A proposal to develop a minor in Cyber-Physical Systems

Name of the proposed minor

Minor in Cyber-Physical Systems

Name of the department(s) involved

Mechanical Engineering, Electrical and Computer Engineering, Aerospace Engineering

Name of contact person(s)

Soumik Sarkar, Mechanical Engineering, Email: soumiks@iastate.edu

Joseph Zambreno, Electrical and Computer Engineering, Email: zambreno@iastate.edu

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1. **Description of the new degree program**

a. **Brief description of the minor**

With the fourth industrial revolution upon us, physical systems are being designed to have a cyber component, that enables remote access, monitoring and control. In these systems, ubiquitous sensing, and advanced data management capability are taking us from automation to autonomy via a deep interconnection between the cyber and physical entities. Cyber-physical systems (CPS) are becoming abundant in many application sectors including manufacturing, energy, health care, transportation and agriculture. Safety-, time- and life-critical systems are relying on CPS concepts to become more efficient, robust, resilient, flexible and scalable. As CPS applications become more pervasive, the engineering education system needs to produce a next generation CPS workforce who can design, produce, and maintain these systems.

With this motivation and encouraged by the demand from the industry stakeholders of ISU College of Engineering, this CPS minor will focus on sensing, advanced information processing (data analytics and machine learning), and controls aspects of Cyber-Physical Systems. Specific CPS application sectors such as energy/power systems, manufacturing, biomedical devices, autonomous systems, transportation, and agriculture will be in focus. Students with a minor in CPS will complete 15 credits, 9 of which will come from three required 3-credit courses.

We propose to develop these three new CPS courses - CPS 2XX, CPS 2YY and CPS 3XX. Students can take CPS 2XX and CPS 2YY in any order or together (if offered in the same semester), while CPS 3XX will require both CPS 2XX and CPS 2YY as prerequisites, hence, has to be taken after them. Plans for the new courses are briefly described below:

CPS 2XX: **Cyber-Physical System Fundamentals** (Initially will be offered by ECPE, cross-listed with ME, AeroE and potentially other Engineering departments)

(2-2), Cr. 3.

Prereq: sophomore classification, Engr 160 or equivalent

Course description: Fundamentals of cyber-physical systems, including introduction to digital systems design, embedded platforms and programming, sensing and actuation, and performance analysis; Introduction to data communication concepts, including systems-level view of signal processing and electronic circuits, networking standards and protocols. Laboratory exercises with embedded circuits, signals, and measurement applications.

Learning Objectives: The primary objective of this course will be to prepare students with various foundational tools for design and analysis of CPS.:

- Introduction to number systems and digital representation of data
- Interfacing microcontrollers with external physical systems
- Programming and design applications for cyber-physical systems
- Analysis and design of electronic circuits for cyber-physical systems
- Express fluency with techniques for data communication

CPS 2YY: Introduction to Cyber-Physical Systems (Initially will be offered by ME, cross-listed with ECPE, AeroE and potentially other Engineering departments)

(3-0), Cr. 3

Prereq: sophomore classification, Engr 160 or equivalent

Course description: This course will introduce the basic concepts of cyber-physical systems (CPS); physical and cyber considerations and constraints for design, analysis, performance monitoring and control of human-engineered physical systems; basic concepts of sensing, information processing and feedback actuation. There will be substantial hands-on computer programming activity relevant to CPS applications.

Learning Objectives: The primary objective of this course will be to provide an introduction and overview of the concepts of cyber-physical systems to the students in order to motivate them to study and practice CPS, make them aware of the core concepts and terminologies and point them to future courses to acquire a holistic knowledge of CPS science and engineering appropriate for the undergraduate level.

- Introduction to closed loop systems - sensing, modeling and feedback control
- Basics of sensing – data types, estimation, performance monitoring, basics of machine learning – computer vision, perception and time series analysis
- Basics of modeling – physics based, data-driven, system id, prediction, forecasting
- Basics of control – continuous, discrete, hybrid automatic control approaches
- Concepts in CPS design – time (real-time requirements), power and safety constraints, communication and computational constraints

CPS 3XX: **Cyber-Physical Systems Applications** (Initially will be offered by AeroE, cross-listed with ME, ECPE and potentially other Engineering departments)

(1-4), Cr. 3

Prereq: CPS 2XX, CPS 2YY

Tentative course description: This course will focus on applications based on the fundamental knowledge acquired in CPS2XX and CPS2YY and from students' major program preparations to bring the concept of designing cyber physical systems integrating physical and cyber spaces together. Application will be through a hands-on approach where students will work on problems in a team environment. This problem-based course will expose students to different CPS application sectors such as energy, manufacturing, biomedical devices, autonomous systems, aeronautical and ground transportation systems and agriculture.

Learning Objectives: The primary objective of this course will be to provide students with practical and hands-on experience in applying skills in cyber physical systems. Students will use skills obtained from other courses and learn how to design, build and test cyber physical systems and apply them to real world scenarios.

- Introduction to design and analysis steps for real world CPS
- Analysis of real world CPS data
- Implementing decision and control for real world CPS
- Concepts in project management as related to CPS projects

Note: As with all the new CPS courses, this course is multidisciplinary and will be under active development. Feedback from faculty, students and industry leaders will be pursued and the course will use that feedback to continuously make adjustments as needed. The initial course delivery plan is to have a primary course instructor who will design the overall course logistics, schedule and additional content that will be taught in this course. The instructor will guide students through the hands-on portion of the course and instruct students to work through the problem-based course content. Ideas for problems that students can solve will be sought out from faculty and industry leaders. As the course grows, additional faculty and industry involvement is expected to be requested. As with all CPS courses, this course delivery approach will be reviewed and revised as necessary after the first offering by the CPS curriculum committee.

