Modeling and Analysis for Sustainable Development Based on Collaborative Control Theory (CCT)

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

"Knowledge through information; Wisdom through collaboration"

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Motivation / Objective

- **Sustainability challenges**: Strategically reduce waste, energy, hazards; overcome cultural / political differences; sustain profitability and viable communities
- **Sustainability decisions**: Complex, interdependent, need advanced modeling and control techniques, effective collaboration

Collaborative Control Theory

(CCT)
Principles and framework

+

Decision Support

Models,
Algorithms,
Protocols

→

Enhance the sustainability in various problems

What is sustainability?

Many definitions, three common bottom lines of sustainability:

Environmental, Social, and Economic sustainability

Source	Definition
Oxford English Dictionary, 1989	Capacity to keep a person or community from failing; maintain at the proper level; support life and nature with needs
Rosenbaum, 1993	Using methods, systems, materials that would not deplete resources or harm natural cycles
Vieria, 1993	Development that looks at a site's natural land, water, and energy resources as integral aspects of the development
Valentin & Spangenberg, 2000	Sustainable development is structured around four thematic imperatives: economic, social, environmental , and institutional, and six inter-thematic links, one for each bi-dimensional interconnection
Swiss Federal Statistical Office, 2005	Three main elements: Social solidarity; Economic efficiency and Ecological responsibility; and 45 postulates classified in 20 categories
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.

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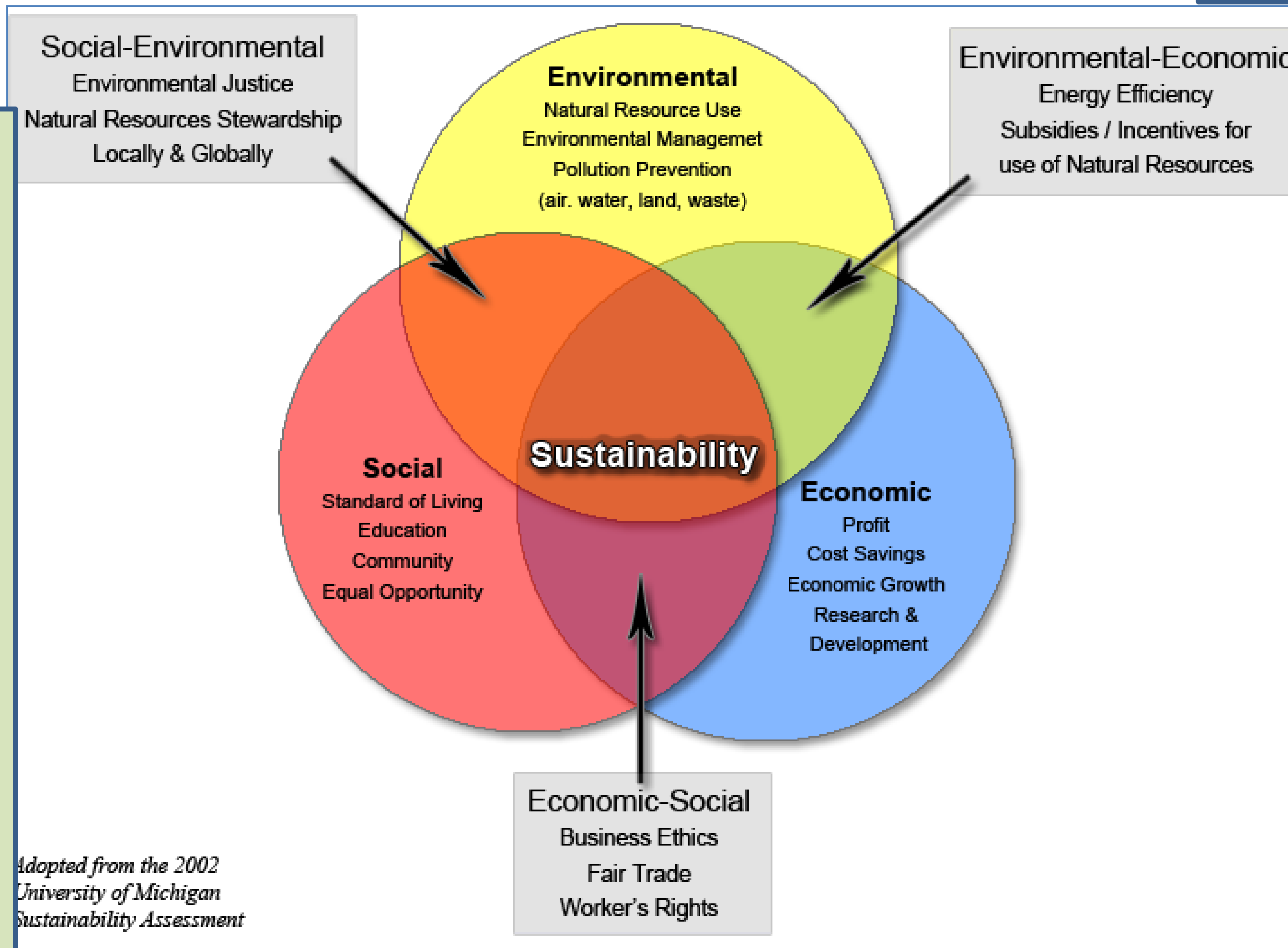
Sustainability and Collaboration



Collaboration, & Cyber-support for effective collaboration

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Sustainability issues in various industries

Common to all sustainable industries:

- A process of continuous Improvement
- Assess/reassess areas to improve sustainability performance
- Sustainable construction industry: Construction sites and production facilities for construction suppliers

- Sustainable transportation industry: Combine societal needs, efficiency, and impacts on the natural environment
- Environmentally conscious and product recovery manufacturing:
  - Life cycle analysis; Material selection; Design for environment + for disassembly + for recycling
  - Reverse logistics
  - Remanufacturing and disassembly

2012 *Production Planning & Control* Special Issues

Special Issue Topic	Sample Article Topics	Authors
Sustainable Mfg. Garetti, Mummolo, Taisch(eds.) *PPC* 23(2-3)	Environmental sustainability value cycle	Barber, Beach, Zalkiewski
	Sustainable supply chain design	Abdalla, Diabat, Simchi-Levi
	Environmental costing for sustainable mfg.	Cagno, Micheli, Trucco
	Sustainable managmnt. of end-of-life systems	Godichaud, Tchangani, Peres, Iung
	Reverse supply chain and product recovery	Loomba, Nakashima
Sustainable Collaborative Networks – Case Studies Matos & Boucher (eds.) *PPC* 23(4)	Carbon friendly supply chains	Jaegler, Burlat
	Clothing industry sustainable supply networks	MacCarthy, Jayarathne
	RFID adoption in Italian silk industry	Quetti, Pigni, Clerici
	Fuzzy model for food safety risk assessment	Wang, Li, Shi
	Collaborative networks for product services	Lelah, Mathieux, Brissaud, Vincent
	Collaborative network success and trust	Becket, Jones

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Collaboration is Key

CCT, Collaborative Control Theory, is useful

Value of Collaboration (VOC)

- Effective collaboration can overcome sustainability 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 achieve better sustainability through collaboration.

