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# A NEW M&S ENGINEERING PROGRAM WITH A BASE IN COMPUTER ENGINEERING

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## ABSTRACT

The reality of the current academic climate, in particular faced with drops in enrollment over the next decade as a result from drops in birth rates, is forcing hard choices for small programs such as the Modeling & Simulation Engineering (M&SE) program at Old Dominion University (ODU). The quality of the program and its benefit to its constituents do not offset the impracticality of continuing such programs. Two primary options for such programs are closure or consolidation. ODU decided on the latter course of action for M&SE. Due to the computational nature of the existing program, a decision was made to place M&SE as a major under the Computer Engineering degree. This paper presents the justification for this decision and the resulting curriculum and the hard decisions made to allow it to fit under computer engineering. A discussion of feedback from constituents such as the industrial advisory board for the existing M&SE program is included.

## 1 INTRODUCTION

The current academic climate makes it hard to sustain niche programs. Universities are anticipating a large drop in enrollment starting in 2025 due to drastic drops in birth rates following the recession in 2007. (Kline 2019) Numerous universities have started to announce the elimination or consolidation of degrees and departments, starting prior to COVID-19. For the sustainability of such programs, no matter the strength or merits of the program, it becomes beneficial to align these programs with well-established programs. This allows the sharing of resources to include personnel and available course offerings. However, this only makes sense if it benefits both programs.

Modeling and simulation (M&S) engineering as an undergraduate program falls under this category. While several graduate programs exist, Old Dominion University (ODU) chose to create the first undergraduate program in 2010. The program has graduated very high quality students who have gone onto top tier graduate programs and high paying careers both in industry and government. Employers have greatly valued the characteristics of the graduates making them highly sought after, often receiving multiple job offers very early in their senior year.

However, the program has suffered the common pitfalls of niche programs, primarily in the form of insufficient advertising/recruitment to properly educate the community about the program. This results in constantly worrying about state requirements for a program, in this case the State Council of Higher Education for Virginia (SCHEV) requires enrollment of 36 full-time equivalents (FTEs) and 9 graduates per year (the existing MSIM program at ODU is 32.9 and 9.2) (State Council of Higher Education for Virginia 2021). But the university recognized the merits of the program and requested a proposal to

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enable continuance in a viable form. Circumstances required some hard decisions to enable the continuance of Old Dominion University's undergraduate program in Modeling and Simulation Engineering, though in a new form. This required identification of a suitable "home" for the program followed by a restructuring of the curriculum. The new curriculum must meet the needs of the new home while maintaining the rigor of the original degree to provide strong M&S practitioners that are of value to the community.

The "home" for M&S engineering was determined to be within the existing computer engineering degree at Old Dominion University, an established program that already exceeds the SCHEV requirements, removing the SCHEV concerns. This takes advantage of the strong computational engineering focus of the existing program to benefit the computer engineering program while providing the M&S engineering students a stronger grounding in engineering with a clear application domain. The result is that students get a computer engineering degree with a M&S engineering major. The curriculum was then developed so that graduates satisfy computer engineering requirements while providing a depth of knowledge in M&S. Students entering the university in the fall of 2021 may take advantage of the new curriculum.

This paper presents the new undergraduate major in M&S engineering. It highlights the benefits to both computer engineering and modeling and simulation. The curriculum structure is defined with the decision process leading to the final product. Initial feedback obtained from ODU's existing M&S industrial advisor board is provided.

## 2 BACKGROUND

### 2.1 M&S Engineering Undergraduate Degree

#### 2.1.1 History

Old Dominion University has been one of the early leaders in developing M&S academic programs. Master's Degree programs were started in 1998 and a Doctoral Degree program was established in 2000. Then in 2010, an undergraduate degree program was initiated. This program awards the Bachelor of Science Degree in Modeling and Simulation Engineering (BS-M&SE). Simultaneously, the Department of Modeling, Simulation and Visualization Engineering (MSVE) was established within the College of Engineering and Technology to administer all M&S academic programs. The first BS-M&SE degrees were awarded in May 2013 and the initial ABET accreditation visit for the program occurred in fall 2014. The establishment of an M&S academic department and the development of an undergraduate M&S program have been described in the literature. The department organization and its contribution to the overall mission of the university are described in (Mielke et al. 2011). The initial planning for the undergraduate program is described in (Leathrum and Mielke 2011), curriculum development is presented in (Leathrum and Mielke 2012), and preparation for the initial ABET accreditation review is presented in (McKenzie 2015) with complete ABET results in (McKenzie et al. 2015).

