Group 1: Reliable, safe, and secure systems you can trust your life with
Top Priority 1: Cost Effective Verification and Validation of Complex Cyber-Physical Systems

- Whole system V&V: extreme cost pressures, multiple time scales, discrete, continuous and stochastic elements.

- **Key Tasks and Milestones**
  - Establish precise abstraction relationship between models included in V&V
  - Compositionality (holy grail)
  - Quantitative verification

- **Benefits**
  - Increased reliability, fewer recalls
  - More features and systems for the cost
Top Priority 2: Design Metrics for Reliability, Safety, and Security in CPS

• Develop design metrics for reliability and safety in CPS that are objective, measurable, and comparable over time. Solid metrics/measurements are needed (strength of code, security, etc.)

• Key Tasks and Milestones
  – Risk framework for coming up with acceptable levels
  – Metrics for major phases of development: Design, test, deployment, and ongoing operations
  – Metrics/measurements at the meta level for each situation, and to underlie the meta levels (e.g., strength of materials, load, etc.)

• Benefits
  – Improved assurance of safety, security, and reliability
Top Priority 3: Lack of Common System of Systems Definition/Description

• Determining how to align a heterogeneous group of ‘system technologies’ (technology, application, people, etc.) to collectively accomplish key outcomes in an efficient, non-iterative approach

• **Key Tasks and Milestones**
  – Develop a way to universally (visually) represent system behavior
  – Establish a common language
  – Provide real-time feedback between impact of local decisions

• **Benefits**
  – Lower cost for integration
  – Cheaper development
Top Priority 4: Modeling and Model Fidelity

• Formal precise models at the right level of abstraction for design of CPS are lacking. Models must include precise specification of properties relevant to the purpose of the model

• Key Tasks and Milestones
  – Construct ontology of model types.
  – Create process assets (tasks, guidance, checklists, examples, etc.)
  – Education/training on high-fidelity modeling
  – Create tooling to automate some parts of modeling (construction, mining, translation, verification)

• Benefits
  – Code and test syntheses
  – Automated test execution
  – Reduction in project time/cost
Opportunities for Collaboration

• Collaboration will be necessary
  – For example, in systems integration, collaboration would be focused on methods or common language and models as an outcome (rather than a technology)
Group 2: Networked, cooperating, human-interactive systems
Top Priority 1: Human modeling for CPS

- Need to better model human strengths and weaknesses and corresponding machines strengths and weaknesses (mixed initiative). Models need to be adaptive, implementable at varying degrees of sophistication, and compelling to their human counterparts.

- **Key Tasks and Milestones**
  - Architect a container for the physical and cognitive models
  - Establish a “grand challenge” for human-machine interactions

- **Benefits**
  - Natural, seamless interactions between humans and CPS
  - Increased career longevity and quality of life
  - Human acceptance of and comfort with working with machines

Group 2: Networked, cooperating, human-interactive systems
Top Priority 2: Uncertainty characterization and quantification

- Understand the implications of the inputs and their variabilities on system operation.

- **Key Tasks and Milestones**
  - Develop a modular, composable approach to uncertainty quantification
  - Conduct a baseline study to understand performance and range of inputs

- **Benefits**
  - Better understanding of the potential risks to system operation
  - Feedback to design
  - Enable graceful degradation

Group 2: Networked, cooperating, human-interactive systems
Top Priority 3: Market, business model, and governance

• Building an infrastructure foundation that is interoperable, the correct balance of open source and proprietary, and under the same set of standards.

