# Overview of
# Systems Engineering & Modeling for UVs

**People:**

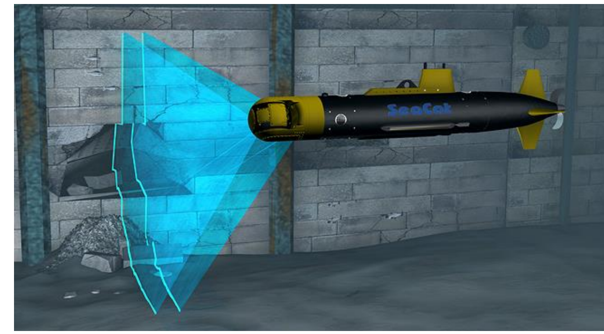

- **George Bollas,** *Associate Professor, Chemical and Biomolecular Engineering, and Director, UTC Institute for Advanced Systems Engineering, UConn (Lead)*
- **Gretchen Macht,** *Assistant Professor, Mechanical, Industrial, and Systems Engineering, URI*
- **Gregory Jones,** *Adjunct Professor, Mechanical, Industrial, and Systems Engineering, URI*
- **Krishna R. Pattipati,** *Board of Trustees Distinguished Professor, UTC Professor in Systems Engineering, Electrical and Computer Engineering, UConn*
- **Manbir Sodhi,** *Professor, Mechanical, Industrial, and Systems Engineering, URI*
- **Amy Thompson,** *Associate Professor in Residence, Institute for Advanced Systems Engineering, UConn*

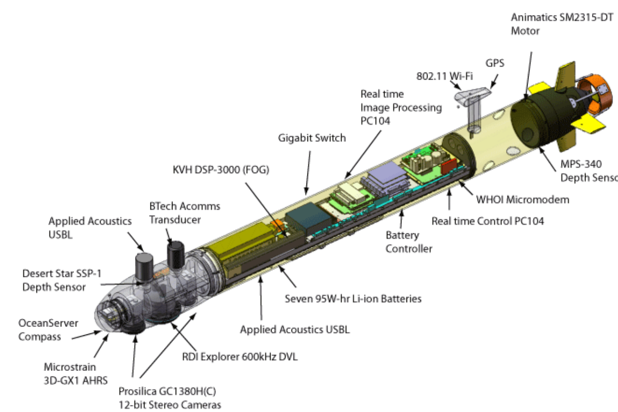
# Capabilities

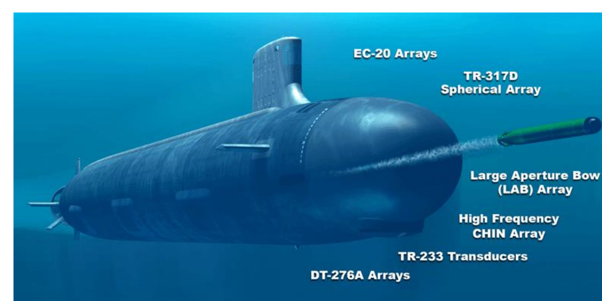
- Systems Engineering
  - Model-based requirements formalization
  - System design and Integration
  - Design of testing for validation & verification
- Data Analytics
  - Anomaly detection, Identification, Isolation
  - Signal processing, target tracking/classification
  - Data fusion, Information Stewardship
- Modeling and Simulation & Operations Planning
  - Physics-based system-level modeling
  - Data-driven modeling
  - Physics-informed machine learning for Real-Time optimization
- Control & Optimization
  - Undersea vehicle guidance & control
  - Embedded systems & real-time software
  - UV system design & optimization
- Planning and Decision support
  - Context Representation, Inference and Forecasting
  - Context Communication
  - Context Driven Decision Making

# Undersea Vehicle Technology Applications

- **Integration & Compatibility with other Systems:** Subsystems and the data they collect need be complementary and compatible.
- **Model-Based Requirements Formalization** Subsystem, component, and inter-UV requirements need be formalized for consistency, interoperation and correctness
- **Cyber-Physical System Modeling** Platform-based modeling of UV systems and components using physics-based, data-driven and hybrid approaches
- **Data Analytics & Communication** Data reduction and near real-time communication of sensory data
- **Navigation, Maneuverability & Path Planning** Path planning and sensor orientation through optimization and advanced controls.
- **Autonomy** Embedded systems enabling effective operation in the uncertain undersea environment without the need for direct human supervision
- **Sensor networks location, selection and optimization** Deliver the *right* information from the *right* source in the *right* context to the *right* decision maker at the *right* time for the *right* purpose





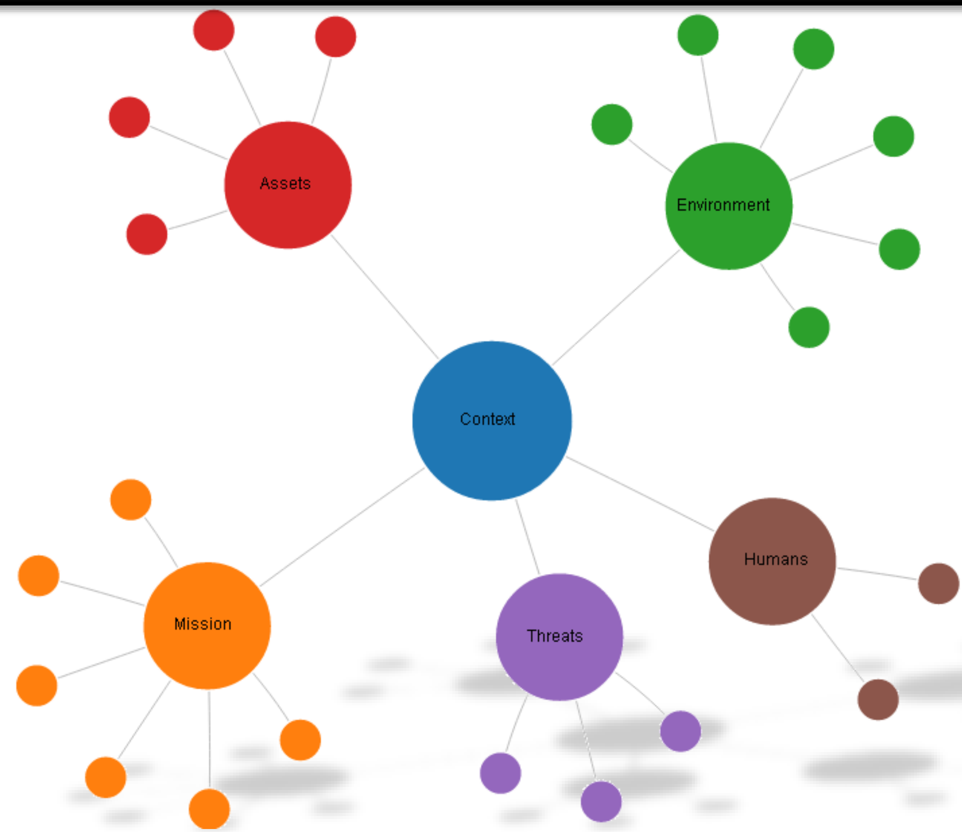



# Context in Mission Planning

**In agile mission planning, context :**

– is an interlinked, dynamically evolving multidimensional (Mission, Environment, Assets, Threats/Tasks (MEAT) and Human) information space

– determines uniqueness, categorization and saliency of information




- Facilitates 6R's concept (deliver the *right* information from the *right* source in the *right* context to the *right* decision maker at the *right* time for the *right* purpose)
- Automatically suggests/ executes actions based on the context ~metaheuristic
- Enables contextual information to be attached to data for later retrieval and decision making

**Publication**: M. Mishra, D. Sidoti, G. Avvari, P. Mannaru, D. F. M. Ayala, K. R. Pattipati and D. L. Kleinman, "A Context-Driven Framework for Proactive Decision Support with Applications," *IEEE Access*, May 2017.

