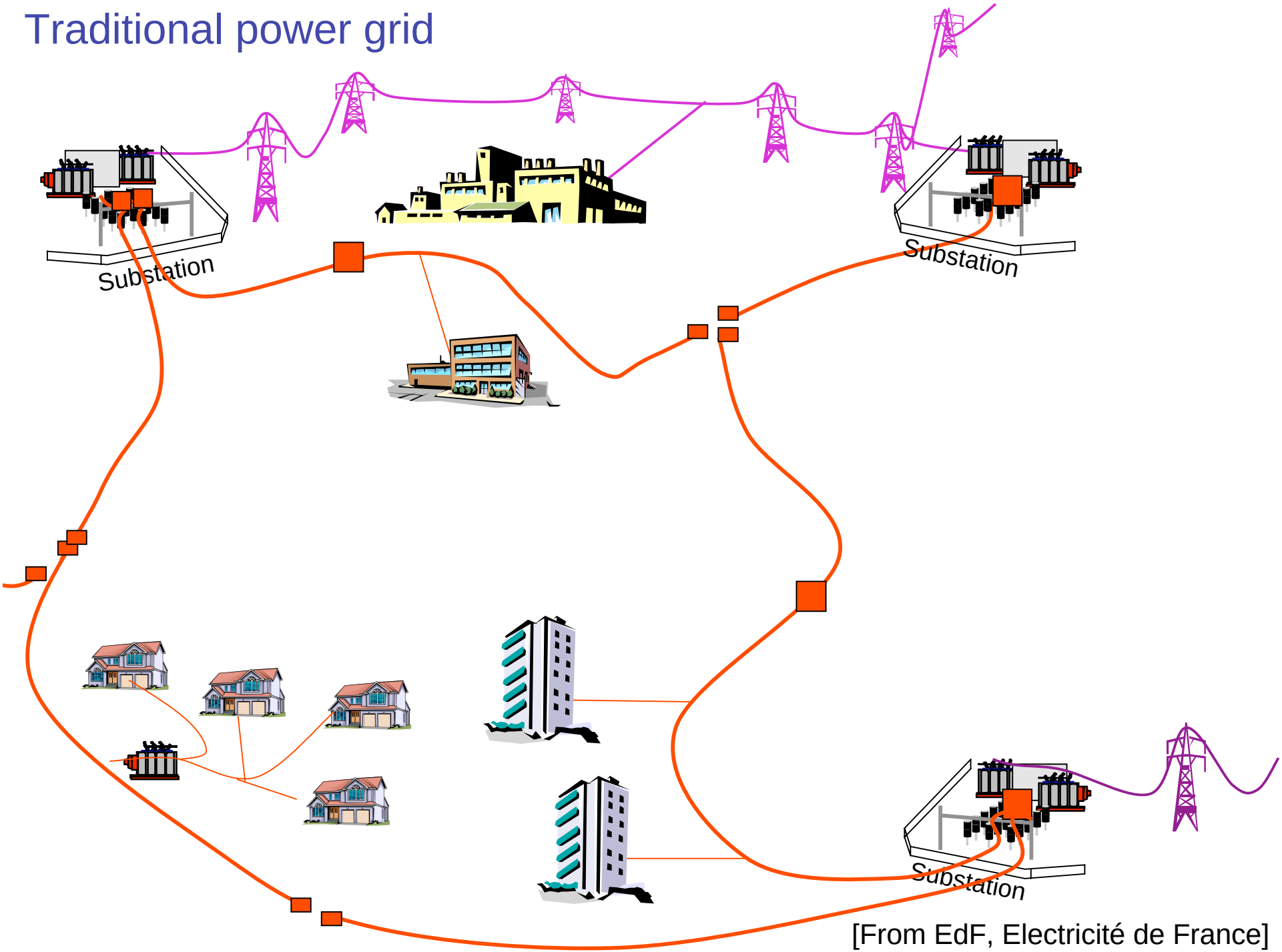
Modeling Interdependencies between the Electricity and Information Infrastructures

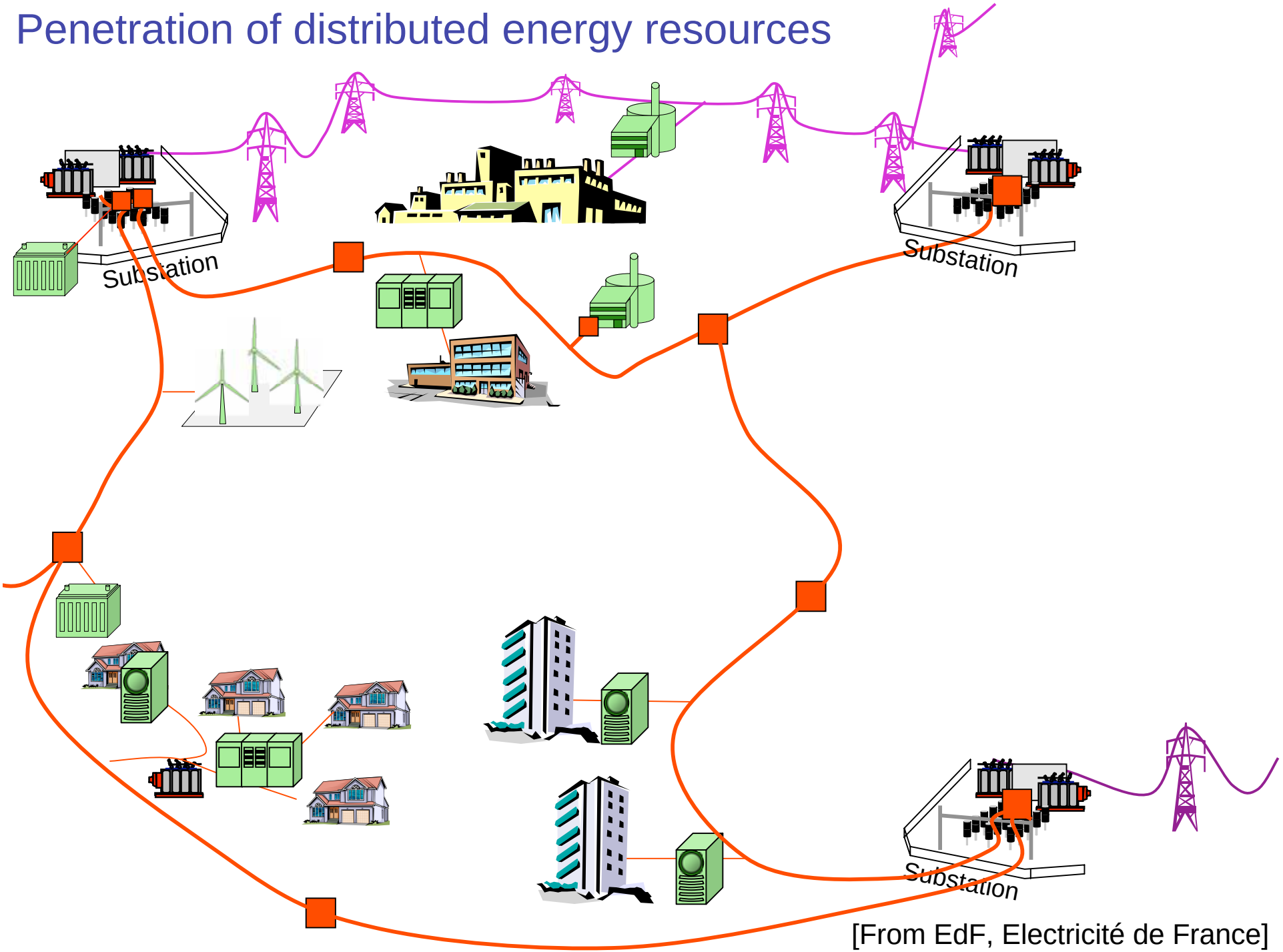
Jean-Claude Laprie, Karama Kanoun, Mohamed Kaâniche

