# Sustainability and Resiliency in Supply Networks

PRISM Lab/Purdue

**PRISM Center**
**Production, Robotics, and Integration Software for Manufacturing and Management**

"Knowledge through information; Wisdom through collaboration"

PRISM Global Research Network


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IFPR
IFPR-APR

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APIEMS Asia Pacific Industrial Engineering and Management Society

# What is sustainability?

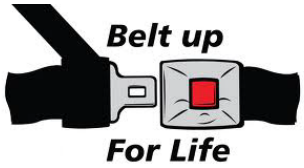
| | |
|---|---|
| U.N. General Assembly, (2005) | The reconciliation of **environmental, social** and **economic** demands - the "three pillars" of sustainability |
| Villeneuve, (2006) | Four dimensions define sustainable development: Ecological, economic, social, and ethical. |

# What is supply network resiliency?

| | |
|---|---|
| Christopher and Peck (2004) | The ability of a system to return to its original state or move to a new, more desirable state after being disturbed |
| Pettit et al. (2010) | The balance between a supply network's vulnerability and its capacity to overcome disruptions through management controls. |

# Vision

- **Sustainability is like a seat-belt … it may not improve driving, but it can save our lives**




- **Sustainability strategic challenges**:
  - Reduce waste, energy, hazards;
  - Overcome cultural / political differences;
  - Sustain profitability and viable communities
- **Resiliency challenge: Enable sustainability despite disruptions**
- **Sust. & Resil. decisions**: Complex, interdependent, need advanced modeling and control techniques + effective collaboration

***Collaborative Control Theory***

(CCT) Principles and framework

***Decision Support***

Models, Algorithms, Protocols

***Enhance sustainability & Resiliency***

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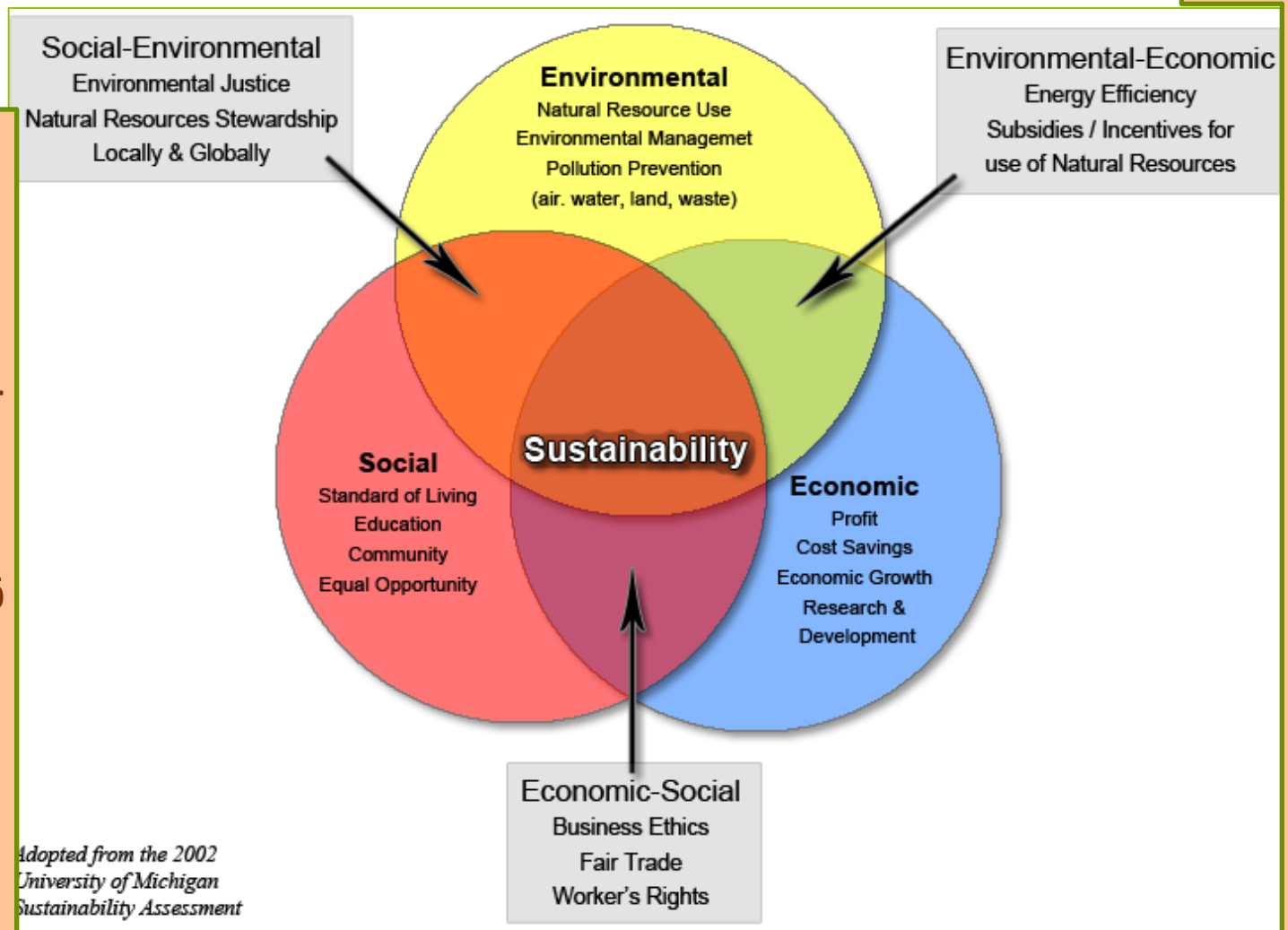
# Sustainability, Resiliency and Collaboration