**Project: Context-Driven Proactive Decision Support Concepts, Algorithms and Protocol for Agile Mission Planning in $C^4ISR$, ONR, \$1,042,965; 8/15-12/18, PI: Pattipati**

# Systems Engineering/Modeling

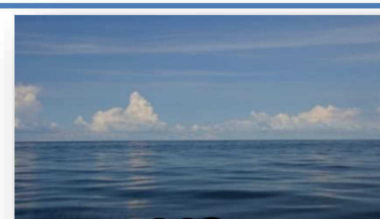
## Waterspace Planning (WaSP)

- **Spatio-temporal indexing & conflict detection** (Asset context)
- Algorithms for dynamic conflict identification and resolution to **COMSUBPAC & NRL-MRY**
- Multiple objectives (e.g., max. probability of safe route, minimize risk, hazard avoidance)
- *What we learned*: Can reduce human workload from **120 hours to 2-4 hours** via optimization
- *Approaches*: R-trees, TPR-trees, linear programming and quadratic programming

## Navigation in Uncertainty (NiU)

- **Dynamic multi-objective path planning under uncertainty** (Environment & Asset context)
- Algorithms for asset routing to **OPT** and **WaSP** for **MTC2 & NRL-MRY; available for NITES-Next**
- Multiple objectives (e.g., max. ship safety, training opportunities, min. fuel consumption, time to destination)
- *What we learned*: **Can reduce fuel consumption by 33%** if waiting (e.g., for training) is allowed
- *Approaches*: Dynamic programming, second order cone programming, robust optimization

- **March 2009:** USS Hartford collides with the USS New Orleans upon surfacing
- **Repair cost: $120+ million**



VS.

- The US Navy **spends ~$35B per year on fuel**
- Optimized weather routing **can realize significant savings on fuel costs**

**COMSUBPAC** – Commander, Submarine Force, U.S. Pacific Fleet
**NITES-Next** – Naval Integrated Tactical Environmental System Next Generation
**OPT** – Operational Planning Tool
**MTC2** – Maritime Tactical Command and Control

**Project: Atmospheric Effects Analysis and Prediction, Naval Research Laboratory, $780,383; 3/01/2016-3/19/2019, PI: Pattipati.**
**Project: Context-Driven Proactive Decision Support Concepts, Algorithms and Protocol for Agile Mission Planning in C[4]ISR, ONR, $1,042,965; 8/15-12/18, PI: Pattipati**

# Systems Engineering/Modeling

- 2012 U.S. UAS Report to Congress: Human errors accounted for **68%** of UAS mishaps
- Oct. 3, 2009: an MQ-1B Predator in Afghanistan crashes into mountain **due to operator error**
  - **Damage estimated at $3.9 million**

- US consumers **spend $150 billion per year on drugs**
  - Of this, **~$37 billion is spent on cocaine alone**
- In 2009, **JIATF-S** was credited with **more than 40% of global cocaine interdiction**

| Dynamic Scheduling of UASs (SCOUT) | Targeting in Uncertainty (TiU) |
|---|---|
| • **Open vehicle routing** (Asset & Human context)<br>• Algorithms for dynamic scheduling of UASs to rank order operators, transitioned to **NRL-MRY**<br>• Machine learning-based cognitive context detection via pupillary and gaze measurements<br>• *What we learned*: 1) there is a **tradeoff between optimality and algorithm runtime;** 2) **pupil diameter and gaze patterns are useful measures of operator workload**<br>• Approaches: Path time equalization and rollout; heterogeneous hidden Markov models | • **Dynamic resource allocation problem** (Environment, Assets, & Threat context)<br>• Algorithms for dynamic allocation and coordination among surveillance & interdiction assets intended for **NRL-MRY, JIATF-S**<br>• *What we learned*: On average, giving the option to switch cases during patrol **results in 7% more detections; solutions in less than 2 seconds**<br>• Approaches: Approximate dynamic programming, S-D assignment, branch & cut |

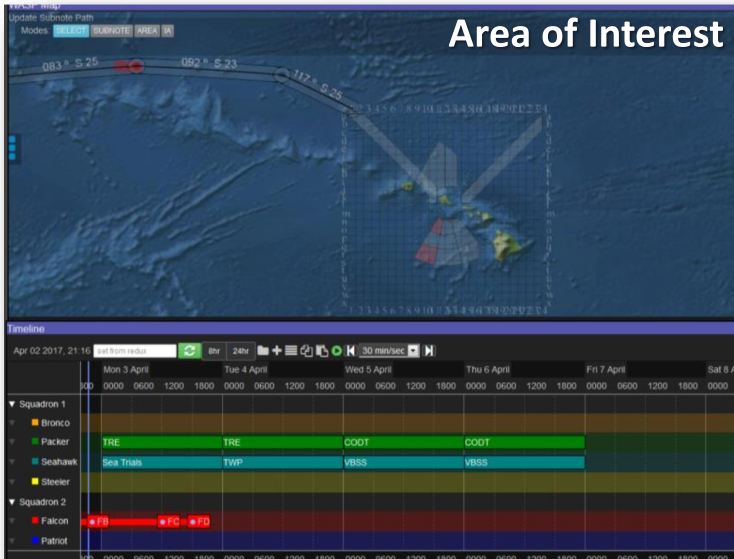
**Key: Rapid mission planning in a highly dynamic and unpredictable mission environment requires a proactive decision support system, that which is anticipative and adaptive/adaptable to changes in mission**

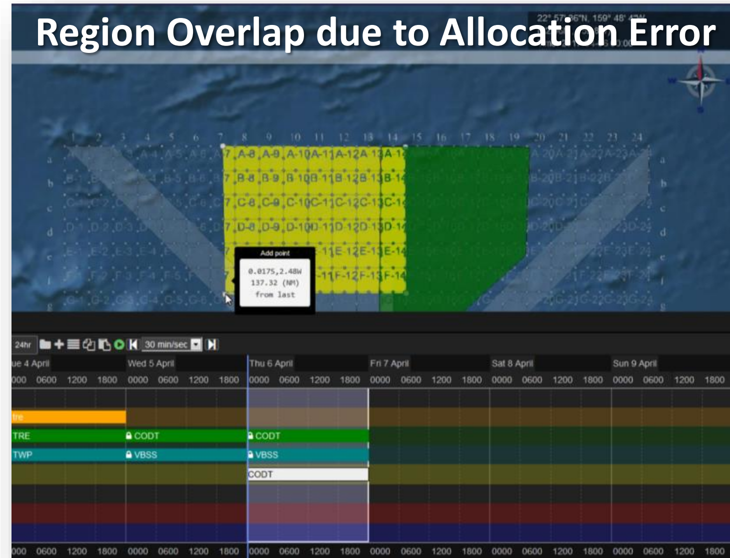
**SCOUT** – Supervisory Control Operations User Testbed; **UAS** – Unmanned Aircraft System; **JIATF-S** – Joint Interagency Task Force-South