Traditional power grid



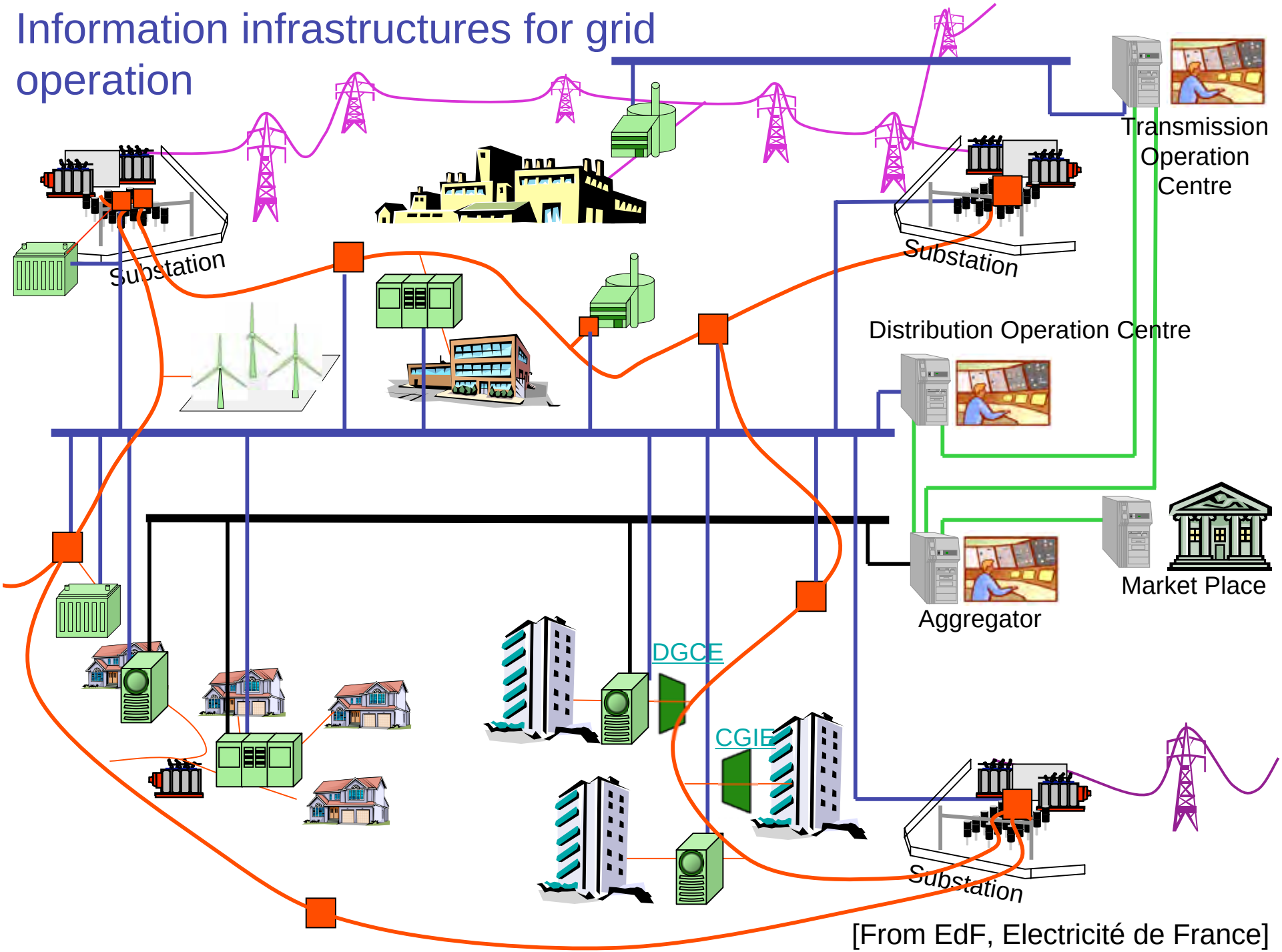
[From EdF, Electricité de France]

Penetration of distributed energy resources

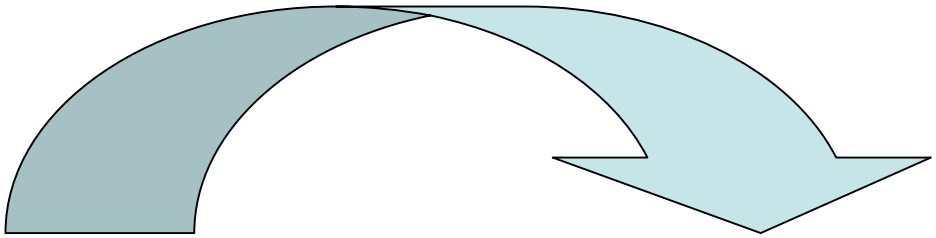


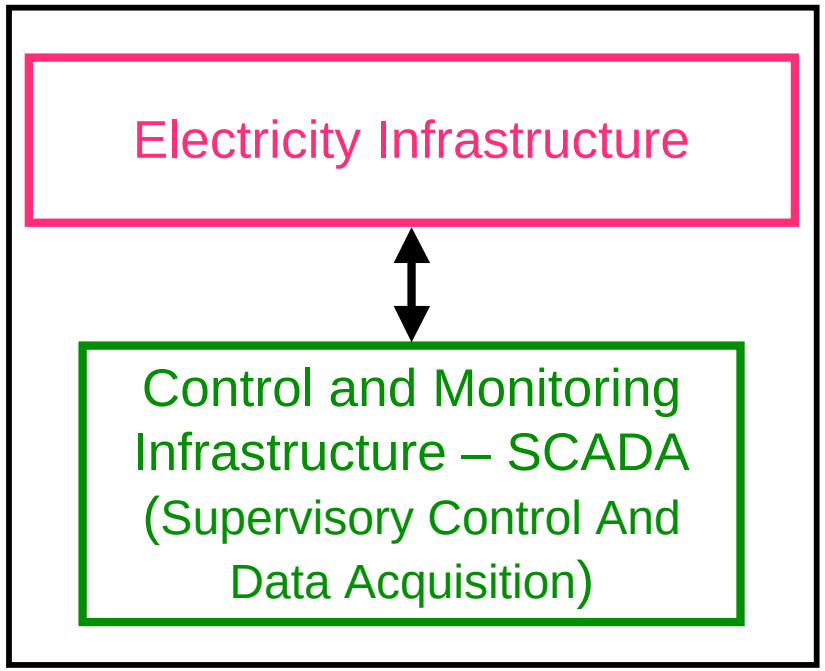
[From EdF, Electricité de France]

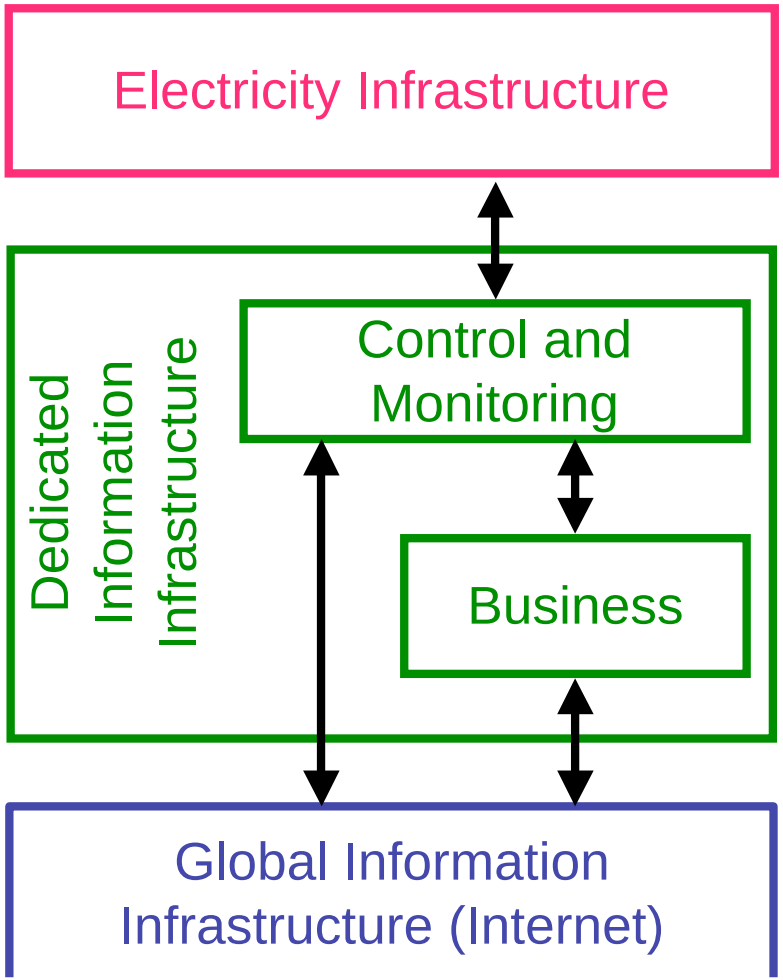
Information infrastructures for grid operation

