Designing Robust Value-Creating Supply Chain Networks

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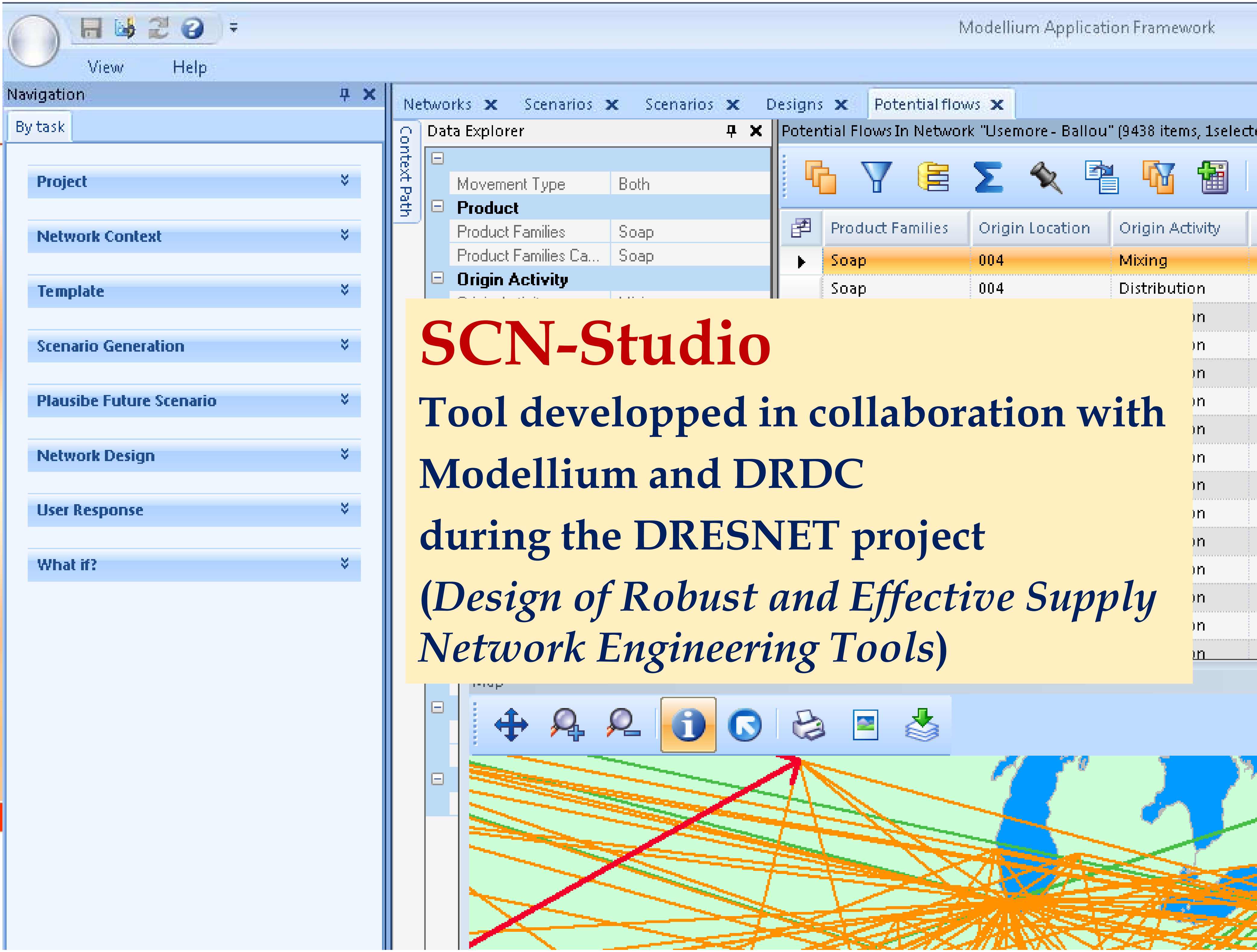


SCN-Studio

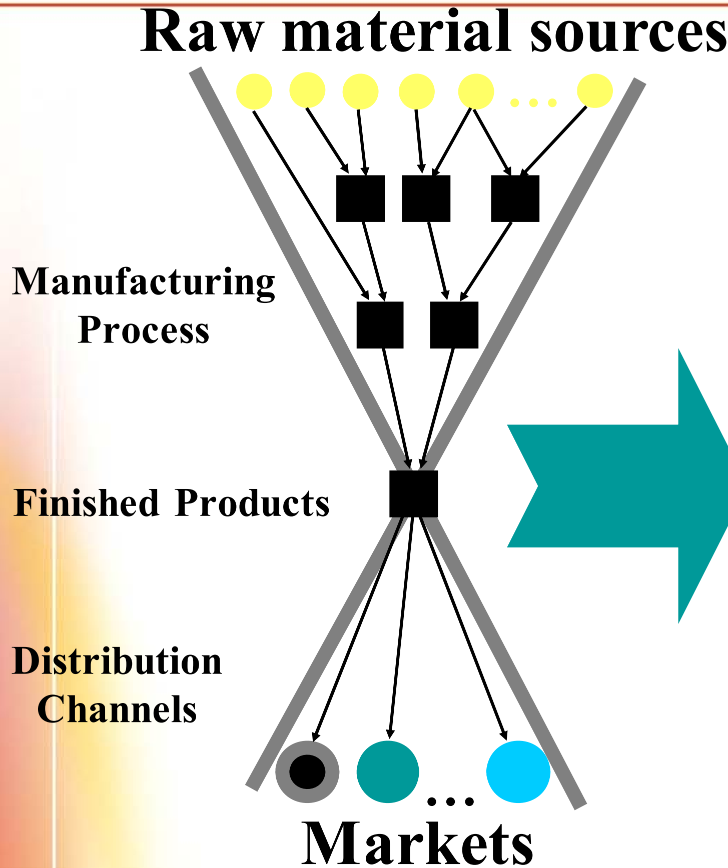
Tool developped in collaboration with Modellium and DRDC during the DRESNET project

(Design of Robust and Effective Supply Network Engineering Tools)

Designing Robust Value-Creating Supply Chain Networks

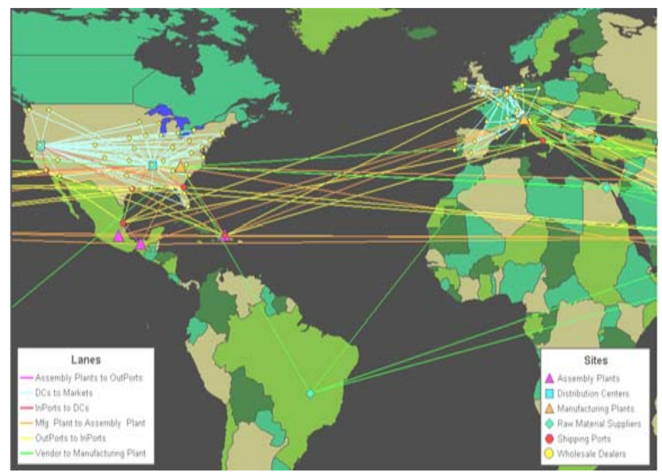
1. Problem Context
2. Modeling SCN Processes and Structures
3. Taking Uncertainty into Account
4. SCN Design Methodology
5. Research Challenges

1. Generic Design Problem



Value Creation

Deployed Supply Chain Network



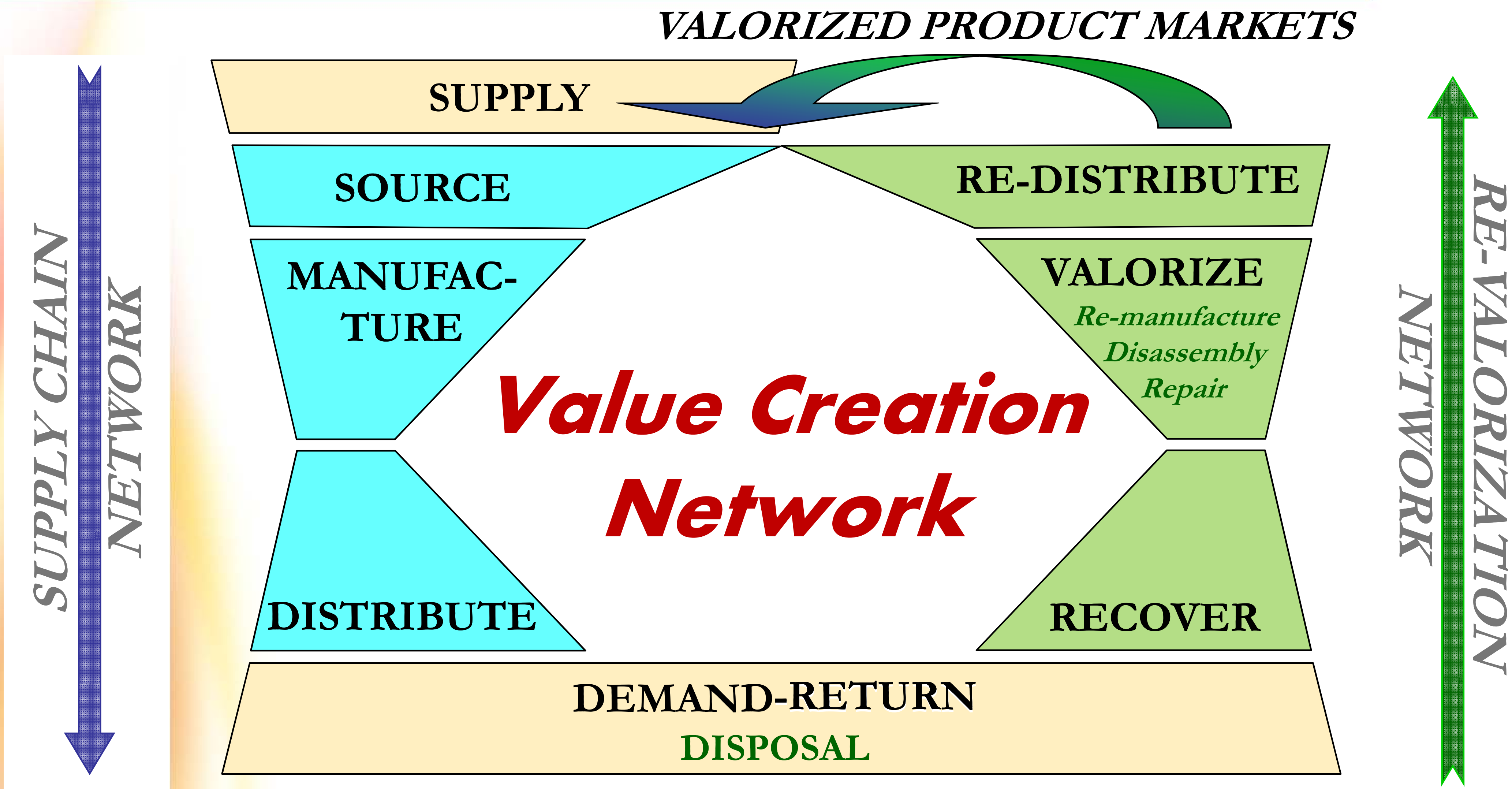
SC Risk Exposure

Disruptions

Value Destruction

Robustness ?

Re-Valorization Network



SCN Design Modeling

Methodological Expansion

Robust Design

Robust and efficient design under uncertainty

- Hazardous/catastrophic **disruptive events** (risk modeling)
- Adequate user decisions **anticipation**
- **Resilience** strategies for sustainable stakeholder value

Large SPs

Stochastic problems over a long planning horizon

- Business as usual context (random events modeling)
- Real options and hedging
- Positioning by anticipation to capture promising contracts

Large MIPs

Location-Allocation Problems

- Generic production-distribution networks
- Multiple facility / transportation options
- Externalization decisions with partner selection
- Multiple value offers to product-markets
- Value maximization …

Functional Expansion

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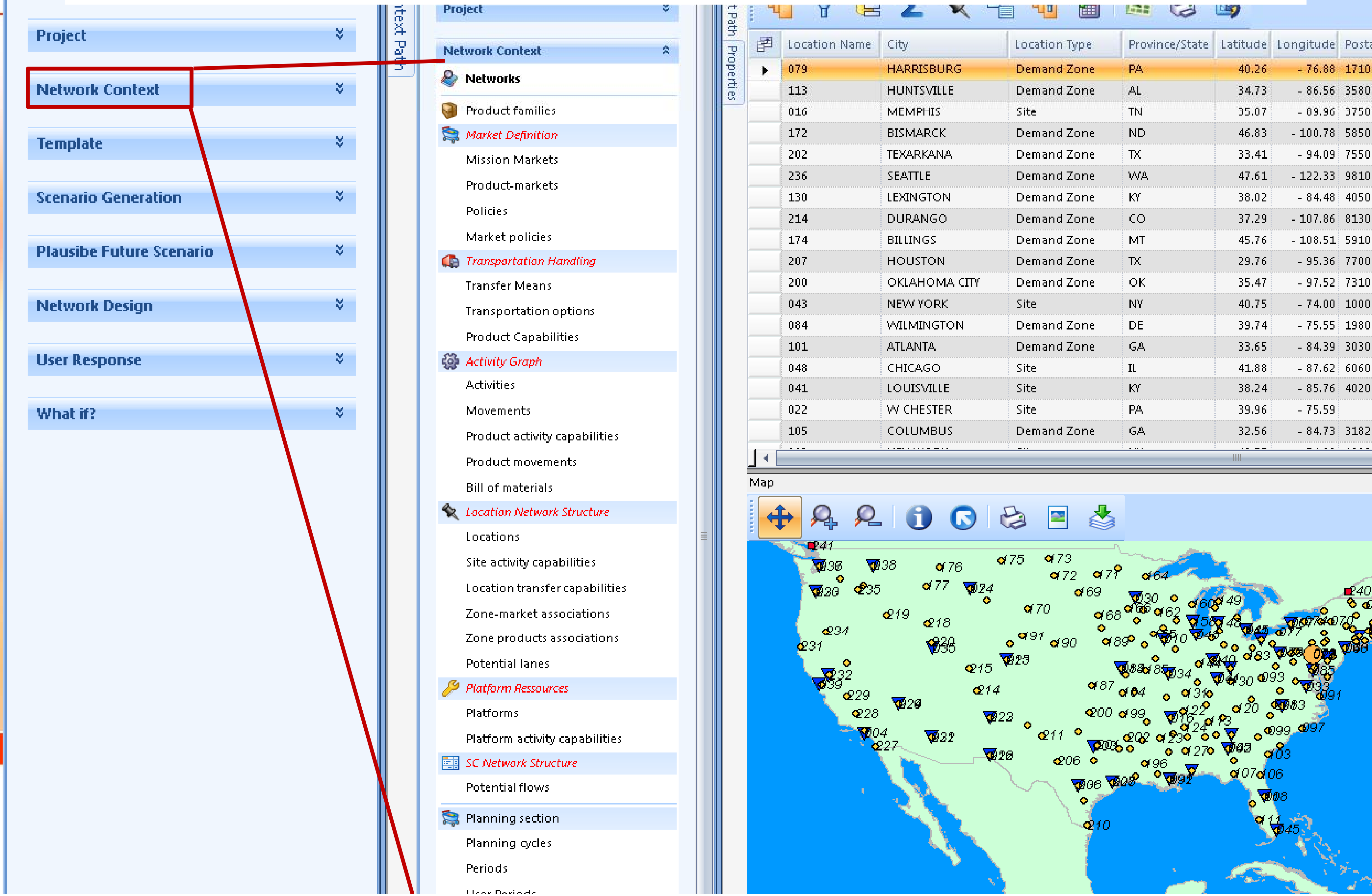
2. Modeling SCN Process and Structures



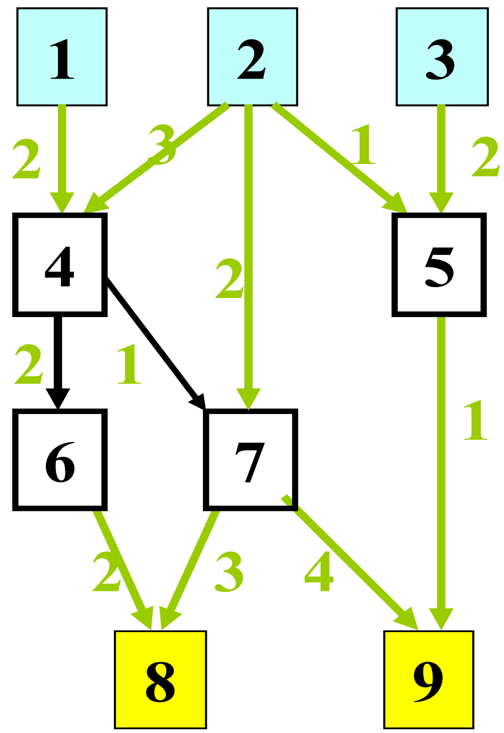
Location Name	City	Location Type	Province/State	Latitude	Longitude	Posta
079	HARRISBURG	Demand Zone	PA	40.26	- 76.88	1710
113	HUNTSVILLE	Demand Zone	AL	34.73	- 86.56	3580
016	MEMPHIS	Site	TN	35.07	- 89.96	3750
172	BISMARCK	Demand Zone	ND	46.83	- 100.78	5850
202	TEXARKANA	Demand Zone	TX	33.41	- 94.09	7550
236	SEATTLE	Demand Zone	WA	47.61	- 122.33	9810
130	LEXINGTON	Demand Zone	KY	38.02	- 84.48	4050
214	DURANGO	Demand Zone	CO	37.29	- 107.86	8130
174	BILLINGS	Demand Zone	MT	45.76	- 108.51	5910
207	HOUSTON	Demand Zone	TX	29.76	- 95.36	7700
200	OKLAHOMA CITY	Demand Zone	OK	35.47	- 97.52	7310
043	NEW YORK	Site	NY	40.75	- 74.00	1000
084	WILMINGTON	Demand Zone	DE	39.74	- 75.55	1980
101	ATLANTA	Demand Zone	GA	33.65	- 84.39	3030
048	CHICAGO	Site	IL	41.88	- 87.62	6060
041	LOUISVILLE	Site	KY	38.24	- 85.76	4020
022	W CHESTER	Site	PA	39.96	- 75.59	
105	COLUMBUS	Demand Zone	GA	32.56	- 84.73	3182