Elective courses: The remaining 6 credits will be selected by the students from a menu of courses listed below. At least one of the two elective courses has to be of the 300 level or above.

ME 370: Engineering measurements
ME 421: System dynamics and control
ME 411: Automatic Controls
ME 418: Robotics
ME 456: Machine Vision
ME 475: Modeling and Simulation
EE 324: Signals and Systems II

EE 333: Electronics System Design
EE 425: Machine learning: A Signal Processing Perspective
EE 476: Control System Simulation
CprE 230: Cyber Security Fundamentals
CprE 388: Embedded Systems II: Mobile Platforms
CprE 488: Embedded Systems Design
CprE 414: Introduction to Software Systems for Big Data Analytics
CprE 419: Software Tools for Large Scale Data Analysis
CprE 421: Software Analysis and Verification for Safety and Security
CprE 458: Real-Time Systems
ABE 403: Modeling, Simulation, and Controls for Agricultural and Biological Systems
ABE 404: Instrumentation for Agricultural and Biosystems Engineering
ABE 410: Electronic Systems Integration for Agricultural Machinery
I E 413: Stochastic Modeling, Analysis and Simulation
I E 432: Industrial Automation
I E 487: Big Data Analytics and Optimization
AER E 365X: Avionics and Controls Laboratory
AER E 407: Formal Methods
AER E 433: Spacecraft Dynamics and Control
AER E 463: Introduction to Multidisciplinary Design Optimization
AER E 464: Spacecraft Systems
C E 449: Structural Health Monitoring
C E 553: Traffic Engineering
C E 556: Transportation Data Analysis

All of the courses listed here are either currently offered or under modification/development in the College of Engineering. In order to be included in the approved course list, course content must be at least 50% CPS related. CPS related means content significantly covers any of the following in an engineering context:

1. Systems theory - sensing, modeling and control
2. Data analytics, machine learning, computational engineering
3. Cyber systems, embedded systems

The final POS for each student in the minor will be approved by the minor steering committee or their designate to ensure uniform program oversight.

One advantage of a minor in Cyber-Physical Systems at ISU is that, as shown above, there are currently many courses related to a variety of CPS-related topics that are being taught in various departments by our COE faculty. As new courses are developed in CPS, they can be added to this list after being approved by the minor's curriculum coordination committee.

b. Statement of academic objectives

CPS concepts offer a true integration of the cyber and the physical space where cyber systems are aware of physical constraints, e.g., time, energy; and physical systems are aware of cyber space constraints, e.g., data storage/processing capability, communication constraints. While the current ISU engineering curriculum has various parts of a CPS framework such as control

theory, cyber-security and sensor systems, the main goal of this minor will be to provide students a holistic idea and knowledge base for the inherently multidisciplinary CPS concepts and their application in various sectors as described earlier. Furthermore, a significant focus will be on building programming skills and awareness among the engineering students. Specific learning outcomes will be assessed in individual courses within the minor through course homework assignments, projects, and exams in the respective courses.

c. Need for the proposed minor

With the advent of the fourth industrial revolution, manufacturing, power, transportation and many other industries are increasingly following the trends of machines augmented with ubiquitous sensing, connected over wireless networks, leveraging precise data-driven decisions for enhanced autonomy, efficiency, scalability and safety. Concepts of cyber-physical systems (CPS), internet of things (IoT), cloud computing and artificial intelligence are proving to be the key enablers for this next generation industry practices. Naturally, demand for talent and skills for CPS and other advanced technologies as mentioned above is already significant and rapidly growing. This next generation workforce is necessary for new applications such as smart grid, smart cities, autonomous and connected vehicles as well as modernization of traditional industries such as road transportation, healthcare and manufacturing.

To address this workforce development challenge, we must educate engineering students specialized in the area of cyber-physical systems. A recent report by the National Academies [NAreport] articulates this critical need for CPS engineering educational programs. Several industry partners and stakeholders of Iowa State have recognized this need and approached Iowa State College of Engineering with a request to develop educational programs in the area of Cyber-Physical Systems [see Letters of Support]. This proposed CPS minor would be a first step to fill this key gap in our engineering curriculum.

[NAreport] National Research Council. *Interim Report on 21st Century Cyber-Physical Systems Education*. National Academies Press, 2015.

d. Relationship of the minor to the Department's/College's/University's strategic plans

As this is a minor aimed at the entire college of engineering student body, relationship with the college's strategic plan is discussed. The College of Engineering strategic plan [COEplan] focuses on research grand challenges in advanced materials and manufacturing, energy systems, resilient infrastructures, engineered medicine, engineering education, and secure cyberspace and autonomy. Most of these application sectors are directly benefited by CPS research and education. At the university level as well, CPS is one of the core competencies that can benefit multiple colleges beyond the college of engineering. The proposed minor could also help strengthen the educational objectives of the recent NSF mandates such as *harnessing the data revolution*, *future of work*, *understanding the rules of life* and *growing convergence research*.

Therefore, this proposed minor will help the University and the College of Engineering meet its strategic objectives.