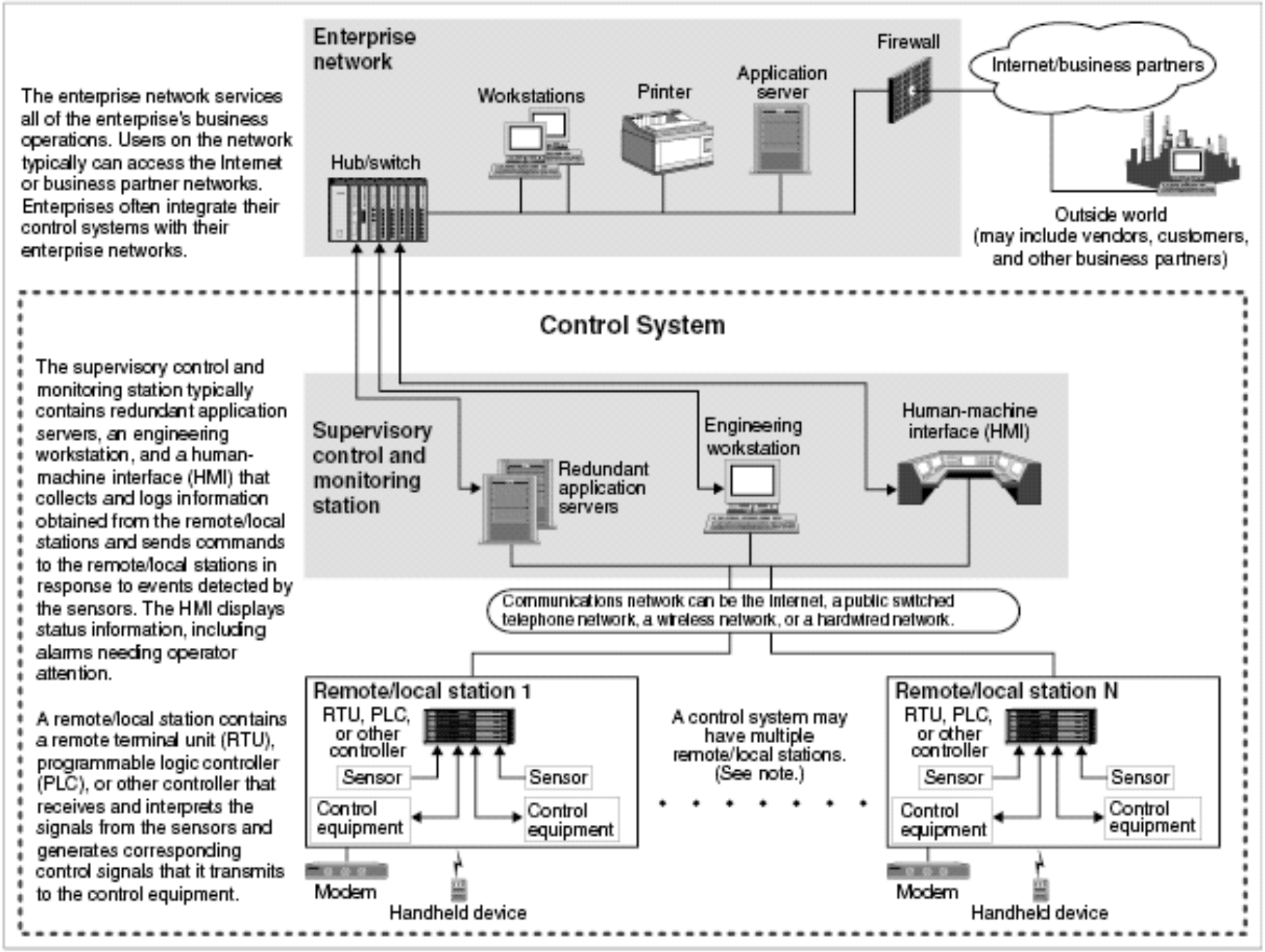


[From EdF, Electricité de France]




Electricity Infrastructure
Control and Monitoring Infrastructure – SCADA (Supervisory Control And Data Acquisition)


Electricity Infrastructure
Dedicated Information Infrastructure
Control and Monitoring
Business
Global Information Infrastructure (Internet)



[Typical Components of a Control System, from GAO report on Critical Infrastructure Protection, March 2004]

Interdependence-related outages

Cascading outage	an outage in one infrastructure causes an outage in another infrastructure
Escalating outage	an outage in one infrastructure exacerbates an outage of a second infrastructure, generally in the form of increasing the severity or the time for recuperation of the second infrastructure
Common-cause outage	two or more infrastructures exhibit the outage in concomitance, due to some common cause, either internal or external

- Examples
  - Cascading outage: August 2003 - Infection and disabling of a safety monitoring system by the SQL Slammer worm at a nuclear power plant in Ohio
  - Escalating outage: August 2003 - Contribution of an alarm software failure to the blackout propagation in Northwest USA and Canada
  - Common-cause outage: March 1989 - Magnetic storm in Quebec, due to solar storm

Models

- Qualitative: (likely) scenarios of outage behavior of infrastructures, consecutive to accidental failures and malicious atacks
- Global: no explicit modeling of infrastructure components