**Collaboration** for coordination, sharing, back-up

**Resiliency** for continuity of supplies despite disruptions and disasters

**Cyber-support** for effective collaboration & resiliency

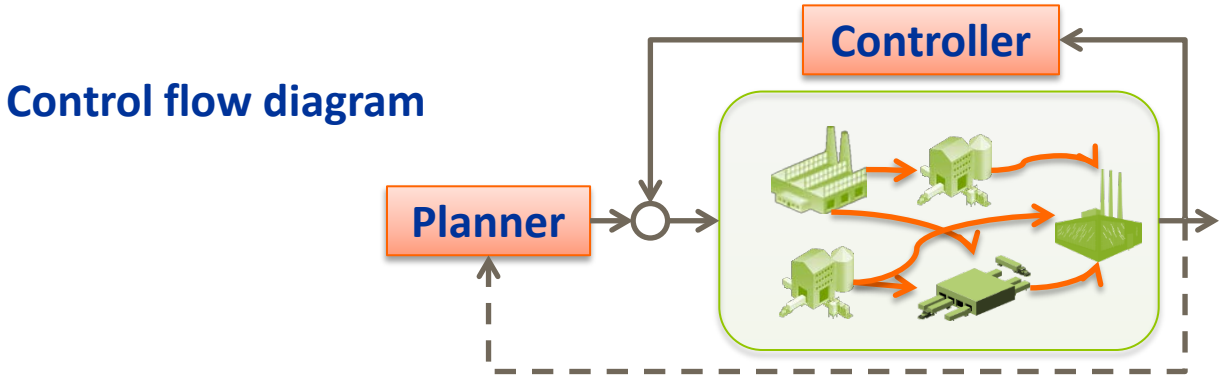
# Sustainability Solutions in Supply Networks

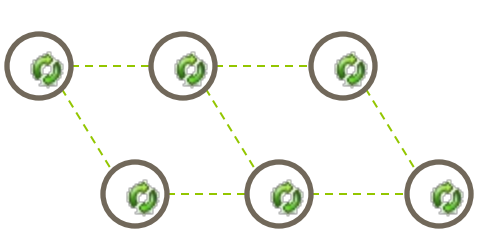
**Social**

| | | |
|---|---|---|
| **Environmental** | • Decision making in supply and service network with cultural impacts (Proctor et al, 2011) | • Corporate social responsibility applied to supply network (Hutchins & Sutherland, 2008) |
| | • Sustainable inventory models (Bouchery et al., 2011)<br>• Supplier collaboration model for sustainability (Seok & Nof, 2012)<br>• Integration of life cycle assessment with sustainable development (Matos & Hall, 2007) | • Analysis of the operations in a supply network from a sustainability perspective (MacCarthy & Jayarathne, 2012) |
| • Assessment of environmental sustainability in outsourced logistics (Facanha & Horvath, 2005)<br>• Integrated intelligent methods and decision analysis for green supplier selection (Kuo et al., 2010) | • Intersection of sustainability and global IT outsourcing (Babin & Nicholson, 2011) ● Lean production complementary to waste reduction and pollution reduction (King & Lenox, 2001) ● RFID impacts on recycled material supply network (Nativi & Lee, 2012) | ● Demand and capacity sharing over a collaborative network to optimize sustainable demand fulfillment and total profit in supply (Yoon & Nof, 2011) |

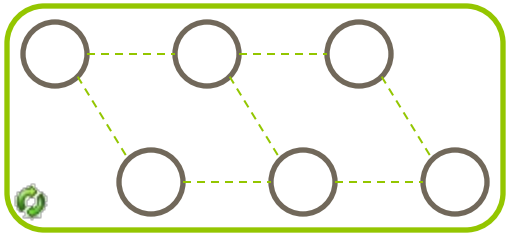
**Economic**

# General Architectures of Planning & Control (P&C) Models of Sust. & Resil. in Supply Networks

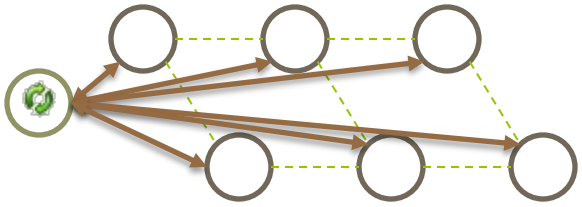


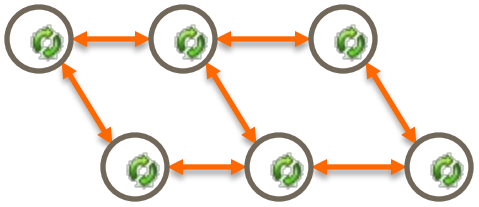
(a) Individual



(b) Encapsulation



(c) Outsourcing



(d) Collaboration

SN participant

Sustainability / Resiliency control resources

# P&C Models (examples)

| Architecture | Model | Example Reference | New Methodology | Data Analyzed | Results |
|---|---|---|---|---|---|
| (a) Individual | Multi-criteria decision analysis (MCDA) | Lahdelma et al. (2005) | MCDA framework k for collecting, storing, and processing all relevant information | Real-life problems | Making the decision process traceable and transparent |
| | Sustainable Economic Order Quantity (EOQ) | Bouchery et al. (2012) | Multi-echelon extension of SEOQ | Empirical data | Different regulatory policies to control carbon emissions, interactive procedure to identify the best option |
| (b) Encapsul-ation | Supply network design model | Nagurney & Nagurney (2010) | Sustainable supply chain network design model | Empirical data | A network optimization modeling framework for supply network examples |
| | Supply net resiliency framework | Petit et al. (2010) | Resource parallelism; net agility, robustness | Empirical | Anticipating & overcoming disruptions |