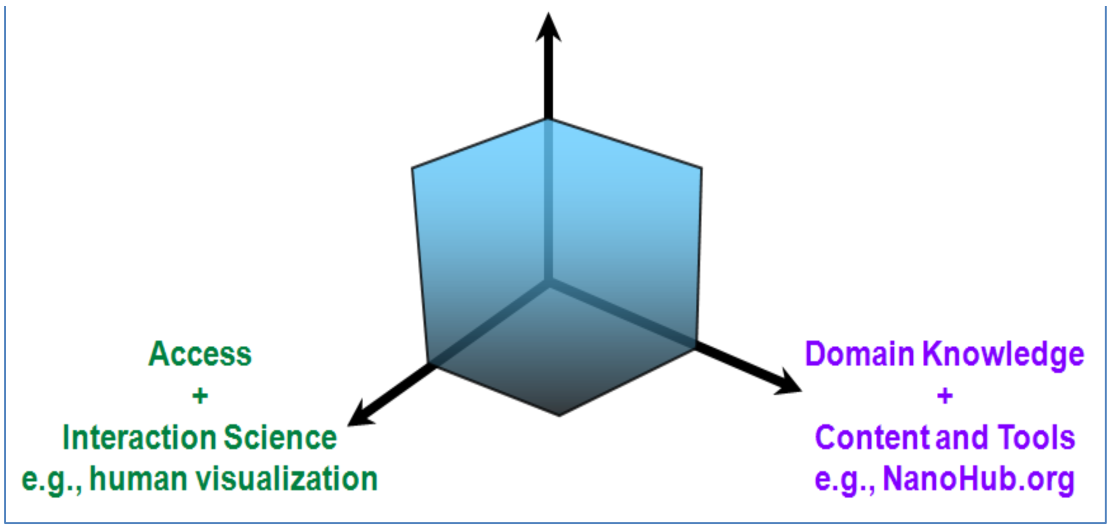
- Webinar: Collaborative Systems for Education, Innovation, and Supply Networks, IIE.org, 2012
- Velasquez & Nof: Ch. 88, *Springer HB of Automation*, 2009
- Nof: CCT for e-Work, e-Production, and e-Service, *Annual Reviews in Control*, 2007

CCT principles, and CSS, Collaboration Support Systems

1. *CRP* : Collaboration Requirement Planning
2. *PARK*: Parallelism + KISS: "Keep It Simple, cyber System!"
3. *CEDP* : Conflict & Error Detection and Prognostics
4. *FTT* : Fault-Tolerance by Teaming
5. *JLR* : Join/ Leave/ Remain in a collaborative network
6. *LOCC*: Lines Of emergent Command and Collaboration

- HUBs ("Internet on steroids") enable CI, Collaborative Intelligence focused on improving human ability to collaborate effectively

Collaboratorium Initiative for CI [Purdue ,08] **= CCT + CSS**



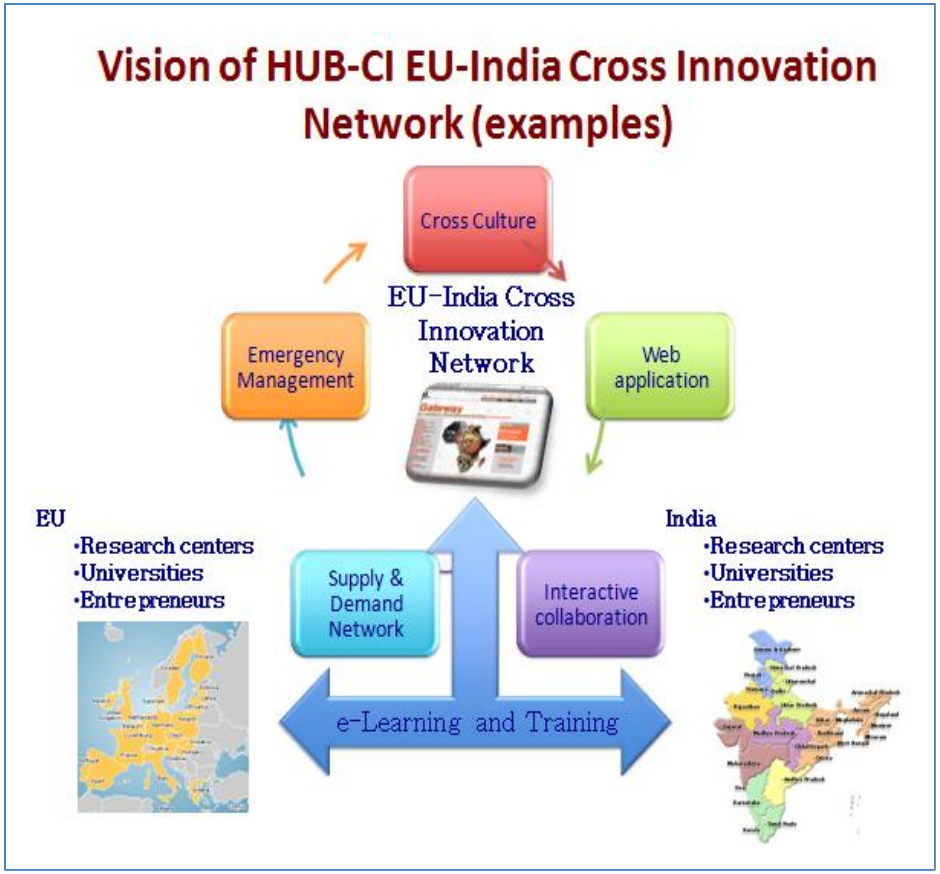
HUB-CI emerging advantages

- Better than existing HUBs based on CCT, HUB-CI is focusing on improving human collaboration through e-collaboration tools and services, by:

1. Significantly enhanced synthesis and integration of knowledge and discoveries
2. Understanding the dynamics of interactive-collaborative research work
3. Timely delivery of critically needed discoveries and shared knowledge

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

Innovation HUB-CI

1. **Cross-culture capabilities** – There is a need for effective tools and ontologies for communicating across multiple languages and cultures through text, illustrations, and multimedia tools.

2. **Multi-cultural interaction and linking multi-cultural infrastructures** – Human, social and environmental factors necessitate support and incentive mechanisms to promote engagement for dialog and knowledge sharing.

3. **Challenged web-based applications** – Working with limited bandwidth and constrained computing infrastructure capabilities (e.g., in remote regions needing human support).

4. **Asynchronous multimedia interactive collaboration** -- "emails" and non-real-time tele-meetings are required so people from different time zones can virtually meet "off line" while progressing effectively to meet time-constrained goals with minimal delays.

Decision support 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
   b. Sustainable delivery scheduling problem
2. Collaborative production line control protocol (CPLCP)
3. Collaborative demand and capacity sharing protocol (CDCSP)

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

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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)

	Characteristics		Sub-protocols
1.	The importance of risk analysis	→	Disruption Analysis (DA)
2.	Conflicts among different objectives and participants	→	Negotiation Management (NM)
3.	Numerous scattered information	→	Knowledge Management (KM)

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S-DSP (Cont.)