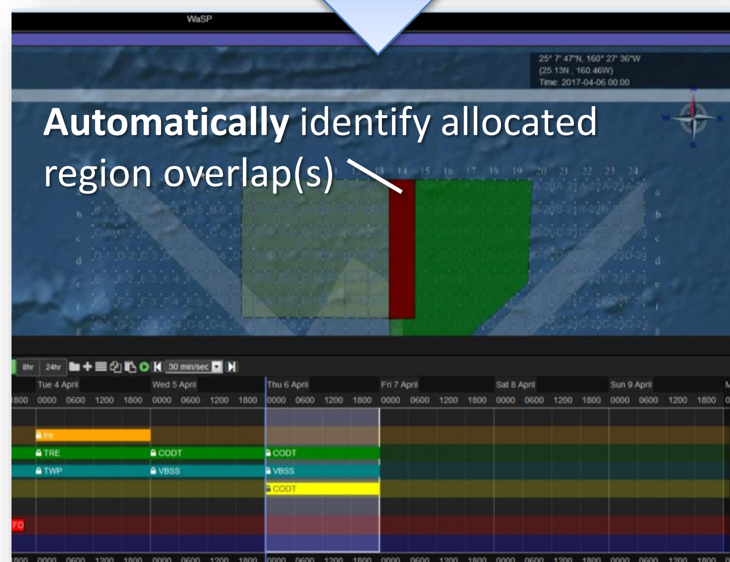
**Project: Agile Information and Decision Support Concepts for Dynamic Planning/Re-planning in $C^2$ of Unmanned and Undersea Systems, ONR, $1,148,080; PI: Pattipati**
**Project: Context-Driven Proactive Decision Support Concepts, Algorithms and Protocol for Agile Mission Planning in $C^4$ISR, ONR, $1,042,965; 8/15-12/18, PI: Pattipati**

# Systems Engineering/Modeling

## Water Space Management



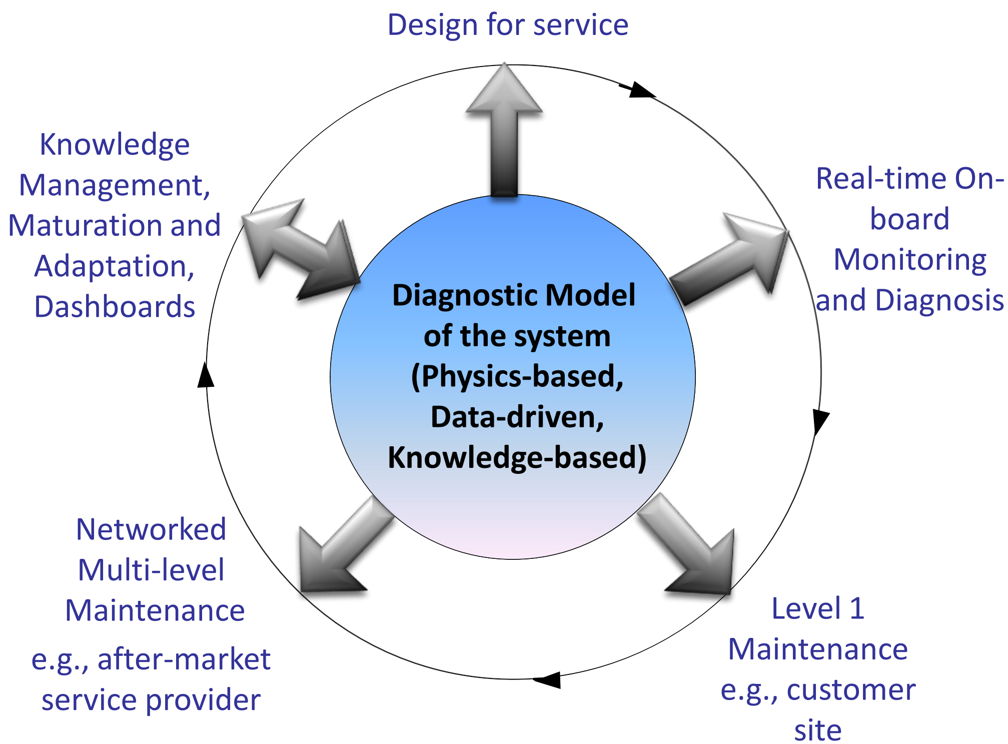




- **Proactive conflict identification** among multiple and heterogeneous assets allocated to possibly multiple regions and tracks via R-trees, TPR-trees, linear programming and quadratic programming approaches
  - *Major* projected **reduction in *operator workload*** (e.g., ~120 hrs → 2-4 hrs) and ***human error*** compared to current CONOPs (currently error prone and manual, using text files & Excel)
  - Fully integrated with NRL-MRY computing systems and NRL-MRY's **WaSP** software
- **Output:** Conflict identification (CONFIDENT) algorithms for WaSP *to* **<u>COMSUBPAC</u>** *via* **<u>NRL-MRY</u>**

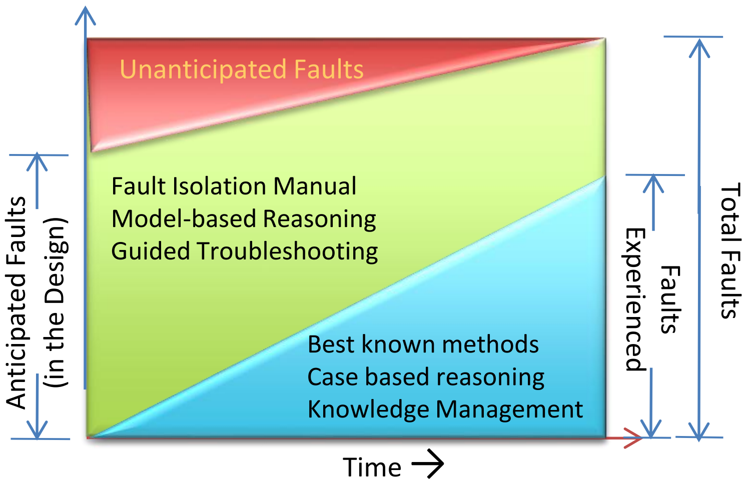
**Publication**: D. McMenemy, D. Sidoti, F. Palmieri and K. R. Pattipati, "A Fast and Efficient Conflict Detection Method for Ellipsoidal Safety Regions," submitted to *IEEE Trans. on AES*, Dec. 2017.

# Diagnostic and Prognostic Methods & Capabilities




- Physics-based Models
  - Concurrent design
  - Impractical for complex systems
- Data-driven Models
  - Rapid deployment
- Knowledge-based Models
  - Complex systems
  - Many-to-many relationships

Key Message: May need to combine multiple approaches for a given application




- Allows for model re-use across all phases of system life-cycle:
  - Concept ➢ Design ➢ Development ➢ Production ➢ Operations and training
- Use of the same model ensures that the results predicted by design analysis are achievable and repeatable in operations

# Optimal Sensor Selection and Information Fusion

**In sensor networks <u>optimality</u> deals with:**

- Environment and sensor network uncertainty and noise (objective is to reduce impact)
- Test design, time domain, sequence of admissible input changes (optimize)
- Sensor types and number needed for detection (minimize cost, weight, volume)

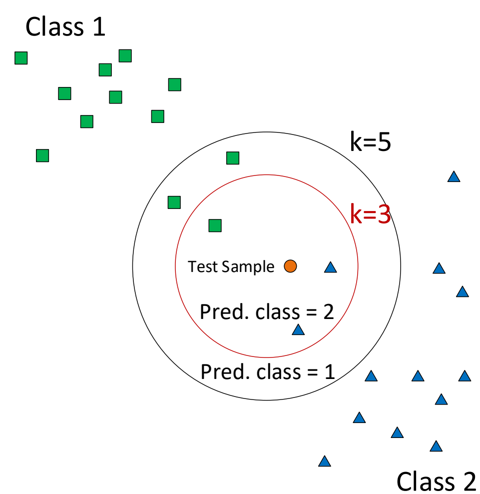
Sensors treated as binary variables in information maximization problems

$$\sum_{i=1}^{N_y} a_i \leq N_y',$$

$$\mathbf{H}(\tilde{\xi}, \varphi) = \sum_{i=1}^{N_y} \sum_{j=1}^{N_y} a_i a_j \sigma_{ij} \mathbf{Q}_i^T \mathbf{Q}_j = \begin{bmatrix} H_{ff} & H_{fu} \\ H_{uf} & H_{uu} \end{bmatrix},$$