#### 2.1.2 Undergraduate Curriculum

The original undergraduate program presented in (Leathrum and Mielke 2012) was developed to not only prepare students as users of simulation, but also capable of developing the next generation of simulation technology. As such, a balance was made between M&S concepts, analysis (mathematics based), and software development, each weighted equally. That balance continues with considering continuous vs. discrete-event simulation, modeling vs. simulation vs. analysis, and use vs. development. As such, undergraduate students enter the workplace with a broader background than classic M&S graduate students.

Core course topics include:

- *M&S courses:* introduction to simulation, discrete-event simulation, continuous simulation, and engineering modeling
- *Mathematics based courses:* calculus, differential equations, probability and statistics, simulation analysis, and discrete structures
- *Software development based courses:* problem solving and programming, object-oriented programming, simulation software design, and computer graphics and visualization

This broad skillset is illustrated in the wide range of very successful capstone projects students have participated in, each with an external customer. Customers include NASA, the US Navy, Lockheed-Martin, Newport News Shipbuilding, and Eastern Virginia Medical School. The wide range of projects have pushed students to use a variety of simulation paradigms, software development techniques, and analyses. One area of weakness that arose in several projects was the ability to interface with hardware, in particular for trainers. Students had to learn the skill on their own to complete projects. This is of note considering the direction of the new curriculum presented here.

### 2.2 Computer Engineering Undergraduate Degree

The Bachelor of Science in Computer Engineering degree has been offered since 1985. The computer engineering program is designed to provide a broad engineering background and a comprehensive foundation in the technical principles underlying the computer area. The technical core consists of coursework from electrical engineering to address hardware aspects of computer engineering and coursework from computer science to address software aspects. The computer engineering core builds on the hardware description language tools introduced in the sophomore year to master the design, test and synthesis of advanced digital circuits. The program requires 128 credits (40 courses plus labs) and it has a built-in minor in Computer Science. The program has four technical electives that allow students to choose a concentration such as Computer Hardware Systems, Data Analytics Engineering, Computer Networks and Cybersecurity.

## 3 CURRICULUM RATIONALE

Once the decision to consolidate the M&S program within a well-established program was made, the set of programs available at ODU was considered. Looking at other universities that have an M&S presence at the undergraduate level, M&S normally resides in an industrial engineering program. At Old Dominion, the most natural equivalent would be in Engineering Management & Systems Engineering. The primary drawback with this option is the lack of an undergraduate degree as they only support a minor in engineering management.

Looking elsewhere, the next logical solution is computer engineering. Computer engineering was attractive for several reasons:

- Students would get a deeper understanding of potential application domains for simulation, analog circuits for continuous simulation and digital circuits for discrete event simulation.
- The original M&S curriculum placed a high emphasis on students being capable of simulation development. The students spend a significant amount of time understanding the software development process to include both application and simulation executive development. Computer engineering naturally supports the computational engineering aspect of M&S.
- Often student projects and research efforts encounter a need to interact with hardware. Example projects students have participated in include autonomous vehicles, driving simulators, and medical training simulators. This may involve developing hardware control, interfacing with hardware, or developing haptic devices. These hardware skills have to be learned outside the classroom. For that reason, students with a computer engineering

background, either coming from a community college or entering the graduate program from ODU's computer engineering program, tend to excel, the latter getting jobs at companies such as Google and MathWorks.