Modeling SCN Process and Structures

Raw materials $p \in RM$

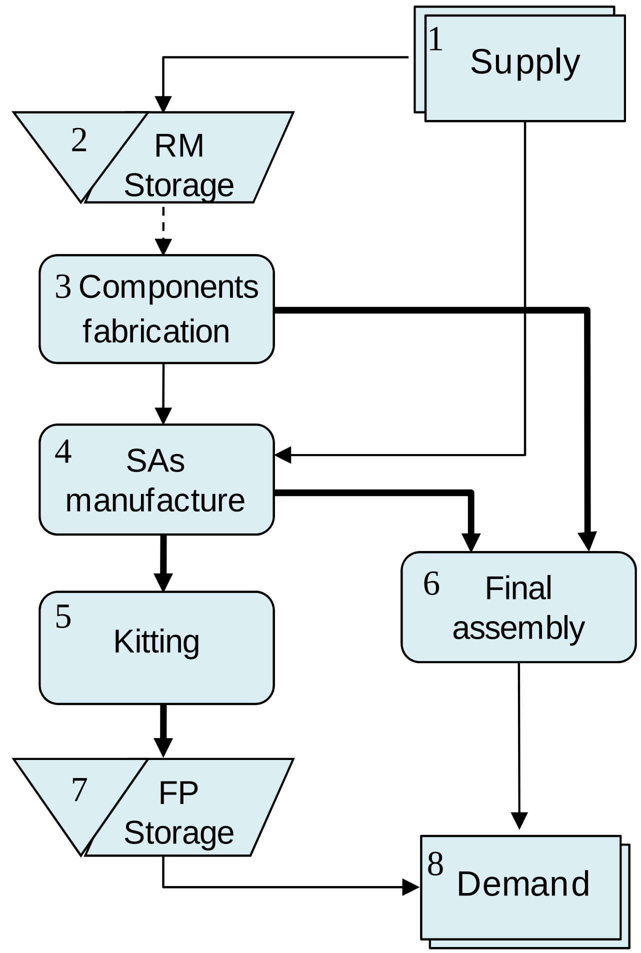
Manufactured products $p \in MP$

$p \in P$



$p \in FP$ Finished products

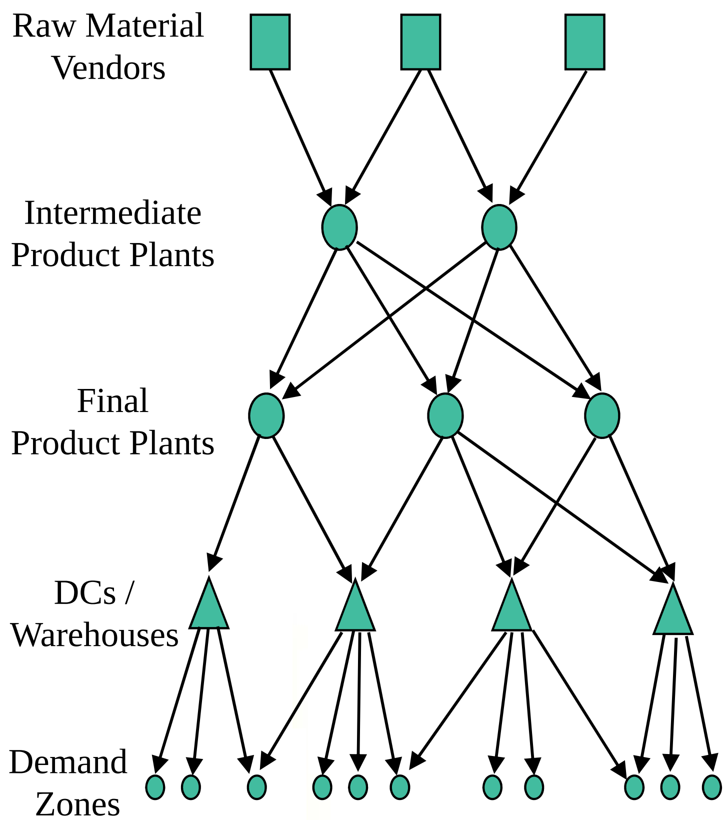
VS

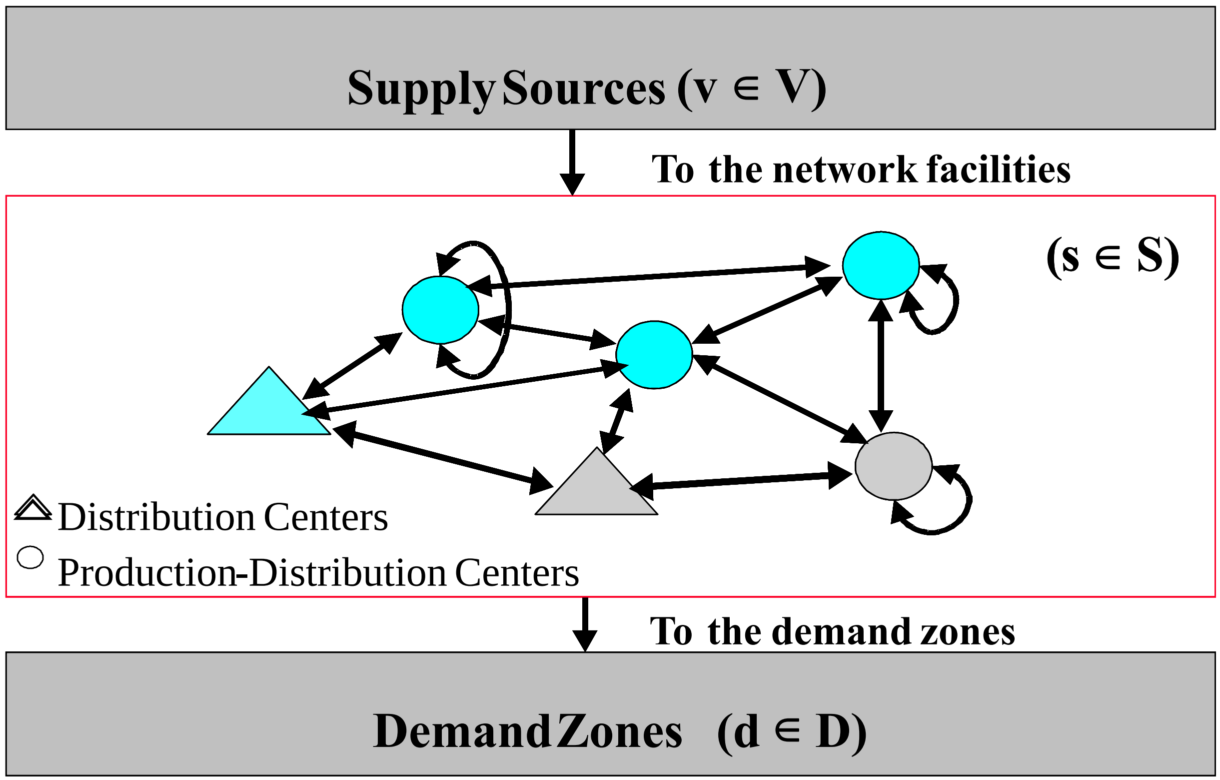


Bill-of-material (BOM) for assembly /disassembly process

Process graph with recipes

Modeling SCN Process and Structures

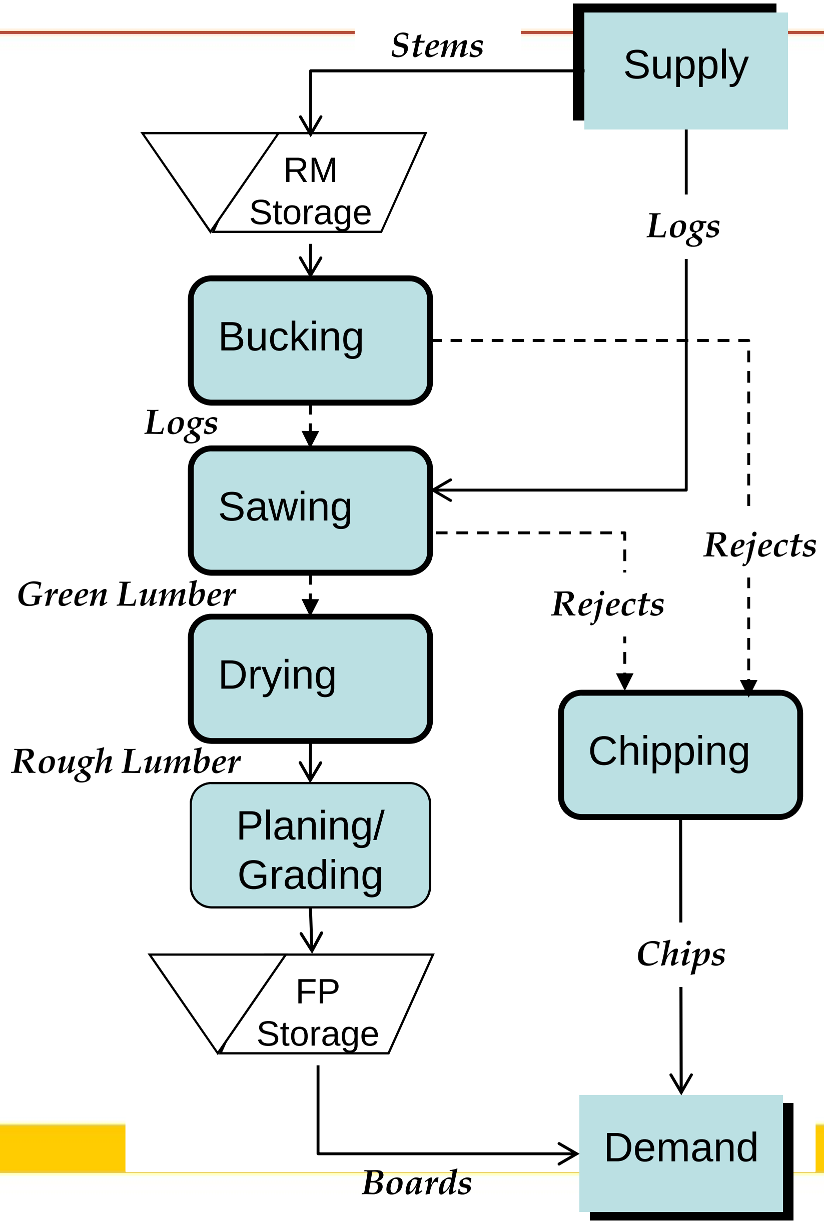




Echelon structure VS General structure

Generic Process Modeling Formalism

Activity Graph *for the Forest Product Sawing Industry*



Activity types:

Supply:

Consolidation / transfer:

Transformation:

Storage:

Demand:

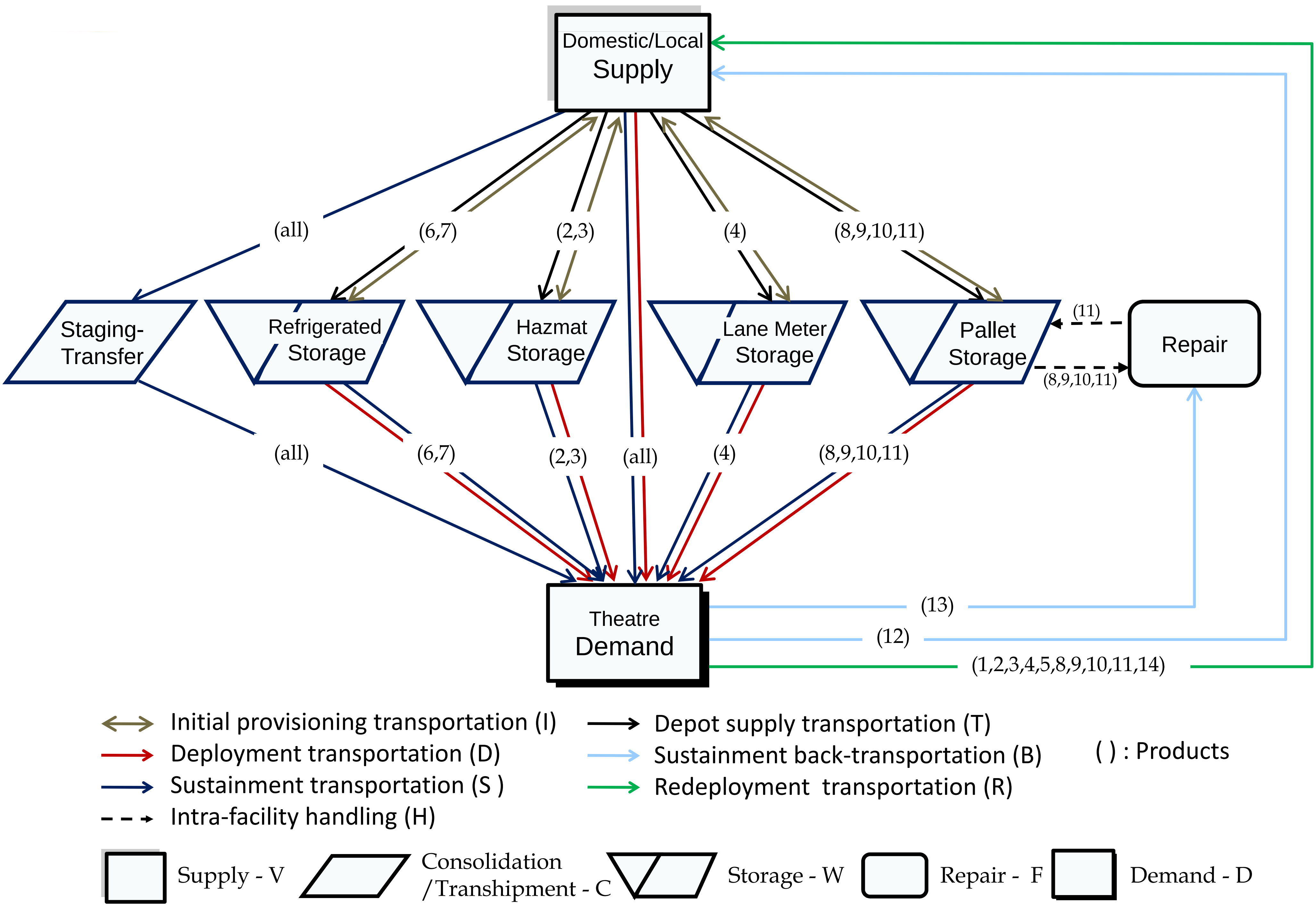
Movement types:

Inter-location: (transportation)

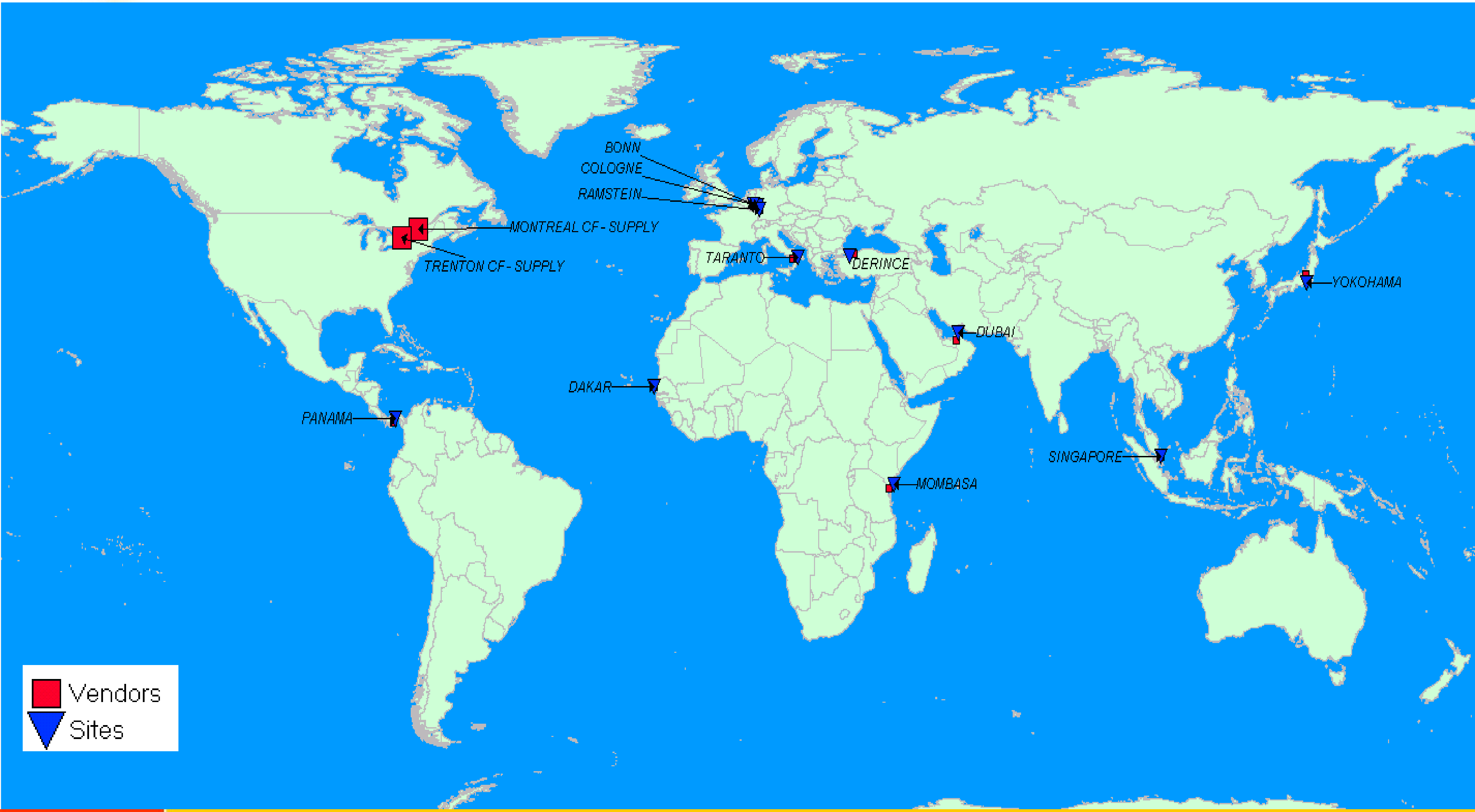
Intra-location: (material handling)