• **Key Tasks and Milestones**
  – Determine a “state of practice” to identify issues, opportunities, and stakeholders (1 year)
  – Conduct a test pilot project within one industry (2-3 years)
  – Draft a set of draft standard guidelines using the pilot project as a proof-of-concept (concurrent with pilot study)

• **Benefits**
  – Smoother, faster roll-out of technology
  – Drives down costs for manufacturers and consumers

Group 2: Networked, cooperating, human-interactive systems
Group 3: Engineering across the digital-physical divide

Pieter Mosterman, MathWorks
Priority 1: Testing, Verification, Validation & Certification

- Scale the challenge of system level testing, verification, validation and certification in engineering CPS

- **Key Tasks and Milestones**
  - Certification that is performance based as opposed to process based
  - Early use of modeling and simulation
  - Voluntary certification organizations for CPS
  - Affordable/reusable test infrastructure (cost reduction in the next 5 years)
  - Provably correct model testing tools (2 years)

- **Benefits**
  - Improves customer confidence
  - Early adoption reduces overall cycle-time
Priority 2: Universal Language and Standard for Interoperability

• Integration of disparate designs requires standards for interoperability. How do you design a universal language that anticipates requirements of designers?

• Key Tasks and Milestones
  – Develop consensus standards
  – Stabilized blueprint
  – Demonstration project

• Benefits
  – Lower costs
  – Increased reliability
  – Reduce complexity of interfaces
  – Ease of education
  – Accelerates crisis mitigation (broad support base)
  – Standards inform certification process
Priority 3: Abstraction Infrastructure to Bridge the Digital-Physical Divide

• Develop a multidomain framework and abstractions for engineering CPS

• **Key Tasks and Milestones**
  – Needs inventory across existing systems to identify bottlenecks and design abstractions for the corresponding problems
  – Approach for combining various semantics to understand the combined meanings
  – Abstractions that are highly configurable, while preserving meaning
  – Flexible and open framework that is highly evolvable which is supported by technologies and to support this

• **Benefits**
  – Better understanding of systems for design space exploration
  – Enable composition
  – Information reuse across abstractions
  – Reconciliation of various design paradigms
  – Integration confidence
Top Priority : Co-design of CPS

• Ability to design, analyze, and build CPS systems cost effectively and securely

• Key Tasks and Milestones
  – Develop formulations and abstractions of a ‘Science of CPS’
  – Develop engineering methods for co-design
  – Demonstrate engineering co-design project
  – Define metrics to measure CPS security, performance...

• Benefits
  – Maximize system simplicity
  – Reduce development and recurring costs
  – Increased security
Opportunities for Collaboration

• Fast-track CPS curriculum development
  – Industry driven, academic implementation
• Government early adoption of standards to enable development baseline
• Accelerating the development of affordable testbeds – cost sharing government, industry, academic
• Accelerate the development of open-source CPS systems
• Development of prove-ably correct models
• Industry provide test-cases for CPS to university-research
• Government funds more interdisciplinary research
  – Inspire true CPS research programs
  – Reward true cross-disciplinary work
Group 4: Architecture and platforms for cyber-physical systems
Top Priority 1: Lack of Scientific-based Metrics for X (Security, Privacy, Safety, and Resilience)

• Different properties are measured over distinct, but not necessarily disjoint features of each system. Can common representations that acknowledge such nuance be found and how can complexity be evaluated based on them?

• **Key Tasks and Milestones**
  – Mine existing engineering practice for attributes and models involved with X
  – Compare combinations of models for reasoning about X in real systems
  – Scientific review and refinement of models, methods, and approaches for evaluating X

• **Benefits**
  – Greater reliability with respect to X (fewer, lower impact, and less widespread consequences of failures)
  – More informed, effective, and understandable policy and engineering decisions and outcomes
Top Priority 2: Time and Architecture

• Facilitating time management (sync, scale, comm, scheduling) for distributed CPS applications (design, rapid prototyping, production).
• Layered architectures based on functionality
  – Communication, Utility, and Application
  – Time management among/across layers
• Key Tasks and Milestones
  – Reference architecture (1 year)
  – Standards, Languages, and Protocols for specifying time requirements (3-5 years)
• Benefits
  – Time correctness
  – Disassociation of time management and application logic
    • Expandability
    • Lower cost
    • Easier deployment
Top Priority 3: Systematic Structured Design of CPS

• We need to design CPS in a structured way, which systematically relates signals and symbols. Both for interprocess and interpersonal communications across domains.