- A significant portion of the faculty more naturally fit computer engineering. The existing department, and prior to that the Virginia Modeling, Analysis and Simulation Center, were initiated by efforts from within Electrical and Computer Engineering with a core of faculty moving to the new department to support the effort. Thus there has always been a heavy computational flavor to the program.

Expanding on the first point, electronic circuit simulations are one of the earliest and most successful applications of computer-based simulation. Modern very large-scale integrated circuits (VLSI) contain hundreds of millions or billions of transistors and their manufacturing processes are prohibitively complex and expensive. A faulty integrated circuit (IC) product caused by design errors can easily spell financial disasters for IC manufacturers. Therefore, the correctness and performance of IC designs must be verified by electronic circuit simulations before its fabrication process starts. It was an obstacle in the history of IC industry that had to be overcome in order for the IC industry to survive and advance. As a result, a number of industry standard languages and environments were developed for circuit simulations, such as SPICE (Simulation Program with Integrated Circuit Emphasis), a general-purpose, open-source analog electronic circuit simulator, and VHDL (Very High Speed Integrated Circuit Hardware Description Language) simulators for digital and mixed-signal such as field-programmable gate arrays and integrated circuits. With these simulation tools, digital and analog circuit designs can be simulated and verified to an extremely high level of accuracy. Without circuit simulations, modern electronic devices such as personal computers and smartphones would not have been possible. Circuit simulation has always been a rich community for simulation, but historically there is little overlap with the classic M&S community, something that this program could address.

Thus, the decision was to develop a program that favored the simulation developer over the user. The curriculum should continue to give students a broader spectrum of the M&S process than industrial engineering programs. However, they should also be introduced to the breadth of the topic, delving into alternative application areas such as manufacturing and transportation.

## 4 CURRICULUM DESIGN

The reformation of the M&S curriculum under the umbrella of computer engineering presented the opportunity to revisit the structure of the curriculum. The new "home" of the curriculum allows the curriculum to be viewed through the lens of computational engineering rather than systems or industrial engineering. This allows the development of a computational skillset early in the academic sequence, and then to develop a simulationist on top of that foundation. It is also considered easier to introduce a simulationist with a computational foundation and a strong background in electrical and computer engineering to systems and industrial engineering concepts than vice versa. So if a student wishes to pursue the systems and industrial engineering approach to M&S, they can easily do so by pursuing a minor in engineering management or further graduate studies in M&S or systems engineering at ODU. In addition, should a student wish to pursue a deeper computational understanding of classical electrical and computer engineering by considering advances in circuit simulation, they could continue a graduate school path to do so, something the prior curriculum did not directly support.

### 4.1 Requirements

Any curriculum development comes with a set of requirements that must be met, often outside the core content of the program. This includes university requirements such as general education as well as discipline requirements such as meeting ABET requirements to achieve accreditation. The requirements relevant to satisfying a computer engineering degree are described.

- 25% common core. The State Council of Higher Education for Virginia (SCHEV) requires that a major within a degree must share at least 25% of the core.
- Discussions with electrical and computer engineering faculty emphasized the need to cover certain content outside of classical M&S, whether by inclusion of a course or integrating content into M&S courses. These topics included: circuit analysis, digital circuit design, linear systems, discrete time signal processing, and microcontrollers.
- Students must be capable of participating in computer engineering capstone projects.

While all reasonable requirements, each places a burden on the curriculum development requiring choices to be made on what content is necessary in the core. In addition, a goal was to follow the computer engineering curriculum as close as possible to make the M&S engineering program attractive to students. This included increasing the number of technical electives to give students freedom to explore.

### 4.2 Curriculum Description

Whereas the original M&S engineering curriculum provided a strong balance between M&S, mathematics, and software, the new curriculum must balance more components. In addition to the previous content areas, computer engineering and electrical engineering are now included. Figure 1 presents the core for both computer engineering and M&S engineering, highlighting the commonality. The course topics are color coded to illustrate the balance. Common engineering courses are not shown where mathematics (Calculus I and II and Differential Equations) are a focus along with the sciences (Physics and Chemistry).