# P&C Models (examples, cont.)

| Architecture | Model | Example Reference | New Methodology | Data Analyzed | Results |
|---|---|---|---|---|---|
| (c) Outsourcing | Life-cycle assessment of each party's sustainability | Facanha & Horvath (2005) | The impacts of logistics outsourcing on environments | Real data from automobile industry | Comprehensive analysis of environment impact by the life-cycle of automobile logistics |
| | Economic energy management model | Babin & Nicholson (2011) | Analysis of sustainability in global IT outsourcing provider | Public data | Global IT outsourcing is growing maturity for environmental and social responsibility standards |
| | Design of resilient supply nets | Klibi & Martel (2012) | MIP solution of backup depots and multiple sourcing | Montecarlo scenario generation | Coverage by backup supply depots based on proximity |

# P&C Models (examples, cont.)

| Category | Model | Example Reference | New Methodology | Data Analyzed | Results |
|---|---|---|---|---|---|
| (d) Collaboration | Collaborative network for enterprises to share their demands and capacities | Yoon & Nof (2011) | Affiliation/ dissociation decision models | Experim-ental data | Single enterprise and collaborative network use coordinated to achieve mutual benefits |
| | Collaborative solution for product supply and delivery | Seok et al. 2012 | Sustainability decision support protocol | Experim-ental data | Collaborative solutions for supply network achieve maximum sustainability |

# Collaboration (e-Collaboration) is Key

## Value of collaboration by CCT, Collaborative Control Theory

- Effective collaboration can overcome sustainability and resiliency challenges:
  - Resolve conflicts, negotiate agreements, prevent errors
  - Fault tolerance by teaming and back-up
  - Optimize sharing (of transportation, resources), reuse, etc.
- CCT comprises six design principles plus a common analytic framework to enable different systems to achieve better sustainability through collaboration.
- HUBs ("Internet on steroids") enable CI, Collaborative Intelligence focused on improving human ability to collaborate effectively
- Cyber-supported collaboration → emerging Industrial Internet

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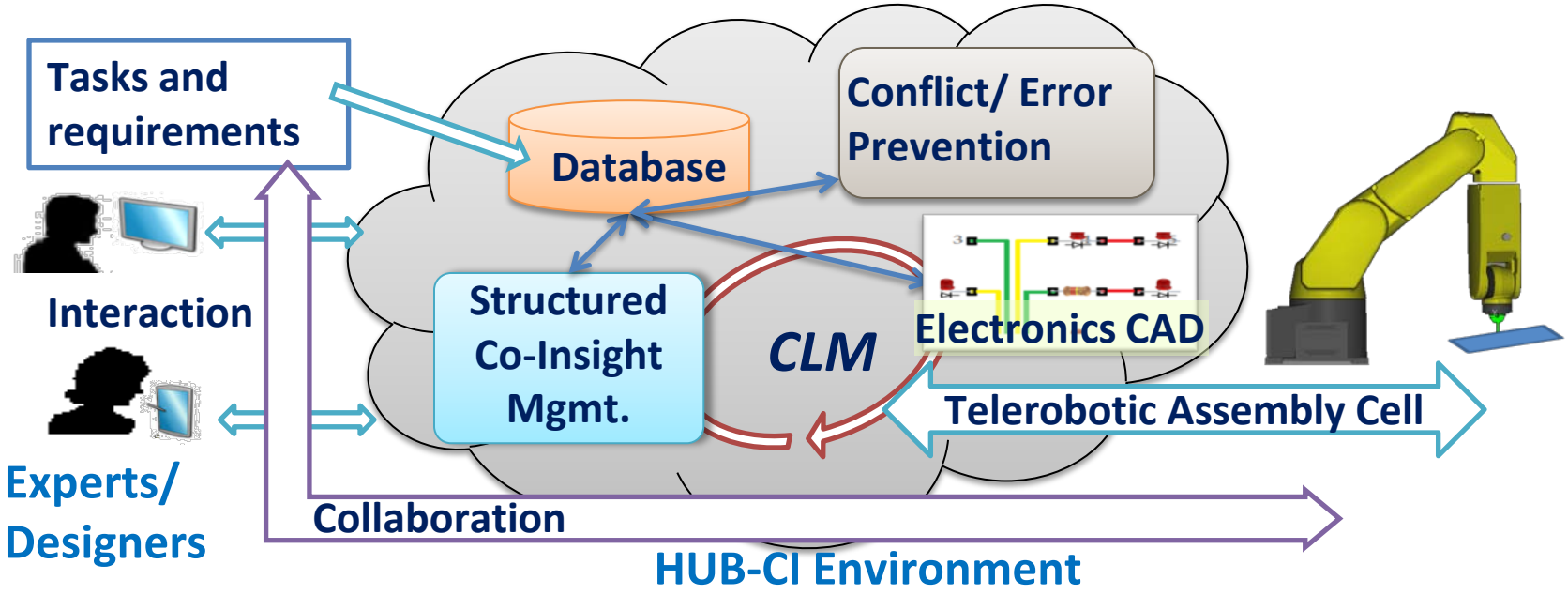
- Webinar: Collaborative Systems for Education, Innovation, and Supply Networks, IIE.org, 2012
- Velasquez & Nof: Ch. 88, *Springer HB of Automation*, 2009
- Nof: CCT for e-Work, e-Production, and e-Service, *Ann, Rev. in Control,* 2007

# P&C models, algorithms and protocols* based on CCT for sustainability enhancement in real cases

1. Sustainability decision support protocol (S-DSP)
   a. Sustainable supplier selection problem -- S/W works, India; NanoHUB, global
   b. Sustainable delivery scheduling problem – Automotive, USA; Reverse logistics, Costa Rica
2. Collaborative production line control protocol (CPLCP) – Paper products, El Salvador
3. Collaborative demand and capacity sharing protocol (CDCSP) – Airline companies, global; electronic assembly, USA