[COEplan] https://www.engineering.iastate.edu/dean/strategic-plan/

e. Relationship of the minor to other programs at Iowa State University

The closest program at the Iowa State College of Engineering to the proposed CPS minor is the newly formed cybersecurity major. However, these two programs will be entirely complimentary. The cybersecurity program focuses on computer security principles during analysis, design, and operation of the physical, software and human components of a system, including system integration and implementation. In contrast, the CPS minor will focus on sensing, advanced data analytics, control and communication to design, operate and monitor performance of cyber-physical systems.

Some of the other minors such as biomedical and energy engineering focus on specific application sectors. In contrast, the CPS minor would focus on the tools that will enable advances in these specific sectors. The NDE minor does deal with sensing and information processing for decision-making. However, the CPS minor will have a much broader scope as outlined above, NDE being one of the potential applications of the CPS concepts.

f. Relationship of the minor to programs at other Iowa colleges and universities

There is no existing undergraduate program similar to the proposed minor at other Iowa colleges and universities. University of Iowa has a Master of Science in Engineering and Information Technology (MSEIT) program [UI_MSEIT] that has a similar interdisciplinary approach to offer a graduate level program with both cyber and physical components. However, the level of course material and teaching approach will be significantly different in the proposed minor as it is being specifically prepared for undergraduate classification.

[UI_MSEIT]
www.engineering.uiowa.edu/future-students/graduate-studies/mseit-program/program-length-and-curriculum

g. ISU Special features or conditions to initiate the minor

The science and engineering of CPS are inherently interdisciplinary in nature, requiring expertise in engineering, computer science, mathematics, statistics, and the entire breadth of the physical sciences with various application focus areas such as manufacturing, transportation and agriculture. Therefore, Iowa State and specifically the college of engineering is uniquely positioned to initiate this minor as the COE departments offer all the necessary strategic focus areas and faculty expertise in various CPS sectors. Furthermore, the new Student Innovation Center (SIC) will be a great resource to facilitate various CPS related student activities (specifically, the industry focused project works for CPS 3XX).

h. ISU (personnel, facilities, equipment) preparedness to initiate and maintain the minor

As mentioned in the response above, ISU has adequate personnel, facilities and equipment to establish and maintain the proposed CPS minor program.

i. How does student demand for the proposed program justify its development?

Many industry stakeholders of Iowa State and potential employers are looking for future recruits with interdisciplinary CPS background (see letters of support). Therefore, there is a strong demand from the student body within the college of engineering for such a program.

2. Describe the state and/or national workforce need and/or demand for graduates of the proposed program currently and in the foreseeable future (provide documentation about the current sources of data used to estimate need and demand).

Today, there is a lack of interdisciplinary CPS education at the undergraduate level not only at Iowa State but most schools around the country. Typically, a separate focus exists on the cyber domain within the computer science and engineering departments, while the physical aspect or the CPS applications are taught in individual engineering departments such as electrical, mechanical, civil, Ag & biosystems engineering. Therefore, the main purpose of this minor is to break the silos and provide students with interdisciplinary CPS education that cannot be offered via existing programs. Many industry stakeholders and employers are requesting students with such interdisciplinary CPS background, rather than training them within the companies with long-term education programs (see letters of support). Therefore, this minor can help students land on a fast career path in various companies/industries that are critical for US competitiveness in this age of Industry 4.0 (as described in the National Academies report mentioned above).

3. List all other public and private institutions of higher education in Iowa currently operating programs similar to the proposed new degree program. (For comparison purposes, use a broad definitional framework, e.g., such identification should not be limited to programs with the same title, the same degree designation, having the same curriculum emphasis, or purporting to meet exactly the same needs as the proposed program.)

As mentioned in 1f response above, no similar undergraduate program exists in other Iowa institutions.

4. Estimate the number of majors and non-majors students that are projected to be enrolled in the program during the first seven years of the program.

a. Undergraduate

Undergraduate	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7
Non-Majors	10	15	20	30	40	40	40

c. What are the anticipated sources of these students?
Regular undergraduate enrollment within the college of engineering.

5. If there are plans to offer the program away from the campus, briefly describe these plans, including potential sites and possible methods of delivery instruction. Will off-campus delivery require additional HLC accreditation?
There is no plan for off-campus delivery of the program.
6. Has the proposed program been reviewed and approved by the appropriate campus committees and authorities?
In the process.

7. List date the program proposal was submitted to the Iowa Coordinating Council for Post High School Education (ICCPHSE) and results of listserv review.
Note: will be completed by the Provost Office.

8. Will the proposed program apply for programmatic accreditation? When?
Not applicable.

9. Will articulation agreements be developed for the proposed program? With whom?
No.

10. Will there be opportunities for student internships?
No.

11. Describe the faculty, facilities, and equipment that will be required for the proposed program.
See response to 1h above.

12. From where will the financial resources for the proposed program come (list all that apply, e.g., department reallocation, college reallocation, grants, new to the university)?

Iowa State University utilizes a decentralized financial management model for the development of its annual operating budgets. The Resource Management Model (RMM), is a responsibility-centered and incentive-driven approach to financial planning and management. The model supports departments and colleges in making budgetary decisions that enhance student success (e.g., retention), innovate by meeting market demands from students and employers for degree programs of the future, and discontinue legacy curricula which are either not aligned with industry/employer needs or for which student demand is low. Through the RMM, 25% of net tuition revenue is allocated to academic colleges based on a student's choice of major, and 75% is allocated to academic colleges based on teaching (as measured by student credit hours). Through the infrastructure of Iowa State's budget model, financial resources follow students and are allocated based on majors and teaching that is conducted. Tuition

revenue will include both base tuition and applicable differential rates. The proposed degree program will be funded through this existing, proven financial model, and is expected to be fully self-sustaining over time. In addition to the budget model as described, financial resources may also come from internal reallocations made within the college during the program's startup phase. The level of reallocation will depend, in part, on the numbers of new students attracted to the proposed program, and the number of existing students who choose the proposed program over another program, based on standard and differential tuition rates. The proposed program will not be dependent on grants, contracts, gifts, central university resources, or reallocations between academic colleges.