$$\begin{aligned}
\boldsymbol{\varphi}^* &= [\mathbf{u}_p^*, \mathbf{t}_{sp}^*, N_{test}^* \geq 1, \mathbf{y}_0^*, \tau^*, \mathbf{a}^*] \\
&= \arg \max_{\varphi \in \Phi} \log \left( \frac{|\,\mathbf{H}(\tilde{\xi}, \varphi)\,|}{|\,H_{uu}(\tilde{\xi}, \varphi)\,|} \right) \\
&\text{s.t.} \\
&\mathbf{1}^T \mathbf{a} = N_y', \quad a_i \in \{0, 1\}, \quad \forall i = 1, \ldots, N_y, \\
&\mathbf{f}(\dot{\mathbf{x}}(t), \mathbf{x}(t), \mathbf{u}_p(t), \boldsymbol{\theta}_p, \tilde{\xi}, t) = 0, \\
&\hat{\mathbf{y}}(t) = \mathbf{h}(\mathbf{x}(t), \mathbf{u}_p(t), \boldsymbol{\theta}_p, \tilde{\xi}, t), \\
&\mathbf{y}_0 = \begin{cases} \mathbf{f}(\dot{\mathbf{x}}(t_0), \mathbf{x}(t_0), \mathbf{u}_p(t_0), \boldsymbol{\theta}_p, \tilde{\xi}, t_0) = 0, \\ \hat{\mathbf{y}}(t_0) = \mathbf{h}(\mathbf{x}(t_0), \mathbf{u}_p(t_0), \boldsymbol{\theta}_p, \tilde{\xi}, t_0), \end{cases} \\
&\mathbf{u}_p^L \leq \mathbf{u}_p(t) \leq \mathbf{u}_p^U, \quad \forall t \in [0, \tau], \\
&\mathbf{x}^L \leq \mathbf{x}(t) \leq \mathbf{x}^U, \quad \forall t \in [0, \tau].
\end{aligned}$$

Classification of sensory data




- Select the *optimal* sensor with *optimal* information at *optimal* system configuration at the *optimal* time sequence for the purpose)
- Automatically designs and executes tests for detection of objects using optimal sequences of sensed information and controllable actions
- Deals explicitly with uncertainty

**Publication**: Palmer KA, Bollas GM. Concurrent optimal design of sensor networks and fault detection tests for uncertain systems. A Mixed Integer Non-Linear Programing Approach. In preparation

# Systems Engineering/Modeling

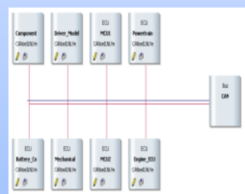
## Real World Applications

### Automotive

- Anti-lock/Regenerative Braking
- CRAMAS® Engine Data
- Li-ion Batteries
- Fuel pumps, ETCS, EPGS

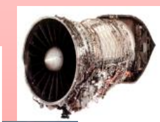
CRAMAS® Platform

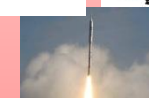
Regenerative Braking



### Aerospace

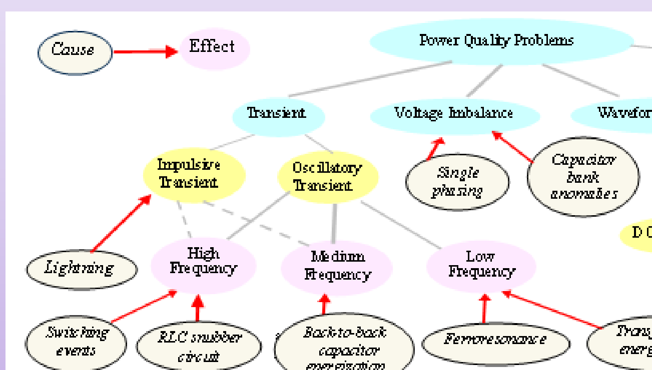
- PW2500
- Black Hawk and Sea Hawk T-700 Engines
- Non-toxic Orbital Maneuvering System
- Boeing 787 ECS
- Reaction Control System (NT-OMS/RCS )
- International Space Station
- Ares-1x Rocket





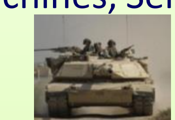
### Power/Buildings

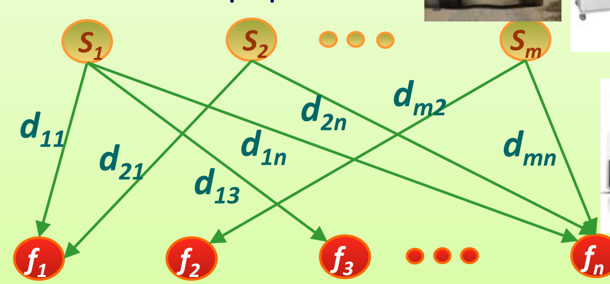
- Power Quality Monitoring
- HVAC Chillers




### Guided Troubleshooting

- Military Vehicles
- Optical Scanning Machines, Semiconductor
- Fabrication Facilities
- Medical Equipment





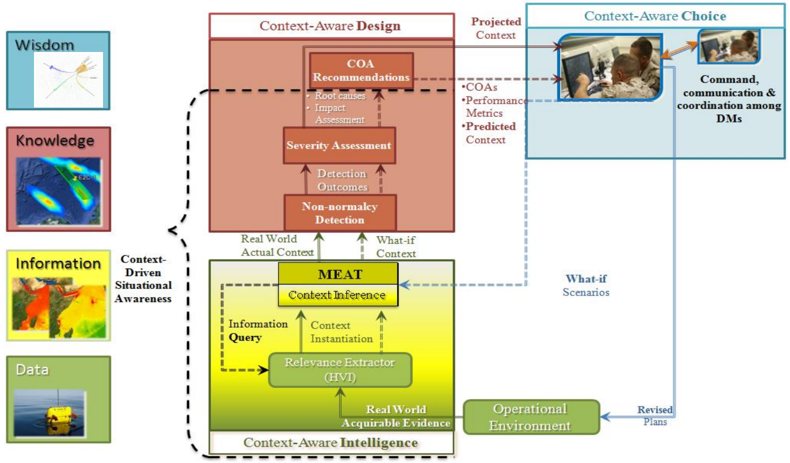
# Systems Engineering/Modeling

**Active Research Project:** Context-Driven Proactive Decision Support Concepts, Algorithms & Protocol for Agile Mission Planning in $C^4$ISR – DOD/Navy/ONR, Krishna R. Pattipati

**Project Objectives:** Develop and validate context-driven decision support concepts that will represent, infer and communicate operational context for agile resource management in dynamic and uncertain mission environment

- Task 1: Context Representation, Inference and Forecasting
- Task 2: Context Determination via Information Selection, Valuation and Prioritization
- Task 3: Context Communication
- Task 4: Context Driven Decision Making (validation)

## PDS Framework:




## Technical Approach:

- Context representation, inference and forecasting
  - Dependency Graphs, Markov Logic Networks
- Uncertainty management, information selection, valuation and prioritization
  - Anti-fragility metric, value of information analysis, game theoretic approaches
- Structured communication protocol
  - Encapsulate context for accurate and timely information dissemination
- Validate Proactive Decision Support concepts and recommend COAs (NiU, WaSP missions)

**Ongoing Research:** PDS Softwares/Testbeds

- CONFIDENT: WaSP deconfliction algorithms (COMSUBPAC, NRL-MRY)
- Proactive TMPLAR (OPT/MTC2 via NRL-MRY)
- Proactive UAS Scheduling for SCOUT (NRL-DC)
- Dynamic resource allocation manager for InTop (NRL-DC)