** Protocol: Distributed algorithm/procedure of algorithms for workflow optimization (vs. Protocol agreements)*

# Collaborative remote design & control of telerobotic production (Zhong and Nof, 2013) Prototyping, USA

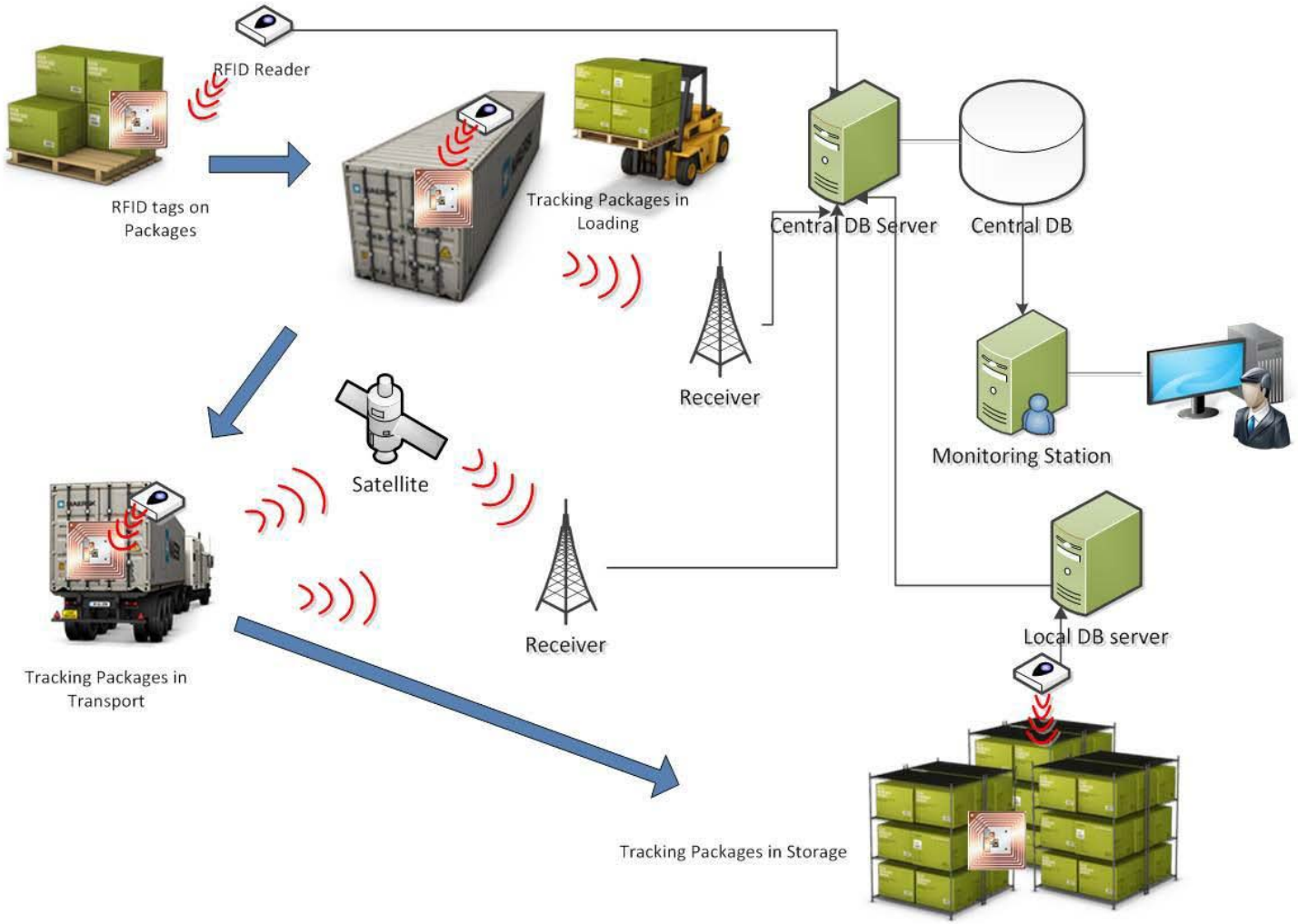



- **HUB-CI environment** -- hosted on a cloud, allowing accesses to the system through the Internet.
- Experts join the network to control telerobots in assembly cells, applying CI tools to support their collaborations.