Further details are available in the management and administration plan.

13. Estimate the total costs/total new costs (incremental increases in expenditures) that will be necessary for the next seven years as a result of the new program. Be as specific as possible.
The college has the necessary faculty in-place to begin offering the program. Through the budget model described above, tuition revenue associated with student credit hour production will support the cost of developing the new courses, teaching classes for this program and any marginal costs for equipment or marketing. This program will not require investments in fixed expenses such as facility renovations, information technology software, or licenses.

14. Describe the marketing plan developed to communicate the new program and recruit students.
The Office of Admissions will incorporate this new minor into the overall marketing strategy for undergraduate student recruitment. The program will be included in print materials, websites, and other marketing strategies to attract students from within the state, from across the country and globally. The program will also be included in the appropriate college and departmental recruiting materials, websites, and outreach programs.

15. Describe the program evaluation plan to determine if the program is meeting the intended objectives, if the expected student enrollment has occurred, funding for the program, and any other components that affect the effective operation of the program.
This program will be incorporated into the university's normal academic review process. That review process assesses whether the program is achieving its mission, providing high quality academic experiences, and fulfilling the enrollment and success metrics identified for the program. In addition to the academic program review, as a part of the college budgeting process the program will be monitored annually for achievement of enrollment goals.

16. Include any additional information that justifies the development of this program.

CPS minor: Administration, Management, and delivery

- The overall program logistics will be managed by the department of mechanical engineering, who will act as the lead department. The program will be listed as a minor in cyber physical systems jointly offered by mechanical engineering, electrical and computer engineering, and aerospace engineering departments. ME will manage the website and provide the details for the student use. ME chair will appoint the professor in-charge for the program who will oversee the curriculum development and delivery of the minor program.

- Each of the three departments (ME, ECPE, AeroE) will deliver one required course for the program (an initial plan is listed in the course descriptions). This arrangement will remain in place until reviewed in future.

- There will be a CPS minor curriculum coordination committee consisting of one representative from each of the three departments. This committee will review and update the contents of the required courses and electives list, as needed.

- Each department will provide advising services to their own students who also enroll in the CPS minor program.

- CoE will provide nominal support to each department for the first year when the new courses are being developed. Subsequently, the CPS minor program will be part of the regular operation of each department.

Governance Document

Cyber-Physical Systems (CPS) Undergraduate Minor Program

Adopted November xx, 2020

The department of Mechanical Engineering will serve as the administering department for the minor program and will manage the overall program logistics. The program will be listed as a minor in cyber-physical systems jointly offered by mechanical engineering, electrical and computer engineering, and aerospace engineering departments. ME will manage the website and provide the details for the student use. The CPS minor will be run by a curriculum coordination committee formed in the following manner.

a) ME chair will appoint the professor in-charge for the program who will lead the curriculum coordination committee, oversee the curriculum development and delivery of the minor program.

b) Apart from the lead professor in-charge, the curriculum coordination committee will also consist of one representative from each of the other two participating departments, i.e., ECPE and AeroE. The representatives will be appointed by the respective department chairs.

c) The term limits and replacements of the members will be determined by the respective department chairs.

The responsibilities of the curriculum coordination committee include:

1. Reviewing and updating the contents of the required courses and their delivery modes. The first review will occur after the first full cycle of offering all three required courses, followed by subsequent reviews as needed.

2. Reviewing and updating the elective courses list as needed.

3. Develop and produce information sheets and publications related to the program.

4. Work directly with advisers in the individual departments and programs to promote the minor.

5. Involve faculty and staff across campus in developing and improving the minor.

6. Be available to advise individual students pursuing the minor.

7. Update the catalog to reflect changes to the minor and its requirements.

8. Provide information about the program to the college and industry stakeholders upon request.

This Governance Statement may be amended by a two-thirds majority vote of the curriculum coordination committee. University governance and academic policy have the final say in the event of any conflict between this governance document and the requirements of the program.

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

College of Engineering
Aerospace Engineering
Electrical and Computer Engineering
Mechanical Engineering

Date: October 29, 2020

To: Soumik Sarkar, associate professor
Department of Mechanical Engineering

Cc: Arun Somani, Associate Dean for Research
College of Engineering

From: Alric Rothmayer, chair
Department of Aerospace Engineering

Ashfaq Khokhar, chair
Department of Electrical and Computer Engineering

Caroline Hayes, chair
Department of Mechanical Engineering

RE: Cyber Physical Systems (CPS) minor support

The three (3) departments (Aerospace Engineering, Electrical and Computer Engineering, Mechanical Engineering) will each teach at least one (1) core course for the CPS minor when the minor starts (tentatively Fall 2021) and will be offered at least once per academic year until the minor can be reviewed (tentatively scheduled for the Summer of 2022) and the offering frequency can be reassessed.