**Impact:** Increase efficiency of asset utilization at the tactical and operational levels

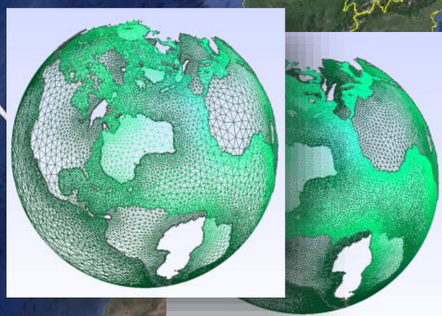
**Transitions:** CONFIDENT to NRL-MRY & COMSUBPAC; TMPLAR to NRL-MRY, COMSUBPAC, MSC, NAVSEA, and MTC2/OPT; UAS Scheduler in SCOUT™ to NRL-DC; InTop algorithms to NRL-DC

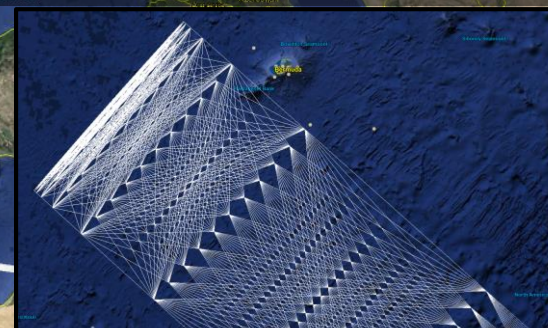
# Systems Engineering/Modeling

# TMPLAR

**Tool for Multi-objective PLanning and Asset Routing**

**OPT –** Operational Planning Tool
**WaSP –** Waterspace Planning
**MTC2 –** Maritime Tactical Command and Control
**USW-DSS –** Undersea Warfare Decision Support System
**NITES-Next –** Naval Integrated Tactical Environmental System Next Generation





- Modern and modular
- Auto-gridding, straits, waiting option (estimated **33% increase** in fuel efficiency)
- Spectrum of optimization routines
- Enables multi-objective optimization
- **Implemented** in **OPT** and **WaSP** for **MTC2** and (perhaps) **USW-DSS**
- **Available for NITES-Next implementation**

**Publication: 1.)** D. Sidoti, G.V. Avvari, M. Mishra, L. Zhang, B.K. Nadella, J.E. Peak, J.A. Hansen, and K.R. Pattipati, “A Multi-Objective Path Planning Algorithm with Time Windows for Asset Routing in a Dynamic Weather-Impacted Environment,” *IEEE Trans. on Sys., Man and Cybernetics: Systems*, vol. 47, no. 12, June 2016, DOI: 10.1109/TSMC.2016.2573271, pp.3256-3271.

**2.)** G. V. Avvari, D. Sidoti, M. Mishra, B. Nadella, L. Zhang and K.R. Pattipati, “Robust Multi-Objective Asset Routing in a Dynamic Weather-Impacted Environment,” submitted to *IEEE Access*, 2018.

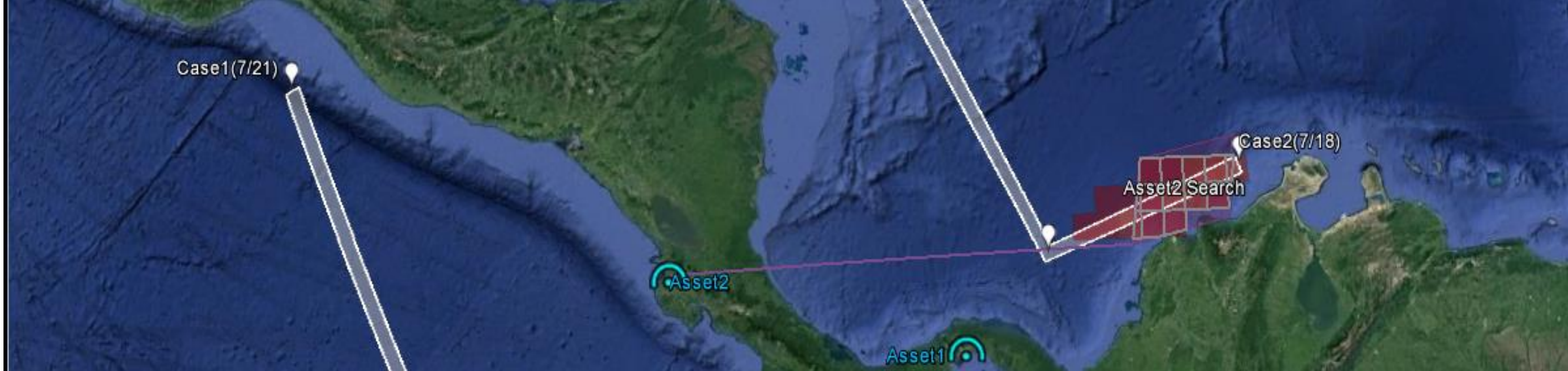
featured in: https://today.uconn.edu/2017/11/navy-using-new-uconn-software-improve-navigation/
http://www.professionalmariner.com/March-2018/Software-developer-says-new-routing-tool-might-have-saved-El-Faro

# Systems Engineering/Modeling

# COAST

**Courses Of Action Simulation Tool**

**JAWS –** Joint Asset Win Strategy (Sandia Nat'l Labs)
**JIATF-S –** Joint Interagency Task Force – South
**NRL-MRY –** Naval Research Laboratory – Monterey, CA




- Mixed-initiative planning functionality to optimize around the targeteer's needs
- Suite of sequential and parallel optimization routines
- Enables multi-objective optimization
- Implemented in **JAWS** for **JIATF-S** and **NRL-MRY**

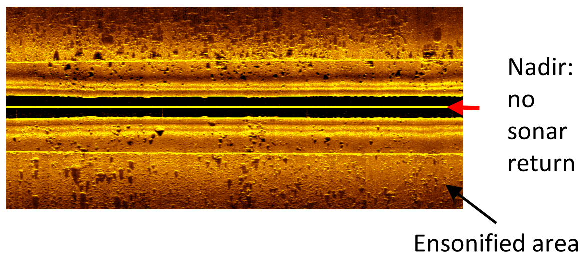
**Publications:** 1. D. Sidoti, X. Han, D.F.M. Ayala, M. Mishra, S. Sankavaram, W. An and K.R. Pattipati, "Context-Aware Dynamic Asset Allocation for Maritime Interdiction Operations," accepted to *IEEE Transactions on SMC*, DOI:10.1109/TSMC.2017.2767568, 2017.

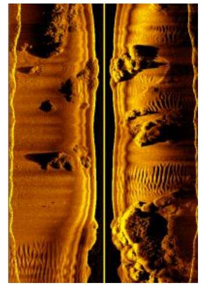
2. M. Mishra, W. An, X. Han, D. F. M. Ayala, D. Sidoti, K. R. Pattipati, D. L. Kleinman, "Context-Aware Decision Support for ASW Mission Planning in a Dynamic Environment" in IEEE Transactions on Systems, Man, and Cybernetics: Systems, vol. PP, no. 99, pp. 1-18, DOI: 10.1109/TSMC.2017.2731957, 2017.