**Collaboration**: human-automation; human-human; cyber-physical devices, etc.

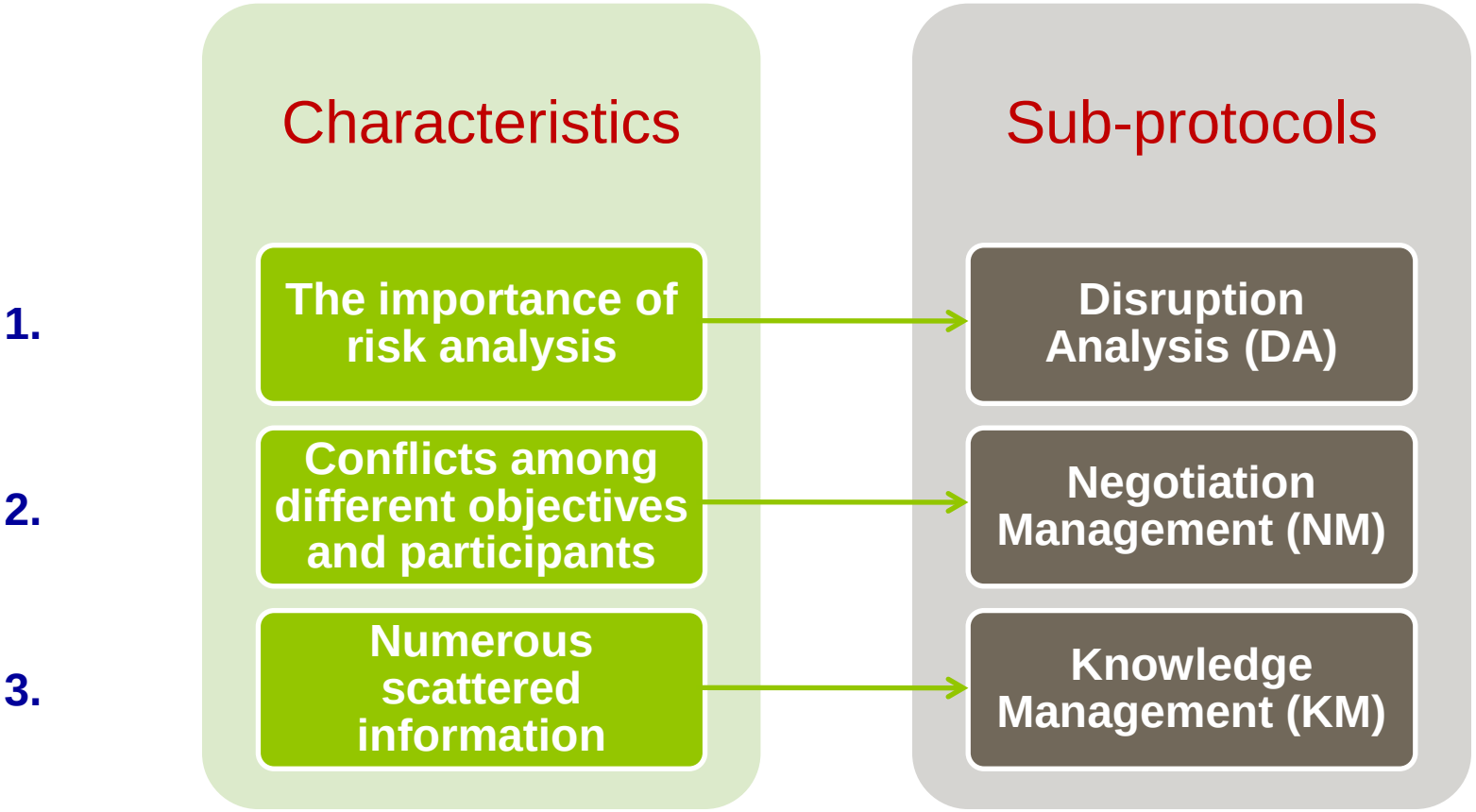
# Supply network security with RFID tags:

## Prevent thievery, hijacking, tampering with fault-tolerant planning & control [Tkach et al., 2013] Personal Care products, Brazil



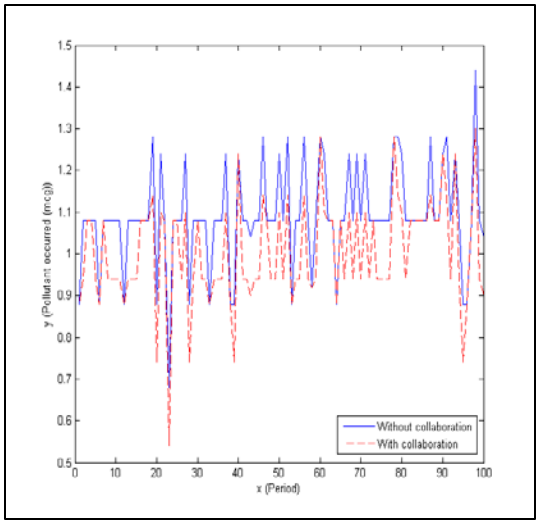
# Decision Support Protocol - S-DSP (Seok & Nof, 2011)

Model: Decisions for complicated sustainability conflicts; it consists of three sub-parts: (1) Disruption Analysis (DA), (2) Negotiation Management (NM), (3) Knowledge Management (KM)



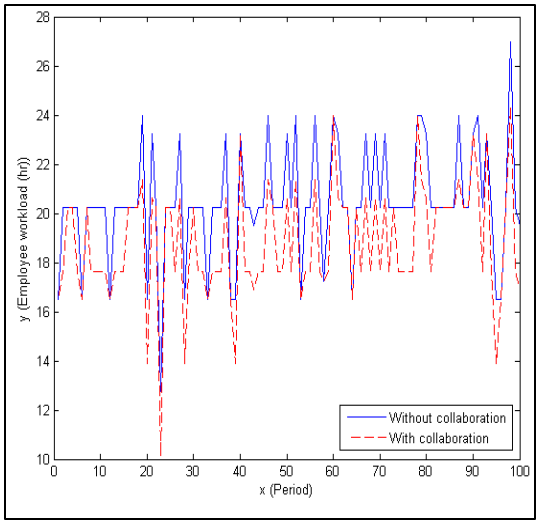
# Case: **Collaborative delivery scheduling and sustainability**