Characterization

- Focus primarily on cascading and escalating outages

Outage cascading from an infrastructure to another one

↓

Constraints on the other infrastructure

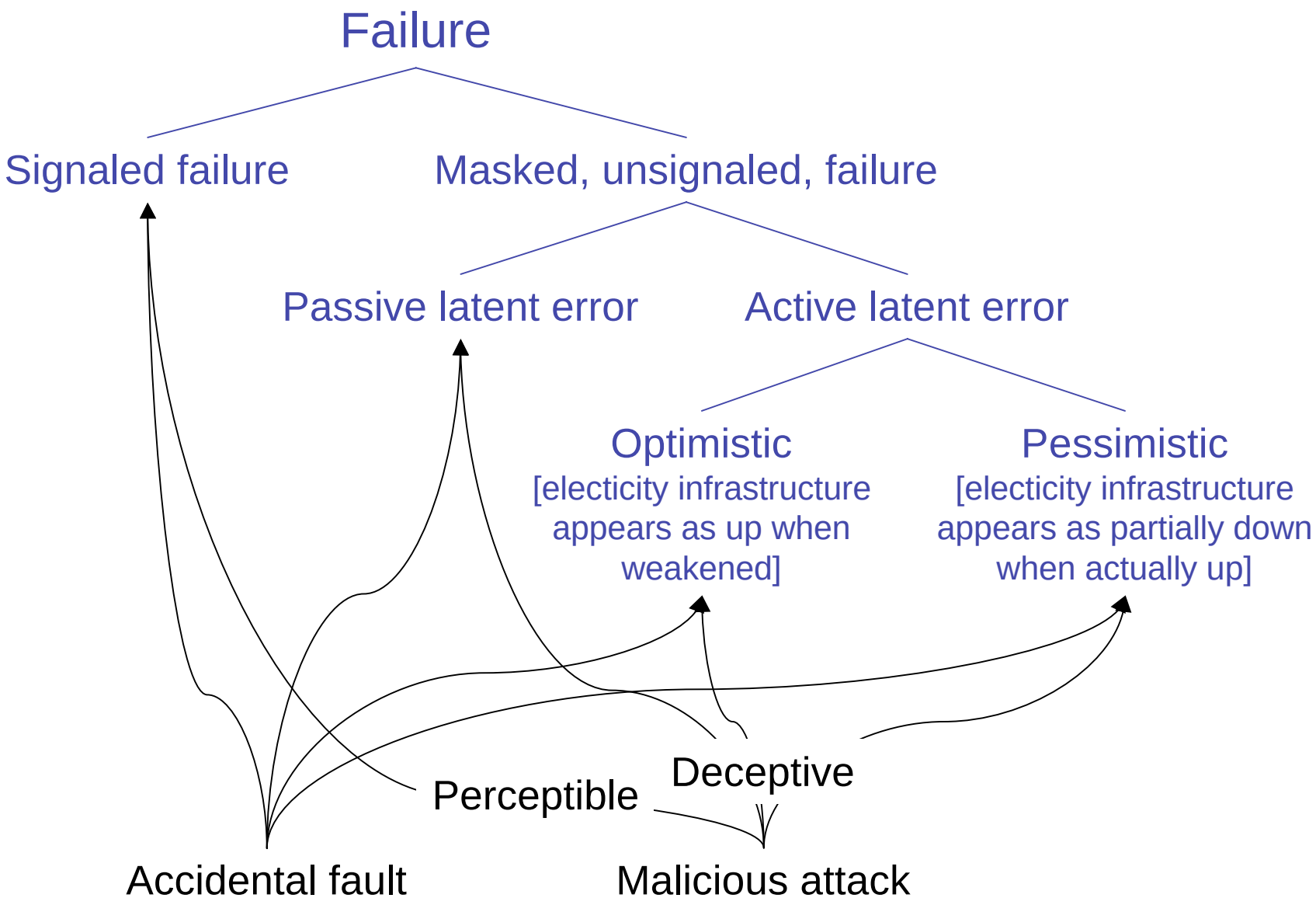
↓

Service degradation
e.g., lower performance, undue isolations, manual control

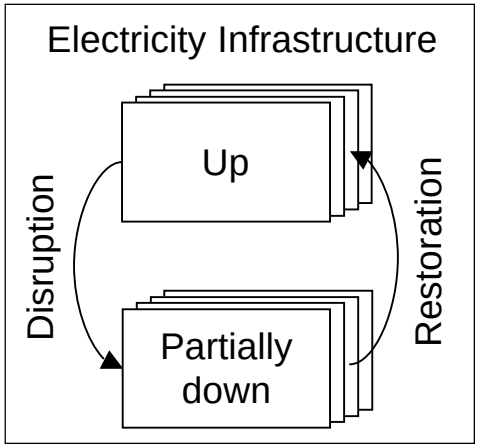
Electricity infrastructure: untimely configuration changes (unnecessary off-line trips of production plants or transmission lines)

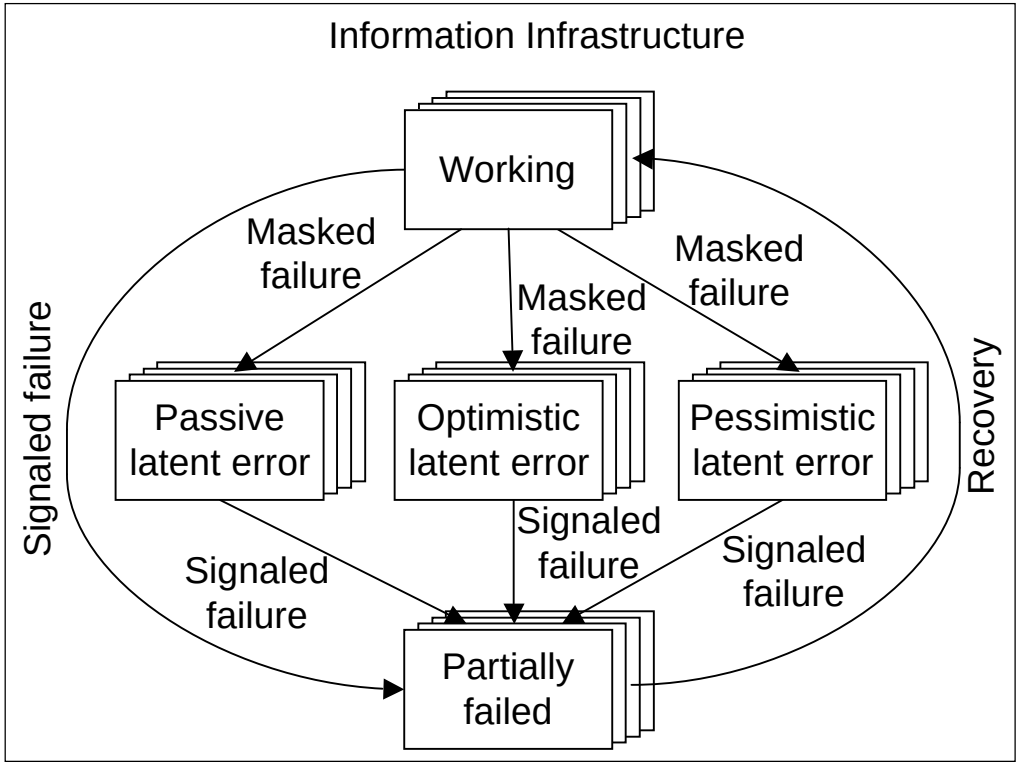
Information infrastructure: partial power supply shortage (e.g., business infrastructure)

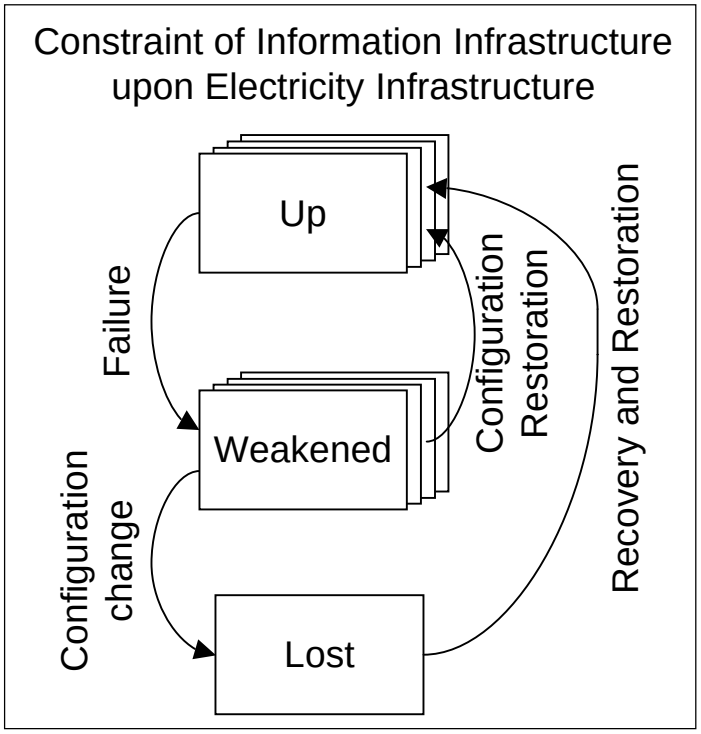
Generic	Information infrastructure	Electricity infrastructure
Normal operation	Working	Up
Outage	Failure	Disruption
Dysfunction	Partially failed	Partially down, Lost
Recuperation	Recovery	Restoration
Constrained	Lessened	Weakened

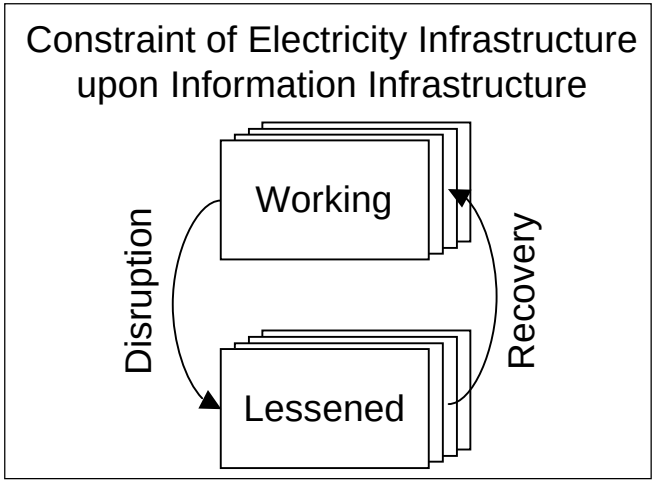

Failure
Signaled failure
Masked, unsignaled, failure
Passive latent error
Active latent error
Optimistic
[electicity infrastructure appears as up when weakened]
Pessimistic
[electicity infrastructure appears as partially down when actually up]
Perceptible
Deceptive
Accidental fault
Malicious attack

