

Integrated Stochastic Network Model for a Reliability Assessment of the NEES

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Outline

- Motivation.
- Integrated stochastic network model
- Modeling challenges.
- Overview of system reliability assessment.
- Possible solution approaches.
- Stochastic Maximum Flow Problem.
- Some interesting characteristics of the problem.
- Use of algebraic structures for network reliability
- The work in the context of this project

Motivation

- The President's Commission on Critical Infrastructure Protection has identified electric power as a critical infrastructure sector.
- Deregulation has forced the energy system to use the existing resources more efficiently. Congestion in the energy network increases vulnerability of the system.
- Increasing legal/environmental restrictions obstruct the expansion of the system, forcing the utilities to meet the energy demand with existing networks.

Motivation

- Vulnerability to disruptions
 - Natural causes
 - Equipment failure
 - Labor unavailability
 - Communication failures
- Influences of different events on price and availability.

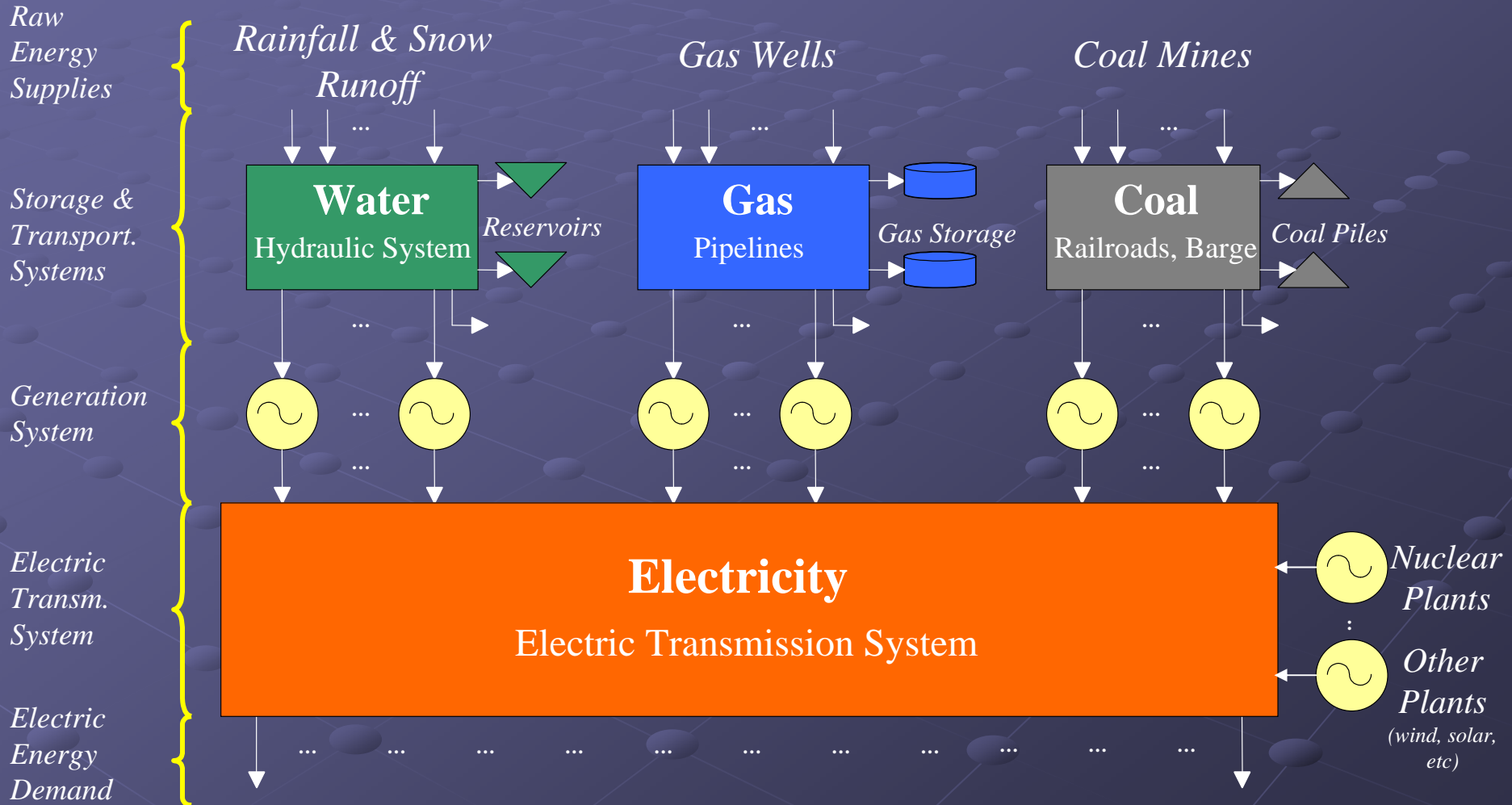
Motivation

- Perception of risk affect the decision making process, and therefore prices (just see gas prices!!).