# Systems Engineering/Modeling

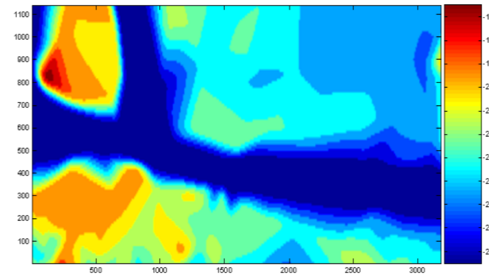
**Active Research Project:** Search Strategies with UUVs, considering bathymetric and sensor characteristics – Manbir Sodhi

UUV Side Scan Sonar Trace



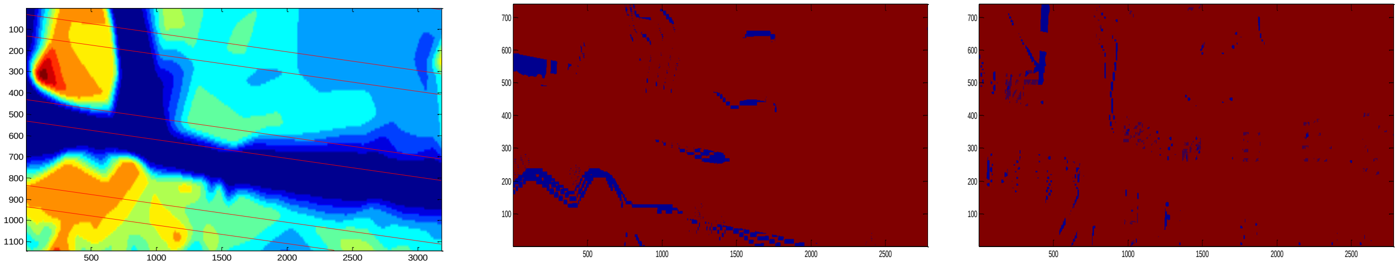
*Field cluttered with rocks*



Harbor Bathymetry at (x4)

**Other search problems using UUVs :**

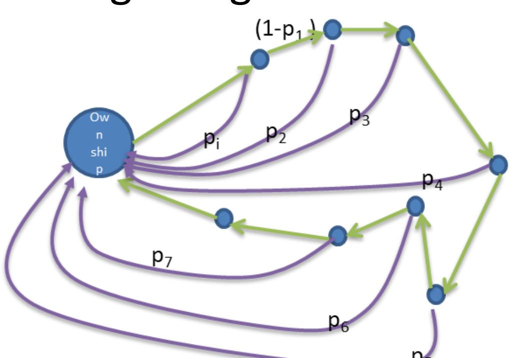
1. UUVs with job times.
2. UUVs with multiple targets.
3. Multiple vehicle search strategies.



*AUV running at 5m altitude along 175 degree direction with a 200m range sidelooking sonar. The blue pixels represent the shadow, the red ones the insonified regions. The shadow area is 3.9% of the whole image.*

*Same scenario, but now the direction is 85 degrees and the fraction of the shadow is only 1.9%.*

## Searching Using UUVs with reward probabilities




Optimal solution can be determined by investigating locations ordered such as*:

$$\frac{p_{[1]}d_{[1]}}{(1-p_{[1]})} \leq \frac{p_{[2]}d_{[2]}}{(1-p_{[2]})} \leq \ldots \leq \frac{p_{[n]}d_{[n]}}{(1-p_{[n]})}$$

This can be used to obtain a lower bound for the cost.

*Agnetis, A., Detti, P., Pranzo, M and Sodhi, M., Journal of Scheduling.

# Capabilities

- URI Computing clusters:
  - CUDA based
  - Multi-CPU based.
- UConn Storrs HPC cluster
  - CPU Cores: 6,328
  - CPU Architecture: Intel Xeon x64
  - Total RAM: 33TB
  - Interconnect FDR Infiniband
  - Shared Storage: 1PB Parallel Storage
  - Accelerators: NVIDIA GPUs and Intel Xeon Phi
  - Peak Performance: 250 Teraflops
  - Campus Connection: 20Gbps Ethernet
- Embedded computing
  - FPGA
  - FOG Computing
- Simulation Capabilities:
  - Matlab, Simulink, Modelica, FMI
  - VTI CORE
  - C++, python, Julia.
  - Promodel, Simio, Arena, GAMS.

Innovation Partnership Building (IPB) at the UConn Tech Park

The Institute will be hosted in a 2000 sq.ft. space in the UConn Technology Park, which provides access to world-class computational facilities, the Pratt & Whitney Additive Manufacturing Center at UConn, the Connecticut Center for Cybersecurity and recently funded efforts by the DOD-sponsored Advanced Robotics for Manufacturing Institute and the DOE-sponsored Clean Energy Smart Manufacturing Innovation Institute.

# Systems Engineering/Modeling

## WHY SYSTEMS ENGINEERING?

The convergence of computation, communications, and control enable cyber-physical systems (CPS) to have learning and predictive capabilities capable of adapting to changing situations. Motivated by the increasing complexity of advanced products and the digital revolution, the UTC-IASE trains engineers in urgently needed CPS-related disciplines that are pivotal to innovation and product enhancement in the globally competitive economy. With its industrial base and focus and excellent faculty, the UTC-IASE is positioned to advance the science base of CPS and to accelerate its technological translation into sustained industrial growth.

## INDUSTRY SECTORS OF FOCUS

Aerospace | Smart Cities | Robotics | Manufacturing | Energy

# Systems Engineering/Modeling

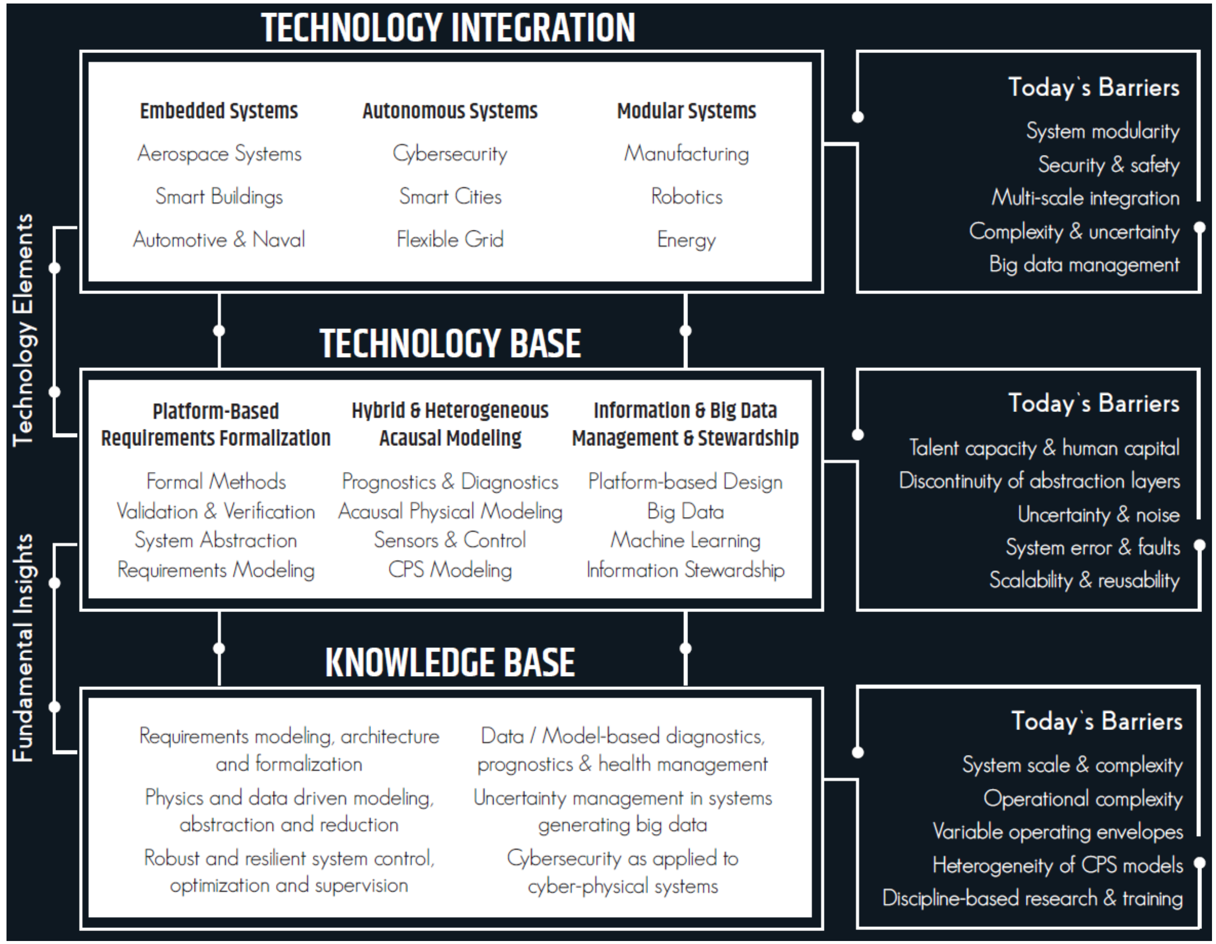
## Leveraging a Network of Excellence in Systems Engineering