Of note compared to the previous M&S based curriculum is the elimination of courses, an M&S intro course, a modeling course, and a simulation analysis course. The latter two will be offered as elective courses. The only content lost from the introduction course is Monte Carlo simulation. As the courses are further developed, space to include Monte Carlo simulation will be found as it is unacceptable for graduates not to experience the three main paradigms, discrete, continuous, and Monte Carlo.

The remainder of this section describes key courses in the new M&S engineering curriculum as developed under a computer engineering degree, focusing on how they benefit the curriculum, producing stronger students.

#### 4.2.1 Key M&S Courses

The green courses in Figure 1 constitute content carried forward from the previous curriculum. But the courses require modification to cover important content from eliminated courses. Modifications to the courses are described here with an emphasis on content added and ties to the computer engineering curriculum.

*Discrete System M&S:* This course is the most difficult to adapt to the new curriculum. The prior instantiation of this course introduced some basic modeling (queueing models and event graphs) and simple analysis (input modeling and output analysis, mostly using software tools), and then spent the bulk of time focusing on simulation concepts. Now the course becomes the primary repository of content for discrete modeling and simulation analysis. Students will have the opportunity to utilize electives to strengthen these areas, but not all students will choose that experience. A more in-depth modeling experience will include state automata and Petri Nets. But the inclusion of computer engineering students softens this blow as they will have already seen state automata in digital circuit design. In addition, examples are readily available from digital circuits. The analysis component will need to spend more time on theory, but most importantly this will now become the primary source of verification and validation (V&V) as well as the design of experiments. Covering V&V at an undergraduate level was already a challenge; now students will simply be introduced to the concept unless they take the analysis

elective course. It is anticipated that the analysis elective will be STRONGLY suggested for students to take based on employer feedback.