Both: (inter or intra location)

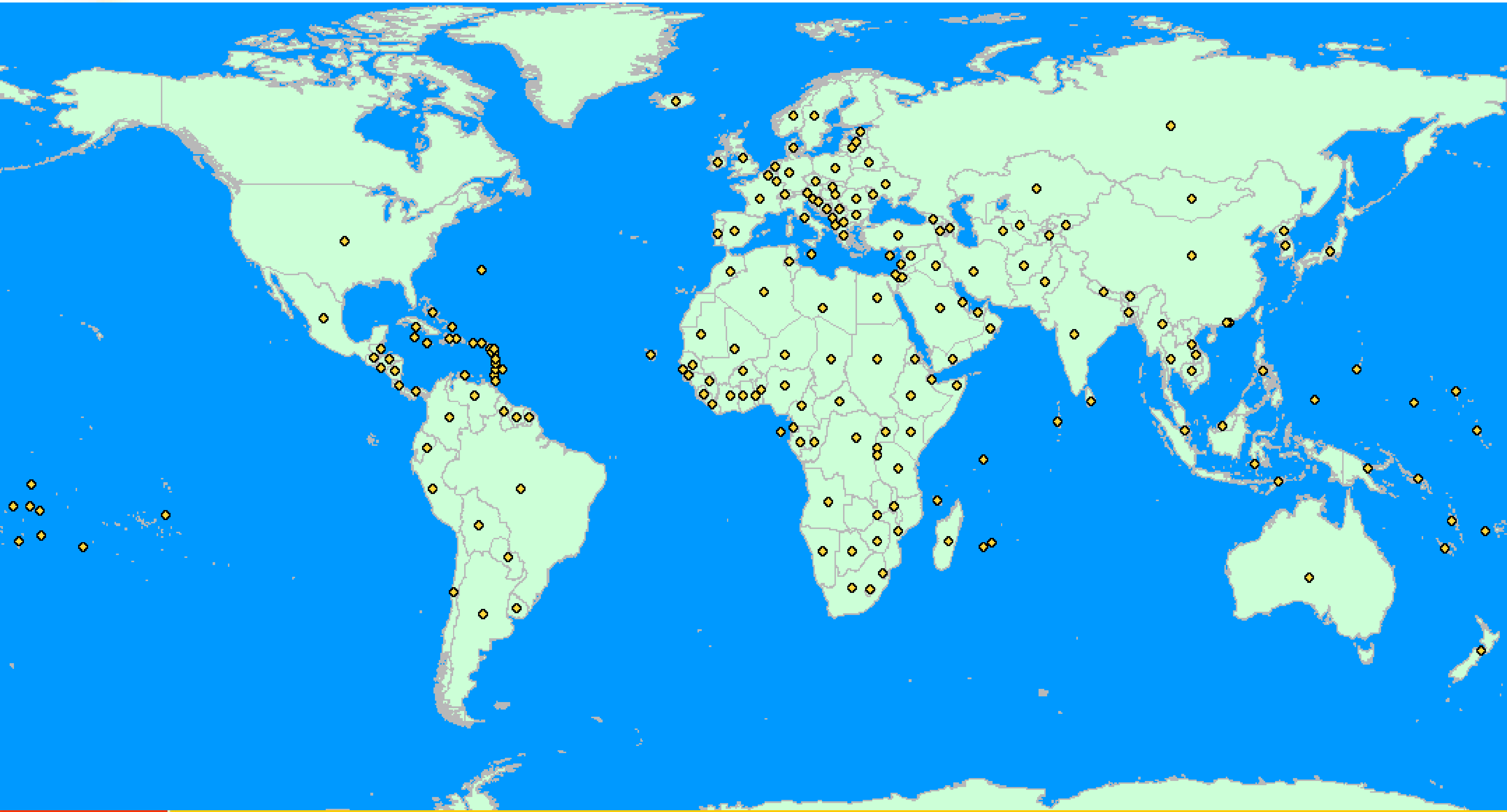
Activity Graph for CF Prepositioning SCN Case



Potential Supply & Depot Locations



Potential Theater Locations (Demand Zones)



Platforms for a Given Site

Current platform layout

Fixed area

Reconfigurable area

Site Location $s \in S$

Alternative Platforms:

$g \in G_s$

Platform 2 layout

Fixed area

Reconfigurable area

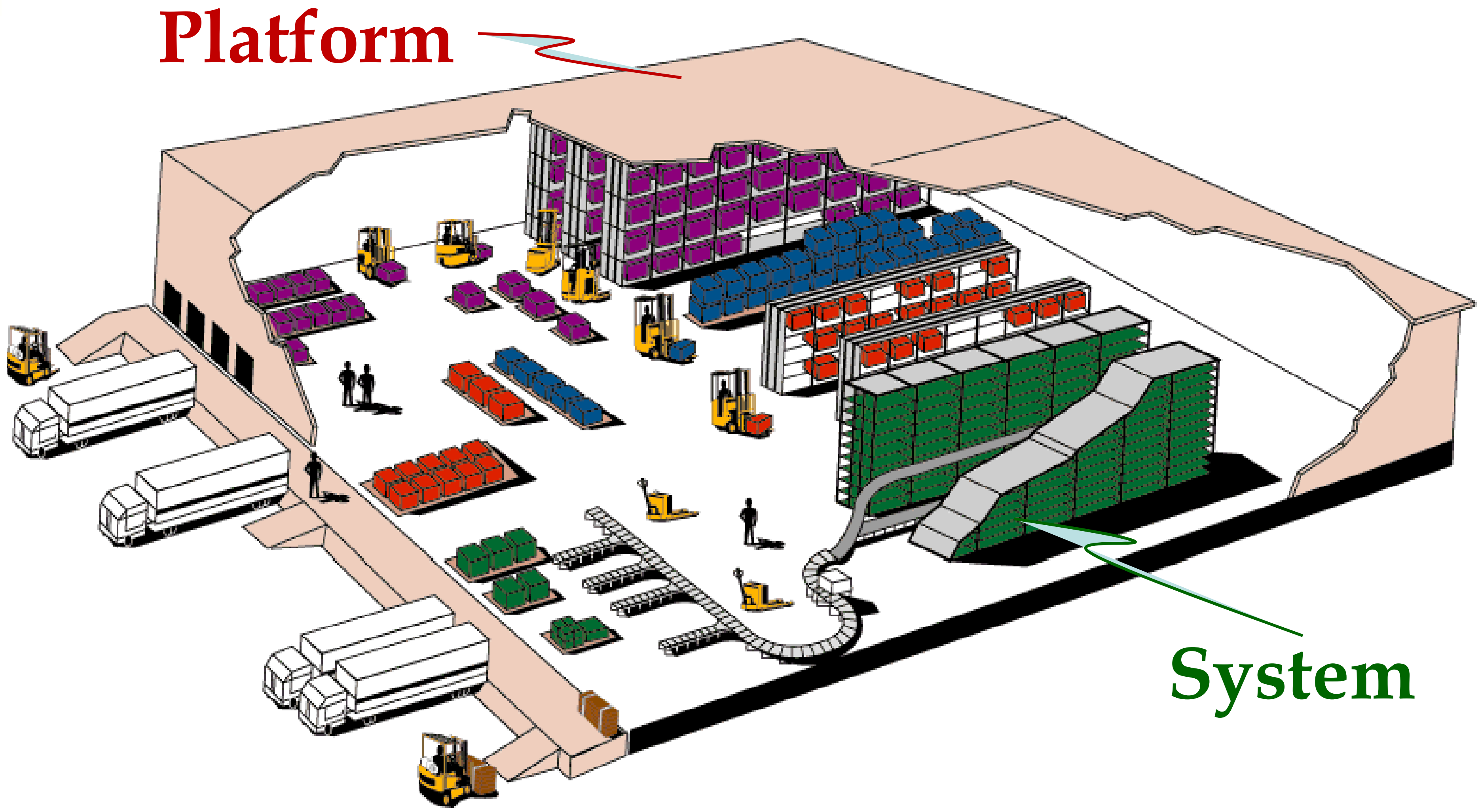
Platform 3 layout

Fixed area

Reconfigurable area

$$Y_{sg} \in \{0,1\};\ s \in S,\ g \in G_s$$

Systems in a Platform



Potential Platforms on a Site

DEPOT SITE (ex: Dubai)

Platform 1

Cost 1

-Opening
-Usage
-Closing

Capacity 1

-Storage
-Repair
-Handling

Platform 2

Cost 2

-Opening
-Usage
-Closing

Capacity 2

-Storage
-Repair
-Handling

Platform 3

Cost 3

-Opening
-Usage
-Closing

Capacity 3

-Storage
-Repair
-Handling

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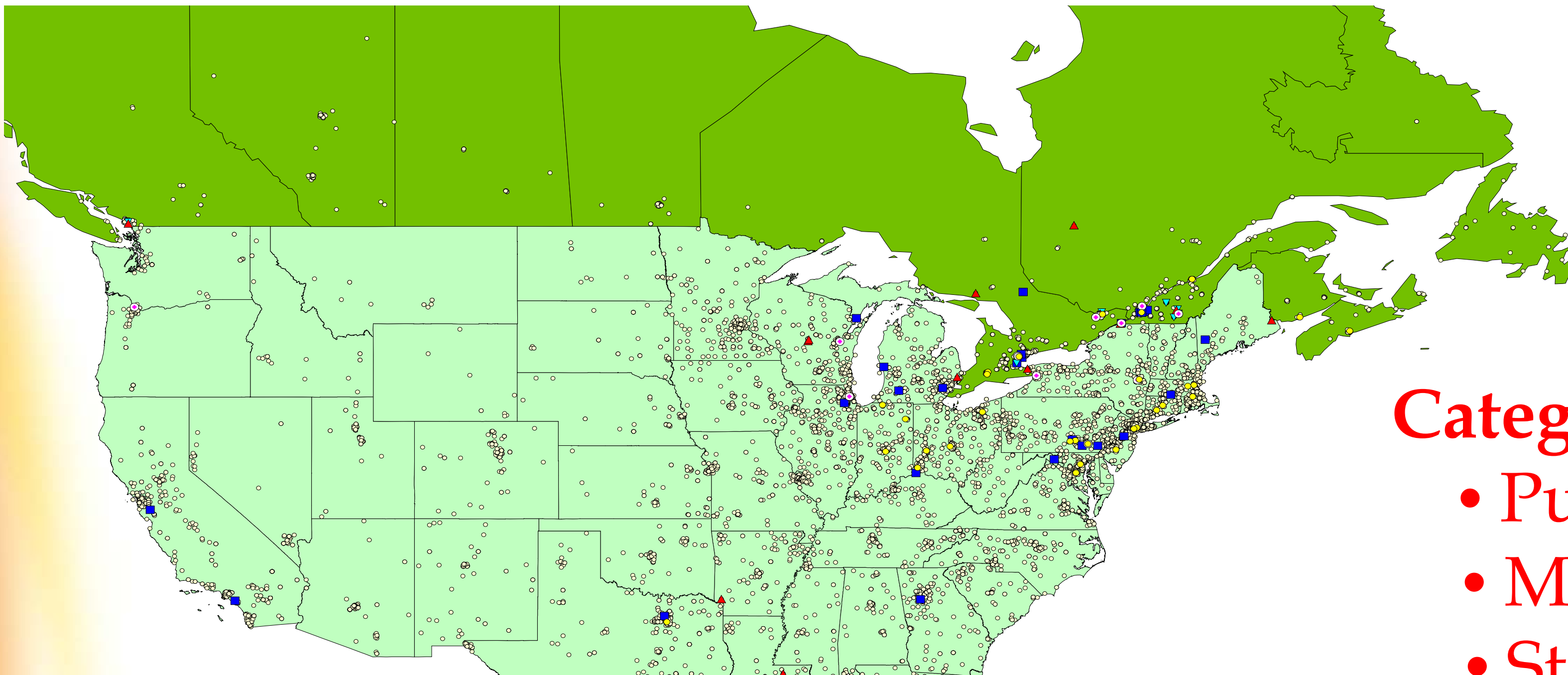
Market Offers

Demand zones (ship-to-points) are associated to ***product-markets*** defined using product ***categories*** and sales ***regions***



Categories:
- Pulp
- Make
- Stock

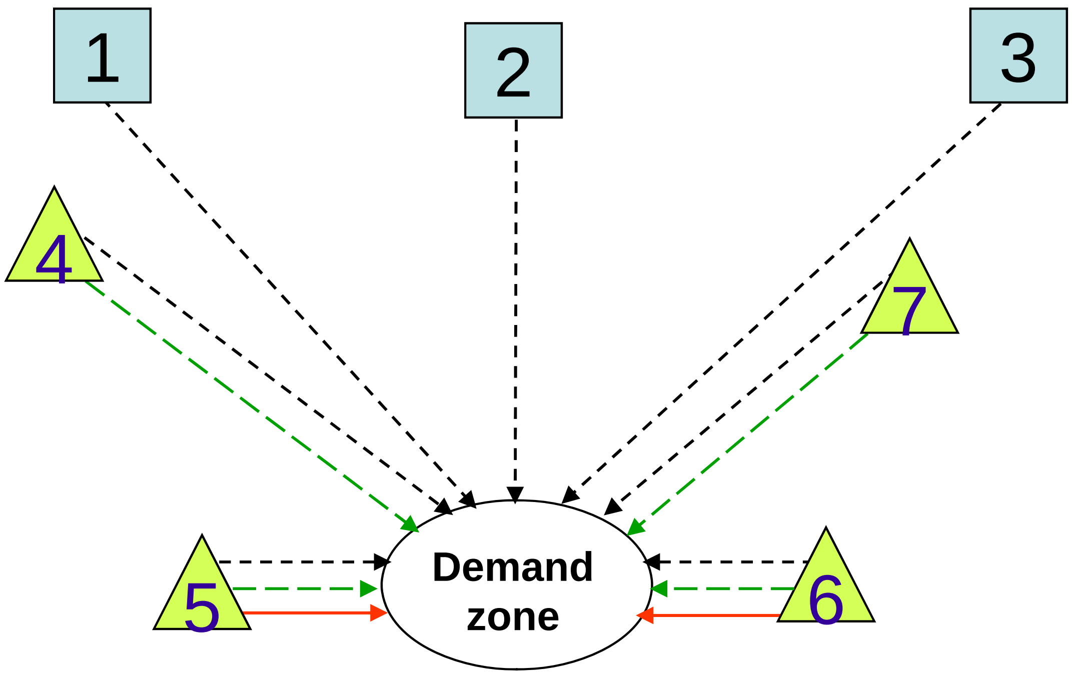
Domtar: Printing & Writing Papers

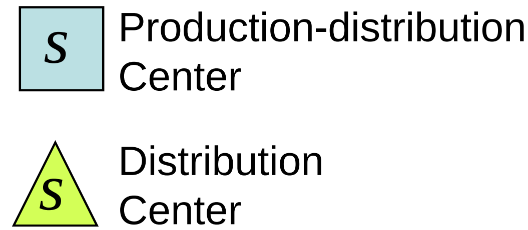
Number of ship-to-points: 14 160

Modeling Offers for a Product-Market

Offers are modeled using *Market Policies* based on (Price, Response time)