Disruption Analysis (DA)

- Prediction and management of possible disruptions related with specific sustainability issue, based on historical information and similar case studies.
- DA can choose and use appropriate analysis tools for risk analysis: fuzzy logic, stochastic methods including MCMC, forecasting methods, and Bayesian models.

Negotiation Management (NM)

- For better decision making, **negotiations for different objectives** of participants in supply networks are processed.
- **Multiple Criteria Decision Aids** (MCDA); Weighted Sum Model (WSM), Weighted Product Model (WPM), Value Analysis (VA), fuzzy logic, Genetic Algorithm (GA) and Artificial Neural Networks (ANN) are applied for negotiations.

S-DSP (Cont.)

Knowledge Management (KM)

- Constant updating and analysis of databases and accurate connections between these databases and other sub-protocols:
  - DB1: **Relevant case studies and regulations/agreements** of specific sustainability issues are organized according to the type of related members and characteristics of issues.
  - DB2: Various methodologies which help the **decision making process** are classified into two classes -- strategic and mathematical (operational) methods.
  - DB3: All other **related and critical information**, especially from outsources, are saved. Historical data of each member's demands, orders, accidents, violations, and specific events are saved here.

CCT principles in Decision Support Protocol, S-DSP

JLR

Who participates in *this* "game"?

- With multiple parties, additional constraints and parameters of existing, negotiated formulations need to be considered.
- JLR analysis and decisions lead to add (or remove) "players" parameters, so the projected sustainability can be estimated effectively.

LOCC

Optimize negotiation flows?

- Practically all industries are affected by sustainability goals, with mutually useful dynamic information flow between them, e.g., environmental policy changes.
- LOCC models use these information flows to negotiate and develop collaborative formulations and emergent organization changes.

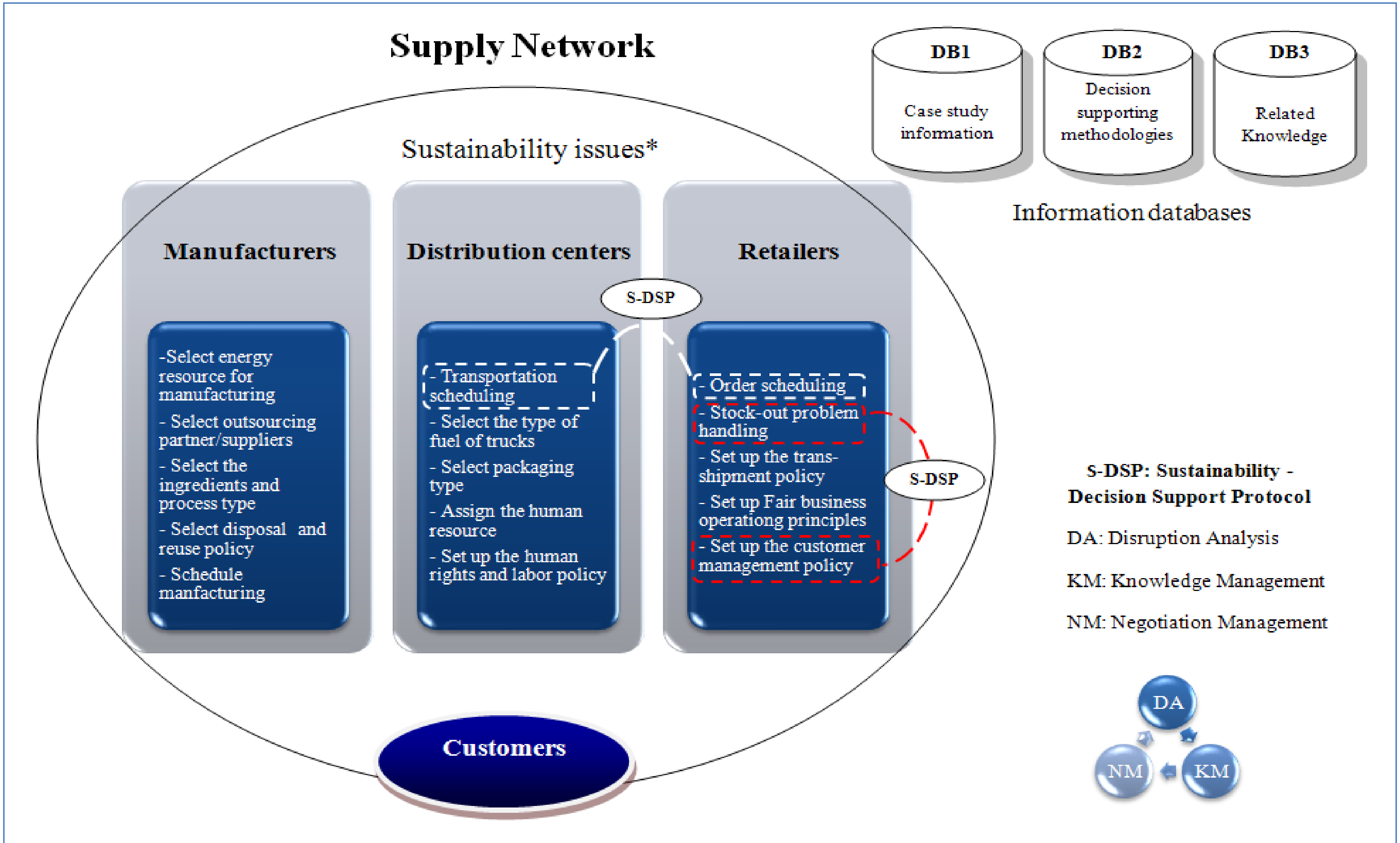
CRP

PARK

Adapt parallel negotiation streams?

- Multiple sustainability criteria must be considered effectively and in parallel based on the characteristics of each party and within various situations.
- CRP/PARK are helpful when new constraints are added. Within CRP-II, the formulation can be revised in real time, adapted to temporal changes and constraints.