Motivation

- We may consider reliability, generally speaking, as a measure of the performance of a device or system. Therefore, assessment of system reliability has become very important in order to evaluate the likelihood and severity of conditions that may result to be harmful, to discover where the system is more vulnerable, or to recognize ways to improve the performance of the system.

The National Electric Energy System (NEES)



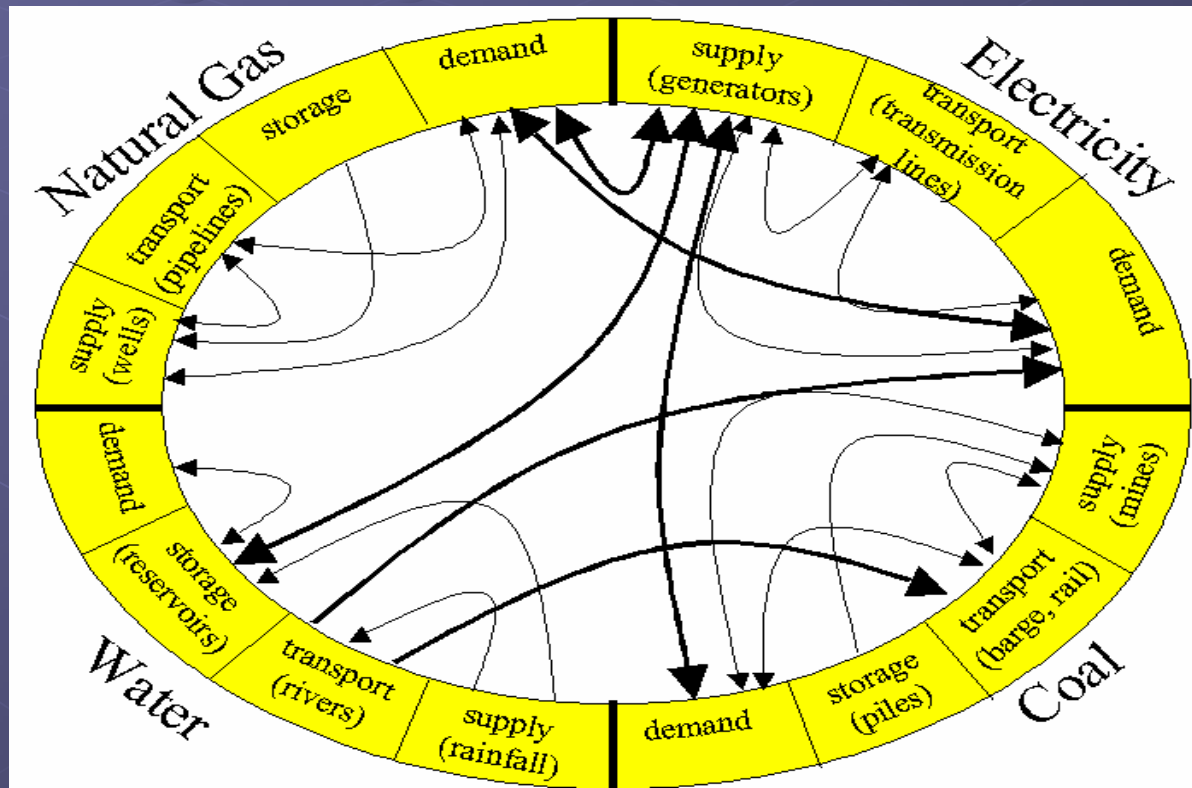
Why an Integrated Model?

- Impact of events in one subsystem may affect the other systems
- What can we get from an integrated analysis?
 - A better understanding of the interdependencies in the system
 - Identify alternative energy supplies
 - Help to prevent resource adequacy problems

Why an Integrated Model?