## Significant impacts of employing S-DSP with CCT - - -

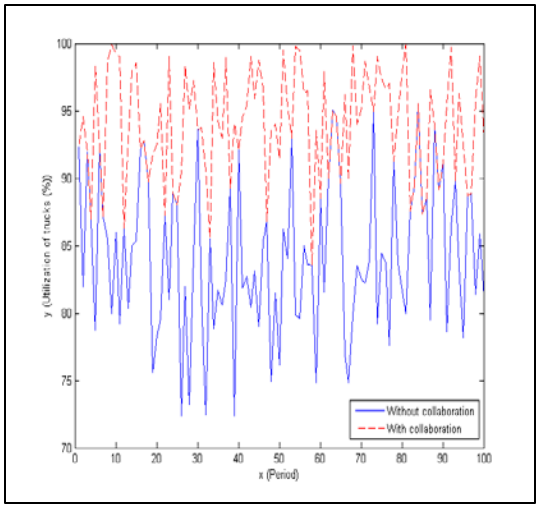



a. **Air pollutant (by delivery process) decreased**

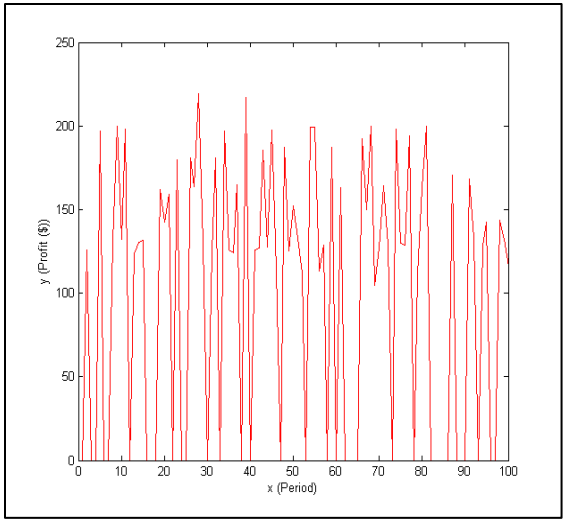
b. **Employee workload decreased**




Both reduced by between 9.7% and 20.6% with 12.8% average improvement




c. **Manufacturers' trucks utilization increased on average by 19.3%**




d. **Manufacturers' additional profit -- always non-negative**

Seok et al., *ARC*, 2012



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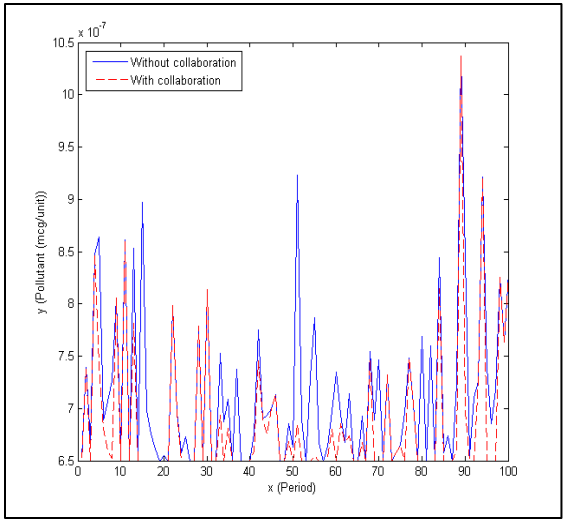
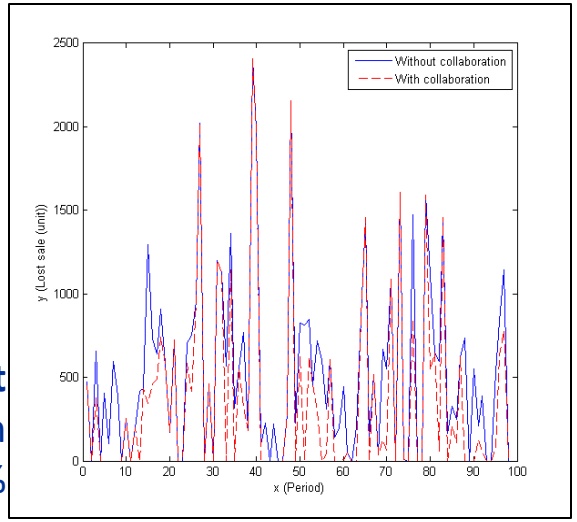
# Case: **Collaborative production scheduling and sustainability**

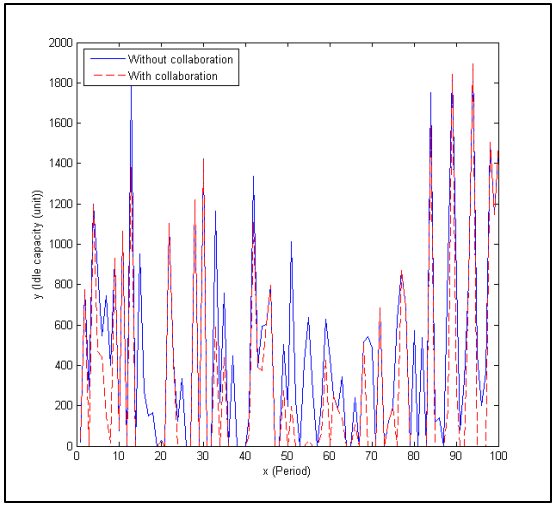
## Significant impacts of employing S-DSP with CCT - - -