Applying S-DSP in Supply Networks



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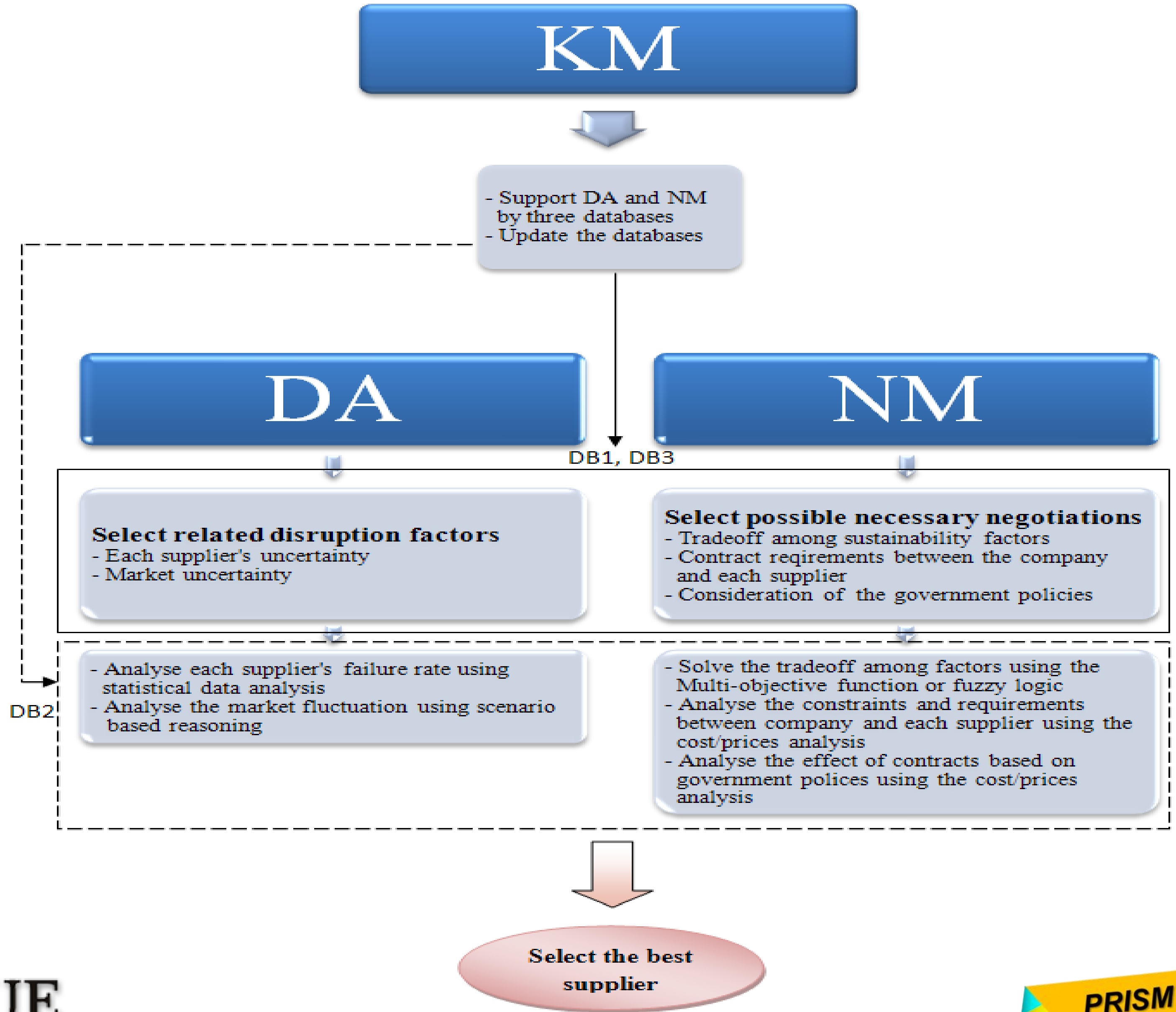
S-DSP for Sustainable Supplier Selection



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S-DSP for Sustainable Delivery Scheduling

DA

- Consider the demand fluctuation

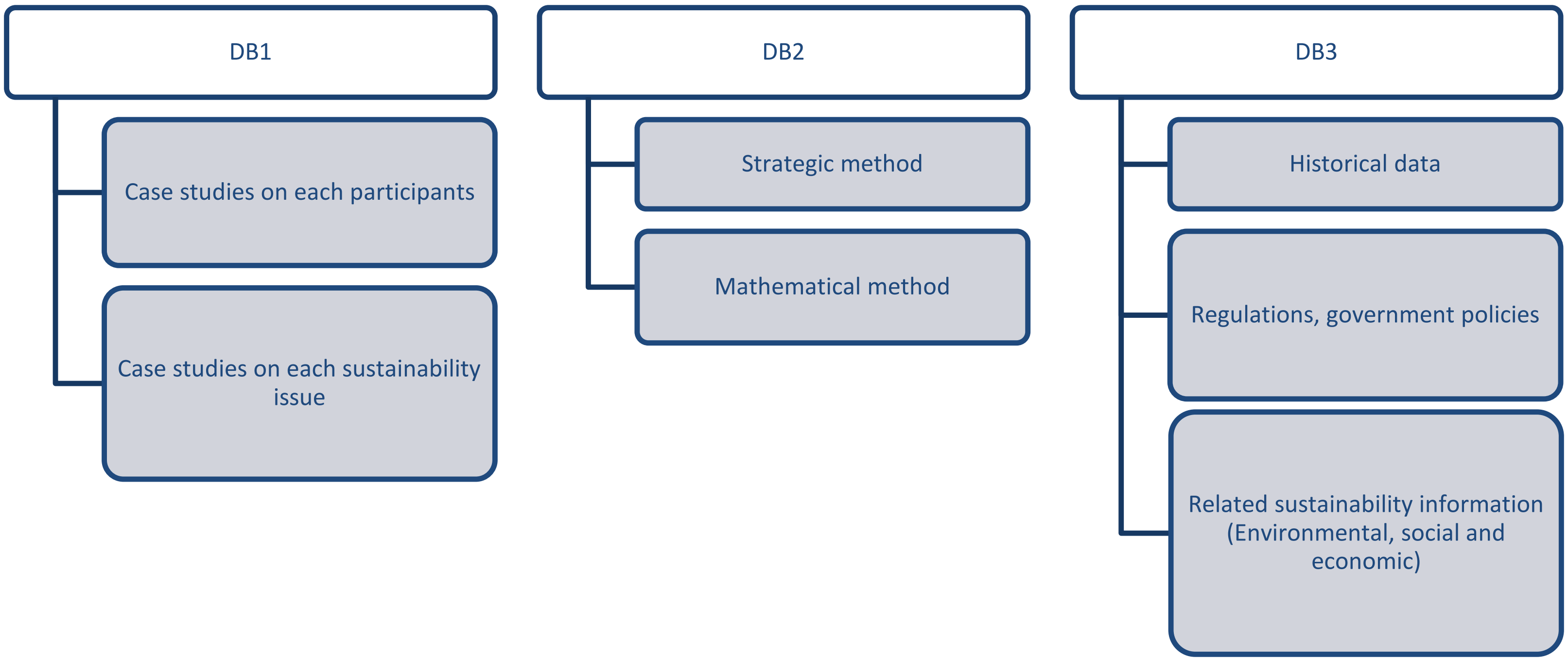
NM

- Decide whether manufacturers A and B cooperate or not during each period
- CRP-II and JLR provide useful guidelines for the work of NM

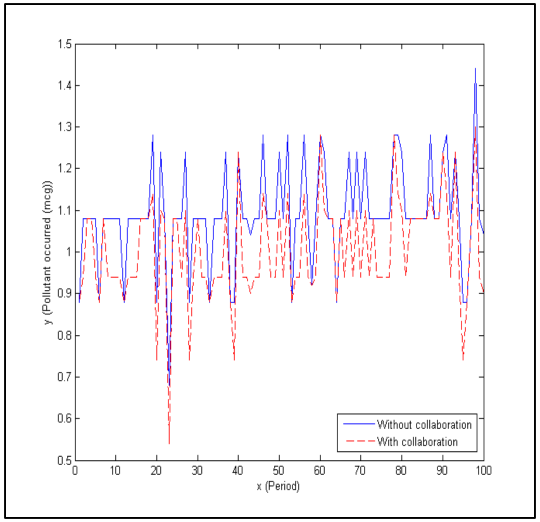
KM

- Request order quantity from each retailer (demand)
- Available number of trucks and capacity of each
- Location information of manufactures and retailers
- Related costs, delivering cost, and other costs