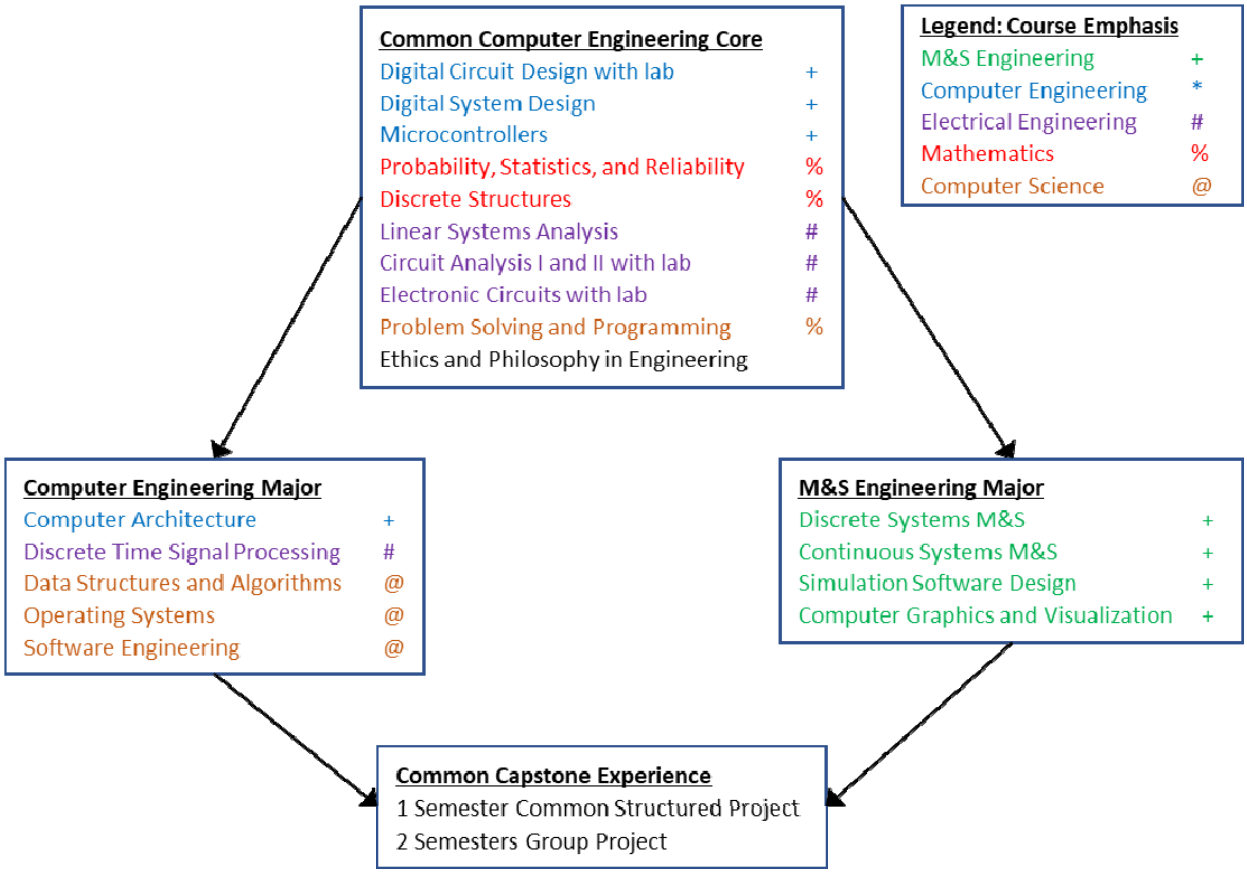


Figure 1: Core course topics for Computer Engineering and Modeling and Simulation Engineering.

*Continuous System M&S:* Development of this course has similar issues to the discrete course. In particular, modeling concepts covered in the modeling course must now be introduced here. Previously the course utilized block diagrams for modeling and then spent a significant time developing numerical techniques so students understood the implementation of the models as simulations. Now stock-flow diagrams and bond graphs will be introduced as well. In addition, this course must cover some core computer engineering content not covered since the students are not required to take the digital time signal processing course. They will get an introduction to signals to include sampling. The primary benefit of integrating with computer engineering courses is the presence of core electrical engineering courses. This presents the opportunity for considering much more complex systems for simulation. Previously examples frequently required beginning with teaching the concept being simulated. An example was a very simple RLC circuit. But now there are a rich set of examples from analog circuits from which to draw.

*Simulation Software Design:* This course generally builds on concepts from the discrete course, but now considering software implementations. Primary topics include data structures and algorithms (with a focus on supporting both simulation executive and application development), and software architecture. Course modifications result in this course becoming the sole source of object-oriented design, though this is not considered a heavy burden since the concept originated from simulation in the 1960's with the development of the language Simula. (Dahl and Nygaard 1966) The new curriculum also presents the

opportunity to introduce multithreading and coroutines as a method to implement the Process Interaction Worldview in a simulation executive. It can also take advantage of the requirement of digital circuit simulation to handle simultaneous events (a concept generally glossed over in the general M&S community) to justify its coverage at a software level. The largest burden actually becomes covering university requirements lost from eliminated courses.

*Computer Graphics and Visualization:* This course has the largest impact from the new curriculum. Like the simulation course, it must cover university requirements. But the biggest change is that while the continuous simulation course introduces signals, this course develops the depth covering digital image and signal processing basics such as sampling and discrete Fourier transforms. Contemporary computer display devices such as LCDs and LEDs are based on raster graphics that represents images as an array of pixels. Computer graphics hardware and software employ a pipeline architecture that transforms a 3D scene into a 2D image to be displayed on raster devices. Therefore, there exists an inherent, strong relationship between computer graphics and digital image processing. Various digital signal and image processing techniques such as filtering and anti-aliasing are constantly used by computer graphics to produce rendering images that are photorealistic or with any other visual effects. The recent advancement of computer graphics hardware offers an array of new capabilities, such as the programmability of the frame buffer and dedicated hardware for common image processing operations. The inclusion of sampling and discrete Fourier transforms will be offset by removing student assignments on low level texture mapping, such as manually creating texture coordinates, which is usually done by artists, not programmers.