=> Set of admissible delivery sites



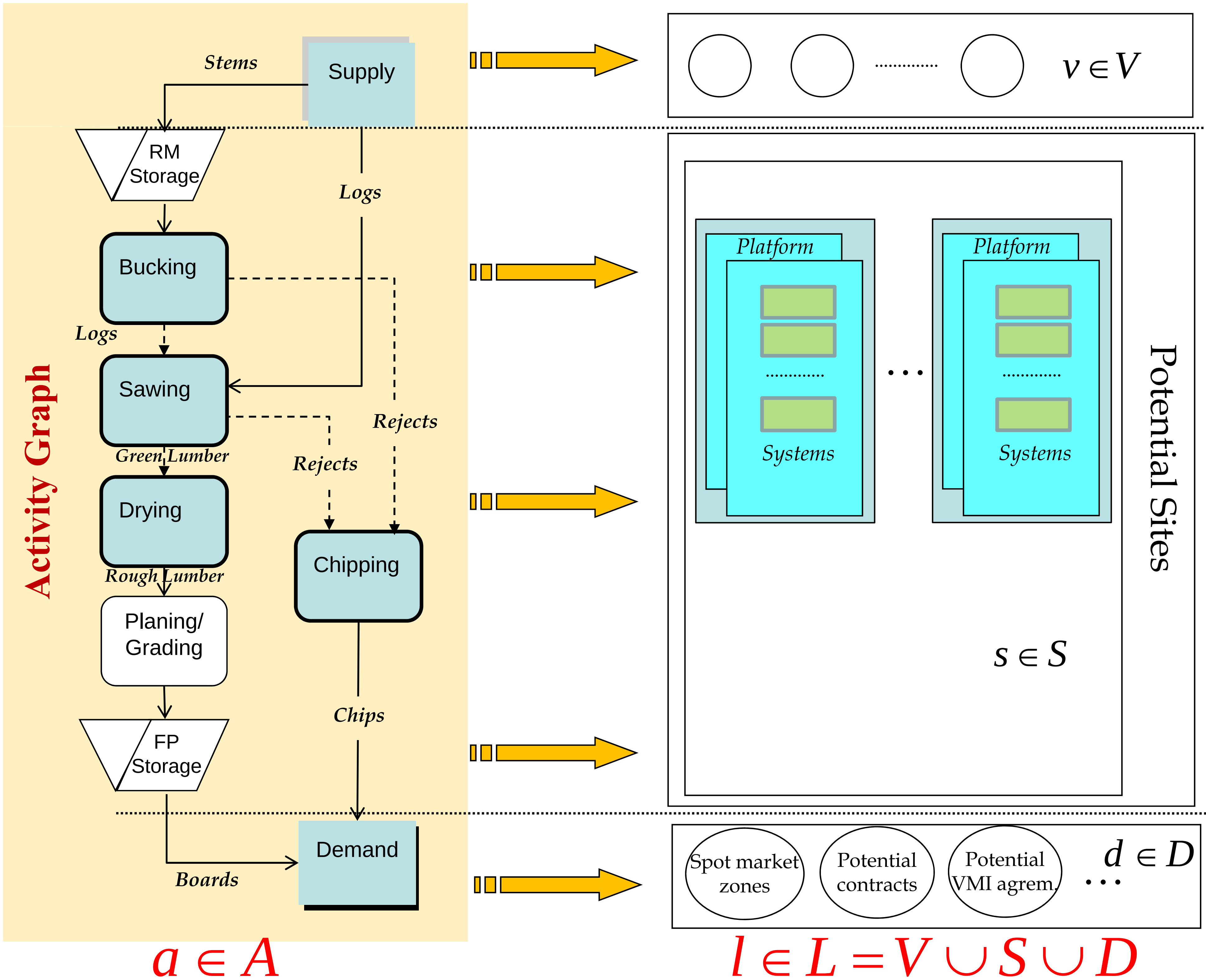


Offers based on *order winning* and *qualifying* criteria

$$S_1^i = \{1,2,3,4,5,6,7\}$$

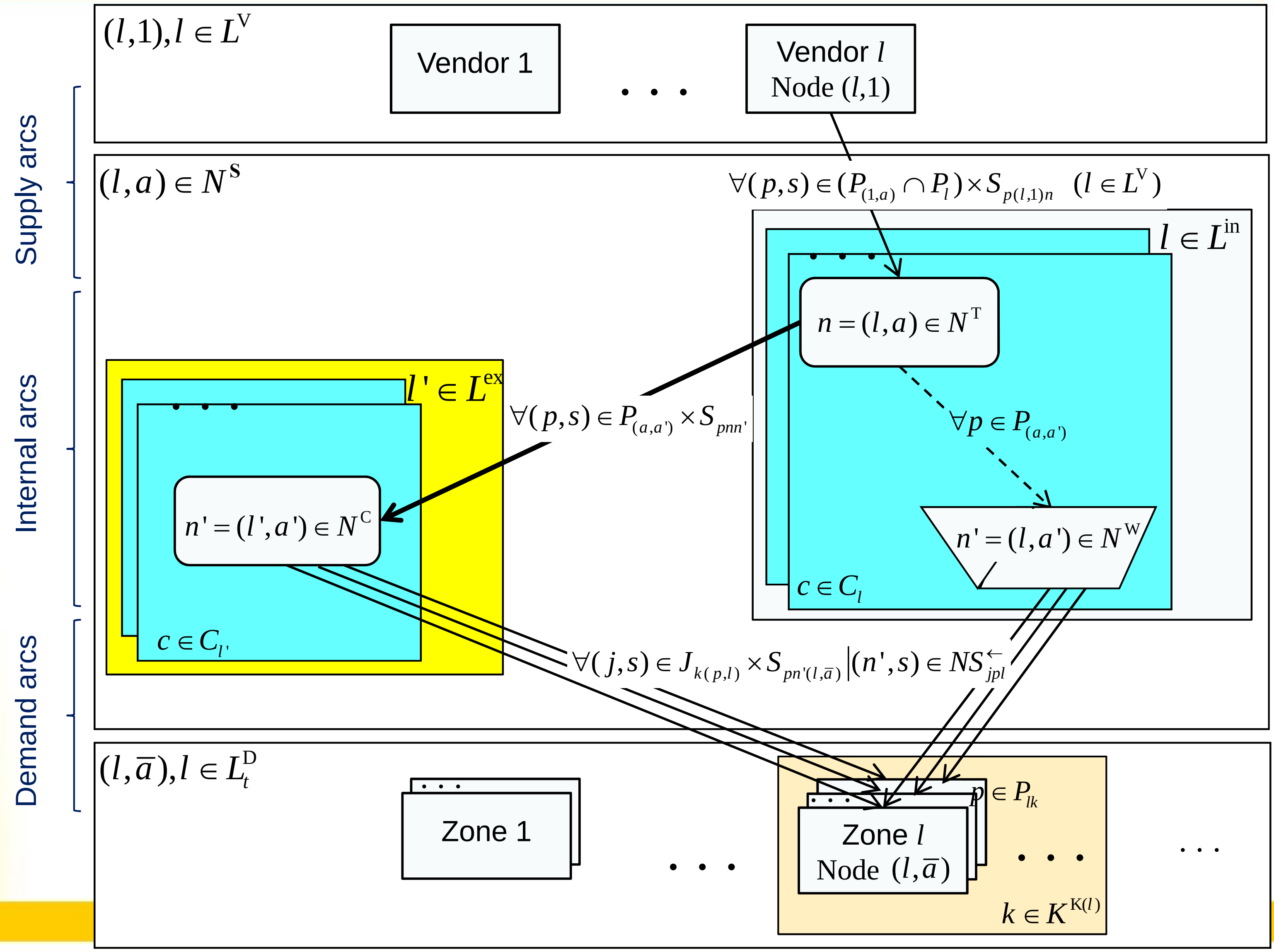
$$S_2^i = \{4,5,6,7\}$$

$$S_3^i = \{5,6\}$$



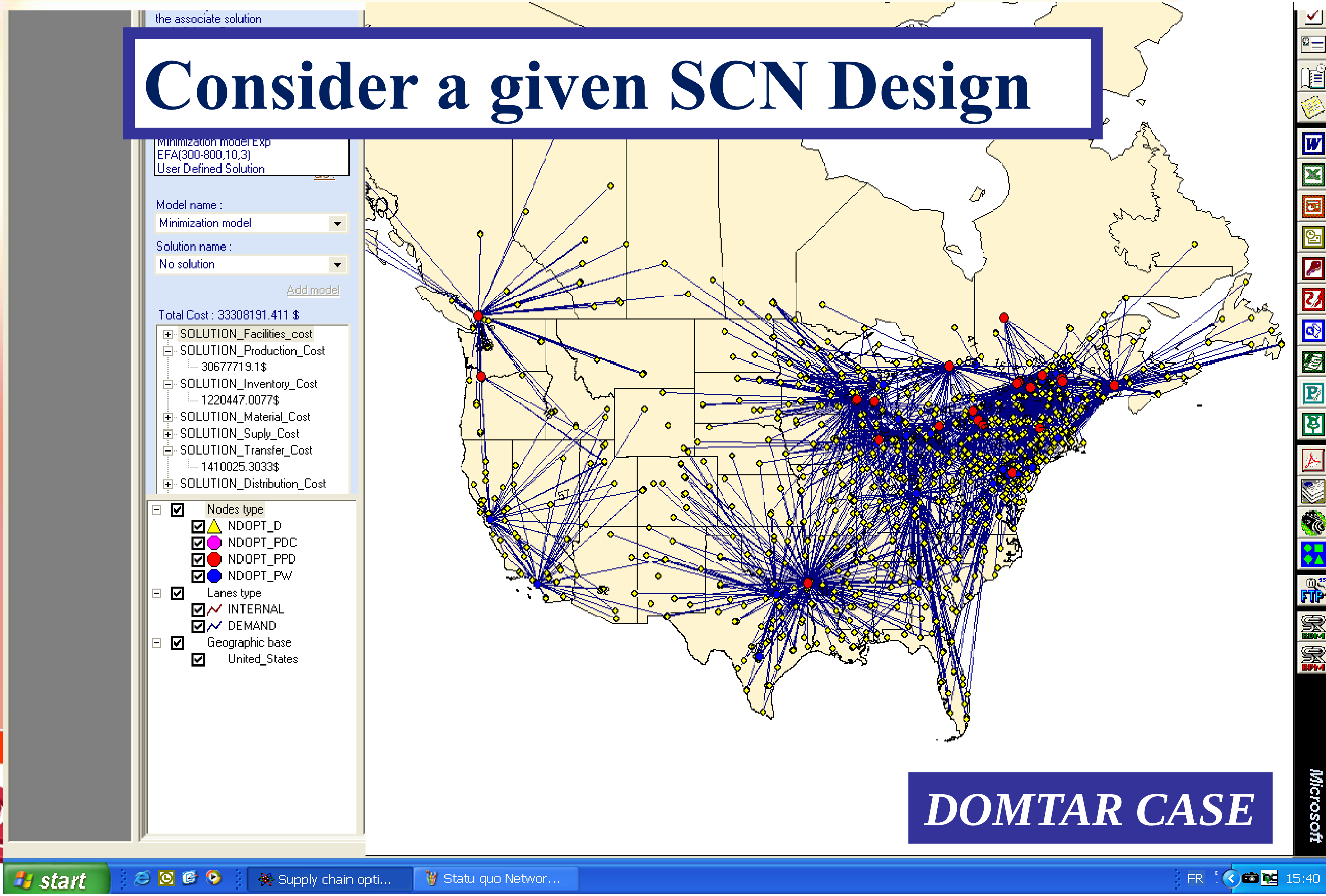
Activity Graph
Supply
Stems
RM Storage
Logs
Bucking
Logs
Sawing
Rejects
Rejects
Green Lumber
Drying
Chipping
Rough Lumber
Planing/ Grading
Chips
FP Storage
Demand
Boards
$v \in V$
Platform
Systems
Platform
Systems
Potential Sites
$s \in S$
Spot market zones
Potential contracts
Potential VMI agrem.
$d \in D$
$a \in A$
$l \in L = V \cup S \cup D$