Data / Knowledge Bases

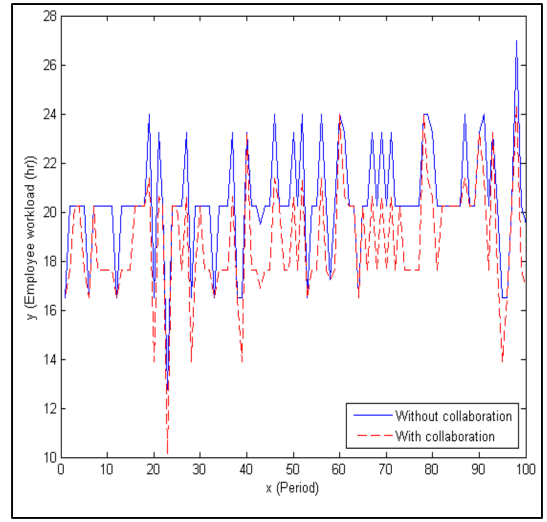


Case: Collaborative delivery scheduling and sustainability
Significant impacts of employing S-DSP and CCT - - -

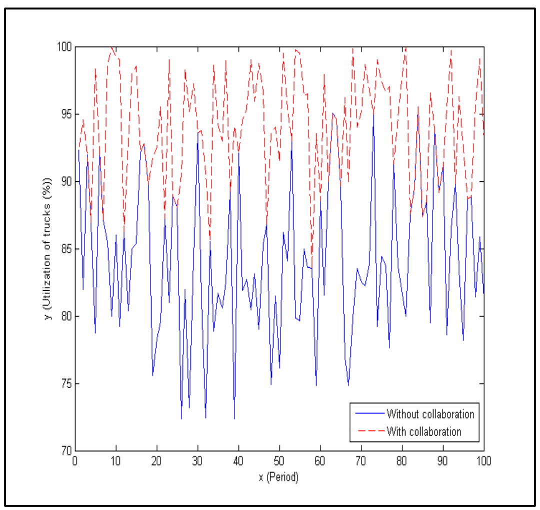


a. Air pollutant (by delivery process) decreased

b. Employee workload decreased

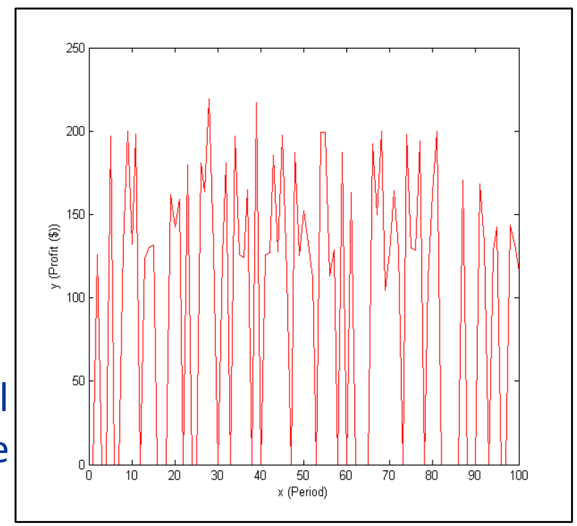


Both reduced by between 9.7% and 20.6% with 12.8% average improvement



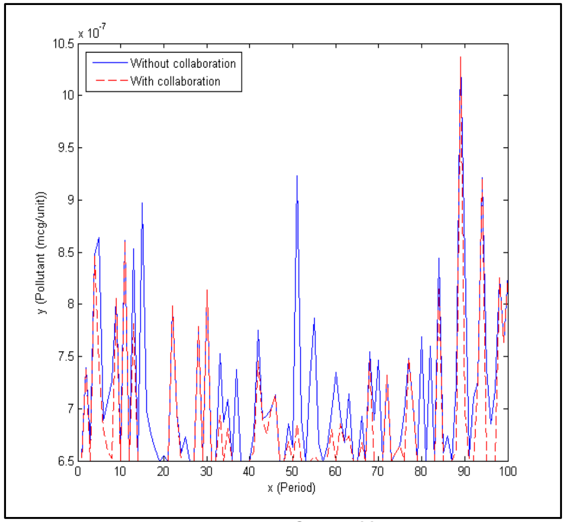
c. Manufacturers' trucks utilization increased on average by 19.3%

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

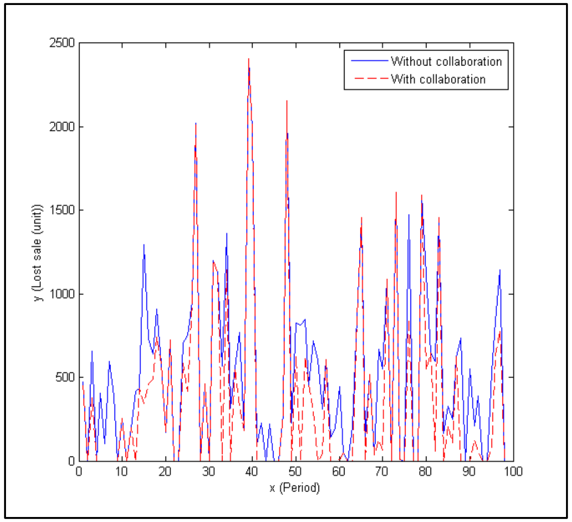


Seok et al., *ARC*, 2012

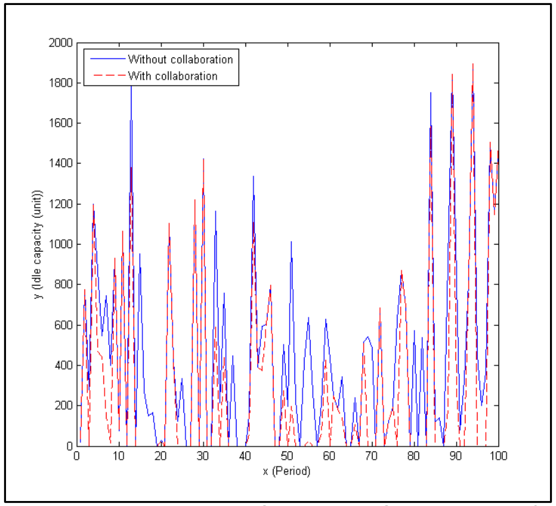
Case: Impacts of employing S-DSP and CCT