◆ Interdependencies

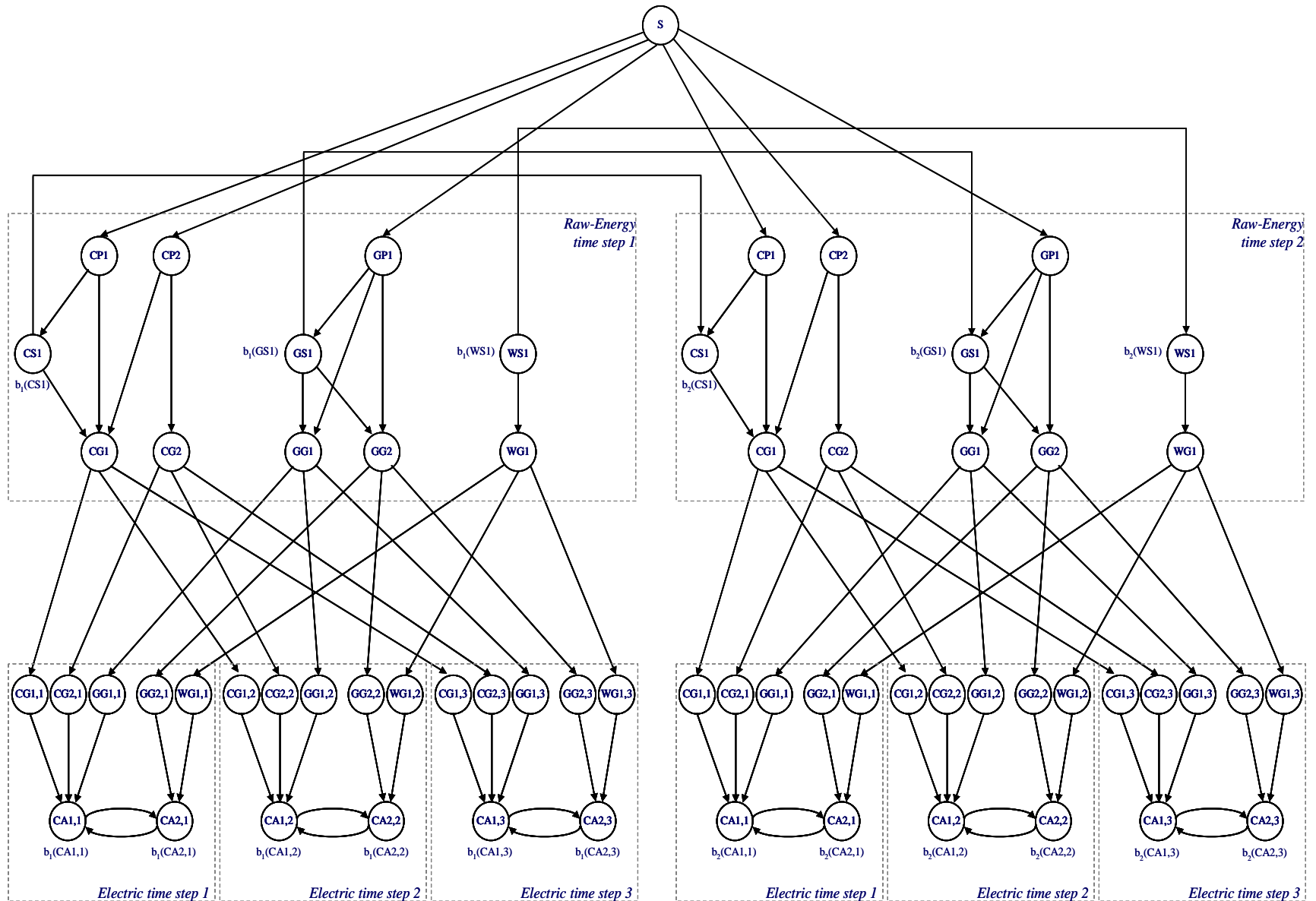
- Intra- and inter-subsystem couplings
- Coupling between basic functionalities



Why a Network Model?

- Energy system facilities can be represented adequately by arcs and nodes.
- It allows to model capacities, costs, efficiencies.
- Energy flows.
- Take advantage of fast and existent network optimization algorithms:
 - Generalized minimum cost (GMC)
 - Generalized maximum flow (GMF)

Why a Network Model?



Why a Stochastic Model?