UTC-IASE focuses areas and capabilities :

a) **Platform-based requirements formalization,**

b) **Hybrid and heterogeneous acausal modeling of cyber and physical system components and systems**

c) **Information & Big Data management and stewardship.**




These technologies enable progress in the areas of embedded, autonomous and modular systems, which is infeasible with today's discipline-based structure of research and education.

# George Bollas – UTC-IASE UConn

**Brief Bio:** Dr. George Bollas is an Associate Professor with the Chemical & Biomolecular Engineering Department, and the Director of the United Technologies Corporation Institute of Advanced Systems Engineering at the University of Connecticut. Prior to joining UConn, he was a postdoctoral fellow at the Massachusetts Institute of Technology and before that he received his BS and PhD in Chemical Engineering from the Aristotle University of Thessaloniki in Greece. His current research portfolio includes the design and optimization of complex systems, real time optimization and model-based supervisory control; model-based fault detection identification and accommodation; Bayesian design of tests for fault-detection and isolation; deterministic model reduction; and physics-informed machine learning. Dr. Bollas is the recipient of the NSF CAREER and ACS PRF DNI awards, the UConn Mentorship Excellence and AIChE Teacher of Year awards, and member of the Frontier of Engineering Education of the NAE.

## Research Capabilities & Expertise

- Acausal, equation-oriented system modeling
- Uncertainty propagation & quantification
- Fault Detection and Isolation
- Information Stewardship
- System Design & Optimization
- Model reduction
- Cyber-physical Systems
- Systems Engineering

## Research/Technology Capabilities as related to undersea vehicles

- Modeling Thermal-fluid systems for undersea vehicles
- Sensor selection and data analytics
- Model-based design of tests and planning for undersea vehicles exploration
- Deterministic large-scale model reduction
- Fault detection, isolation and prognosis algorithms and fault-tolerant control
- Workforce talent for the development of new technologies

## Problems the technology can address as related to undersea vehicles

- UV modeling (thermal fluid systems, engine systems, etc.)
- Model reduction for the purpose of real-time optimization within tight state spaces
- Model-based requirements formalization
- Anomaly detection of data recorded internally and externally in UVs
- Built-In Test (BIT) design for UV systems and subsystems
- Active and passive tests for FDI in UV systems and subsystems

**Available facilities, highlighting unique capabilities:** The UTC Institute for Advanced Systems Engineering (UTC-IASE) is a hub for world-class research and education focused on model-based systems engineering of complex systems that are built from and depend upon the synergy of computational and physical components. The Institute research and educational programs address foundational scientific areas of: (a) requirements formalization and systems engineering; (b) physics and data driven modeling; (c) advanced system control and optimization; (d) system diagnostics, prognostics and health management; (e) uncertainty; and (f) big data systems engineering principles of cybersecurity. The Institute is located in a 2000 sq.ft. space in the UConn Technology Park, which provides access to world-class computational facilities, the Pratt & Whitney Additive Manufacturing Center at UConn, the Connecticut Center for Cybersecurity and recently funded efforts by the DOD-sponsored Advanced Robotics for Manufacturing Institute and the DOE-sponsored Clean Energy Smart Manufacturing Innovation Institute.

## Example Publications and Further Reading

- Palmer KA, Hale WT, Bollas GM. Optimal Design of tests for heat exchanger fouling identification, Appl. Thermal Eng. 2016;95:382-93.
- Palmer KA, Hale WT, Bollas GM. Built-in Test Design for Fault Detection and Isolation in an Aircraft Environmental Control System, IFAC Papers Online. 2016;49(7):7-12.
- Bollas GM, Palmer K, Prasad D, Park Y, Maljanian J, Poisson R, Jacobson C. Plate-fin Heat Exchanger Fouling Identification. US Patent Application #201562172486, EU Patent Application #16173593.1 - University of Connecticut and United Technologies Corporation, 2016.

# Krishna R. Pattipati – UTC-IASE UConn

**Brief Bio:** Dr. Krishna Pattipati is currently the *Board of Trustees Distinguished Professor* and the United Technologies Corporation (UTC) *Chair Professor* of Systems Engineering in the ECE Department at the University of Connecticut (UConn). His current research activities are in the areas of agile planning and proactive decision support, diagnosis and prognosis techniques for cyber-physical systems, machine learning, and combinatorial optimization. He has published over 500 scholarly journal and conference papers in these areas (number of citations: 11,933; h-index: 56). He was the recipient of the IEEE Centennial Key to the Future Award in 1984 and served as the Editor-In-Chief of the *IEEE Transactions on SMC: Part B-Cybernetics* during 1998-2001. He was co-recipient of the Andrew P. Sage Award for the Best *IEEE SMC Transactions* paper for 1999, the Barry Carlton Award for the Best *IEEE AES Transactions* paper for 2000, the NASA Space Act Awards in 2002 and 2008 for contributions to Diagnostics and Real-time Inference, the UConn AAUP Research Excellence Award in 2003, and the UConn School of Engineering Teaching Excellence Award in 2005. Professor Pattipati has won numerous best paper awards at various *IEEE Automatic Testing* and *Command and Control conferences*. He was an elected *Fellow of the IEEE* in 1995 and of the *Connecticut Academy of Science and Engineering* in 2006. He is a Co-Founder of Qualtech Systems, Inc. and Aptima, Inc.

**Research Capabilities & Expertise:** Application of systems theory and optimization techniques to solve problems of interest to Commercial Industry and National Defense, including:

- Fault Detection, Diagnosis and Prognosis (FDDP) in CPS
- Adaptive Charging and Fuel Gauging of Li-ion batteries
- Machine Learning for Anomaly Detection and Active Learning
- Proactive Decision Support (Resource Allocation, Vehicle Routing, Intelligent Autonomy, Water Space Management)

**Research/Technology Capabilities as related to undersea vehicles**

- Condition-based maintenance of undersea vehicles
- Multi-domain mission planning
- Workforce Talent in Optimization and Inference

**Problems the technology can address as related to undersea vehicles**

- Big Data Analytics and Machine Learning
- Search, Routing and Mission Planning
- FDDP
- Testability Analysis and Design for Service
- Architectures for CBM+
- Sensor Fusion

**Example Publications and Further Reading**

- S. Deb, M. Yeddanapudi, K. Pattipati and Y. Bar-Shalom, "A generalized S-D assignment algorithm for multi-target multi-sensor state estimation," *IEEE Trans. On Aerospace and Electronic Systems*," vol. 33, no. 2, pp. 523-538, April 1997.
- S. Deb, K.R. Pattipati, V. Raghavan, M. Shakeri, and R. Shrestha, "Multi-signal Flow Graphs: A Novel Approach for System Testability Analysis and Fault Diagnosis," *IEEE Aerospace and Electronics Magazine*, May 1995, pp. 14-25.
- M. Mishra, D. Sidoti, G. Avvari, P. Mannaru, D.F.M. Ayala, K.R. Pattipati and D. L. Kleinman, "A Context-Driven Framework for Proactive Decision Support with Applications" *IEEE Access*, May 2017.
- D. Sidoti, G. V. Avvari, M. Mishra, L. Zhang, B. Nadella, J. A. Hansen, and K. R. Pattipati, "A Multi-Objective Path Planning Algorithm with Time Windows for Asset Routing in a Dynamic Weather-Impacted Environment," *IEEE Transactions on Systems, Man and Cybernetics: Systems*, Vol. 47, Issue 12, p. 3256-3271, December 2017.