• **Key Tasks and Milestones**
  – Principle theory for structured design of CPS
  – Tools based on that theory for robust and structured CPS design and understanding
  – Demonstrations of quick CPS implementation from generic plug-and-play components

• **Benefits**
  – Modularity
  – Reductions in costs of sensors and actuators
  – Reduced time-to-market
Top Priority 4: How to Ensure the Correctness of CPS Systems

• Ensuring correctness in the presence of complexity, dynamic uncertainty in the environment, adversaries, and human interactions

• **Key Tasks and Milestones**
  – Define correctness as much as possible
  – Run-time bounds checking outside of original understanding of correctness
  – Adaptation with incremental verification

• **Benefits**
  – Save lives and prevent economic loss
  – Reduce costs and design time
Top Priority 5: A trustworthy, holistic infrastructure for the evaluation of CPS

- 1) Lack of infrastructure for traditionally closed systems
- 2) How to leverage the strength of different evaluation methods?

**Key Tasks and Milestones**
- Integration of different evaluation methods
- Develop an effective user-interface for specific components
- Seamless integration of different tools that support compositionality and prediction

**Benefits**
- Supports the life-cycle of CPS development, including cost reduction
- Supports open innovation
Opportunities for Collaboration

• Areas where collaboration most critical
  – Government involvement in public infrastructure, national security and high risk (emerging) areas (e.g., medical device integration)

• Ways collaboration can be improved
  – Standard collaboration agreements
  – Academic access to real case studies – need forum where industry can present problems
  – Crowd sourcing (communicating) problem
  – Support a CPS IMI
  – Consider organizational barriers – agencies, companies and universities

• Speak in one voice (industry, agencies, academia) for state, federal public consumption
Group 5: Education, workforce training, and technology transition
Top Priority 1: Need for degrees that cut across multiple departments (stovepipe nature of universities)

• What are the barriers preventing the incorporation of a CPS degree that is stovepiped in terms of university structure, administration, etc.?

• **Key Tasks and Milestones**
  – 1-year: Creation of NIST/NSF-sponsored CPS education centers with industry cooperation
  – 3-year: Prototype programs in select universities
  – 5-year: Deployment of programs across universities

• **Benefits**
  – Provide a more formal method/approach for teaching/training in CPS
Top Priority 2: Value proposition of CPS research to enable rapid development and transition

• Research is often described in too theoretical terms, with too much jargon, making it hard to pull the “gist” and reason to invest in it

• **Key Tasks**
  – Better use and enforce self-evaluation criteria to more simply describe research goals, benefits, and risks
  – Include timelines
  – Place tangible value on tangible industry participation, including creation of an industry alliance or technical committee (IEEE? ACM?) to foster collaboration

• **Milestones**
  – Measure Industry attendees at CPS meetings
  – See increased number of CPS patents
  – Increase number of CPS articles both inside and outside of traditional domains

• **Benefits**
  – Quicker, less painful, and less expensive industry adoption of research
  – Better technical and non-technical understanding of what CPS work delivers, both inside and outside of CPS domains
Top Priority 3: Lack of mechanisms for continuous retraining, incentives, and funds to facilitate radical CPS innovations at universities, schools, industry/government

- CPS is a dynamic field with new methods, tools, techniques, and theories constantly evolving. Concept doesn’t fit easily with traditional stovepipes

- **Key Tasks and Milestones**
  - Certification committee with agencies to outline within 2 years (led by NIST and involving other agencies and universities)
  - Build business case for municipal-scale test site and advocate to investors
    - 6 months for business case  1-year plan
    - 2 years co-funding
    - 4 years break ground

- **Benefits**
  - Educated workforce with fundamental backgrounds with CPS capabilities
  - Ability of society to efficiently and safely implement their visions of complex systems
Top Priority 4: University instructors are not prepared for teaching CPS

• Challenge due to the fact that CPS is not a classic discipline; no textbooks exist, curriculum does not exist, and incentives to solve this are low.

• **Key Tasks and Milestones (1-2 years)**
  – CPS related textbooks
  – Virtual courses
  – CPS Benchmarks (with industry involvement)
  – Identifying incentives
  – Summer workshops tuned to education

• **Benefits**
  – Workforce training for industry (global competitiveness requires trained engineers and scientists)