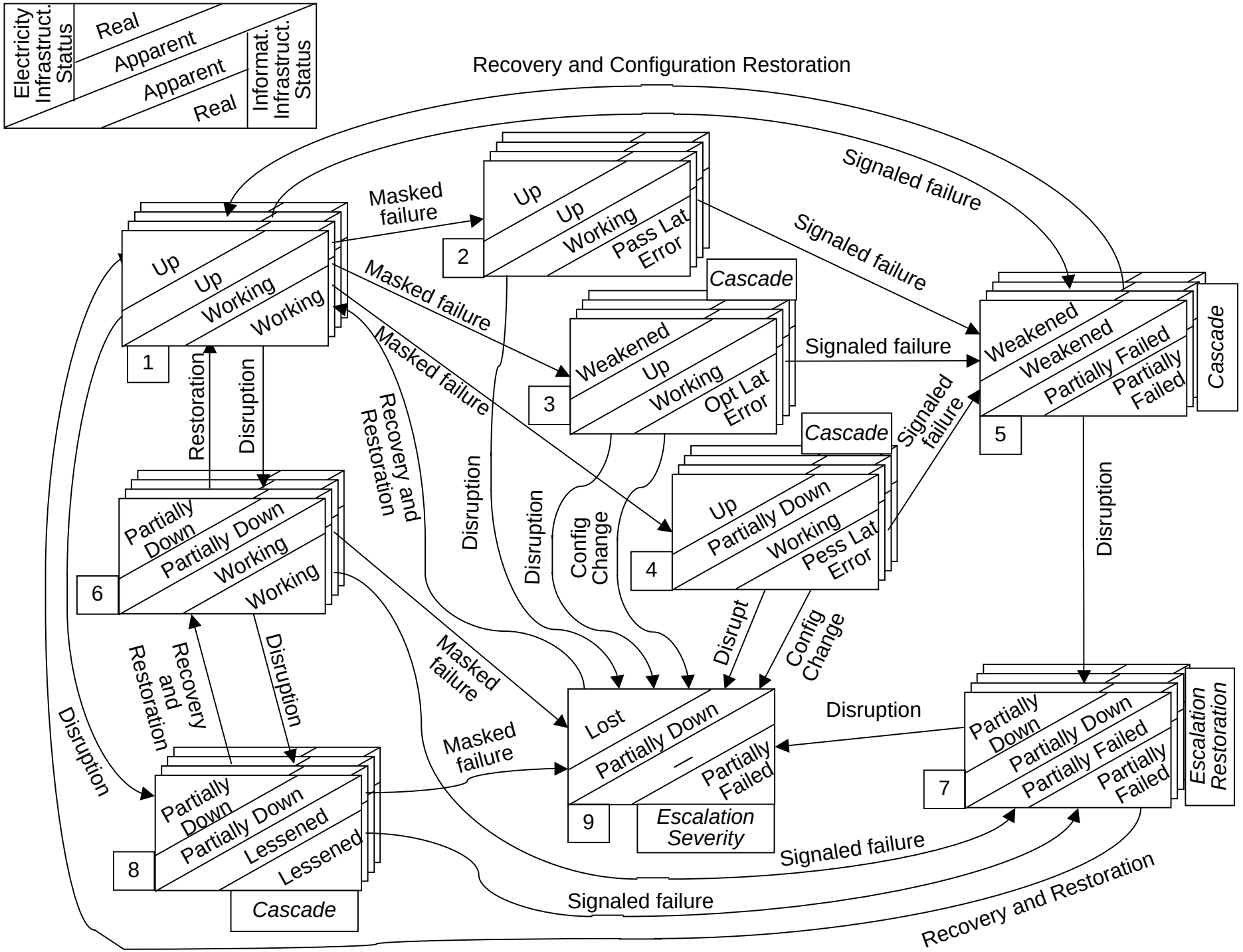
Outage elementary models

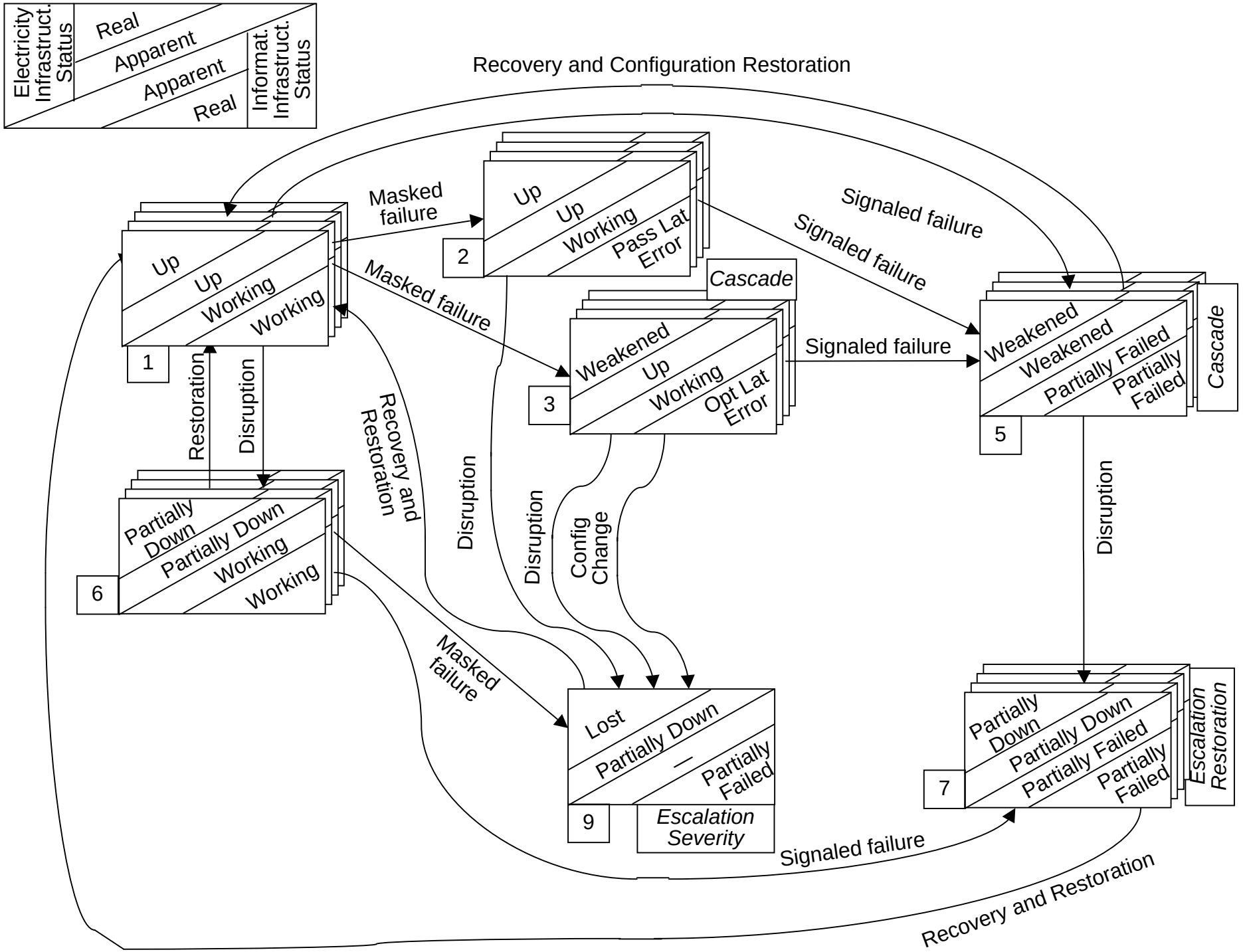


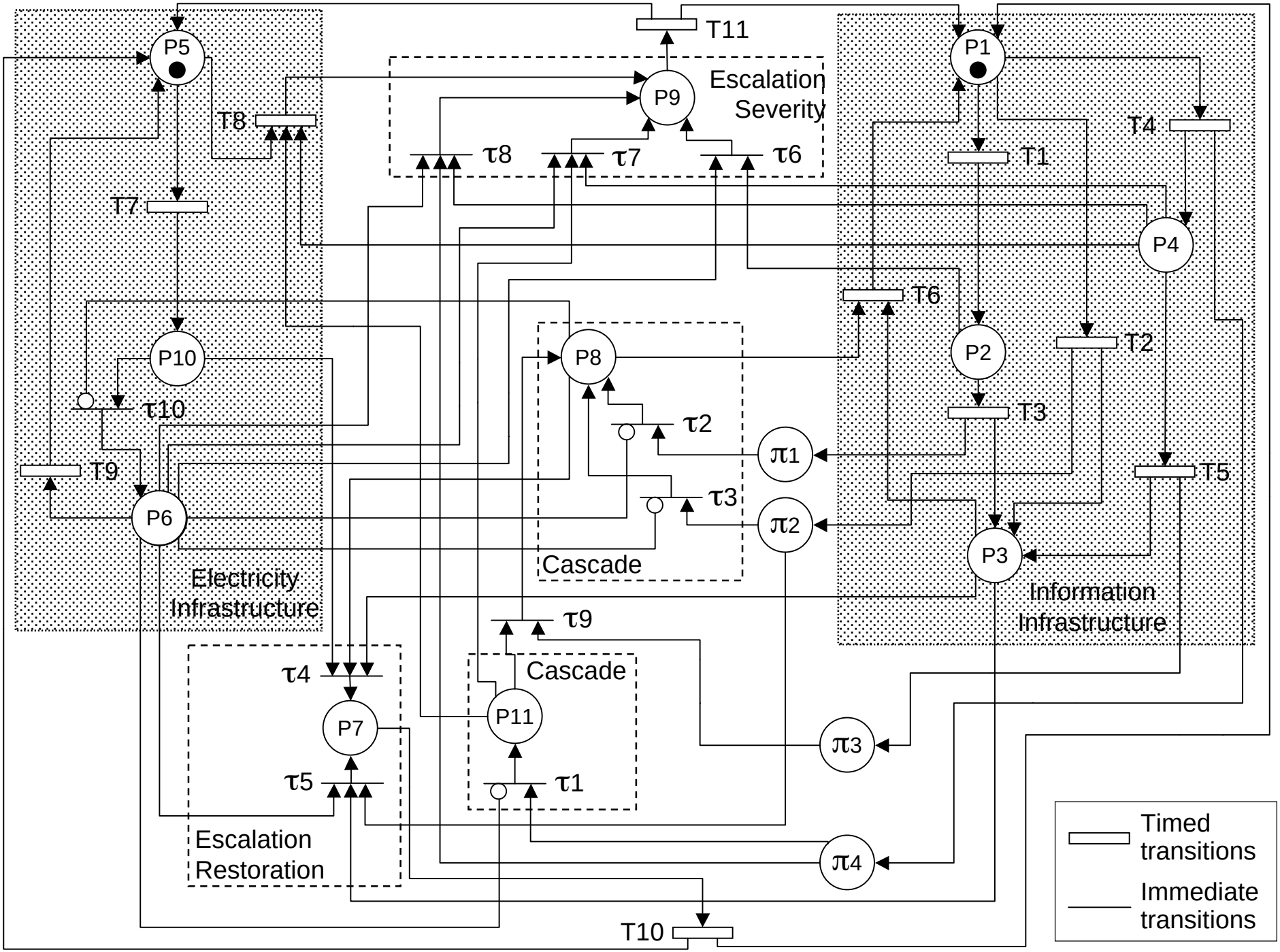






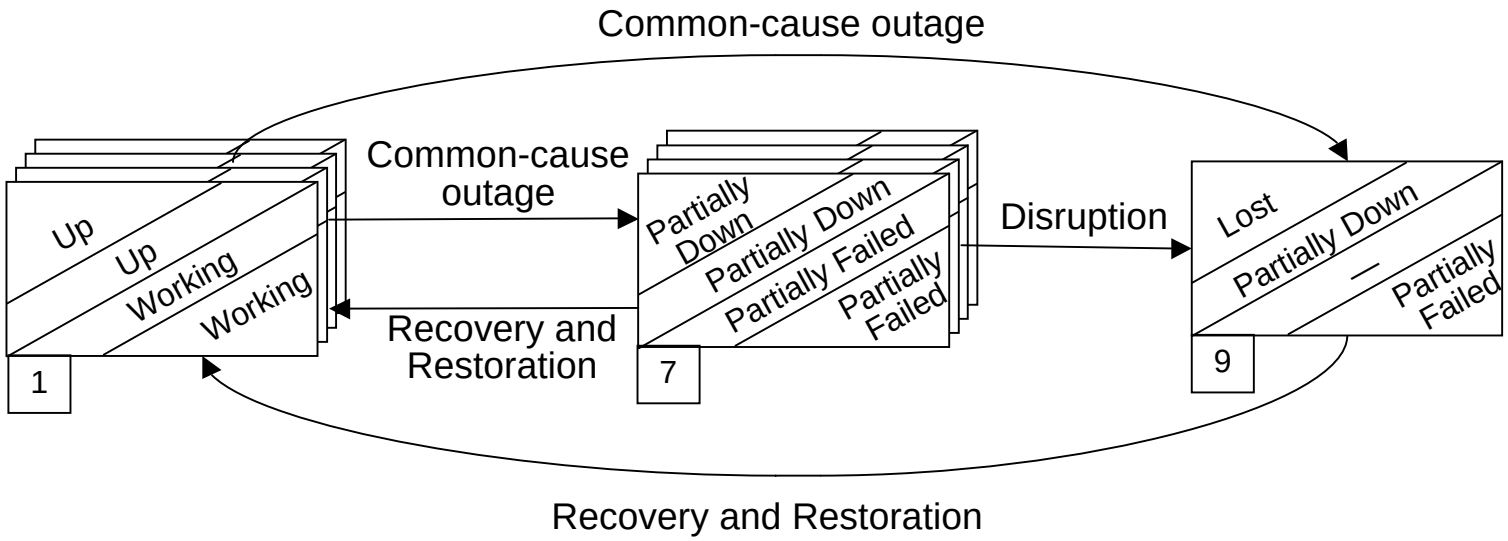

Electricity Infrastruct. Status
Real
Apparent
Apparent
Real
Informat. Infrastruct. Status
Recovery and Configuration Restoration
1
Up
Up
Working
Working
2
Up
Up
Working
Pass Lat Error
3
Cascade
Weakened
Up
Working
Opt Lat Error
4
Cascade
Up
Partially Down
Working
Pess Lat Error
5
Cascade
Weakened
Weakened
Partially Failed
Partially Failed
6
Partially Down
Partially Down
Working
Working
7
Escalation Restoration
Partially Down
Partially Down
Partially Failed
Partially Failed
8
Partially Down
Partially Down
Lessened
Lessened
Cascade
9
Lost
Partially Down
—
Partially Failed
Escalation Severity
Masked failure
Signaled failure
Restoration
Disruption
Recovery and Restoration
Config Change
Disrupt
Recovery and Restoration
Recovery and Restoration