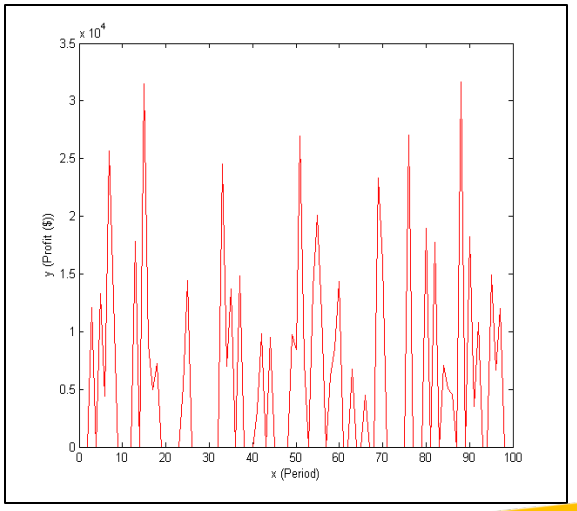

**a. Pollutant per product (occurred by production process) decreased** by 0.5% to 27. 5%, with 6.8% average




**b. Manufacturers' lost sales decreased** on average by 72.5%




**c. Manufacturers' idle capacity** decreased on average by 79.7%




**d. Manufacturers' additional profit**

Seok et al., *ARC*, 2012



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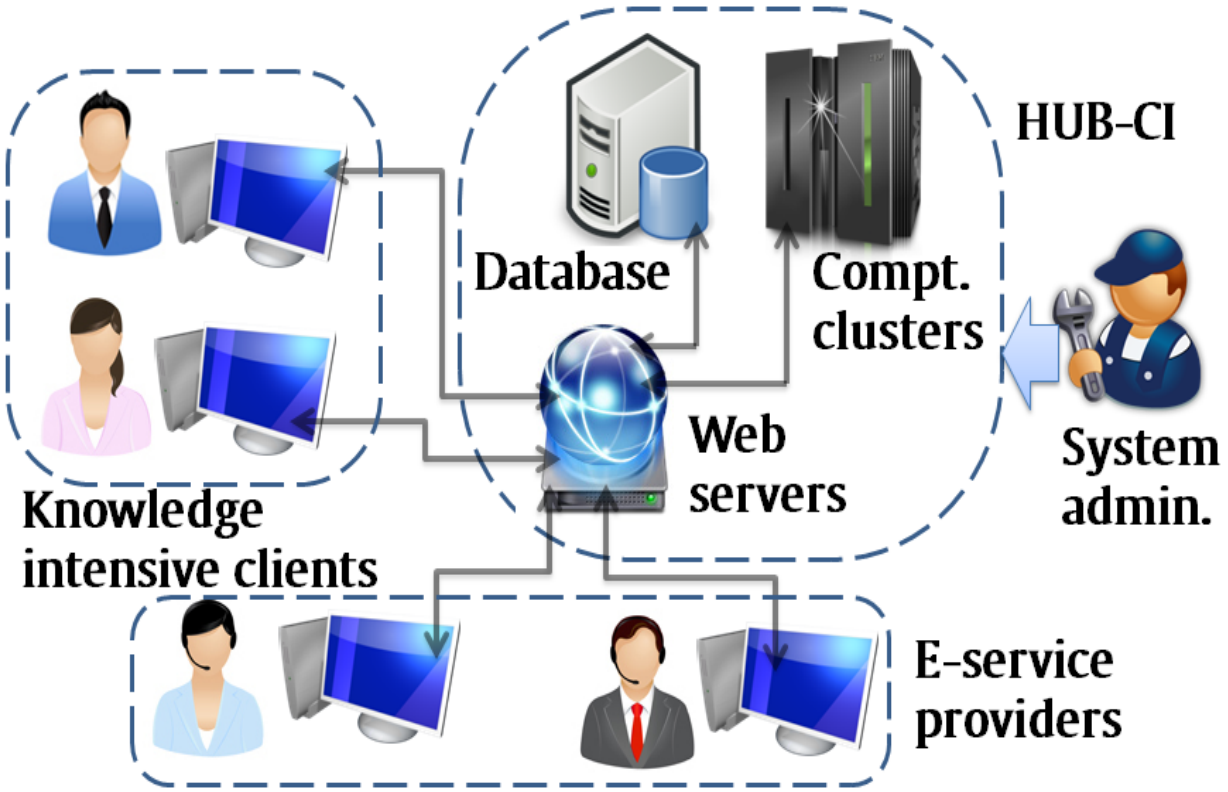
# Knowledge production and logistics [Devadasan et al., 2013]

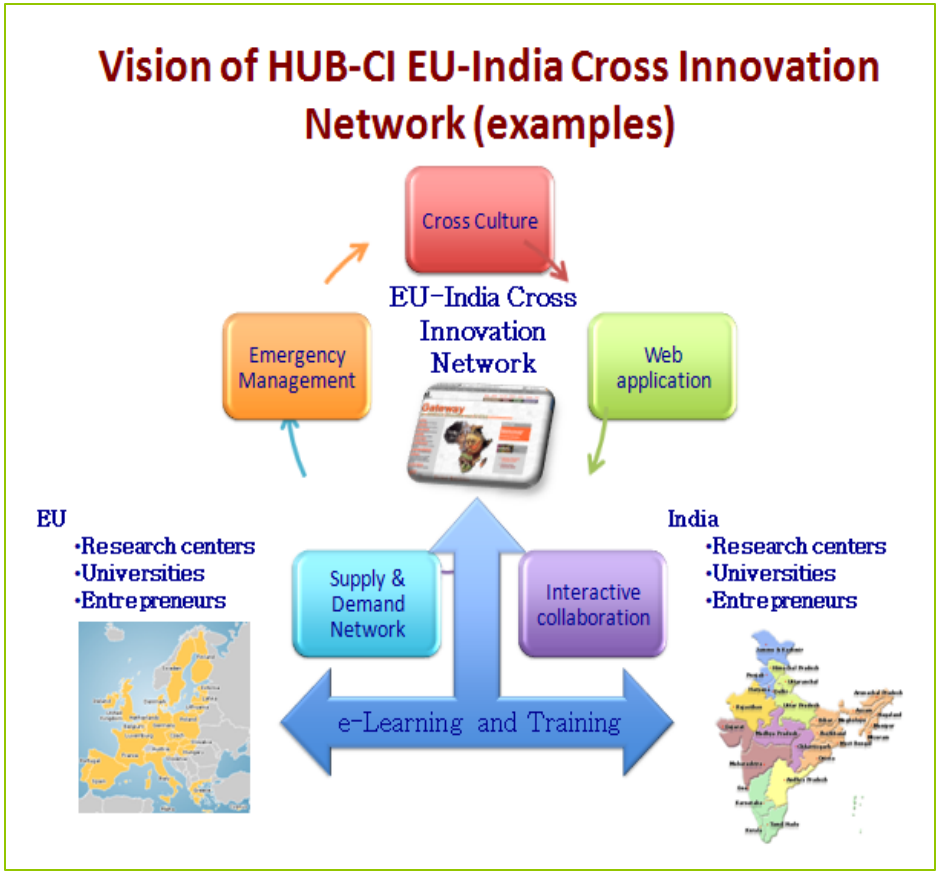
## HUB-CI and Collaborative Network Optimization




1. Measure CI (function of time, cost, defects)
2. Minimize total defects
3. Minimize total cost
4. Seek performance improvement over time

# Innovation network HUB Models & challenges

- Emerging global networks (hubs/clouds) to trade/adapt/engage/learn diverse ideas through collaboration with sustainability
- …challenges:
  - Cross-culture capabilities?
  - Multi-cultural interaction and infrastructures?
  - Challenged web-based applications?
  - Asynchronous multimedia?




