and communicating knowledge.

About 15 to 18 credit hours should be taken from the arts, humanities, social science, natural science and technology, social and behavior sciences, and advanced composition.

6.1 Business Requirements

6.1.1 Communication and Interpersonal Skills
It is very important the graduates of the program are able to assume a leadership position and be able to present their scientific results in a clear and comprehensive manner both orally and in writing. Students taking this course should be able to:

- Write clearly and in a style appropriate to purpose, e.g., progress reports, published documents, and capstone design thesis, construct coherent arguments, and articulate ideas clearly to a range of audiences, formally and informally through a variety of techniques.
- Defend research outcomes at seminars constructively.
- Contribute to promoting the public understanding of one's research field.
- Effectively support the learning of others when involved in teaching, mentoring or demonstrating activities.

6.1.2 Project Management for Transportation Engineers
Project management skills are needed for the students to plan, implement, and evaluate each project. The methodology described in this one credit hour course will enable the students to effectively manage transportation and public work projects. The course will cover the various stages of project management including planning, predesign, design, construction, and maintenance and operations. The objectives of this course are for the students to learn about project organization, planning, scheduling, budgeting, accounting, quality assurance, contracts, managing contractors, permits and agreements, leadership, team building, and negotiation. Diverse, real-world examples to illustrate project management concepts should be included in the course. A typical course will cover the following issues:

- Project parameters--controlling quality, quantity, time, and cost
- Setting performance standards
- Managing resources
- Implementing the plan
- Delegating and controlling work processes
- Completion and evaluation of the project
- Roles/responsibilities
- Project authorization
- Environmental agreements/permits
- Contracts
- Contractor selection and management
- Relationships with stakeholders
- Plans, specifications, and estimates (PS&E)
- Quality assurance
- Inspection
- project documentation
- Accounting
- Labor compliance
- Scheduling
- Claims/change orders
- Safety
- Operations/maintenance responsibilities

6.1.3 Personal Effectiveness, Networking, and Teamworking
Continuing education is very important after graduation.. In this course, students demonstrate willingness and ability to learn and acquire knowledge to:

- Be creative, innovative and original in one's approach to research
- Demonstrate flexibility and open-mindedness
- Demonstrate self-awareness and the ability to identify one’s own training needs
- Demonstrate self-discipline, motivation, and thoroughness
- Recognize boundaries and draw upon/use sources of support as appropriate
- Show initiative, work independently, and be self-reliant

Graduates need to develop and maintain co-operative networks and working relationships with supervisors, colleagues, and peers, within the institution and the wider research and development community. They need to understand one's behaviors and impact on others when working in and contributing to the success of formal and informal teams. Students need to listen, give and receive feedback, and respond perceptively to others.

The credit hours to meet the business requirement are six for technical writing and interpersonal skills, one for *project management and leadership development*, and one for *ethics in engineering*.

7 Core Courses in Transportation Engineering

The core required and elective courses include:

- Transport Data Collection & Analysis
- Transport Policy & Planning
- Environment and Safety in Transport
- Systems and OR Methods in Transport
- Transport Sector Project Formulation
- Traffic Management & Intelligent Transport Systems
- Transport Economics & Society
- Urban Transport Planning
- Public Transport Planning & Operations
- Transport Demand Modeling and Analysis
- Transport Project Appraisal
- Transport System Planning & Design
- Rural & Non motorized Transport

Additional elective courses that may be taken are:

- Highway Planning and Management
- Freight Transport & Logistics
- Advanced Traffic Engineering
- Human Resources Management

The following courses may be considered by those who would like to specialize in traffic engineering:

- Geotechnics
- Traffic Engineering Theory
- Geometric & Pavement Design
- Highway Construction Techniques
- Highway Planning and Management
- Highway Maintenance and Rehabilitation
- Traffic & Highway Capacity Design
- Bridge Engineering
- Transportation System Planning & Design
- Advanced Traffic Engineering
- Rural & Non motorized Transport
- Human Resources Management

It is recommended that a student, with his/her advisor's help, select a set of courses from the above required and elective list to meet the graduation requirements of 128 credit hours. It is also highly recommended that three credit hours be allocated for undergraduate research experience in the student's area of specialization.

8 Multidisciplinary Capstone Project

A team-based project applying principles of M&S for highway and traffic engineering and transportation planning is very important. Such a team-based project would, in general, require the collection of data, analysis, and conclusions for a transportation problem or project. The students would be required to undertake some reference work, meet relevant officials both from within the university and from industry and consult the required design standards, policy, or strategic plans that may be appropriate for the project. Teams would be required to present and defend their work to an evaluation committee that will include representatives from the university and industry. The final report should be comprehensive including all technical, analytical, social and economic dimensions of the given project as well as the simulation results.

9 Conclusions

The first version of a model curriculum for an undergraduate degree in M&S-based Transportation Engineering is proposed. We hope this proposal can be used as a basis for wide-ranging discussions that will lead to a published version sponsored by interested professional bodies such as ASCE, SCS, and SIM SUMMIT.

10 References

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