Potential Supply Chain Network



Modeling Value

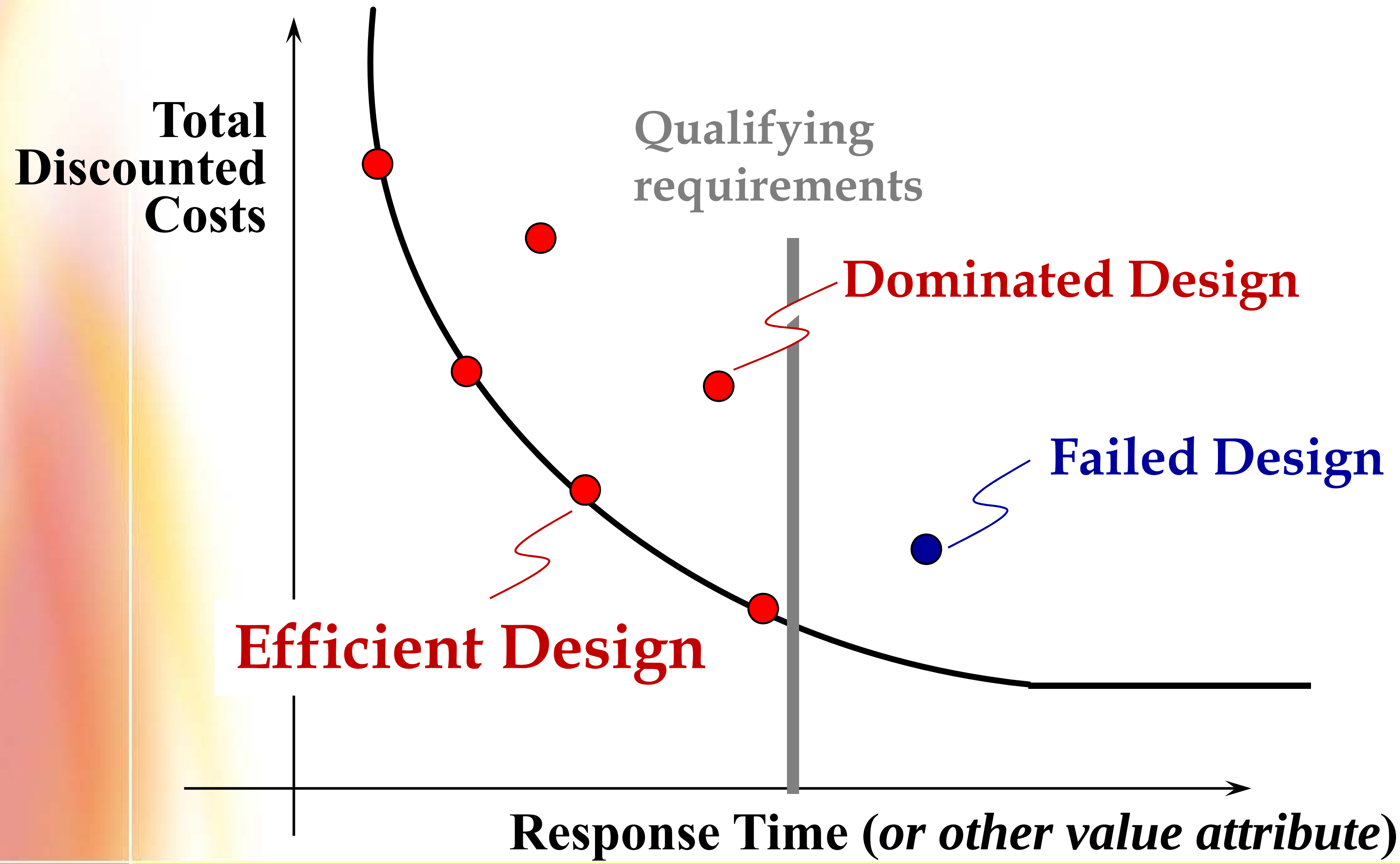
Consider a given SCN Design



DOMTAR CASE

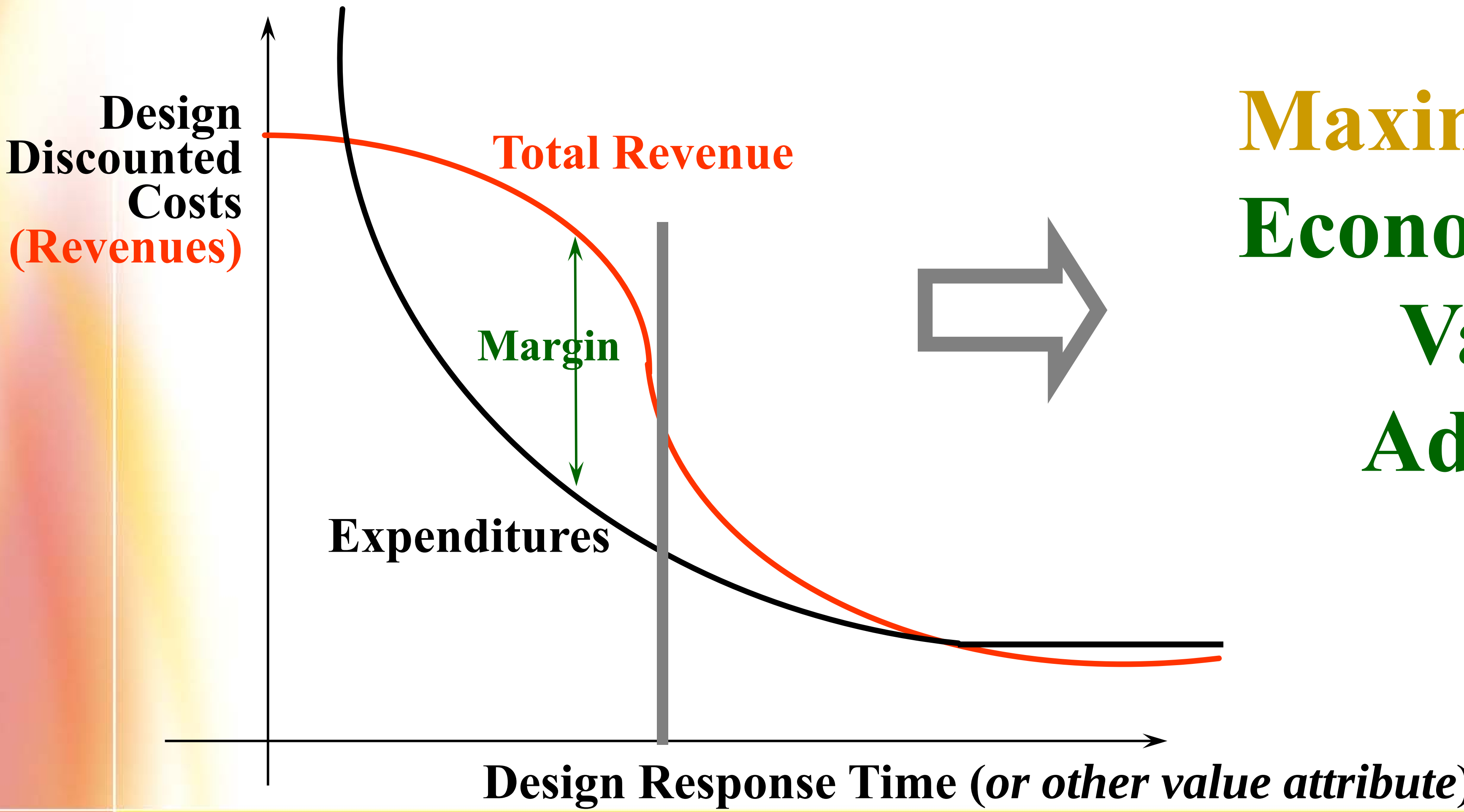
Design Objective

Efficient-Frontier for a given P&C System



Design Objective

Design for *Value*



Maximize Economic Value Added

Type of Model Obtained

Max $\sum_{Countries}\{(1\text{-}Tax)\ \sum_{Sites}[\text{Revenues}$

$- (\text{Platform costs}$

$+ \text{System \& flexible capacity costs}$

$+ \text{Facilities operations costs}$

$+ \text{Procurement and Inventory costs}$

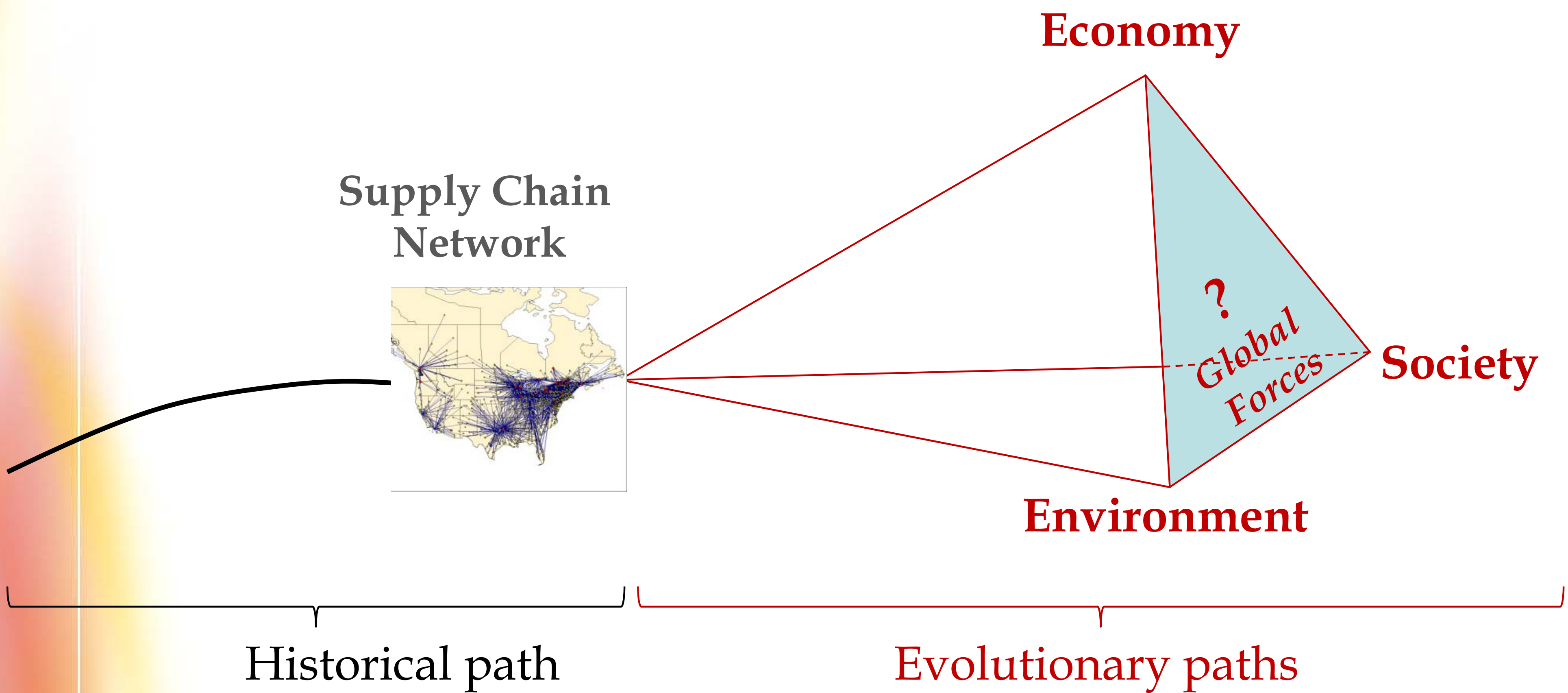
$+ \text{Transportation costs} + \text{Duties...})]\}$

subjet to

Network configuration constraints
Platform/system selection constraints
Supply / Capacity / Demand constraints
Material requirement constraints
Inventory accounting constraints
Flow conservation constraints
Local content and transfer price constraints
…

=> Large MIP (with concave costs)

3. Taking Uncertainty into Account

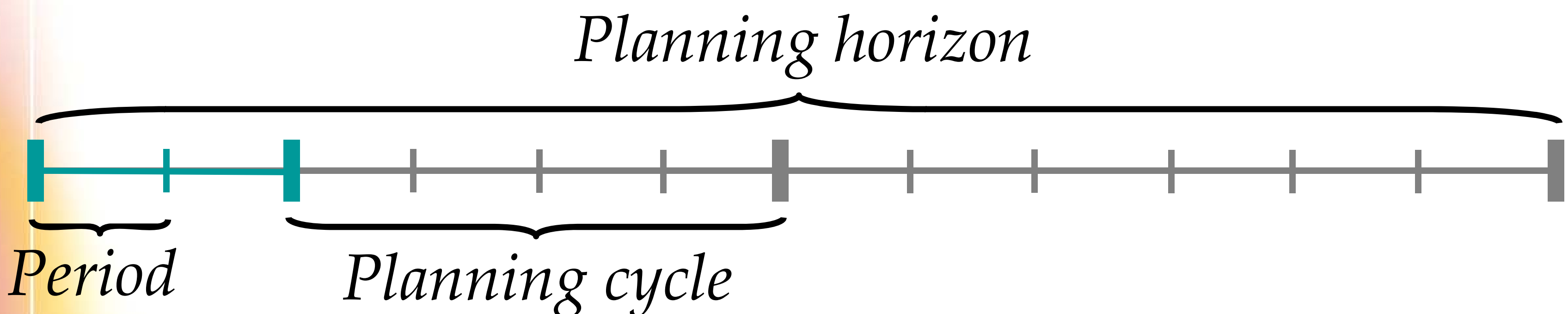


(Shell Global Scenarios to 2025)

- The future is dominated by uncertainty

Designing for the Future

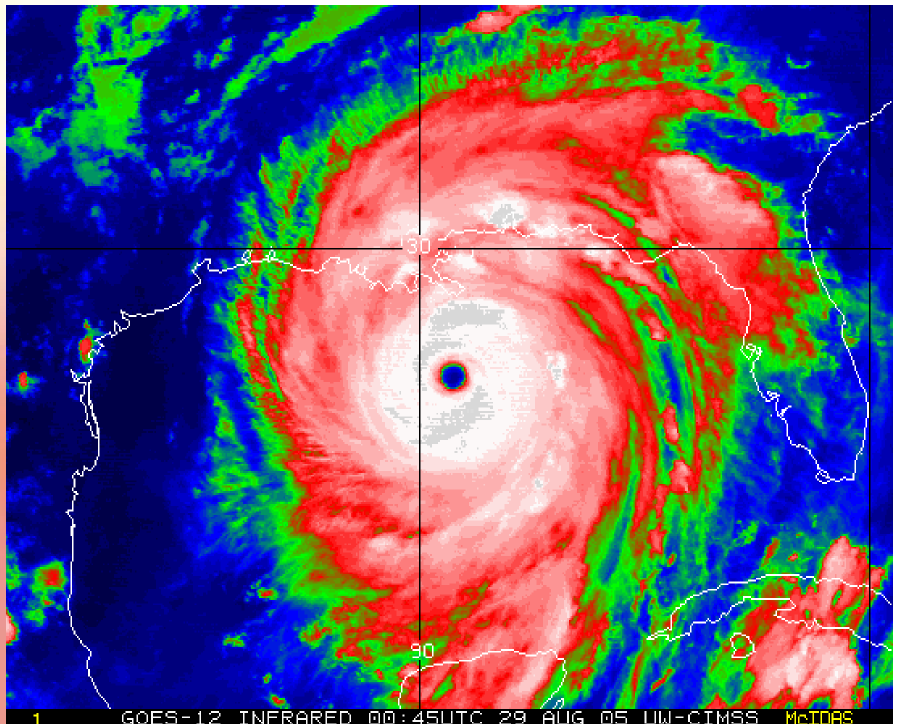
- Planning horizon
  - Capacity investment decisions => 10 years & +
  - Resource allocation decisions => 12 months



- Coping with randomness in a **business as usual** context
  - Stochastic demands, prices, exchange rates…
  - Static stochastic program with recourse for a typical planning cycle
  - Multi-stage (cycles) stochastic program with recourse

Hazardous/Catastrophic Events

Hurricane Katrina



- Destruction of supply chains and transportation infrastructures
- Demand surge for first aid and construction material
- Significant decrease of demand for luxury products
- Approximately 58,000 troops coming from all 50 US states assigned to the theater

Supply Chain Network Risk Analysis

Three Fundamental Questions

- *What can go wrong?*
  - Vulnerability sources identification and filtering
- *What is the likelihood of that happening?*
  - Multihazard zones risk exposure levels
  - Stochastic multihazard arrival processes
  - Attenuation probabilities
- *What are the consequences?*
  - Incidents damage on supply/resources /demand

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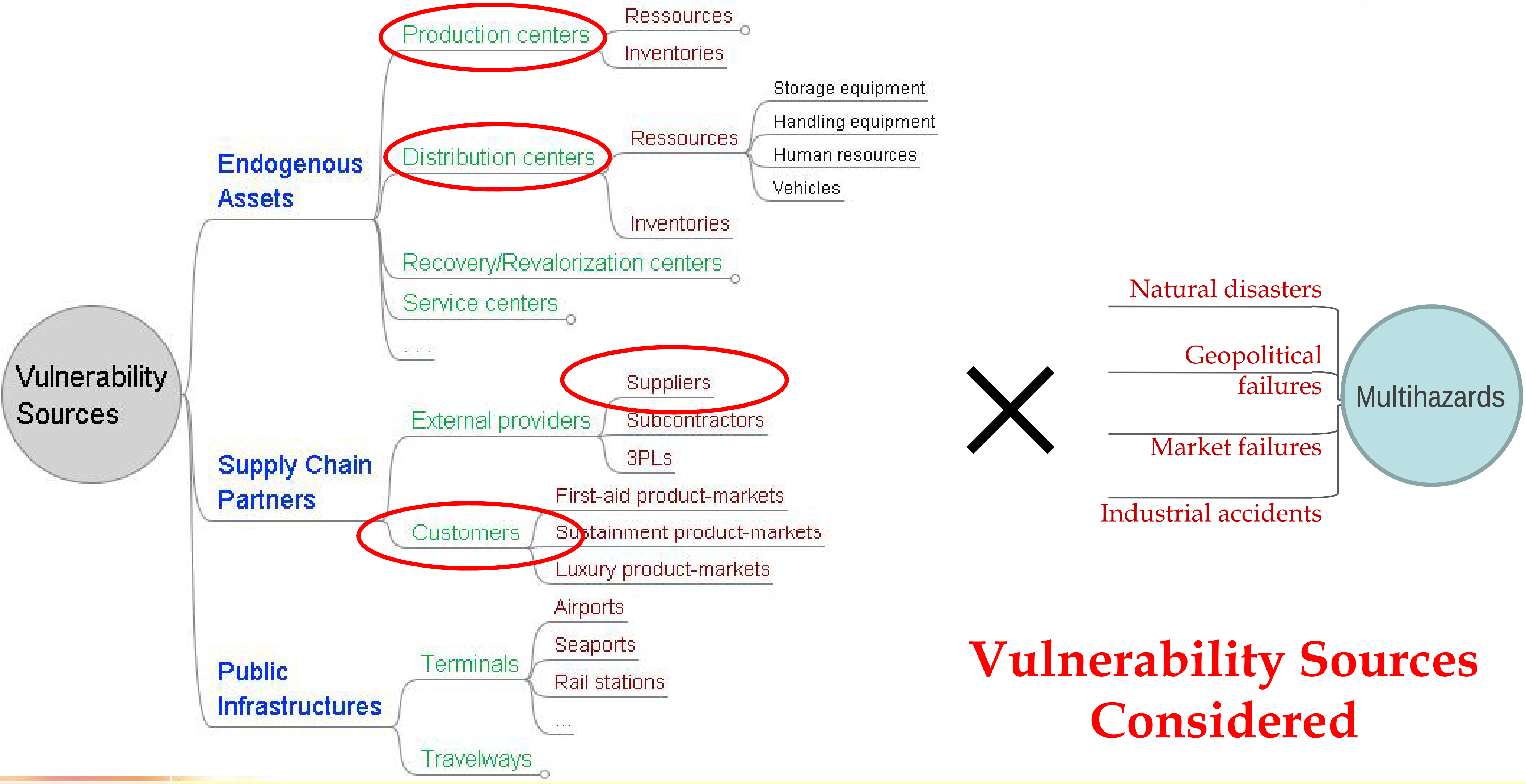
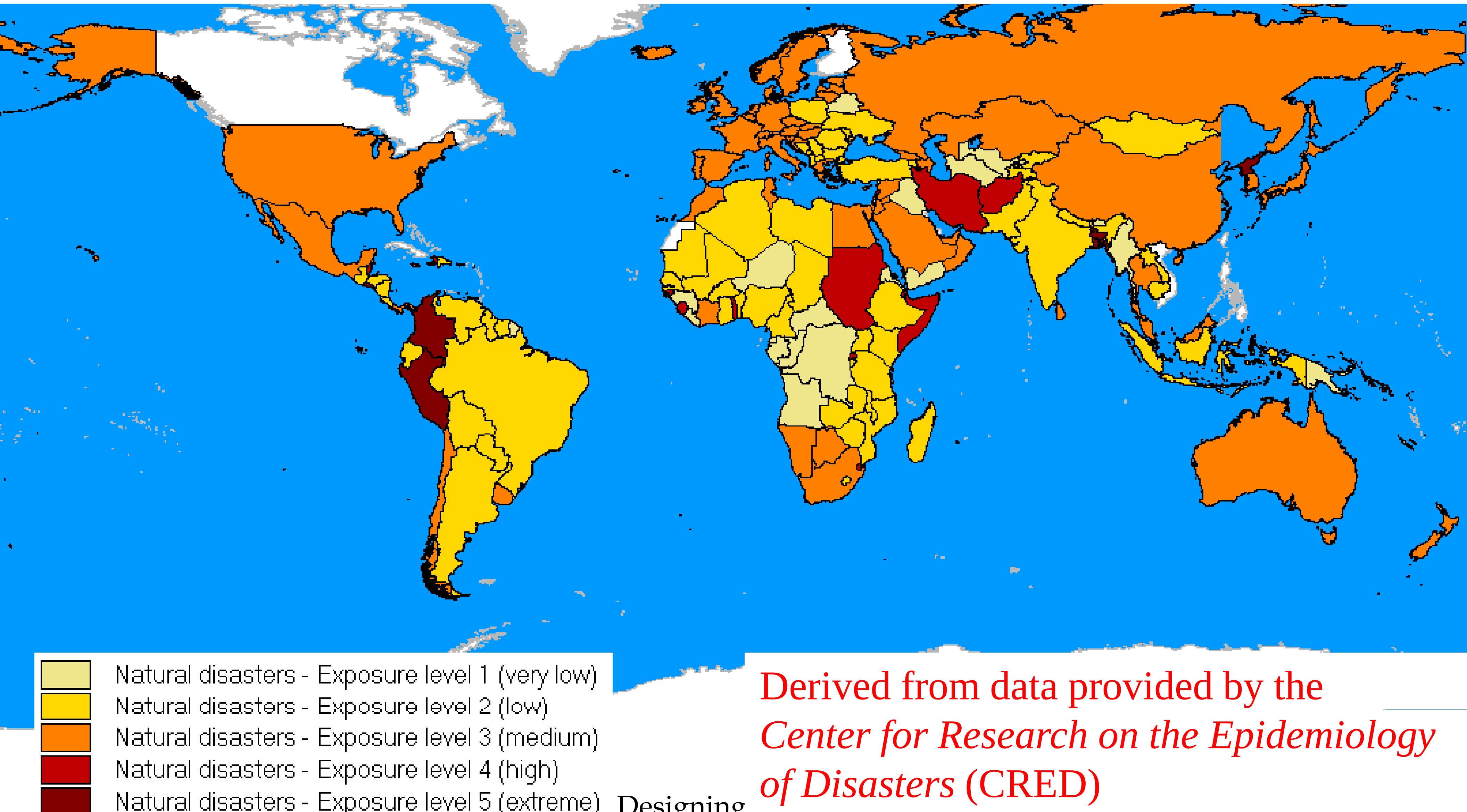
DSN Risk Analysis: *What can go wrong?*