Aerospace Engineering will teach CPS 3XX
Electrical and Computer Engineering will teach CPS 2XX
Mechanical Engineering will teach CPS 2YY

Prof Somani, as a follow-up to our prior correspondence pertaining the Iowa State's CPS proposed minor program. Having reviewed the proposed curriculum for the Cyber-Physical Systems Minor at Iowa State University and after consulting several of my colleagues in Micron who more closely follow and support industry developments in this segment, we believe this coursework as well as offering a minor in CPS is an excellent idea. CPS is emerging as a key area of focus in the industry and is the new frontier in IoT orchestration. We are really glad to see the University setup a minor in CPS which will be well appreciated by the students and potential employers alike. With some of the suggested changes below to the coursework to include project work focused on real-world applications, students will enhance their learning of the CPS fundamentals and increase their ability to differentiate themselves to prospective employers.

With best regards, - Jeff VerHeul, Senior Vice President, Non-Volatile Engineering

Micron's feedback on the proposed Cyber-Physical Systems Minor curriculum:

CPS 2XX : Suggest to include an explicit topic on interfacing micro-controllers to TCP/IP/network/web stacks. This is foundational for CPS/IoT systems, and we think it is the intent of the course but it is not called out as a topic. CPS 2xx should also target a semester project as a key deliverable for the course. Laboratory exercises are good but end-to-end orchestration from the web browser to controlling a physical actuator/sensor in a simple real-world application will be a very helpful way to learn the fundamental of a CPS system.

CPS 2YY is targeted at sophomores. The breadth of the course could be too much for a 2nd year student (feedback control, real-time control, system id, computer vision, prediction, time series analysis, continuous control, digital control, hybrid control etc). Suggest to consider moving the course to 3rd year, add pre-requisites and reduce the breadth.

CPS 3XX is a really good course. Suggest adding case studies from real world IoT orchestration led by industry experts. Also focus on security and real-time data pipelines, how to leverage cloud computing resources like AWS, Azure etc. Suggest moving this course to the senior year, instead of the junior year.

Some other suggestions for aspects to incorporate in the coursework:

- Rapid development of CPS applications using java/C or IOS/Android
- Intro to CPS communication protocols like Wifi, Bluetooth, NFC etc
- Include some cryptographically driven content
- Include CprE 230 : Cyber Security Fundamentals as a pre req.
- Consult TCG, Industrie 4.0, IIC or other similar orgs to brining awareness of industry work and application in this space to make the coursework more practical than theoretical.

Hello Arun,

Dave and I summarized some input from our Technical Leaders in this space on the proposed Minor curriculum. We are happy for further discussion on any of these topics, please let us know.

- The criticality of fail-safe design practices related to product security and safety assurance unique to CPS is highly important and should be called out specifically, at least at the introductory level. We didn't see that in the description of the courses.
    - Suggest CPS 2YY and 3XX add objective about security and fail-safe principals and techniques, which should be reinforced through grading criteria throughout all applicable assignments and labs. 2XX should repetitively touch on these two topics throughout lessons for reinforcement. Students in this minor may later forget some details about time series analysis, for example, but they should never forget their engineering has to be safe AND secure, even when the unexpected happens.
- Suggest more focus on emphasize the engineering needed to design, develop and integrate security and resiliency into embedded computing. This should include and cover development of an understanding of the adversity presented by the cyber aspects and how to apply secure design principles and/or patterns to address the stress that this adversity places on the CPS.
- As you may know, ABET is considering how Cyber should be incorporated. A recent proposal was to include the following language under the Other Content in Criterion 5: "Other Content: The curriculum must include topics related to professional and ethical responsibilities, diversity and inclusion awareness, cybersecurity (protection of computers, programs, hardware, and data from unauthorized attacks), quality, and continuous improvement." We see value in this as all of our programs have Cyber requirements.

Arun, Boeing is happy to continue to partner with this Minor and its development along with the class content. We have several members of our team that would be happy to discuss more.

Thank you!

Ben Nimmergut He/His/Him
Director
Manufacturing Technology Integration – Commercial Airplanes
Boeing Research & Technology (BR&T)

CURRICULUM FEEDBACK FOR IOWA STATE UNIVERSITY

Point-Of-Contact: Jason Betts
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Cedar Rapids, Iowa
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PROPOSED CYBER-PHYSICAL SYSTEMS MINOR PROGRAM

Collins Aerospace is pleased to provide the following feedback for Iowa State University's proposed development of a minor program in the area of Cyber-Physical Systems (CPS). Numerous CPS application sectors, such as autonomous systems, aeronautics, communications, power and controls, and manufacturing are widely designed, developed, and employed throughout Collins Aerospace. The importance and complexity of CPS will expand in future years due to continued advances in embedded systems, sensor technologies, data analytics, and machine learning. Employing a workforce with the appropriate CPS educational foundation, training, and skill development is desired by Collins Aerospace.

Collins Aerospace believes the need for educated CPS engineering professionals is a key enabler to the successful creation of future systems and technologies not only within our company but throughout all of Industry. As Collins Aerospace continues to develop CPS solutions, it is important to have, as part of our workforce, a next-generation of talent with exposure to how sensing, data analytics, and process controls are emerging within Industry. As such, Collins Aerospace recommends this CPS minor be established within the College of Engineering and we look forward to employing CPS educated engineers from your University in the future.

Image Source: www.cps-vo.org

1. SUMMARY OF FEEDBACK

Collins Aerospace supports the curriculum for the proposed minor program by Iowa State University (ISU) in the area of Cyber-Physical Systems (CPS). The three new CPS courses are relevant and appropriate, while providing a strong foundation in the fundamentals of CPS, a comprehensive introduction to the concepts of CPS, and demonstrating the application of CPS by merging the physical and cyber spaces together through hands-on design and integration.