- Elements in the system are subject to failures.
- Where is the randomness in the network?
 - Capacities?
 - Costs/prices?
 - Efficiencies?
 - Supply/Demand?

Modeling challenges

- For each subsystem:
 - Node definition
 - Demand / supply model
 - Arc definition
 - Arc cost model
 - Arc efficiency model
 - Arc capacity model
- Data collection

Modeling challenges

- Storage => multiple time steps
- Different dynamics => Different time steps for each subsystem
- Mathematical / probabilistic model.
- Dimensionality.

Modeling challenges

- Dependency of the random variables.
 - Common cause events
 - Cascading events
- Capacity/Reliability indexes for each node.
- Results visualization and interpretation

Reliability Assessment

- We need to answer the questions:
 - What is the probability that the energy network have enough capacity to supply the demand?
 - Which are the potential bottlenecks in the network given the possibility of failure of some of its elements?
- Results can be useful for the energy system operation and planning

Reliability

- Power system reliability can be defined as:
“the degree to which the performance of the system results in electricity being delivered to costumers within accepted standards and in the amount desired.”
- This definition can also be extended to define the NEES reliability.

Adequacy

- *“The ability of the electric system to supply the aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements” (NERC).*
- Are we interested only on the aggregated electrical demand?

Approaches for system reliability

- In general, there are three main solution approaches for the calculation of the reliability of stochastic systems:
 - Analytical techniques
 - Enumerative techniques
 - Simulation techniques.

Approaches for system reliability

- Analytical techniques are those based on network reduction, decomposition, and factoring, using probability and graph theory. These kinds of techniques have the potential to provide an exact value for the system reliability.

Approaches for system reliability

- Enumerative techniques are those that calculate the reliability of the system by using the individual probabilities of the states (or sets of states) of the state space. For large networks, they can only provide approximate values (or bounds) for the system reliability.

Approaches for system reliability

- Simulation techniques, such as Monte-Carlo or bootstrapping, aim to iteratively reproduce the operation of the system in order to obtain estimates and confidence intervals of its reliability.

Reliability of a Stochastic Network

- Measures of Network Reliability
 - Connectedness related
 - Capacity related

Connectedness measures

- From the probabilities of node or arc failure, a measure of the probability of network connectedness is derived.
- It is most widely used and known.
- Used specially for logic diagrams (protection systems) or in communication networks where the capacities of the arcs are not relevant.
- There is plenty of work done in this area.
- Examples: two-terminal reliability, source-to-all terminal reliability, source-to-k terminal reliability.

Capacity measures

- From the probabilities of node or arc failure, a measure of the probability that network capacity is sufficient to meet demands is derived.
- It is the most appropriate approach when arcs have capacities.
- There is not much work done on this area.
- It can be really challenging to solve, specially for large networks.

Stochastic Maximum Flow Problem

- Mathematical problem to solve:
- **Stochastic generalized maximum flow**
 - Stochastic: Arcs capacities as random variables.
 - Generalized: To take into account losses in transportation / conversion / transmission
 - Maximum flow: What is the probability that the existing network will be able to satisfy the demand? (aggregated and at individual nodes)

Stochastic Maximum Flow Problem

- In networks with random capacities associated to each arc, the examination of the connectedness of the network is not as important as the assessment of the maximum flow that the system is able to transport. There are several solution approaches to the maximum flow problem in deterministic networks, but little work has been done to solve it in the case of stochastic networks.