It is acknowledged that the new curriculum requires the addition of new content to the previous versions of these courses in the form of lost M&S content and required computer engineering content. It is anticipated that will be offset by the ease with which examples can be developed giving students a much deeper understanding of the M&S concepts due to a deeper understanding of the examples developed. Thus students will be better prepared to then apply the M&S concepts to a wide range of application areas given sufficient introduction to the application's model, whether mathematical, graphical, or other.

### 4.2.2 Key Computer Engineering Courses

It has been discussed how the computer engineering courses provide a rich set of examples from which models and simulations can be developed. The primary sources of examples will be drawn from the circuit analysis, digital circuit, and electronic circuit courses. However, the benefits go well beyond just example applications of M&S.

The digital system design course presents an alternative perspective of modeling. It is a hardware design course emphasizing design that then implements the designs using a hardware description language. This process is well structured and follows modeling concepts illustrated in Gajski and Kuhn's Y Chart (Gajski and Kuhn 1983) where the levels of behavioral and structural modeling are related to each other as well as to the physical/geometry model. This expands the students' view of the modeling process.

The linear system analysis course provides content long considered missing in the prior curriculum. The course covers advanced matrix operations and linear algebra. Eigenvalues and the characteristic equation of a matrix are covered. In the previous curriculum, good students were prodded to take a course in linear algebra from the mathematics department, but now all students should have a sufficient coverage of the material.

The microcontrollers course provides students the ability to interface simulations with hardware. They will be better prepared to work on virtual and augmented reality systems, haptic devices, and emulators.

Lastly the probability, statistics and reliability course gives students a solid foundation in the concepts by introducing the concepts with a solid background in hardware. Previously M&S students took

probability and statistics from the mathematics department, but never seemed to understand the application of the concepts. It was not until taking the M&S analysis course where the concepts were utilized did it seem to sink in, but requiring reteaching many of the concepts.

## 5 BENEFITS

A basic premise of the curriculum development was that there should be a benefit to both the computer engineering and the M&S engineering programs, in particular for the students. These benefits are articulated here.

### 5.1 Benefits to Computer Engineering

Bringing the M&SE program under the umbrella of computer engineering adds a new breadth to computer engineering by including a strong computational engineering program. It strengthens ties to local constituents with a heavy reliance on M&S, both in industry with companies such as Newport News Shipbuilding and Lockheed Martin, and in government with NASA-Langley and the US Navy. It also strengthens ODU's involvement in Virginia's Tech Talent Investment Program (News @ ODU 2019).

Computer engineering students will benefit from the inclusion of new courses in the program. Through a couple of elective courses, both electrical and computer engineering students have the opportunity to look under the hood of simulations to understand the computational implications of decisions such as using signals vs. variables in VHDL.

### 5.2 Benefits to M&S Engineering

To summarize the benefits to M&S Engineering, the curriculum is beneficial to both the discipline and most importantly the students. The discipline is benefited by bridging the gap between two M&S fields that previously have been totally disjoint. While simulations in the field of electrical and computer engineering draw heavily on M&S concepts, practitioners rarely interact as evident in the lack of crossover in publications. However, there are rich areas of potential cross-fertilization such as M&S learning from computer engineering's experience with simultaneous events.

Highlighted throughout the paper, the benefit to students is many-fold. Students will now have a well-grounded foundation in a classical engineering field to draw on. Examples from this field offer more complex examples on which to practice their modeling and simulation skills than previously possible. Students also have a wider range of paths following the curriculum, either following a classical M&S path or applying their M&S skills in electrical and computer engineering.