Challenges of EU-India Cross Innovation Network targeted by HUB-CI



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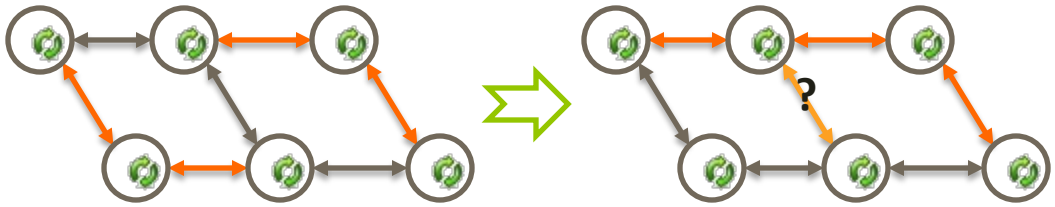
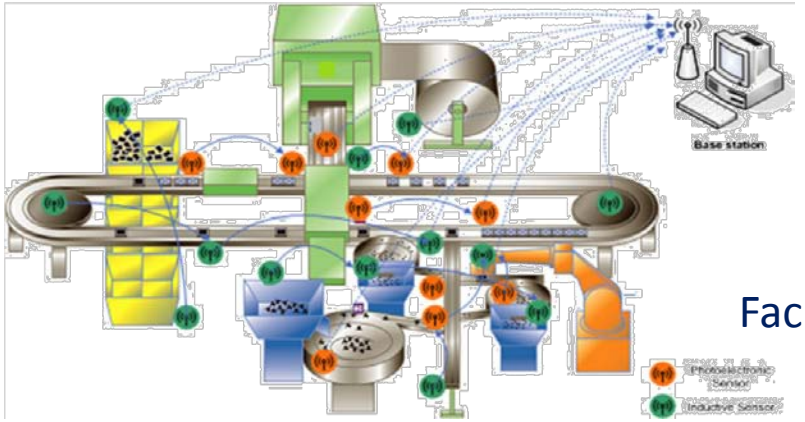
# Summary: Emerging trends & examples

## 1. Trust management




The change in trust leads to the changes in collaboration structure (Ex. Becket and Jones, 2012)

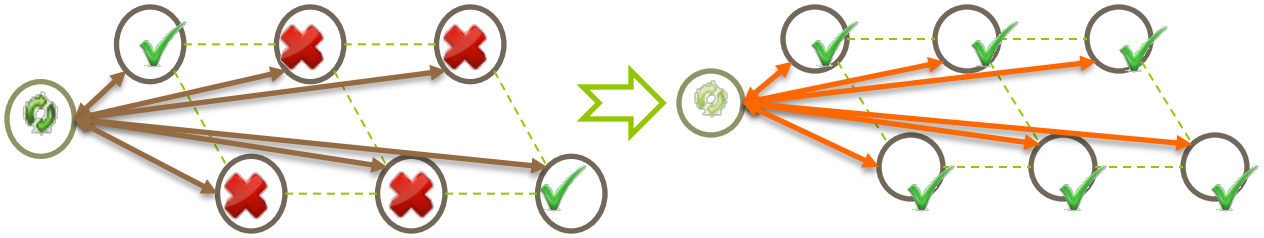
## 2. Emerging Cyber-Physical Systems (CPS) / Industrial Internet




Facility sensor network (Ex. Jeong, et al., 2012)

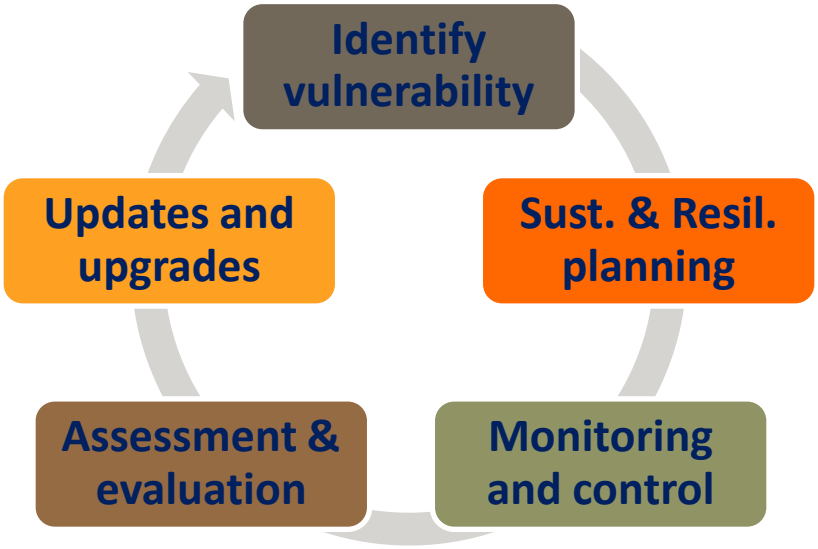
# Emerging trends & examples (Cont.)

## 3. Adaptive P&C to new sustainability demands



Sustainable planner and resilient controller that can be upgraded to meet new metrics (Ex. Seok et al., 2012)

## 4. Sustainability & resilience management lifecycle




(Ex. Barber et al., 2012)

# **Conclusions:** Educational and Research Challenges & Opportunities

- **Sustainability** is *essential* and *complex*, but *must be achievable*
- ***Resiliency*** *is essential and complex, but without it there is no chance for sustainability*
- *Progress is achieved in modeling*, decision processes and algorithms, measurement, and collaborative control for better sustainability & resiliency
- *Emerging:* Trust; Cyber-Physical Systems; adaptive P&C, and Sustainability/Resiliency lifecycle.
- *Collaborative intelligence* over high-performance Internet is emerging. **It may be our "seat-belt."**

# Acknowledgement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