Electricity Infrastruct. Status
Real
Apparent
Apparent
Real
Informat. Infrastruct. Status
Recovery and Configuration Restoration
Up
Up
Working
Working
1
Masked failure
Up
Up
Working
Pass Lat Error
2
Signaled failure
Signaled failure
Cascade
Weakened
Up
Working
Opt Lat Error
3
Signaled failure
Weakened
Weakened
Partially Failed
Partially Failed
Cascade
5
Restoration
Disruption
Partially Down
Partially Down
Working
Working
6
Recovery and Restoration
Disruption
Disruption
Config Change
Disruption
Masked failure
Lost
Partially Down
—
Partially Failed
9
Escalation Severity
Partially Down
Partially Down
Partially Failed
Partially Failed
7
Escalation Restoration
Signaled failure
Recovery and Restoration


P5
T11
P1
Escalation
Severity
P9
T8
T4
τ8
τ7
τ6
T1
T7
P4
T6
P10
P8
P2
T2
τ10
τ2
T3
π1
T9
T5
τ3
P6
π2
P3
Cascade
Electricity
Infrastructure
Information
Infrastructure
τ9
τ4
Cascade
P11
P7
π3
τ5
τ1
Escalation
Restoration
π4
T10
Timed
transitions
Immediate
transitions