Stochastic Maximum Flow Problem

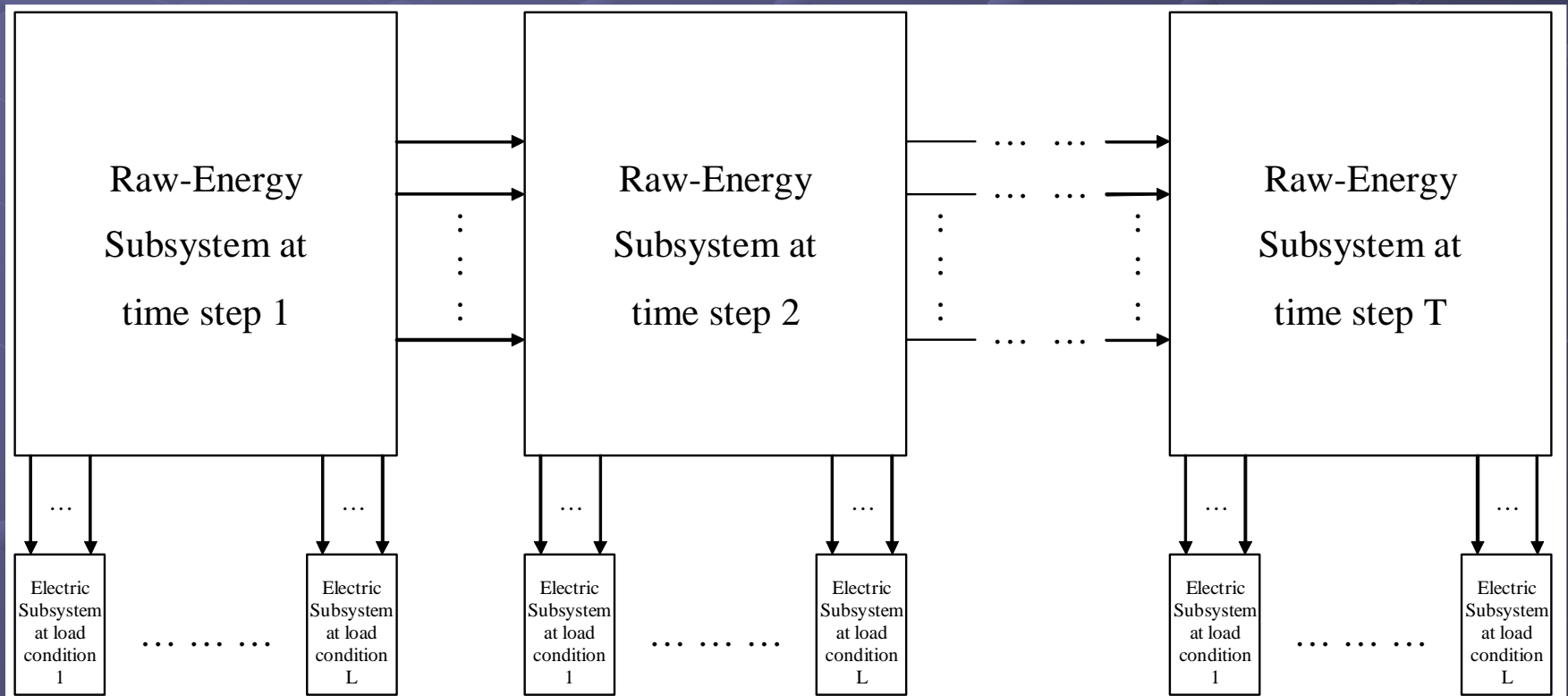
- Consider a stochastic network modeled as a graph where the capacities of the edges have associated a probability distribution. This definition includes, of course, the case where arcs or nodes of the network are unreliable and can fail. The Stochastic Maximum Flow Problem (SMFP) consists of determining the probability distribution of the maximum flow that such stochastic network is able to transport.

Some interesting characteristics of the problem

- Reliability \Leftrightarrow Capacity
- Capacity probability functions: discrete or continuous?
- It seems to be a coherent system (failure in one point decreases the total reliability of the system)
- Dependencies

Some interesting characteristics of the problem

- Flows in raw energy subsystems are generally “unidirectional”. In general, flows go “down” and to the “right”.



Some interesting characteristics of the problem

- This suggests the possibility of calculating the probability distribution of the capacity recursively up to each node, beginning from the source node.

Some interesting characteristics of the problem

● Dependencies:

- Dependencies between different time steps.
- Suitable probability model in 2 or more dimensions (Gumbel, Marshall–Olkin).
- Use of copulas? Copula is a device that fully defines the dependence among a set of random variables.

● Evaluate importance of different elements

- Extend “connectedness” concepts of Birnbaum Reliability Importance and Birnbaum Structural Importance to capacity analysis.

Use of algebraic structures for network reliability

- Algebraic structures (path algebras) can be used to solve analytically several deterministic network problems.
- By defining a proper set of algebraic operations, we can systematically reduce a deterministic network using series and parallel reductions, fan reductions, loop reductions.

Use of algebraic structures for network reliability

- Using more complex structures, we can extend some of these concepts to stochastic networks.
- There are analytical (algebraic) solutions for the connectedness problem of a stochastic network. This approach can handle dependencies, and it can get reliability measures for each node.