Collins Aerospace applies CPS throughout numerous application sectors and is dependent upon a workforce with education of most, if not all, of the individual focus areas of CPS. ISU has structured the CPS minor program to focus on the areas of sensing, advance information processing (to include data analytics and machine learning), and controls. Collins Aerospace agrees with these focus areas and believes it will enable a successful minor program to be established and to foster its growth into a potential major program and beyond. The scope and breadth of CPS is quite large and ISU has prioritized the correct areas. Furthermore, these three focus areas align well with the internal technology roadmaps of Collins Aerospace for a variety of product lines and Research & Development initiatives. Additionally, many of our customers are interested in CPS and have begun including CPS principles and architectures within work solicitations. Therefore, ISU's proposed program is timely and much needed by, not only Collins Aerospace, but many other Industries (which also serve the Iowa economy) as well.

Collins Aerospace encourages ISU to continue growing and expanding their CPS program as the need for CPS educated engineers will increase sharply in the coming years. As ISU is aware, many other Universities are currently offering coursework in the area of CPS. Due to the wide breadth of engineering within ISU and the ability to create transdisciplinary CPS curriculum, Collins Aerospace believes ISU could quickly become an academic leader in CPS and would recommend ISU utilizes these inherent strengths to do so.

While Collins Aerospace believes the proposed minor curriculum is correctly focused and will lead to a solid CPS program, there are several suggestions and recommendations provided that might allow the minor program to become even stronger. These recommendations should be viewed as minor comments and do not need to be addressed in order to provide a valuable program. However, implementation of these suggestions would more closely align ISU's proposed program with the goals and objectives of Collins Aerospace. The areas of constructive feedback are in the following three primary areas:

1. Increased emphasis on the interaction between physical system aspects and cyber
2. Greater depth in the area of Model-Based Systems Engineering (MBSE) and simulation
3. Higher priority of Cyber Security education as it pertains to CPS

These three areas are covered more comprehensively in the following sections. The format of this paper is to provide feedback in each individual section and follow the outline of the "A proposal to develop a minor in Cyber-Physical Systems" paper provided by ISU.

2. CPS 2XX: CYBER-PHYSICAL SYSTEM FUNDAMENTALS

CPS 2XX: Cyber-Physical System Fundamentals

(2-2), Cr. 3.

Prereq: sophomore classification, Engr 160 or equivalent

Course description: Fundamentals of cyber-physical systems, including introduction to digital systems design, embedded platforms and programming, sensing and actuation, and performance analysis; Introduction to data communication concepts, including systems-level view of signal processing and electronic circuits, networking standards and protocols. Laboratory exercises with embedded circuits, signals, and measurement applications.

Learning Objectives: The primary objective of this course will be to prepare students with various foundational tools for design and analysis of CPS.:

- Introduction to number systems and digital representation of data
- Interfacing microcontrollers with external physical systems
- Programming and design applications for cyber-physical systems
- Analysis and design of electronic circuits for cyber-physical systems
- Express fluency with techniques for data communication

Collins Aerospace supports the need to provide an education in the fundamentals of CPS with a focus on cyber and physical aspects. The proposed CPS 2XX curriculum will provide such a foundation and defines the system characteristics required of CPS. Basic computing theory, data representation, and data structures are often left out of CPS curriculum in other Universities but is addressed here. Additionally, the importance of software engineering can also be down-played in other institutions but is clearly elevated here which we agree with.

Recommended areas of improving would be to emphasize, to an even greater extent, the *interaction* of physical and cyber aspects. It is this interaction that many Collins Aerospace engineers spend their time in and often represents the longest phase of a given CPS related project. We believe that engineers who are educated in this area would allow more for efficient implementations and shortened durations which are desired. For example, exposure to the importance and creation of Interface Control Document (ICD) would be a topic to consider including in this curriculum.

To aid in the education of the interactions between the cyber and physical domains, we recommend that MBSE be included at some level in this CPS 2XX curriculum. We feel MBSE is a crucial enabler of CPS due to its ability to define interactions, to include different operating environment contexts (some of which are significantly different), and to accurately depict the required control loop and general process control. We realize that CPS 2YY does include basics of modeling and perhaps it is better to include it in this CPS 2XX fundamentals class?

Finally, we feel Cyber Security needs to be a core concept introduced, in relation to CPS, during this class. In later sections of the ISU's paper, cybersecurity is certainly discussed and it is clear ISU understands the complimentary nature of CPS to the existing cybersecurity major and has structured the programs to keep them independent. However, we recommend this be reconsidered and to allow CPS related cybersecurity topics to be taught in the proposed CPS minor program. For example, we feel it appropriate to focus on typical CPS "adversaries" within the existing curriculum as this is a common threat in deployed CPS products. Specific focus areas might include:

1. Definition of "crown jewels" and what is needed to be protected
2. Attack and countermeasure analysis methodology
3. Countermeasure design
4. Vulnerability assessments (validation)

While we agree the CPS curriculum should not be solely on Cyber Security, we do recommend introduction of how Cyber Security must fit into the design of CPS because this is an area of high focus for CPS related engineering at Collins Aerospace (which is driven from customer needs). Additionally, many or our CPS products are systems of high safety and must address evolving Cyber Security concerns.