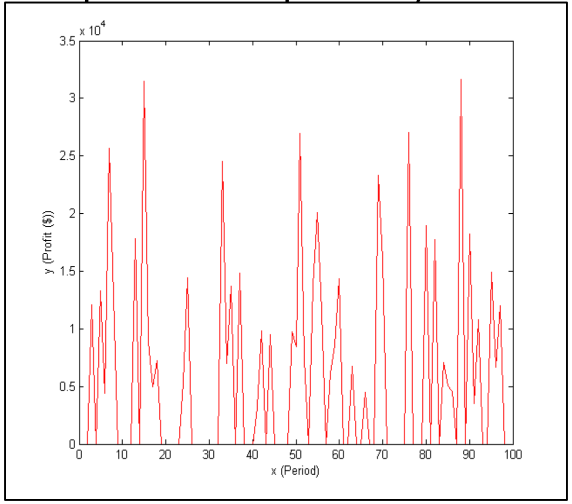
16. Decrease of pollutant per product (occurred by production process)



17. Decrease of manufacturers' lost sales



18. Decrease of manufacturers' idle capacity



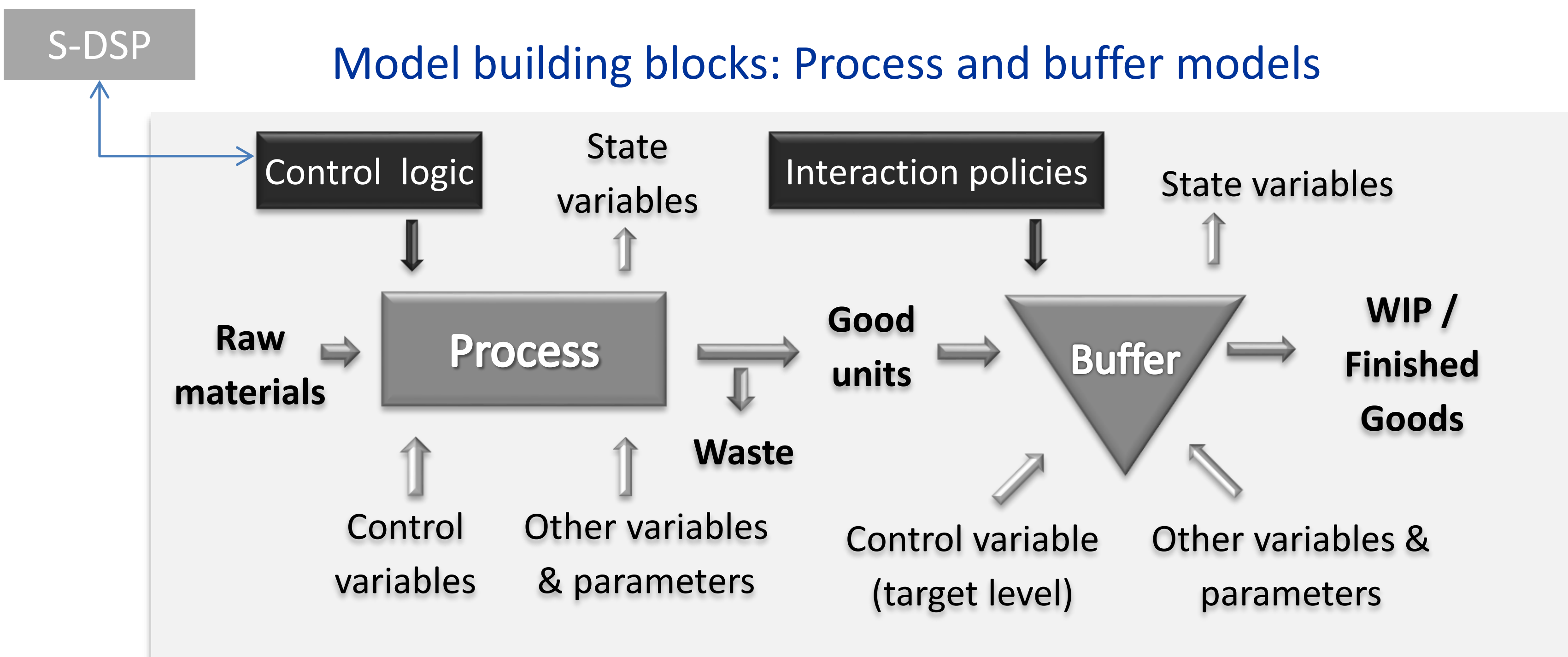
19. Manufacturers' additional profit

Collaborative Production Line Control Protocol - CPLCP

(Levalle et al., 2012)

- Streamlining sustainable raw materials procurement processes
- Rethinking distribution footprints, strategies, and alliances
- Increasing manufacturing performance and efficiency for economic sustainability

Model building blocks: Process and buffer models



CCT Principles in CPLCP

CRP I

- Machines and buffers are collaborative resources
- Collaborative resources' goal is to keep low WIP inventory while maximizing throughput, regardless of the system status
- The best static control policy is defined for every possible combination of process states, assuming that this condition is the steady state

CRP II

- Production rates and buffer levels adjustment based on the system's evolution (actual or forecasted by the *Early Conflict Detection Tool*)