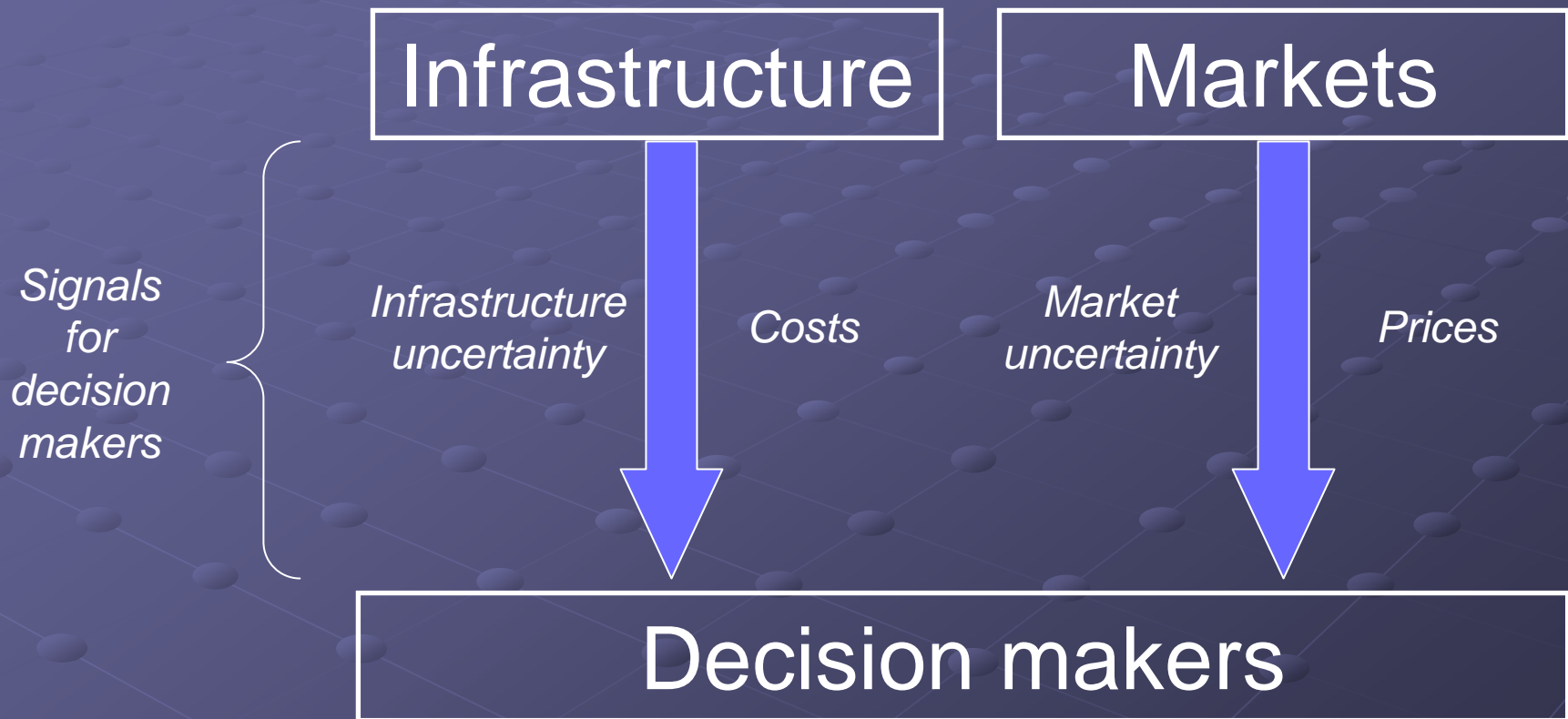
Use of algebraic structures for network reliability

- There is also a solution using algebraic structures for the stochastic shortest path problem. Therefore, by duality, I believe that it could be extended to solve the stochastic maximum flow problem.
- It can be used a more general type of linear programming, where the sum and multiplication operations are replaced by other specially defined operators.

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Information flow and decision making process



- For a given set of market rules, decision makers make decisions based on their costs, the market prices, and their perception of risk.

How does this work fit into this project?

- Besides of the possible value of this research as an independent piece of work and its contribution to the system reliability field, it is necessary to consider how it fits into this project.
- In a few words: My work in the context of this project would be to develop some models of reliability assessment in order to provide some signals of infrastructure uncertainty to the decisions makers.

● Questions???

● Comments???