**Active Federal Funding**

- Atmospheric Effects Analysis and Prediction, Naval Research Laboratory, Amount: $780,383; Duration: 3/01/2016-3/19/2019, Role: PI.
- Context-Driven Proactive Decision Support Concepts, Algorithms and Protocol for Agile Mission Planning in C4ISR, Office of Naval Research, Amount: $1,042,965; Duration: 8/01/2015-12/31/2018, Role: PI.
- Atmospheric Effects on Multi-domain battlespace management and adaptive ASW, to be funded by DOD/Navy/United States, Role: PI

# Amy Thompson – UTC-IASE UConn

**Brief Bio:** Dr. Amy Thompson joined UConn in August 2017 as an Associate Professor-In-Residence and the Associate Director of Academic Programs with the United Technologies Corporation Institute of Advanced Systems Engineering (UTC-IASE) at the University of Connecticut. She currently teaches model-based systems engineering design and coordinates the online graduate programs in Advanced Systems Engineering for the UTC-IASE. Prior to joining UConn, she received her BS in Industrial Engineering, MS in Manufacturing Engineering, and PhD in Industrial and Systems from the University of Rhode Island and she taught Systems Engineering to undergraduate and graduate students for six years at the University of New Haven. She also worked with an interdisciplinary team to create a BS and BA in Sustainability Studies at the University of New Haven and taught courses in design for environment and sustainability. Her current research portfolio includes the application of model-based systems engineering for the design and optimization of complex systems, model-based fault detection and diagnostics (FDD) for HVAC-R systems; design of smart manufacturing systems, facilities, and buildings; supply chain design; and undergraduate, graduate, and online systems engineering education development and assessment. Dr. Thompson is the recipient of the US EPA Environment Merit Award (2017) and the University of New Haven Faculty Excellence Award for Student Advising (2013).

## Research/Technology Capabilities as related to undersea vehicles

- Model-based systems engineering for design and optimization of undersea vehicles
- Designing and assessing undersea vehicles for the system lifecycle and environmental sustainability
- Multi-attribute and multi-objective decision making in undersea vehicle design
- Requirements development and analysis for undersea vehicles
- Verification and validation for undersea vehicles
- Fault detection and diagnostics (FDD) for HVAC-R systems for undersea vehicles
- Manufacturing system and facility design: modeling and simulation of undersea vehicle manufacturing systems and facilities

## Problems the technology can address as related to undersea vehicles

Advancing a model-based systems engineering approach for developing undersea vehicles addresses the following problems in the design and development of undersea vehicles:

- Increasing complexity and reliance on software
- Increasing system extensibility (systems evolve over time)
- Variability in manufacture and environment including a widening supplier base and expanding operational envelopes
- Operational reliability
- Increasing redesign effort and cost late in the system development lifecycle
- Increasing maintainability and supportability costs

## Relevant Publications and Further Reading


- Thompson, A. and V. Maier-Speredelozzi. 2018. Conceptualization and Demonstration of a Supply Chain Relationship Assessment Model for Continuous Improvement, Journal of Supply Chain Management, Submitted March 2018.
- Thompson, A., S. Borrelli (United Illuminating), and L. Darveau (EPA). 2017. HOW Green is Connecticut. EUEC Energy, Utility, and Environment Conference 2017, 20th Annual Conference & Expo.
- Abdulaal, A. and A. Thompson. 2012. Solving a Facility Layout Problem for a Manufacturer Applying a Meta-Heuristic and Lean Objectives. INFORMS Annual Conference, October 2012, Pheonix, AZ.
- White, C, S. Sreebhashyam, and A. Thompson. 2011. Evaluation of the Performance and Capability of a 3-Dimensional Part Printer and its Fused Deposition Modeling Process. Proceedings of the 2011 Industrial Engineering Research Conference, T. Doolen and E. Van Aken, eds. 2011.


## Active Federal Funding

- US Department of Energy, “Bringing Fault Detection and Diagnosis (FDD) Tools into the Mainstream: Retro Commissioning and Continuous Commissioning of HVAC and Refrigeration Systems,” 2017-2020. UConn UTC-IASE: $210,000 of $1.2M grant: DE-FOA-0001518.

# Systems Engineering/Modeling

# Manbir Sodhi – University of Rhode Island

**Brief Bio:** Dr. Manbir Sodhi is a Professor of Industrial and Systems Engineering in the Mechanical, Industrial and Systems Engineering Dept. at the University of Rhode Island. Dr. Sodhi has also been a visiting professor at the Technical University – Braunschweig, Germany, and a visiting scientist with the NATO Undersea Research Center (NURC) in La Spezia, Italy. Dr. Sodhi has participated in research projects funded by national agencies such as NSF, Department of Defense, National Institution of Health and the Department of Transportation, and numerous local and private funding sources. He consults extensively with manufacturing companies for operations planning, facilities design, scheduling, and, process improvements.

## Research Capabilities & Expertise

- Modeling and analysis of highly automated manufacturing systems
- Tool life based of manufacturing processes
- Stochastic modeling
- Signal processing for machine condition monitoring
- Information systems design supporting manufacturing and production
- System design, simulation & optimization
- Machine vision applications in manufacturing
- IOT applications in manufacturing.

## Research/Technology Capabilities as related to undersea vehicles

- Operations models for UUV applications
- Multi-national tests of UUV capabilities (MX3 Test with NATO)
- Large scale optimization models
- Meta-heuristics for combinatorial optimization
- Eye movement tracking in naturalistic environments
- Sustainable manufacturing

## Problems the technology can address as related to undersea vehicles

- Simulation of single and multi-vehicle operations
- Decision support for deployment of submarines and UUVs.
- IOT applications for manufacturing of UVs.

**Available facilities, highlighting unique capabilities:** URIs Industrial and Systems Engineering Program in the Department of Mechanical, Industrial and Systems Engineering is one of the oldest Industrial engineering programs in the US. The department is focused on research and educational programs for sustainable system – which includes economic, environmental and social sustainability. The economic models include decision models that incorporate real time data from machines and other sensors with deterministic and stochastic models. The environmental focus is on reducing the local and global impact of manufacturing and supporting activities on the environment. The social aspects of sustainability address important issues related to the quality of life associated with advancing manufacturing economies. Scientific areas related to these focus areas are: (a) Systems modeling. (b) Deterministic and stochastic systems optimization. (c)

## Example Publications and Further Reading


- Novel self-adaptive particle swarm optimization methods, Pornsing, C., Sodhi, M.S. & Lamond, B.F. Soft Computing (2016) 20: 3579. https://doi.org/10.1007/s00500-015-1716-3
- Dynamic speed control of a machine tool with stochastic tool life: analysis and simulation, Lamond, B.F., Sodhi, M.S., Noël, M. et al. J Intell. Manufacturing (2014) 25: 1153. https://doi.org/10.1007/s10845-013-0756-8
- Varada K, Yuan C, Sodhi M. Multi-Vehicle Platoon Control With Time-Varying Input Delays. ASME. Dynamic Systems and Control Conference, doi:10.1115/DSCC2017-5123.
- Robust Flowline Design for Automotive Body Shops, Müller, Christoph; Spengler, Thomas IIE Annual Conference. Proceedings; Norcross (2014): 3077-3085.