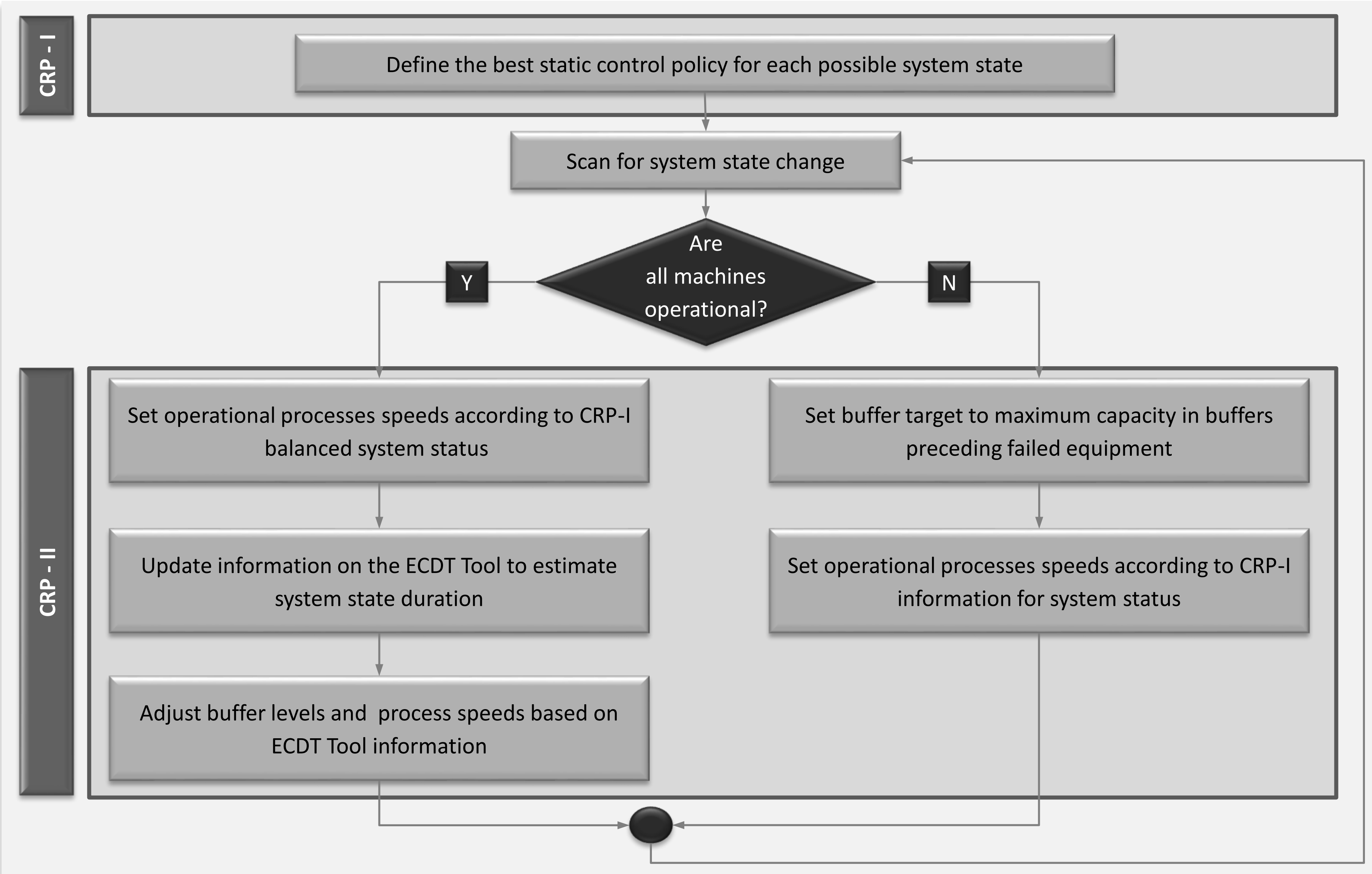
CEDP

- Early Conflict Detection Tool (ECDT) predicts which machine is most likely to be the next to fail (based on historical information of time between failures)
- Conflict forecasting along with a prevention methodology enables the collaborating agents to take actions to minimize the impact of such conflict on the lines' performance

FTT

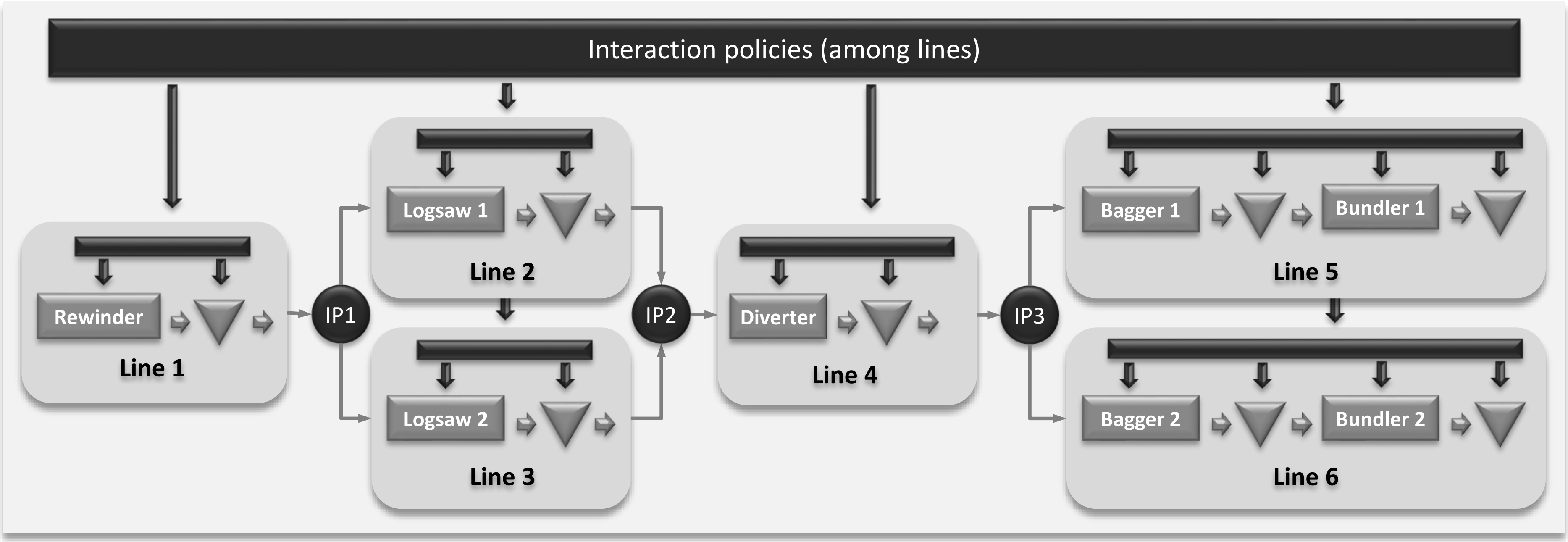
- ECDT coupled with a conflict prevention methodology provide the rules for machines to "help each other" overcome failures, thus making the production line more stable.

Workflow Simulation with CPLCP



Tissue Converting Line Control with CPLCP

- Production line control under uncertainty conditions
- Highly adaptive and anticipatory methodology that enables collaboration between the different components of the lines to overcome failures and maintain sustainable throughput while keeping WIP low.



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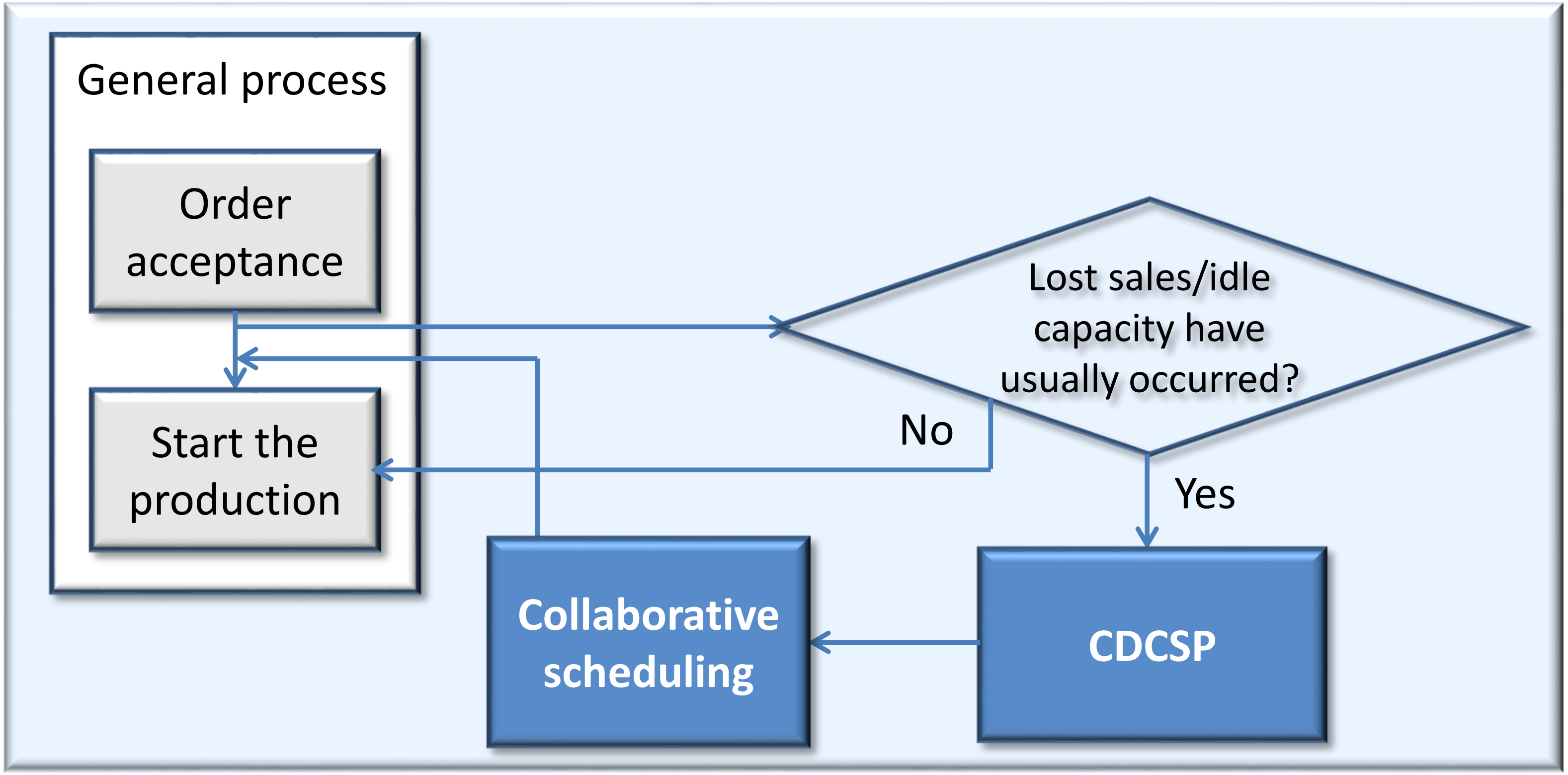
Demand & Capacity Sharing Protocol - CDCSP