3. CPS 2YY: INTRODUCTION TO CYBER-PHYSICAL SYSTEMS

CPS 2YY: Introduction to Cyber-Physical Systems

(3-0), Cr. 3

Prereq: sophomore classification, Engr 160 or equivalent

Course description: This course will introduce the basic concepts of cyber-physical systems (CPS); physical and cyber considerations and constraints for design, analysis, performance monitoring and control of human-engineered physical systems; basic concepts of sensing, information processing and feedback actuation. There will be substantial hands-on computer programming activity relevant to CPS applications.

Learning Objectives: The primary objective of this course will be to provide an introduction and overview of the concepts of cyber-physical systems to the students in order to motivate them to study and practice CPS, make them aware of the core concepts and terminologies and point them to future courses to acquire a holistic knowledge of CPS science and engineering appropriate for the undergraduate level.

- Introduction to closed loop systems - sensing, modeling and feedback control
- Basics of sensing – data types, estimation, performance monitoring, basics of machine learning – computer vision, perception and time series analysis
- Basics of modeling – physics based, data-driven, system id, prediction, forecasting
- Basics of control – continuous, discrete, hybrid automatic control approaches
- Concepts in CPS design – time (real-time requirements), power and safety constraints, communication and computational constraints

CPS 2YY represents a solid CPS introduction which covers many different aspects quite well. Collins Aerospace resonates with the focus on real-time requirements and closed loop systems. Sensing and feedback are core competencies of many CPS systems developed by Collins Aerospace and we recognize the key role sensors play in CPS designs. Machine learning and autonomous systems are a direct application to CPS and, again, are a key technology focus area of Collins Aerospace. Additionally, we believe feedback and control loops in general are highly important in this topic but can often be minimized in some curriculum models and so we agree with its inclusion here. In summary, this curriculum and the educational needs of Collins Aerospace engineers are closely aligned.

While we agree with everything in this curriculum, we believe it might be too much to take on within one course. These topics could certainly be addressed in an abbreviated fashion but, given their importance to CPS, we recommend breaking them out into another class (a fourth class potentially entitled, CPS 2ZZ) to allow for deeper study and understanding. For example, as discussed in our feedback for CPS 2XX, we believe MBSE to be a key component of CPS. While CPS 2YY does cover the basics of modeling, we feel it would be better served to provide more education in this area. Perhaps the basics of modeling could be moved into CPS 2XX to allow a more thorough study of MBE in the CPS 2YY class?

Similar to MBSE, it is important for students to have access to design tools as CPS typically requires additional tools usage when compared to traditional disciplined-based systems. State machine designs, control loop design, modeling heterogeneous components in a system, power grid design tools, embedded system representation tools, hydraulic and mechanical interface designs, etc. are often required in CPS. However, education in these

tools would seem appropriate for more advanced classes so we would recommend a basic overview of commonly utilized and available CPS tools in the minor program.

CPS 2YY may also benefit from including basic methodologies and principles from Systems-of-Systems (SoS) architecture and hierarchies. In addition to capturing the system interactions, this approach would help establish the Lifecycle view and accommodate system evolution. CPS solutions often evolve and the individual cyber and physical aspect will influence and impact each other which can be better understood and designed by taking a SoS approach.

Another potential area to explore is introducing the student to a diverse CPS example population, with a focus on specific examples (as opposed to, higher level System of System examples) in order to help understand the guiding principles these diverse systems share and their associated risks and uncertainties. This could include a survey of functional and performance requirements along with a survey of vulnerabilities and mitigation approaches for CPS.

This proposed class does touch upon human-engineered physical systems but we recommend increased focus on this topic, specifically in the area of human factors. ISU's proposed CPS curriculum is focused on the "how" and "why" (as a good technical degree should) but may lack the user aspect. Collins Aerospace views this as a shortfall in some CPS applications and would recommend a human factor approach with respect to interfaces, interface design, Human Machine Interface (HMI), standards, and workflow awareness.

4. CPS 3XX: CYBER-PHYSICAL SYSTEMS APPLICATIONS

CPS 3XX: Cyber-Physical Systems Applications

(1-4), Cr. 3

Prereq: CPS 2XX, CPS 2YY

Tentative course description: This course will focus on applications based on the fundamental knowledge acquired in CPS2XX and CPS2YY and from students' major program preparations to bring the concept of designing cyber physical systems integrating physical and cyber spaces togethers. Application will be through hands-on semester-long team projects using project based learning. This project-based course will be geared towards exposing the students to different CPS application sectors such as energy, manufacturing, biomedical devices, autonomous systems, aeronautical and ground transportation systems and agriculture.

Learning Objectives: The primary objective of this course will be to provide students with practical experience in applying skills in cyber physical systems. Students will use skills obtained from other courses and learn how to design cyber physical systems and apply them to real world scenarios.

- Introduction to design and analysis steps for real world CPS
- Analysis of real world CPS data
- Implementing decision and control for real world CPS
- Concepts in project management as related to CPS projects

Collins Aerospace supports this curriculum and is pleased to see the importance placed upon the real-world practical and pragmatic design and integration of the cyber and physical domains. Much of what Collins Aerospace is looking for when hiring engineering college graduates is this type of knowledge and lab experience. Our feedback for CPS 2XX highlighted the need to focus on the interactions between the cyber and physical spaces and, if that highlighting took place, then it would naturally and holistically fit well into the CPS 3XX curriculum which we believe would make a well-rounded engineering student. Additionally, if MBSE were more

heavily emphasized as discussed in the earlier sections, then the integrated product could be compared to the model which would enable interesting verification and validation scenarios to be taught.

Collins Aerospace believes an opportunity may exist to partner with ISU in the definition and execution of this class similar to the partnership we currently have through the College of Engineering Capstone projects. Partnering with a real-world CPS development would provide increased understanding of CPS applications and the challenges contained therein.