Vulnerability Sources Considered

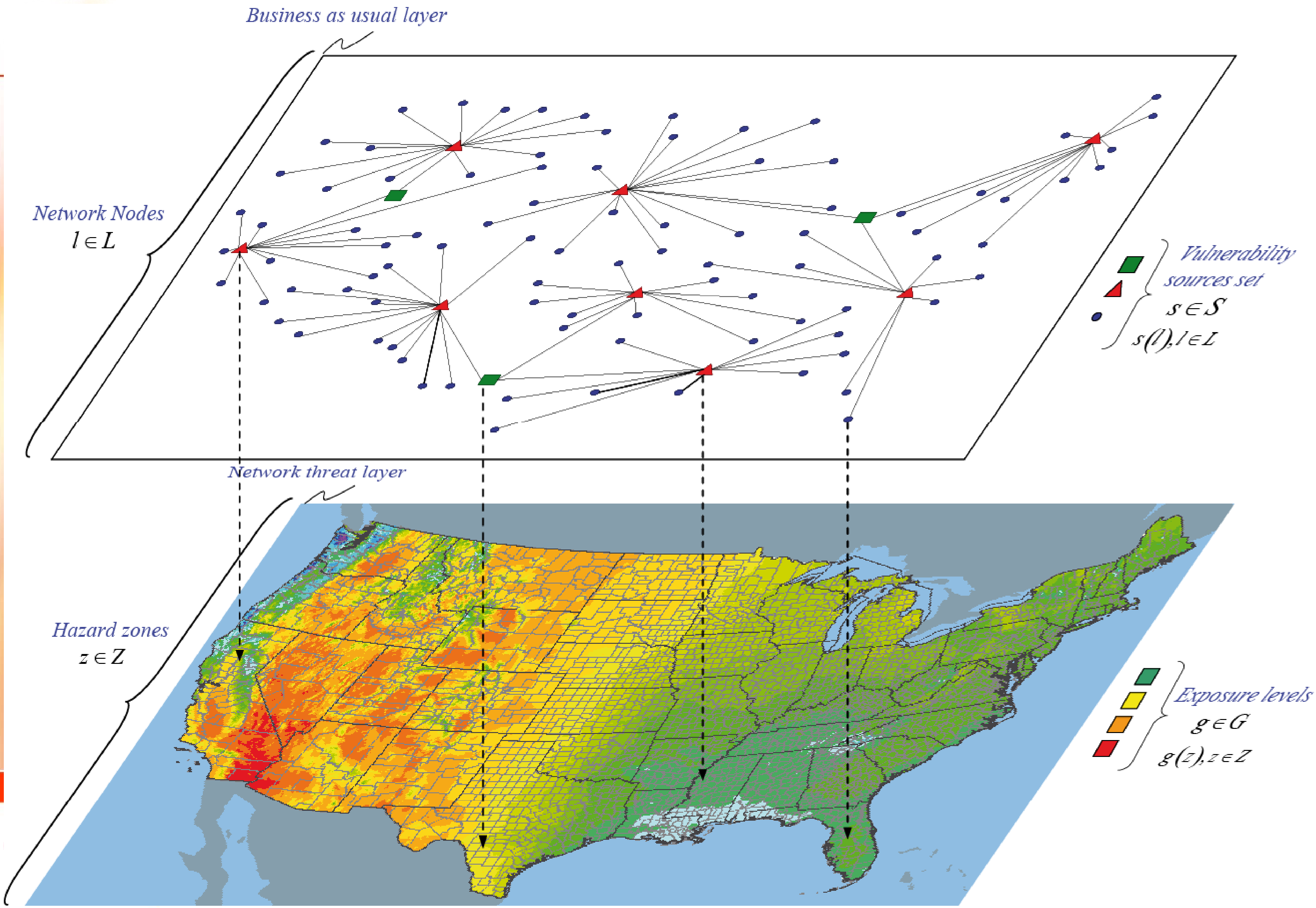
DSN Risk Analysis:
What is the likelihood of that happening ?

Exposure Levels for Natural Disasters



Derived from data provided by the *Center for Research on the Epidemiology of Disasters* (CRED)

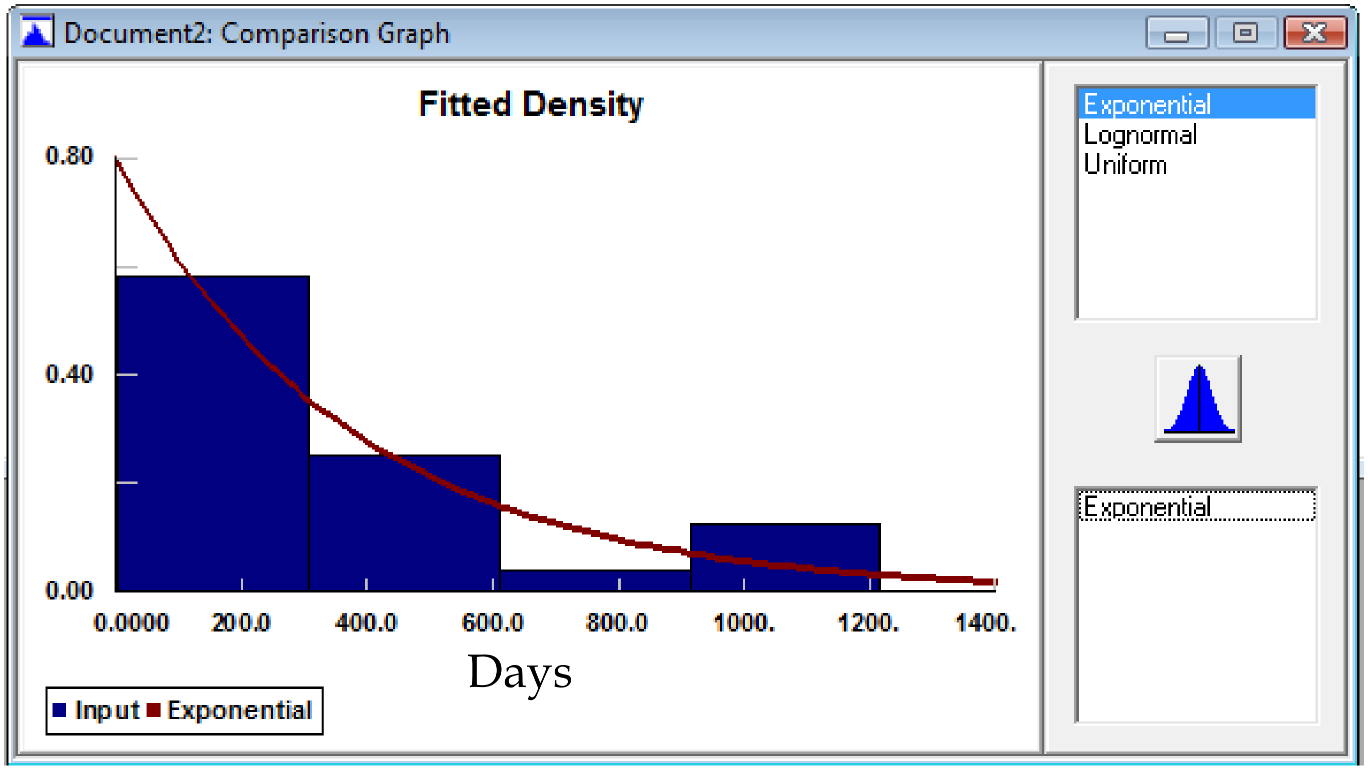
Vulnerability-Exposure Relationship



Inter-arrival Time Distribution

For Natural Catastrophes' Exposure Level 5

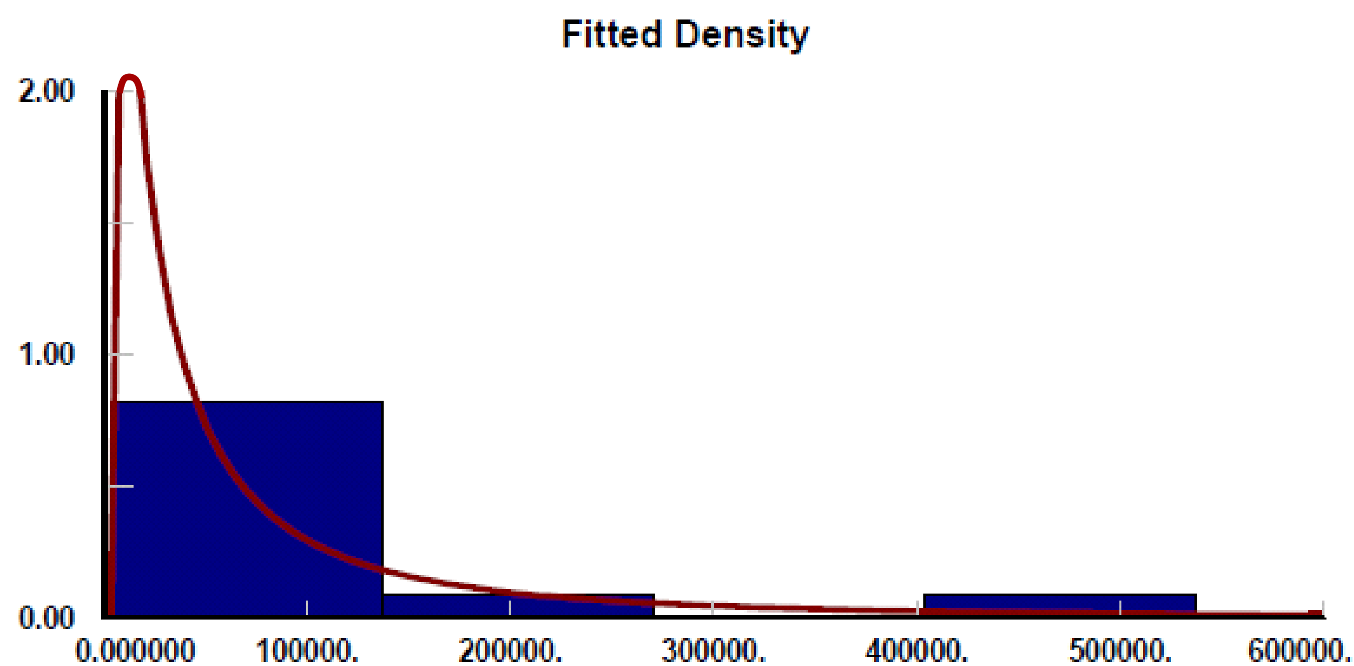
Exponential distribution with mean λ = 350 days



Intensity Distribution

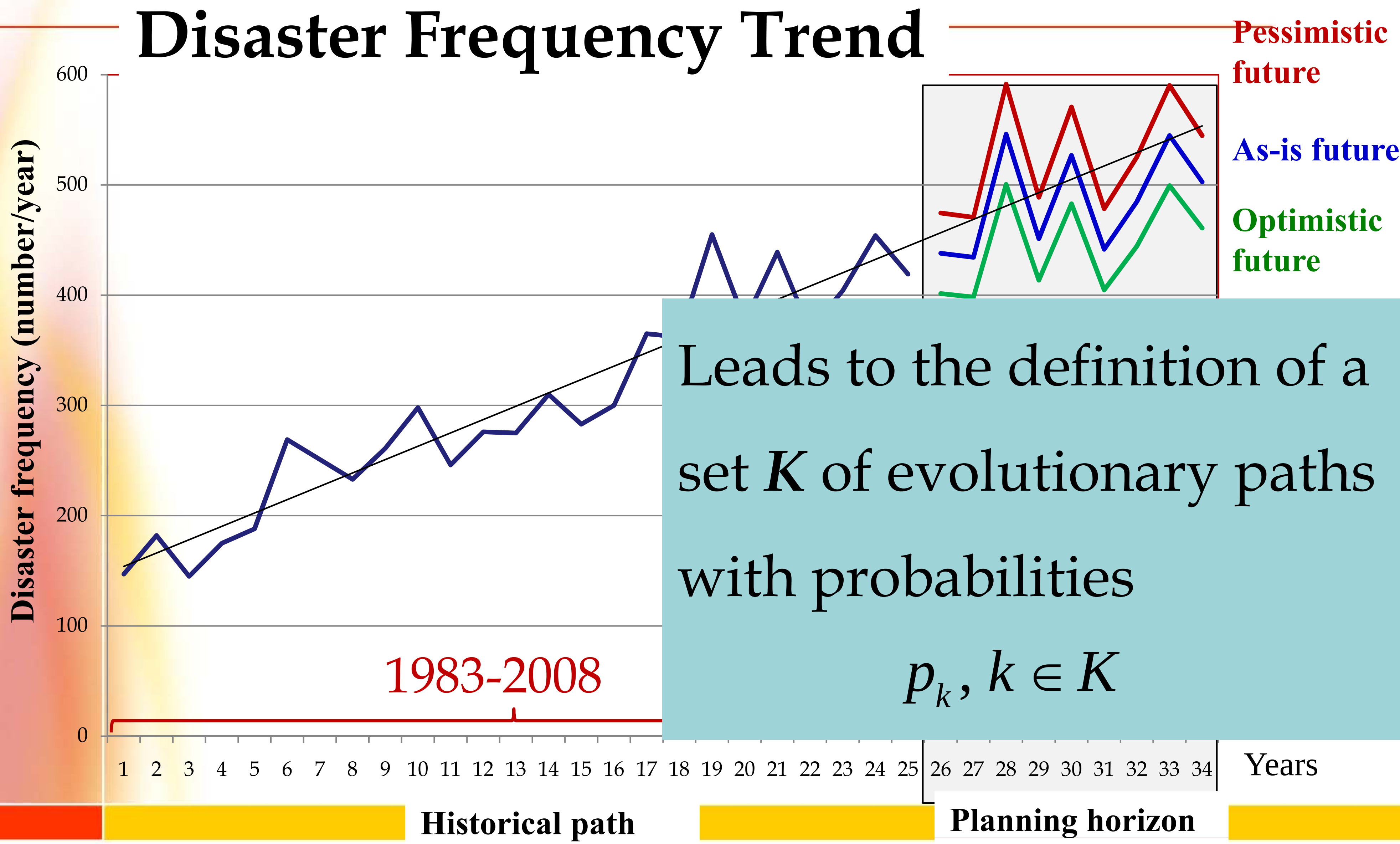
For Natural Catastrophes' Exposure Level 5

Log-Normal distribution



Loss level in $

Evolutionary Paths (Trends)



Leads to the definition of a set K of evolutionary paths with probabilities

$$p_k, k \in K$$

Attenuation Probabilities

- The occurrence of a multihazard in a zone does not necessarily translate into a network hit
- Canadian Forces Case:

  Probability that a mission is initiated in response to the occurrence of a multihazard in a given country

Hazard/Mission type	Location	Probability
...	...	
Natural disaster/Humanitarian assistance	Belgium	0,023
Natural disaster/Humanitarian assistance	Botswana	0,023
Natural disaster/Humanitarian assistance	Chile	0,027
...	...	
Quarrel/Peacekeeping	Greece	0,700
Quarrel/Peacekeeping	Herzegovina	0,700
Quarrel/Peacekeeping	Algeria	0,600
...	...	
War/Peace making	Haiti	0,450
War/Peace making	Poland	0,400
War/Peace making	Cyprus	0,350
...	...	