(Seok & Nof, 2012)

- Enhance companies' sustainability in the long term
  - Improve resource utilization by minimize idle capacity
  - Increase customer satisfaction by reducing lost sales



CCT Principles in CDCSP

JLR

- Collaborative network organization can be formed based on the concept of JLR principle
- The success of any business integration is a function of the degree of cooperation among the integrated sub-systems. Especially for complex, highly distributed and collaborative sub-systems, integration and cooperation become more necessary.

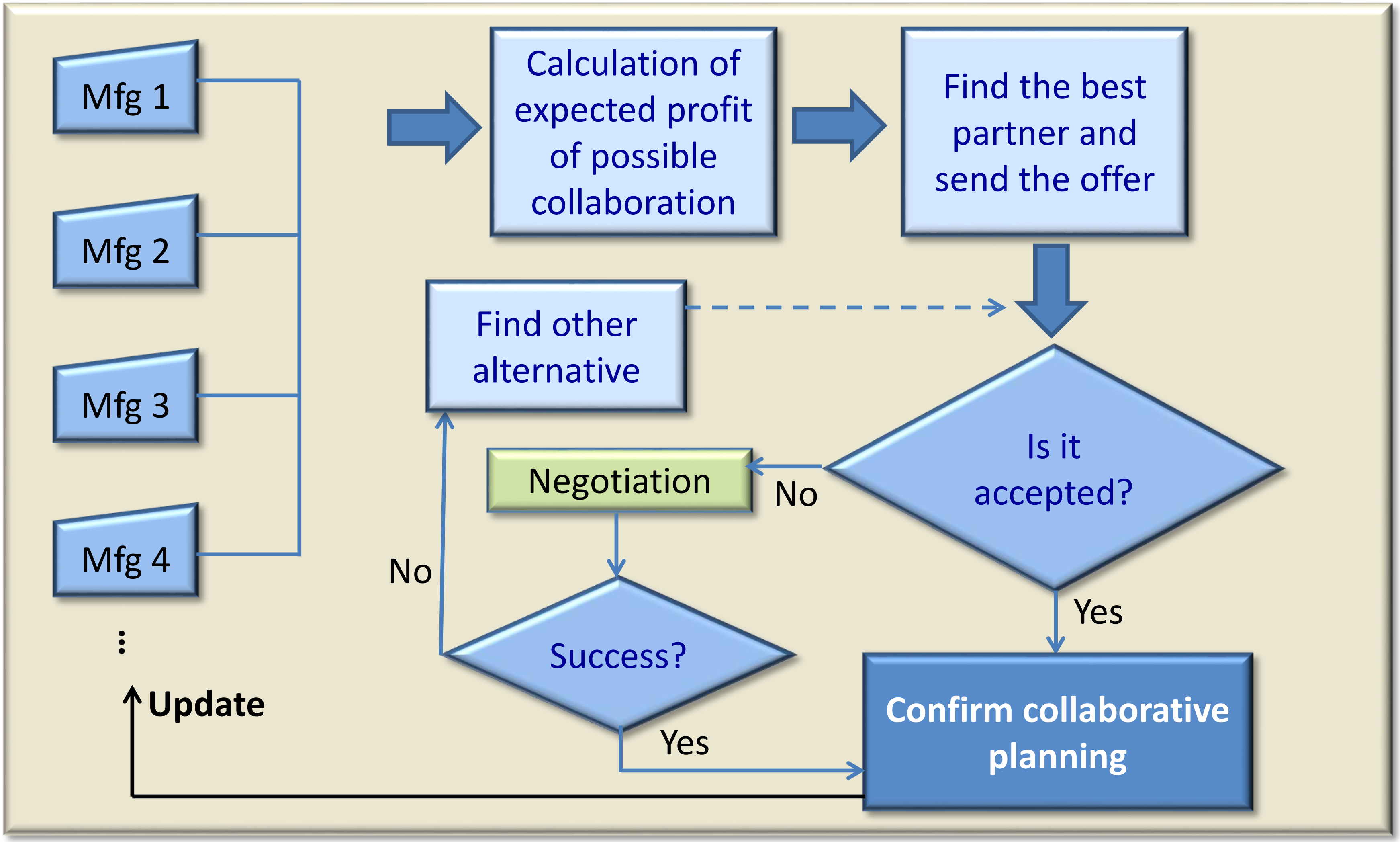
CPR I

- Depend on the characteristics of manufacturers, capacity provider and order provider are differentiated appropriately.

CPR II

- Depend on the change of demand based on market trend and customer behavior, new collaborative partnership can be formed.

Workflow Simulation with CDCSP



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Conclusions

- Sustainability is essential and complex, but must be achievable
- Some progress achieved in modeling, decision processes and algorithms, measurement, control models and control theory
- Collaborative mechanisms and information sharing are needed for better sustainability communication, planning, and control
- Collaborative intelligence over high-performance computing is emerging.

Acknowledgement

- Research reported here has been developed at the PRISM Center with NSF, Indiana 21st Century fund for Science and Technology, and industry support.

- Special thanks to my colleagues, visiting scholars, and students at the PRISM Lab and the PRISM Global Research Network, and in IFAC Committee CC5 for Manufacturing and Logistics Systems, who have collaborated with me to develop CCT and collaborative control knowledge.

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