## 6 INDUSTRIAL BOARD FEEDBACK

The curriculum for Modeling and Simulation Engineering major under Computer Engineering was presented to the Industrial Advisory Board (IAB) of the Department of Computational Modeling and Simulation Engineering at its meeting in Spring 2021. The IAB members expressed disappointment on the upcoming discontinuation of the Modeling and Simulation Engineering degree that serves the needs of various industries locally and nationally, and conveyed their concerns about the new major's ability to meet industry needs. In particular, they were very concerned about the conversion of the analysis course from a required course to an elective course, since analytical skills are critical and highly sought-after in many industries. They understood the tight restrictions on the program, that core analysis content will be moved into other courses and that students will be encouraged to take the course as an elective. But they felt this content was a unique and valued skillset of our undergraduates. The IAB will review the proposed curriculum and provide feedback and a minimum set of required analysis concepts and skills to the ODU M&S team prior to the design of new course content. The next IAB meeting is tentatively scheduled in the beginning of July 2021.

## 7 REPRODUCABILITY

While the new program has been designed to fit within a computer engineering program, and a specific program at that, the hope is that the concepts are transferable to create M&S programs within other programs at other institutions.

There have classically been core M&S courses within industrial engineering programs, but not in other engineering programs. Within engineering, industrial, systems, computer, and software engineering programs make sense, though different programs would have a different focus. Industrial and systems engineering would focus more on M&S applications and analysis. Computer and software engineering programs would cater to the development side.

In the sciences, computer science would fit a similar scenario to computer engineering, with a heavy emphasis on simulation development. Mathematics and big data provide an opportunity to focus on simulation analysis, a frequently underemphasized concept. A strong case is made for the need for data analytics in M&S education for verification and validation (Lynch et al. 2021) introducing concepts such as machine learning.

To facilitate creation of new M&S programs, the authors share the following advice.

- When identifying a candidate program under which to place M&S, look for built-in applications. Computer engineering is rich in both discrete and continuous systems allowing applications to be introduced without necessary background.
- Look for a program that strongly supports one or more core concepts in M&S. Possible concepts include modeling, software development, and data analytics. This ensures that M&S content is being introduced in other courses in the core. A computer engineering program emphasizes modeling and software development. A systems engineering program would emphasize modeling and data analytics.
- Ideally introduce the use of simulation early in the program, prior to reaching the M&S content. The computer engineering program presented here utilizes significant circuit simulation, both digital (discrete) and analog (continuous). Students then become comfortable with simulations and their uses prior to discussing how to create a simulation.
- Consider ways to reach beyond the M&S program. Though not discussed here, the idea has been floated to find a way to introduce M&S to all engineering programs at a basic level. This has the benefit of better educating others about M&S before entering the workforce.

## 8 CONCLUSIONS

A new curriculum for a modeling and simulation engineering major under the umbrella of the computer engineering degree at Old Dominion University is presented along with its rationale. While the constituents raised some concerns, they are willing to work with the faculty in the development of new courses to ensure content is sufficiently covered. Students also have the opportunity to cover missing material in the form of electives in simulation analysis and model engineering. Finally, the existing graduate program will continue providing the opportunity to get a deeper exposure to M&S. The graduate program requires both the analysis and modeling course. Using an accelerated BS/MS program, students can utilize those two courses both as electives in their undergraduate degree and as graduate credit.

The faculty in both the Department of Computational Modeling and Simulation Engineering department and the Department of Electrical and Computer Engineering worked hard in 2020 to get the new program designed and approved. The program is ready to accept new students in the fall of 2021. A transition plan is in place to phase out the old program and phase in the new program, a difficult process in itself as there will be an overlap stretching faculty resources thin. Design of the new courses commences summer of 2021.

This allows new students in the fall of 2021. The plan allows freshmen to enter fall 2021 and progress normally through the new curriculum. However, due to a university decision to allow no new students enrolling in the university to pursue the old program, a plan was also created to allow transfer students to enroll in the new program in fall 2021, thus preventing any discontinuity of the flow of students from Virginia community colleges. These students will follow a hybrid of the two curricula, but will have no elective freedom to ensure proper coverage of the core content.

The faculty have confidence in the new M&SE curriculum and will work closely with the Industrial Advisory Board to ensure that their concerns are accounted for in the course design. The curriculum actually broadens students' education and career pursuits. As Benjamin Franklin is reported to have said, "Out of adversity comes opportunity".

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