SCN Risk Analysis: *What are the consequences?*

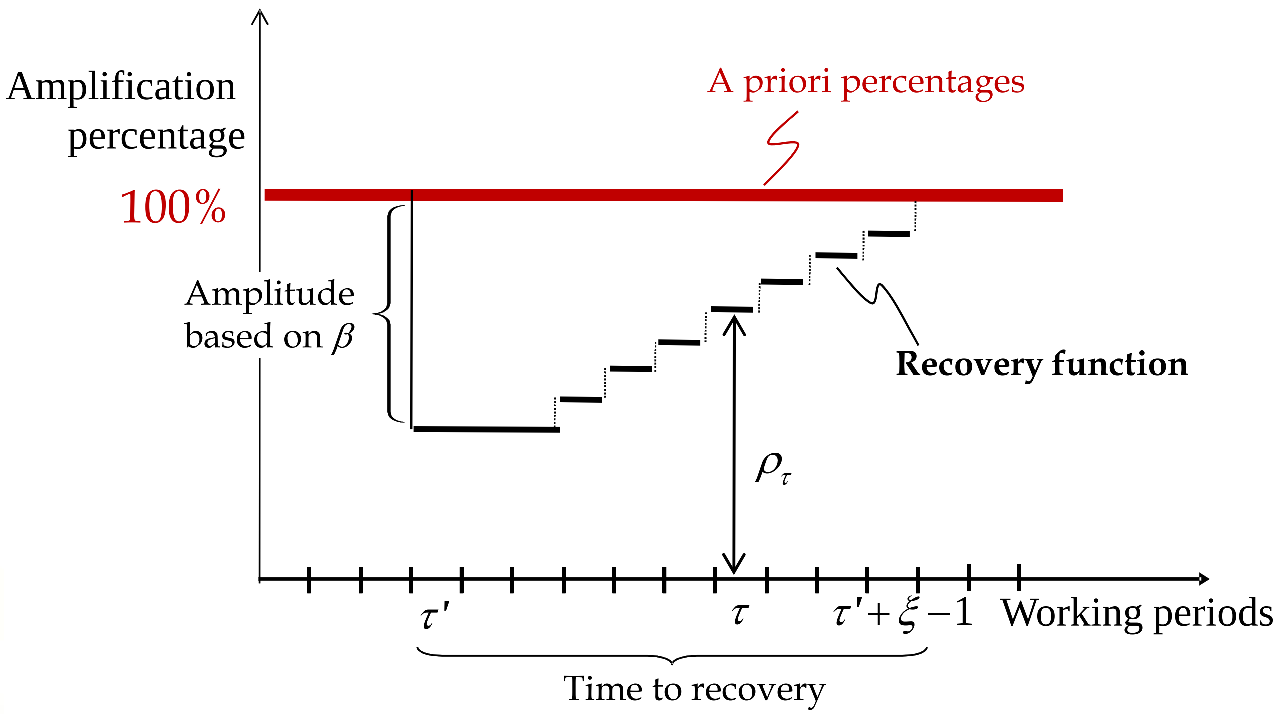
➢ Multihazard Incidents Severity Profile

			Capacity-based Vulnerability Sources $S_c = \{1, 2, 3\}$			Demand-based Vulnerability Sources $S_d = \{4, 5, 6\}$		
			1) **Suppliers**	2) **Plants**	3) **DCs**	4) **First-aid Product-markets**	5) **Sustainment Product-markets**	6) **Luxury Product-markets**
Impact intensity	**Multihazards** $H = \{a, b, c\}$	*a) Natural disasters*	Unfilled supply rate	Capacity loss rate	Capacity loss rate	Demand inflation rate		Demand deflation rate
		b) Market failures	Unfilled supply rate				Demand deflation rate	Demand deflation rate
		c) Industrial accidents		Capacity loss rate				
Time to recovery	**Multihazards** $H = \{a, b, c\}$	*a) Natural disasters*	Time to restoring supplies	Time to restarting production	Time to restarting distribution	Surge duration		Drop duration
		b) Market failures	Time to restoring supplies				Drop duration	Drop duration
		c) Industrial accidents		Time to restarting production				

SCN Risk Analysis: *What are the consequences?*

Recovery Function Example

Capacity loss recovery function



$$c'_{lp\tau} = \rho_{lp\tau} c_{lp},\ \ \tau = \tau', \ldots, \tau' + \xi_l^h - 1;\ \ \boldsymbol{\rho}_{lp} = r_{sp}^h(\beta_{g(l)}^h, \xi_l^h, \boldsymbol{\rho}_{lp});\ \ s \in S^c, p \in P_s,\ l \in L_s$$

Plausible Future Scenarios

- The superposition, over the planning horizon, of
  - An instance of these multihazard processes
  - An instance of the business-as-usual random variables
  - ➢ Yields a **probabilistic scenario** $\omega \in \Omega^P$

Ω^P = Set of probabilistic scenarios

$p(\omega)$ = Probability of occurrence of scenario $\omega \in \Omega^P$

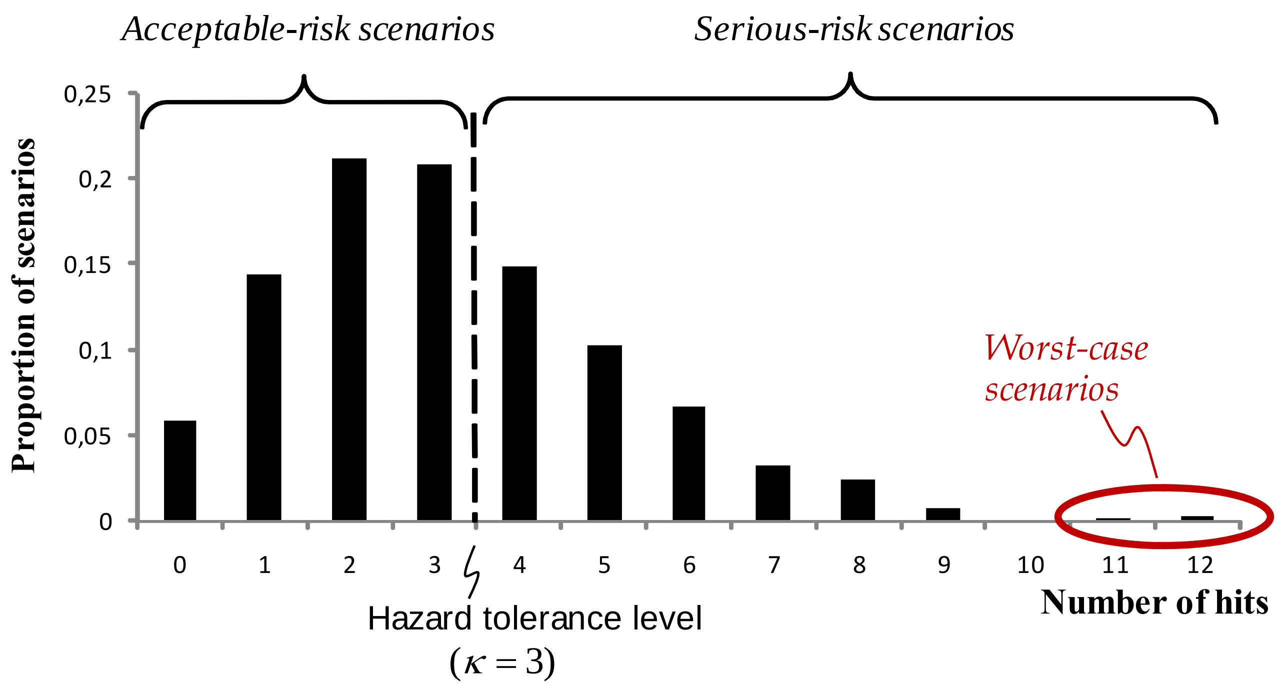
- **Deeply uncertain scenarios** can also be considered
  - Incorporate isolated, non repetitive, extreme events for which a likelihood of occurrence cannot be evaluated

Ω^U = Set of deeply uncertain scenarios

Aversion to Extreme Events Risk

Based on the number of network hits

Ω^P

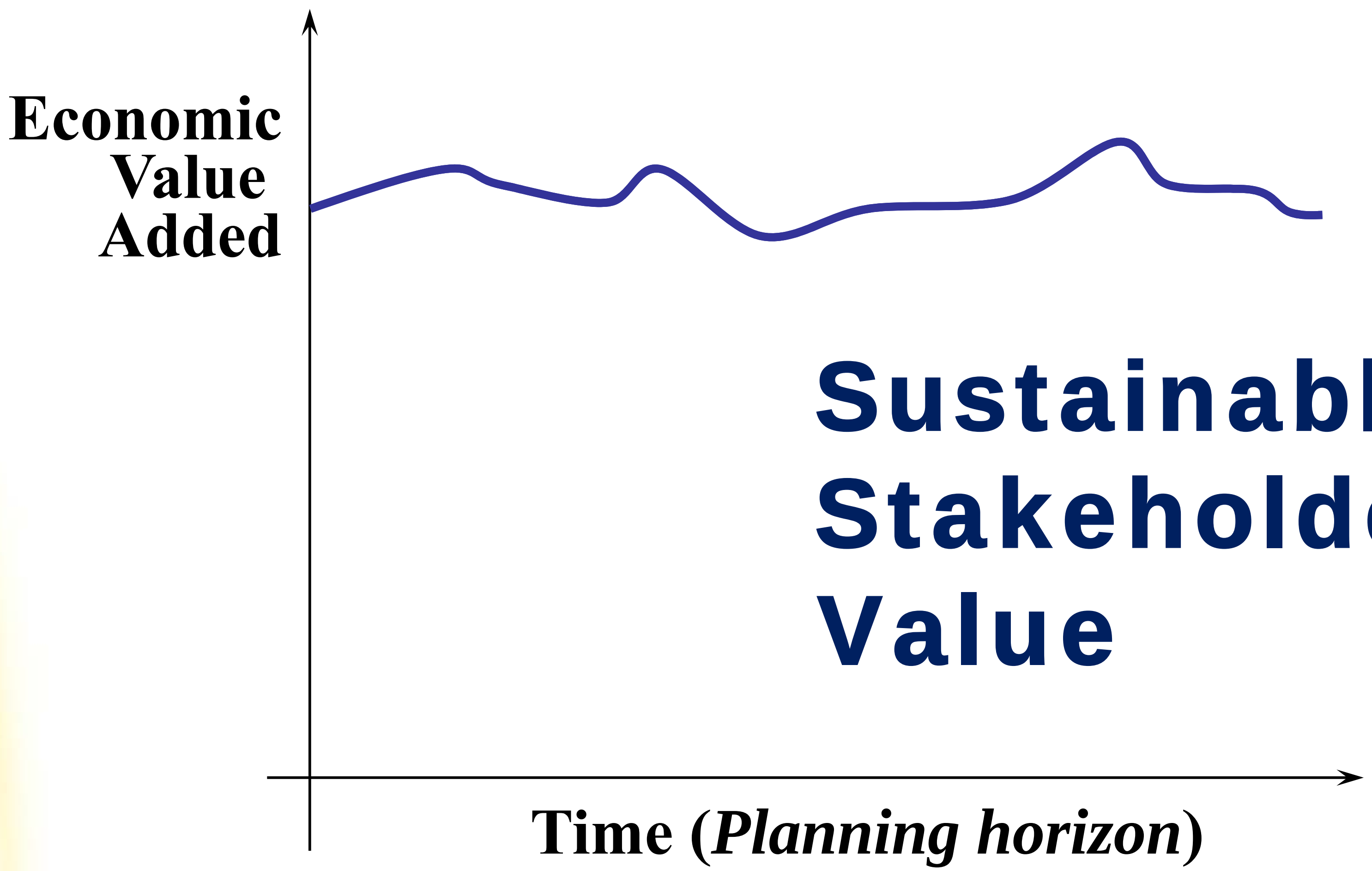


Ω^A = Set of acceptable-risk scenarios

Ω^S = Set of serious-risk scenarios

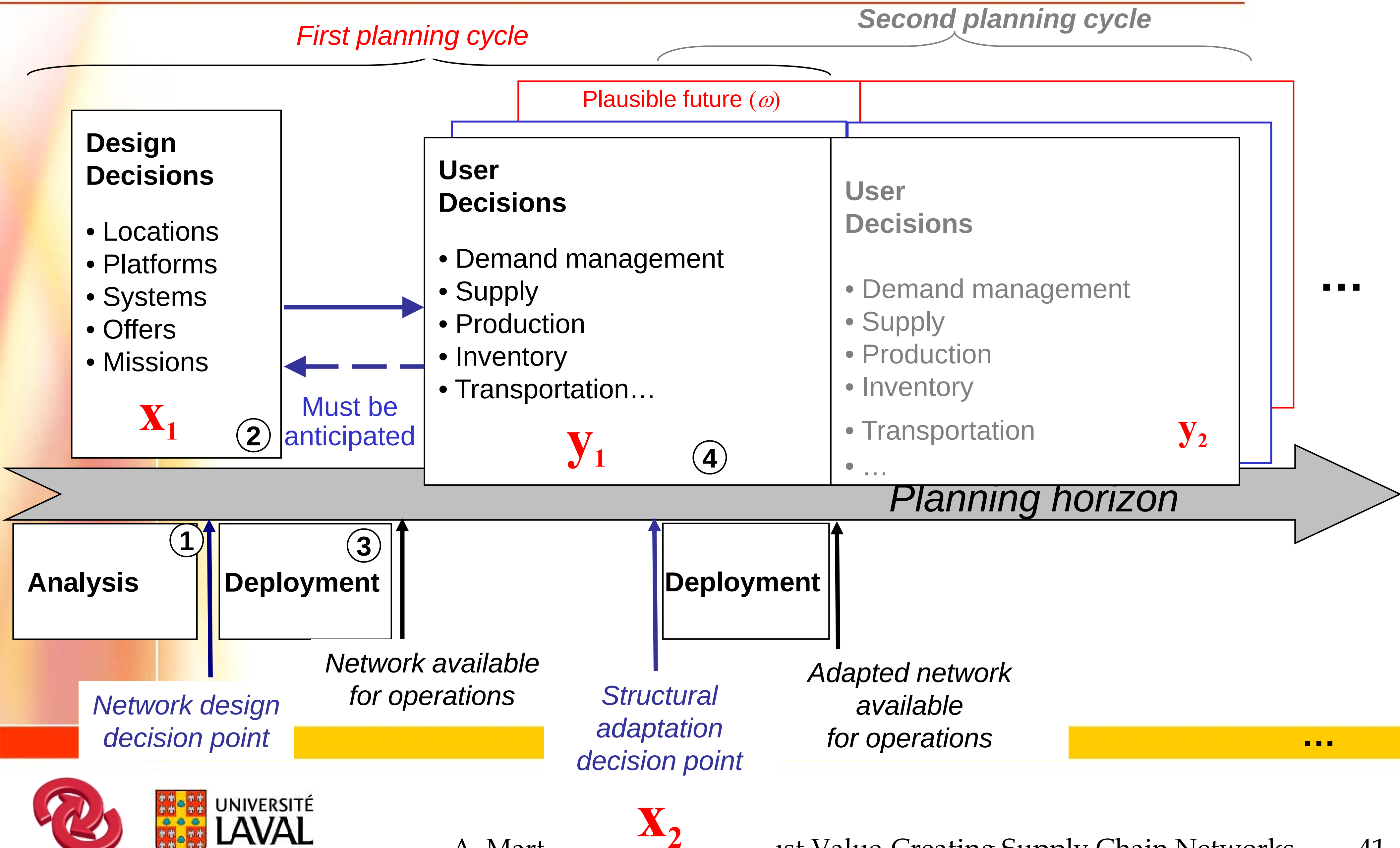
Design Objective

Robust Design



Sustainable Stakeholder Value

4. SCN Design Methodology



Decision-Making Framework

Anticipation
of expected revenues and costs

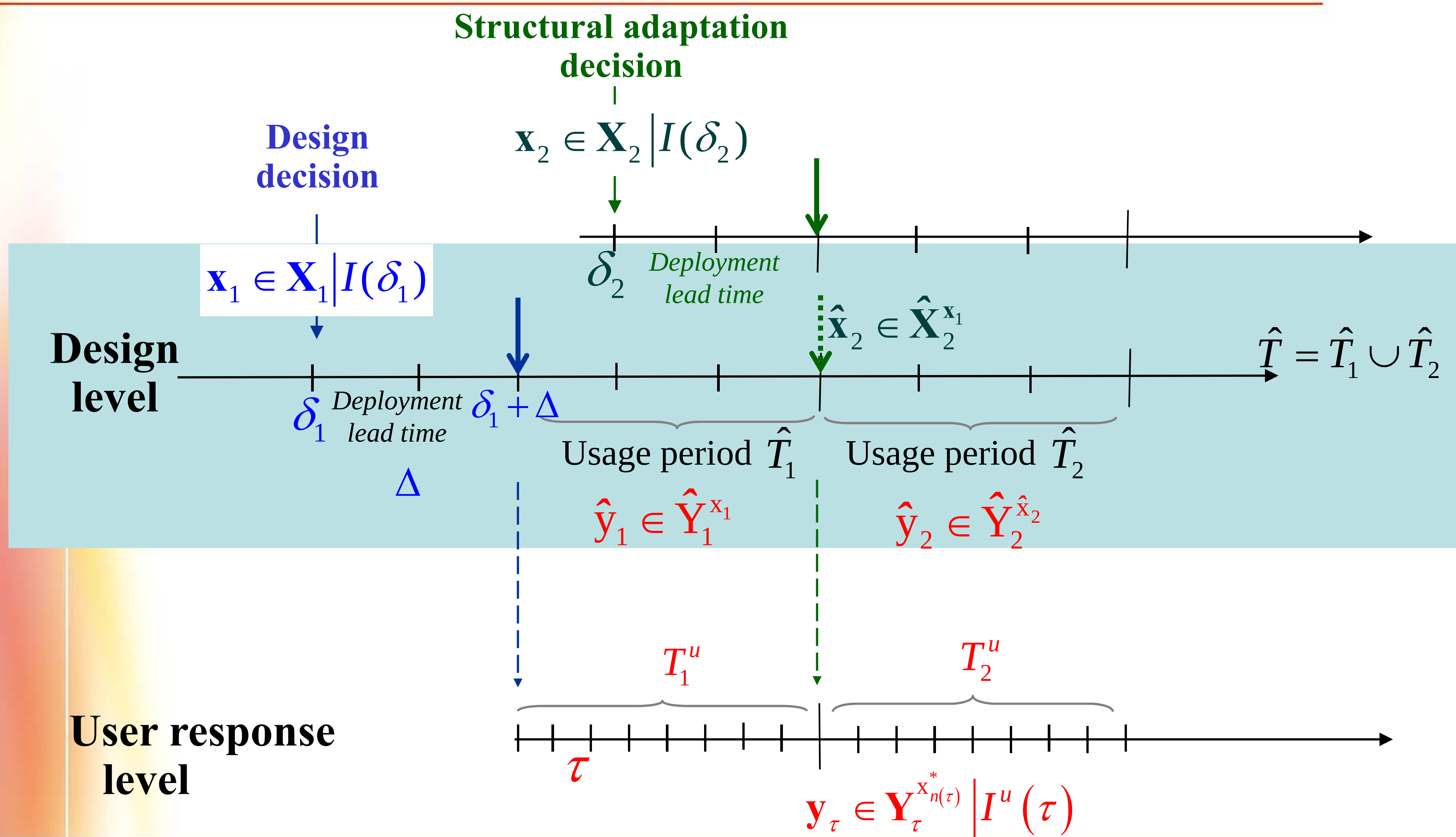
Design Level
- Investment
- Deployment
- Policy making