While we understand the rationale for including project management as it relates to CPS projects, we would recommend removing this to allow for more instruction in the other CPS areas. Project management is certainly an important part of an engineering skillset but, relative to the other CPS topics, we believe it should be of lower priority.

5. COURSE ELECTIVES

ME 370: Engineering measurements
ME 421: System dynamics and control
ME 411: Automatic Controls
ME 418: Robotics
ME 456: Machine Vision
ME 475: Modeling and Simulation
EE 324: Signals and Systems II
EE 333: Electronics System Design
EE 425: Machine learning: A Signal Processing Perspective
EE 476: Control System Simulation
CprE 230: Cyber Security Fundamentals
CprE 388: Embedded Systems II: Mobile Platforms
CprE 488: Embedded Systems Design
CprE 414: Introduction to Software Systems for Big Data Analytics
CprE 419: Software Tools for Large Scale Data Analysis
CprE 421: Software Analysis and Verification for Safety and Security
CprE 458: Real-Time Systems
ABE 403: Modeling, Simulation, and Controls for Agricultural and Biological Systems
ABE 404: Instrumentation for Agricultural and Biosystems Engineering
ABE 410: Electronic Systems Integration for Agricultural Machinery
I E 413: Stochastic Modeling, Analysis and Simulation

I E 432: Industrial Automation
I E 487: Big Data Analytics and Optimization
AER E 365X: Avionics and Controls Laboratory
AER E 407: Formal Methods
AER E 433: Spacecraft Dynamics and Control
AER E 463: Introduction to Multidisciplinary Design Optimization
AER E 464: Spacecraft Systems
AER E 494: Make to Innovate II
C E 449: Structural Health Monitoring
C E 553: Traffic Engineering
C E 556: Transportation Data Analysis

Collins Aerospace appreciates the large depth and breadth of the CPS field of study and understands the difficulty of including the correct mix of classes in order to round out the minor program. The list of electives suggested by ISU is appropriate and in line with the expectations of Collins Aerospace. Nonetheless, we feel some of the electives may provide more value than others in relation to a CPS minor. Therefore, we recommend prioritizing the following electives:

1. CprE 230: Cyber Security Fundamentals
2. ME 475: Modeling and Simulation
3. CprE 419: Software Tools for Large Scale Data Analysis
4. EE 425: Machine learning: A Signal Processing Perspective
5. AER E 463: Introduction to Multidisciplinary Design Optimization

We would like to recommend a complimentary approach to ISU's proposed minor program where specific Engineering Departments may form CPS alliances to jointly teach tightly coupled CPS topics. For example, an introductory cybersecurity class could be augmented with CPS principles. A power electronics class could be

enhanced to include typical CPS interfaces that a power system might possess. An aeronautics class might address autonomous flight algorithms in relation to CPS. By doing this, much of the fundamental concepts of CPS could be included in other classes which would then allow the CPS minor to be more focused on CPS itself. ISU's list of proposed electives might be a good starting point in this endeavor.

A significant challenge for CPS engineering is the considerably different engineering disciplines contained within CPS. To be an effective CPS engineer, one must have a wide background in virtually all disciplines and particularly skilled in Systems Engineering. Furthermore, a CPS design and implementation requires a transdisciplinary and cross-cutting applications of many engineering skills. This also includes soft skills, critical thinking, and technical communication techniques. Therefore, a multi-disciplinary approach with a focus on communication would be an asset when collaborating with other disciplines. The benefit of such an approach would be to allow the CPS minor to remain more sharply focused on CPS while the other core engineering classes could address how CPS fits into their curriculum.

6. REMAINING SECTIONS

The remaining sections of the "A proposal to develop a minor in Cyber-Physical Systems" document pertain to internal ISU matters and, therefore, we will treat these sections as N/A.

Academic Program Approval Voting Record

This document is to be appended as the last page of the proposal for any new or revised academic program to record the successive votes of approval as the proposal moves through its required review and approval steps. Consult Faculty Handbook Section 10.8 or the Faculty Senate Curriculum Committee website for information regarding Committee review and voting requirements for each action.

Curricular Action: (check appropriate boxes below)

1. x New Program □ Name Change □ Discontinuation □ Concurrent Degree for:
2. □ Undergraduate Major □ Graduate Major x Undergraduate Minor □ Graduate Minor
   □ Undergraduate Certificate □ Graduate Certificate □ Other: _____
3. Name of Proposed Change: Minor in Cyber-Physical Systems_____
4. Name of Contact Person: Soumik Sarkar_ e-mail address: soumiks@iastate.edu_____
5. Primary College: College of Engineering_____ Secondary College: _____
6. Involved Department(s): Mechanical Engineering, Electrical & Computer Engineering, Aerospace Engineering

Voting record for this curricular action:

Voting Body	Votes			Date of Vote
	For	Against	Abstain	
Dept. or Program Committee				
Mechanical Engineering	33	2	0	10/29/2020
Electrical & Computer Engineering	47	1	0	10/28/2020
Aerospace Engineering	25	4	1	11/6/2020
College Curriculum Committee				
Engineering College Curriculum Committee	8	0	0	10/30/2020
College Approval Vote				
College of Engineering	156	8	4	11/16/2020
Graduate Council	n/a			
Faculty Senate Curriculum Committee	5	0	0	2/2/2021
Faculty Senate Academic Affairs Council	8	1	0	February 10, 2021
Faculty Senate				