Design

User Response Level

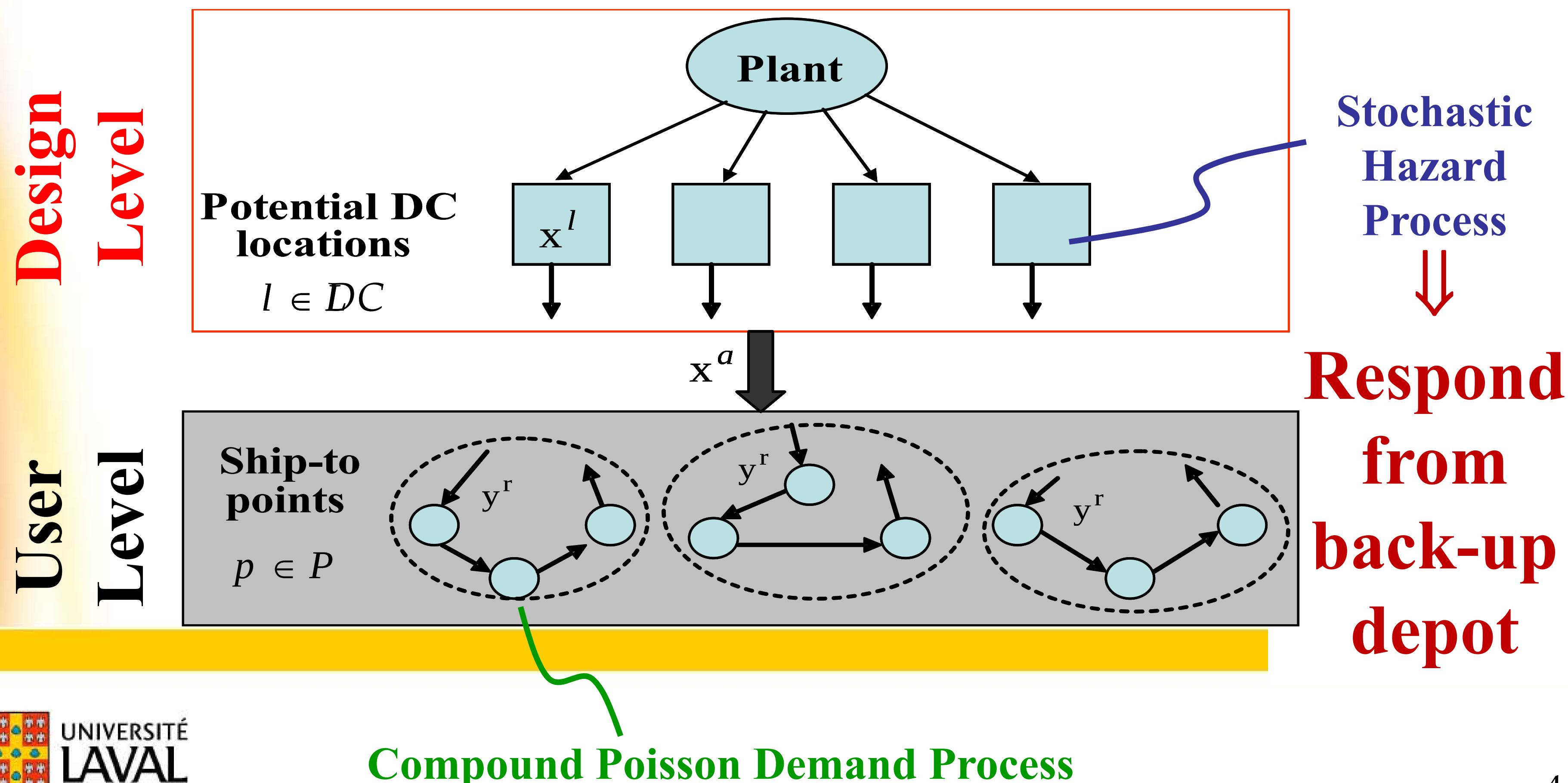
Synchronization of supply and demand based on ***Response Policies*** for:
- Business-as-usual events
- Extreme events

Decision Time Hierarchy



Illustrative Case:
Multi-depot location-transportation problem

- Daily stochastic orders from customers
- Depots vulnerable to extreme events
- How many warehouses and where ?



Strategic Decision Framework

Design Model

$$\max_{\mathbf{x}_1\in\mathbf{X}_1} \mathcal{R}\left\{C(\mathbf{x}_1,.)\middle| I^{\Omega}(\delta_1)\right\},\quad C(\mathbf{x}_1,\omega) = C^d(\mathbf{x}_1,\omega) + \hat{C}^{du}(\mathbf{x}_1,\omega),\ \omega\in\Omega$$

$\hat{C}^{du}(\mathbf{x}_1,\omega),\ \omega\in\Omega$

$\mathbf{x}_1$

$I^{\Omega}(\delta_1)$

Anticipated Adaptation-Response Model

$$\hat{C}^{du}(\mathbf{x}_1,\omega) = \operatorname*{opt}_{\substack{\hat{\mathbf{x}}_2(.),\dots,\hat{\mathbf{x}}_{|N|}(.)\\ \hat{\mathbf{y}}_1(.),\dots,\hat{\mathbf{y}}_{|\hat{T}|}(.)}} \sum_{t\in\hat{T}_1}\hat{C}^u(\hat{\mathbf{y}}_t(\omega)) + \sum_{n>1}\left[\hat{C}^d(\hat{\mathbf{x}}_n(\omega)) + \sum_{t\in\hat{T}_n}\hat{C}^u(\hat{\mathbf{y}}_t(\omega))\right]$$

s.t $\hat{\mathbf{x}}_n(\omega)\in\hat{\mathbf{X}}_n^{\mathbf{x}_{n-1}}(\omega)\ \forall n>1,\ \hat{\mathbf{y}}_t(\omega)\in\hat{\mathbf{Y}}_t^{\mathbf{x}_{n(t)}}(\omega)\ \forall t$

& non-anticipativity of $\hat{\mathbf{x}}_n(\omega)$ $\quad\omega\in\Omega$

$\mathbf{x}_1^*$

User Response Decisions

$$\operatorname*{opt}_{\mathrm{y}_\tau\in\mathrm{Y}_\tau^{\mathbf{x}^*_{n(\tau)}}} \mathcal{R}\left\{C^u(\mathrm{y}_\tau)\middle| I^u(\tau)\right\}$$

$I^u(\tau)$

$\tau\in T^u$

Generic SCN Design Model

Using Stochastic Programming (Shapiro, 2007), Robust Optimization (Kouvelis et al., 1997) and Risk Analysis (Haimes, 2004) concepts, the design problem can be formulated as follows:

$$\max_{\mathbf{x}_1 \in \mathbf{X}_1} \left\{ \mathcal{R}_{\Omega^A|A}\left\{C\left(\mathbf{x}_1,.\right)\right\}, \mathcal{R}_{\Omega^S|S}\left\{C\left(\mathbf{x}_1,.\right)\right\}, \mathcal{R}_{\Omega^U|U}\left\{C\left(\mathbf{x}_1,.\right)\right\} \right\}$$

Conditional return measure

Conditional expected value measure

Conditional dispersion measure

$$\begin{cases} \mathcal{R}_{\Omega^A|A}\left\{C\left(\mathbf{x}_1,.\right)\right\} = \mathbb{E}_{\Omega^A|A}\left\{C\left(\mathbf{x}_1,.\right)\right\} + \varphi_A \mathcal{D}_{\Omega^A|A}\left\{C\left(\mathbf{x}_1,.\right)\right\}, \varphi_A \in [0,1] \\ \mathcal{R}_{\Omega^S|S}\left\{C\left(\mathbf{x}_1,.\right)\right\} = \mathbb{E}_{\Omega^S|S}\left\{C\left(\mathbf{x}_1,.\right)\right\} + \varphi_S \mathcal{D}_{\Omega^S|S}\left\{C\left(\mathbf{x}_1,.\right)\right\}, \varphi_S \in [0,1] \\ \mathcal{R}_{\Omega^U|U}\left\{C\left(\mathbf{x}_1,.\right)\right\} = \underset{\omega \in \Omega^U}{Min}\ \mathcal{D}_U\left\{C\left(\mathbf{x}_1,\omega\right)\right\} \end{cases}$$

Robustness criterion

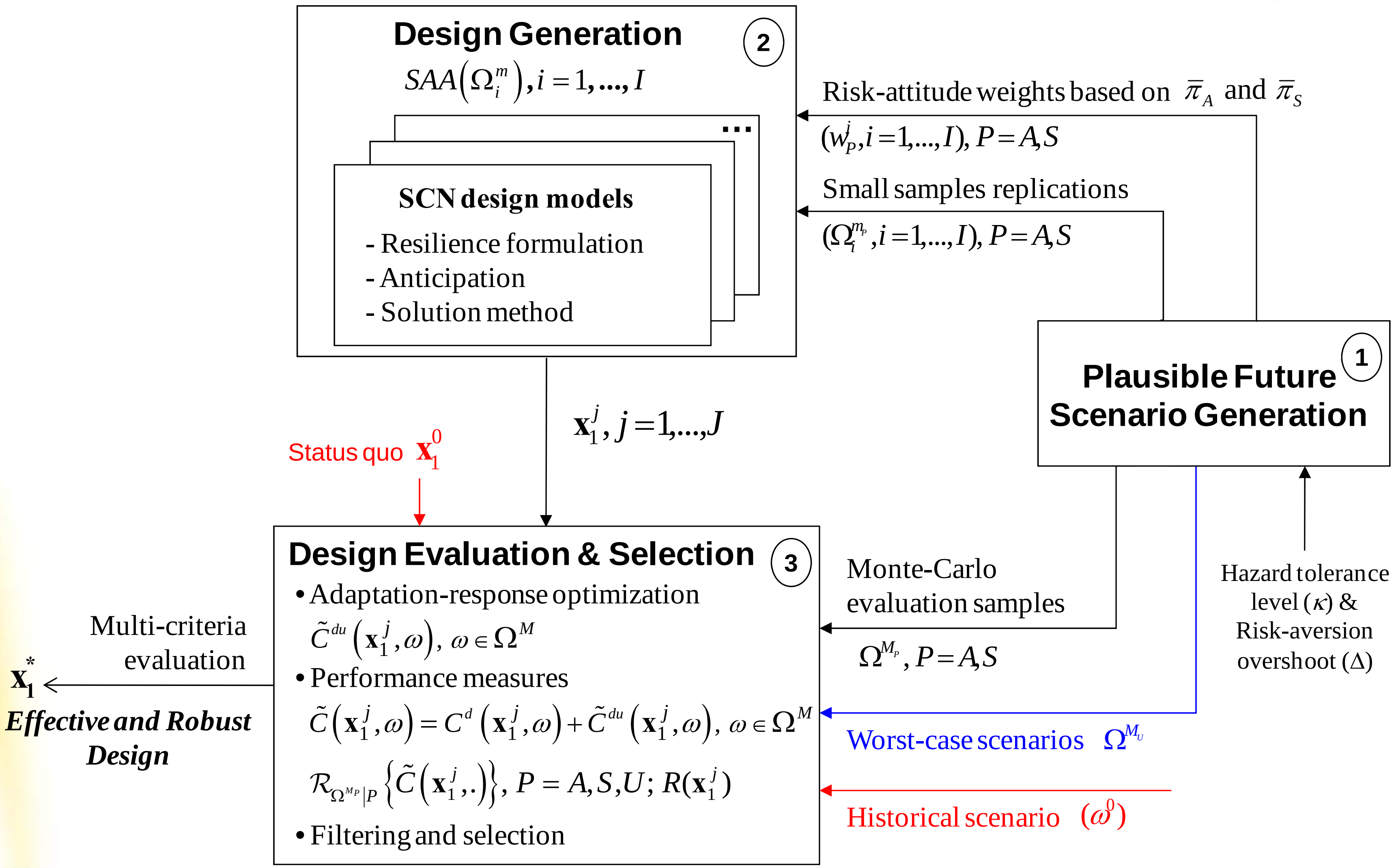
Multiparametric program

$$\Rightarrow \max_{\mathbf{x}_1 \in \mathbf{X}_1} R(\mathbf{x}_1) = (1-\psi)\left[w_A \mathcal{R}_{\Omega^A|A}\left\{C\left(\mathbf{x}_1,.\right)\right\} + w_S \mathcal{R}_{\Omega^S|S}\left\{C\left(\mathbf{x}_1,.\right)\right\}\right] + \psi \mathcal{R}_{\Omega^U|U}\left\{C\left(\mathbf{x}_1,.\right)\right\}$$

Complexity Reduction Approach

- Use approximate anticipations of adaptation-response decisions to simplify the combinatorial structure of the design model (based on spatio-temporal aggregations)
- Use only primordial expected value and risk aversion criteria associated to probabilistic scenarios
- Assuming that the SCN design problem will be solved on a rolling horizon basis, reduce the design model to a multi-cycle two-stage stochastic program with recourse
- Solve the design model for several small samples of scenarios generated using Monte Carlo methods
- Evaluate the designs obtained using a user response model

SCN Design Approach



Design Generation for the Multi-depot location-transportation problem

Several types of models and solution methods can be used to generate alternative designs

- Exact solution to static deterministic location-transportation model
- Exact solution to static deterministic location-allocation model
- Multi-period versions of the previous models
- Previous models with customers aggregated into demand zones
- Stochastic versions of the previous models with different scenario samples
- Stochastic models with resilience structures (back-up depots…)
- Heuristic solutions to the previous models
- Solution with different expected value / dispersion weights
- …

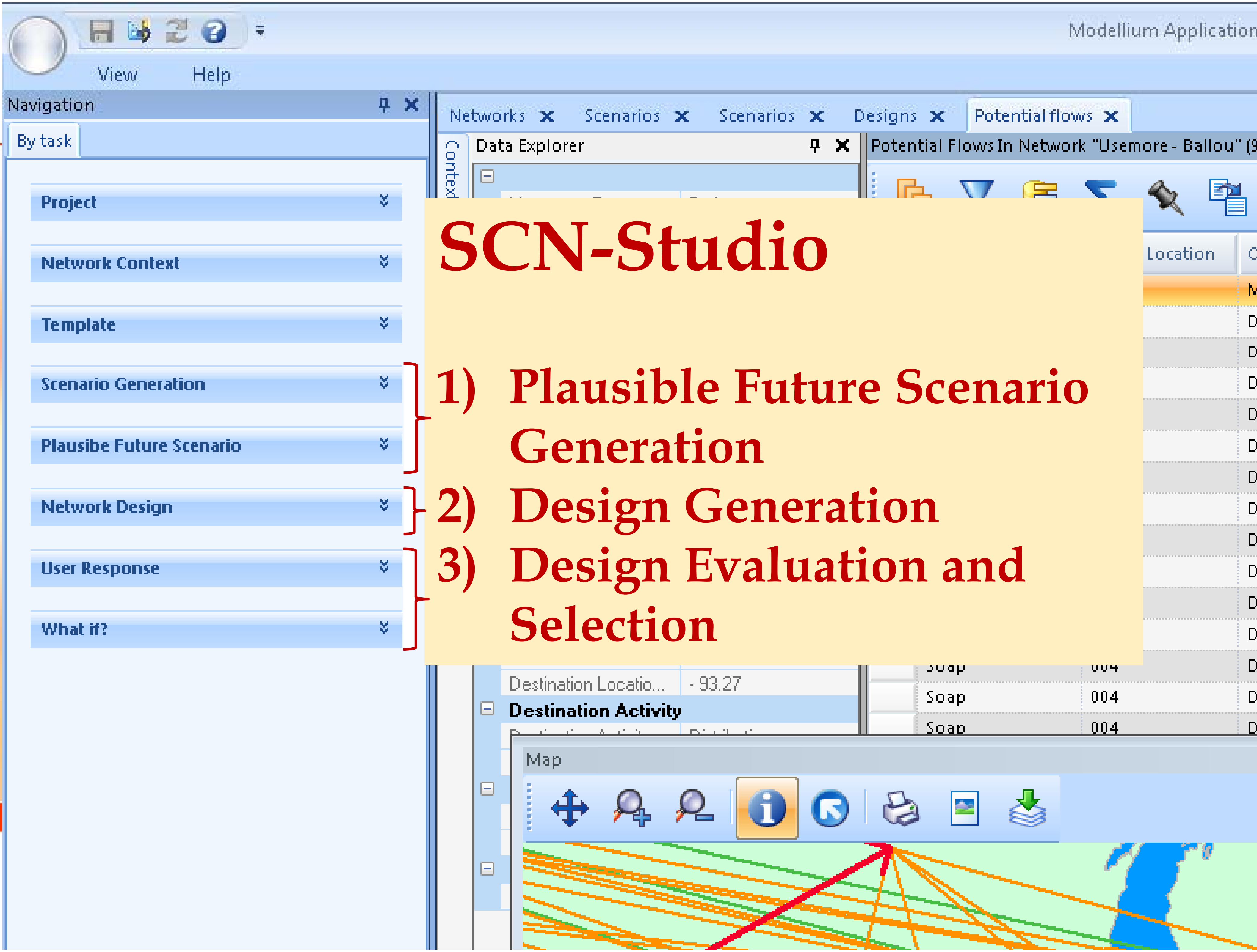
Design Evaluation/Selection for the Multi-depot location-transportation problem

- Based on a large sample of Monte-Carlo, worst-case and historical scenarios
- For each design $\mathbf{x}_1$ and each day τ of scenario ω :
  - Assign customer orders to depots based on response policy
  - Request transportation at depots for truckloads
  - Solve depots routing problems

  To get the design value $R(\omega,\mathbf{x}_1)$
- Compute adequate performance measures
  - Expected values
  - Dispersion measures (mean-semideviation, conditional value at risk…)
  - Resilience measures …
- Select the best design using multi-criteria decision methods

SCN-Studio

1) Plausible Future Scenario Generation
2) Design Generation
3) Design Evaluation and Selection



4- Research Challenges

- SCN risk analysis
- SCN multihazard modeling
- Scenario development and importance sampling
- Value based SCN design models
  - Dependence on value attributes & Financing
- Modeling for robustness
- Modeling resilience and responsiveness
- Solution methods

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