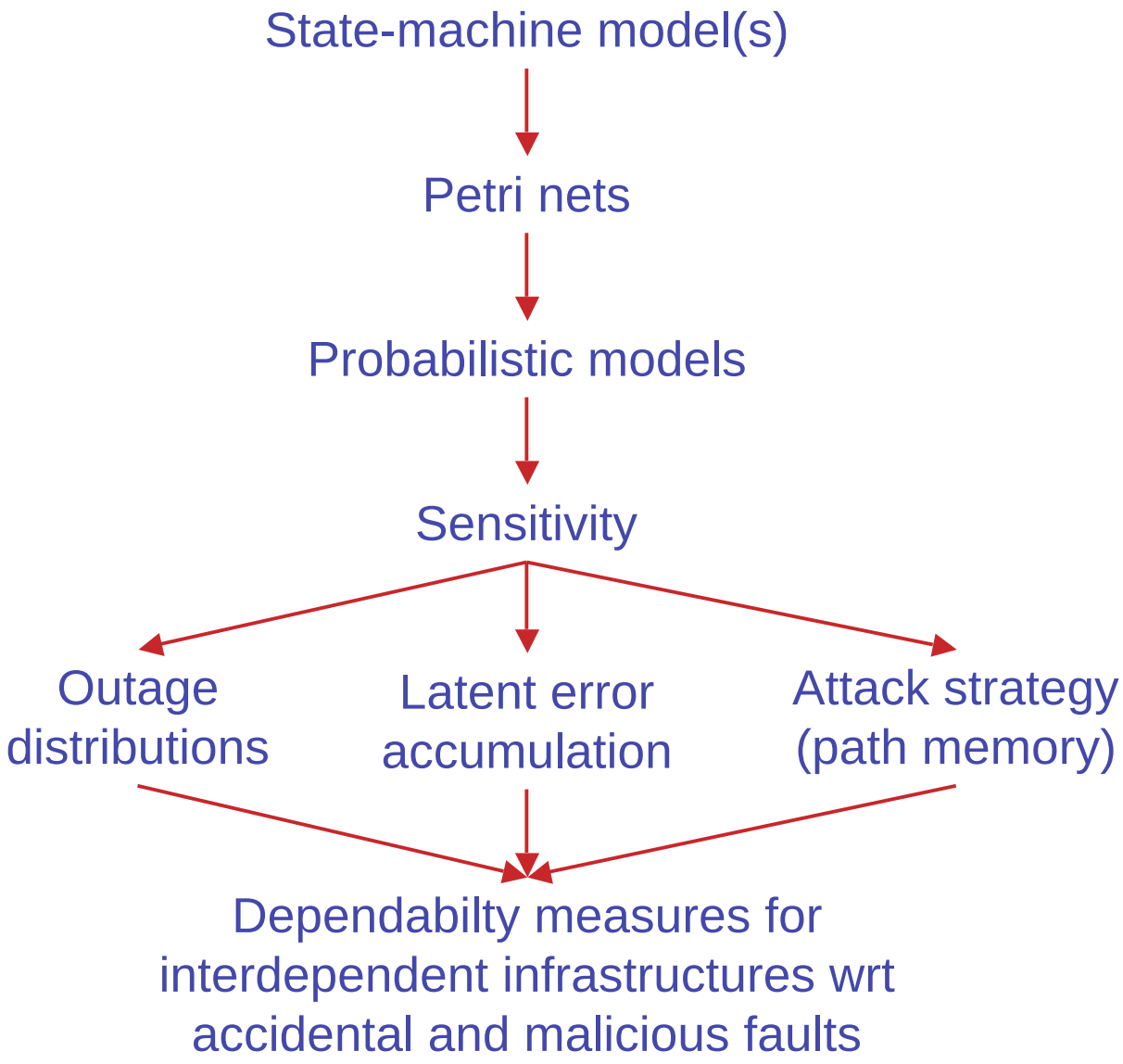
Common-cause outages

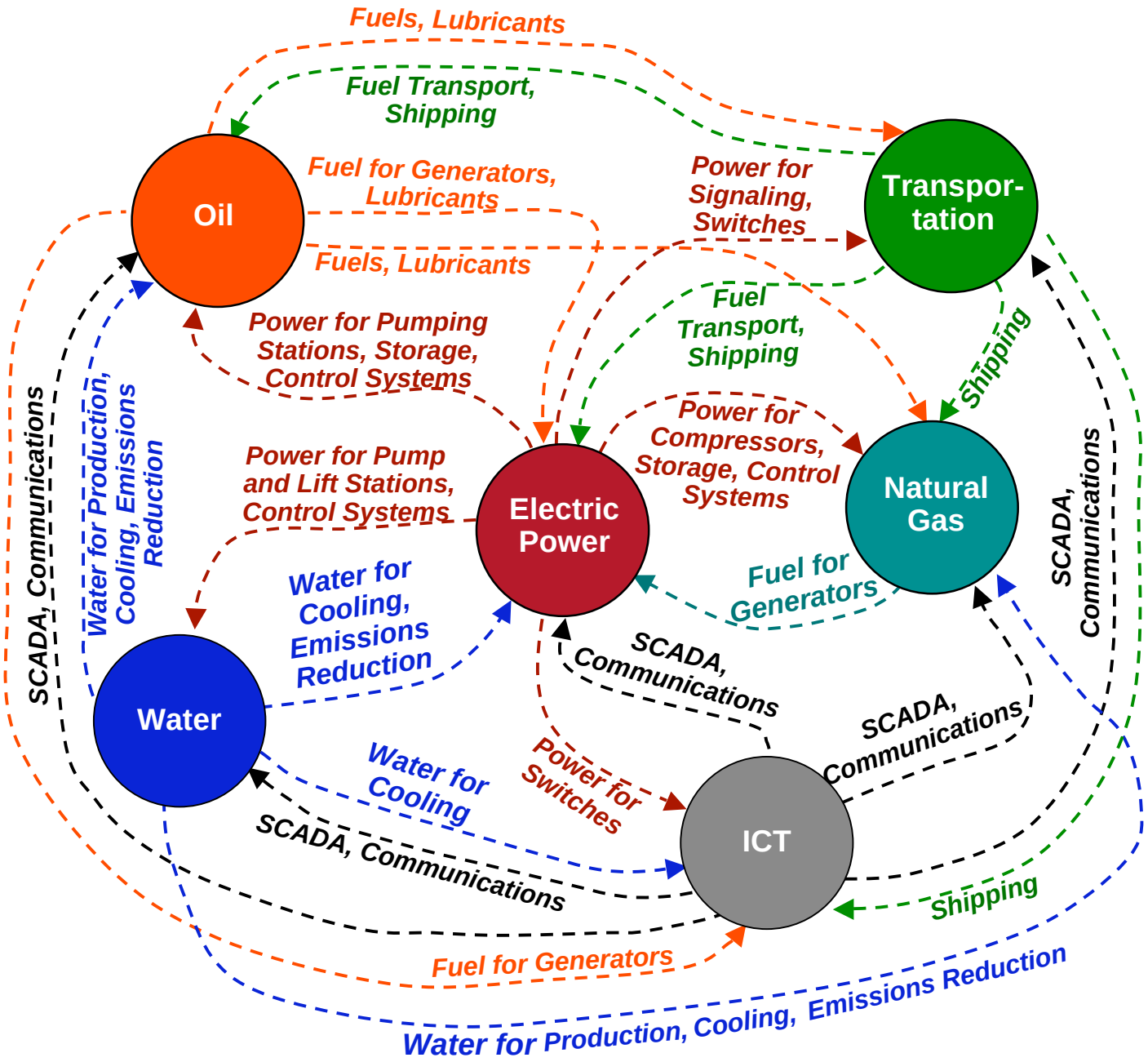
- Occurrence when infrastructures in normal operation



- Occurrence in other states ➜ states 7 or 9 (escalating)

On-going work





[From Rinaldi, Peerenboom, Kelly, 'Critical Infrastructure Interdependencies', IEEE Control Systems, Dec 2001, pp. 11-25]

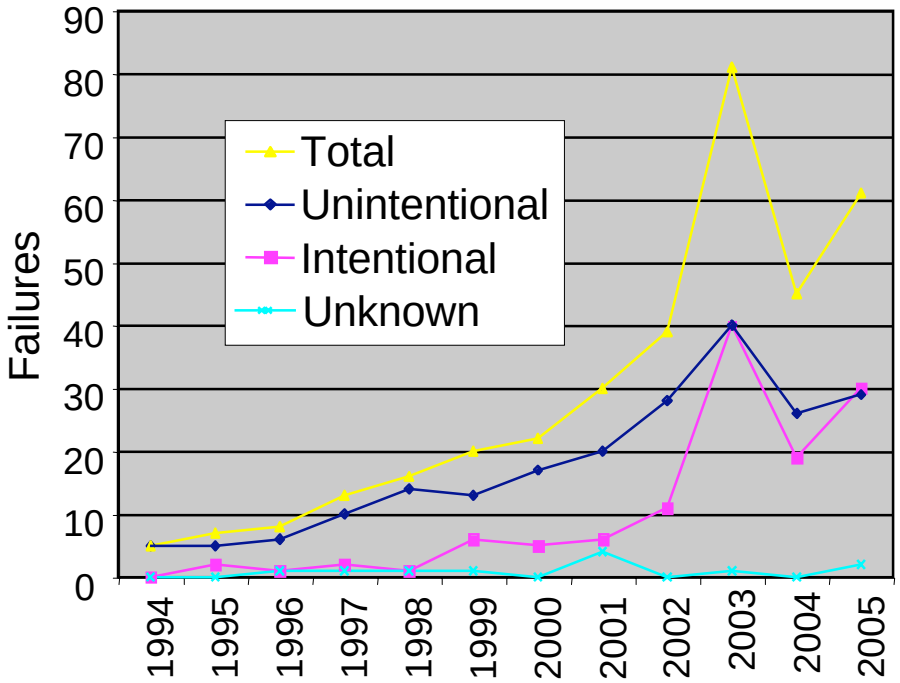
Critical infrastructures:

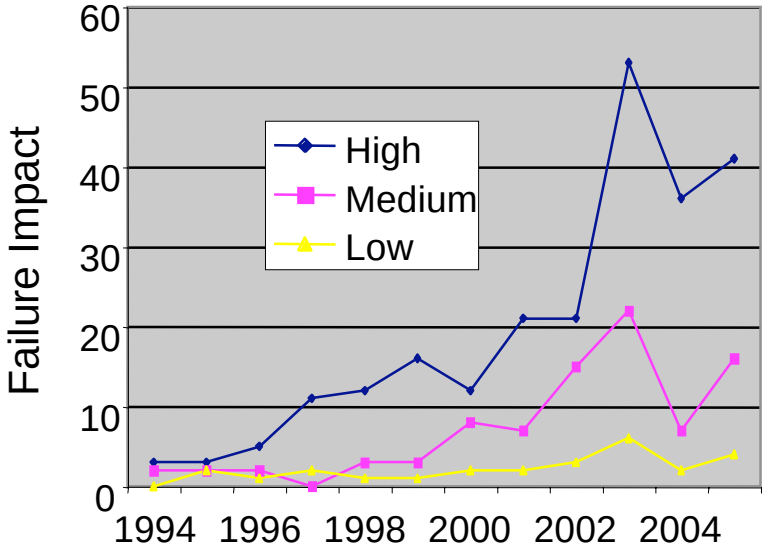
- IT Infrastructure
- Telecommunication Infrastructure
- Water Supply
- Electrical Power System
- Oil and Gas
- Road Transportation
- Railway Transportation
- Air Transportation
- Banking and Financial Services
- Public Safety Services
- Healthcare System
- Administration and Public Services

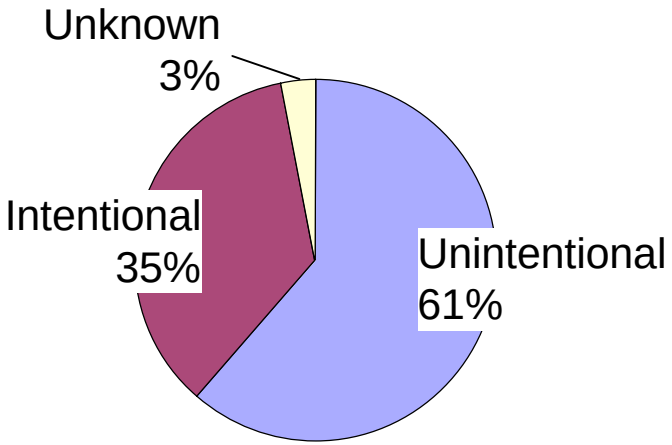
[From J. Moteff and P. Parformak, ‘Critical Infrastructure and Key Assets: Definition and Identification’, Congressional Research Service Report for Congress, Oct. 2004]

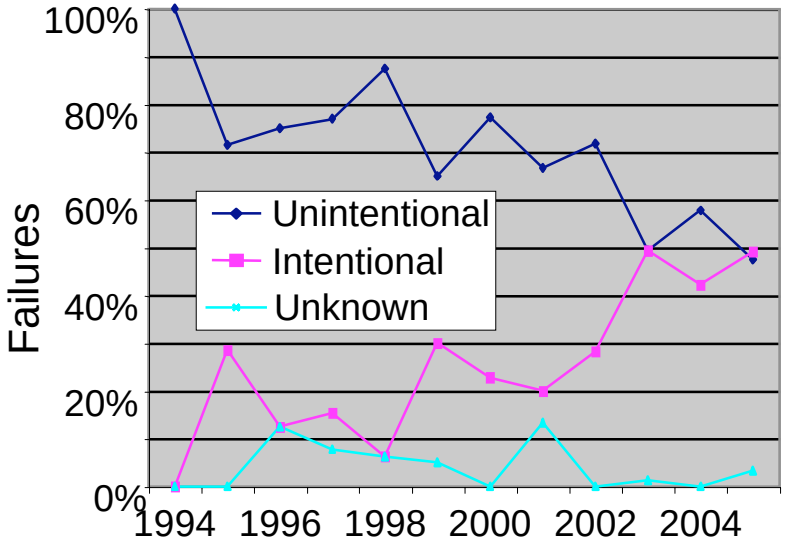
Analysis of 347 documented computer-related infrastructure failures

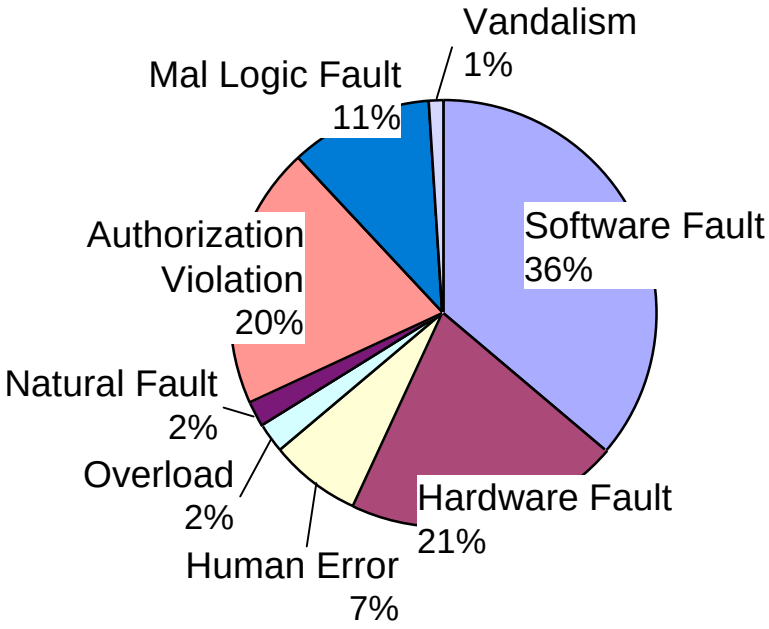
[From H.A. Rahman, K. Beznosov, J.R. Marti, 'Identification of sources of failures and their propagation in critical infrastructures from 12 years of public failure eports', Proc. CRIS 2006, 3rd Int Conf on Critical Infrastructures]



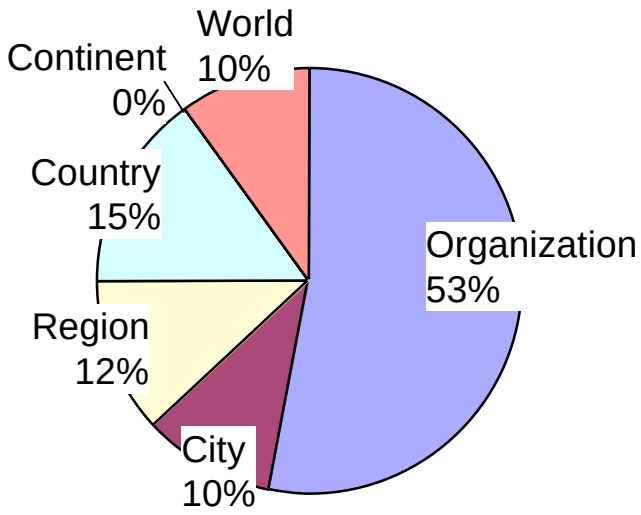




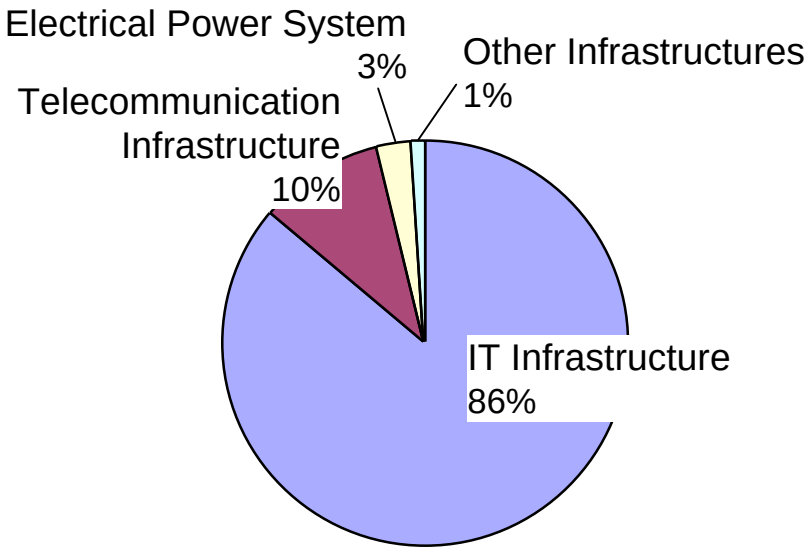




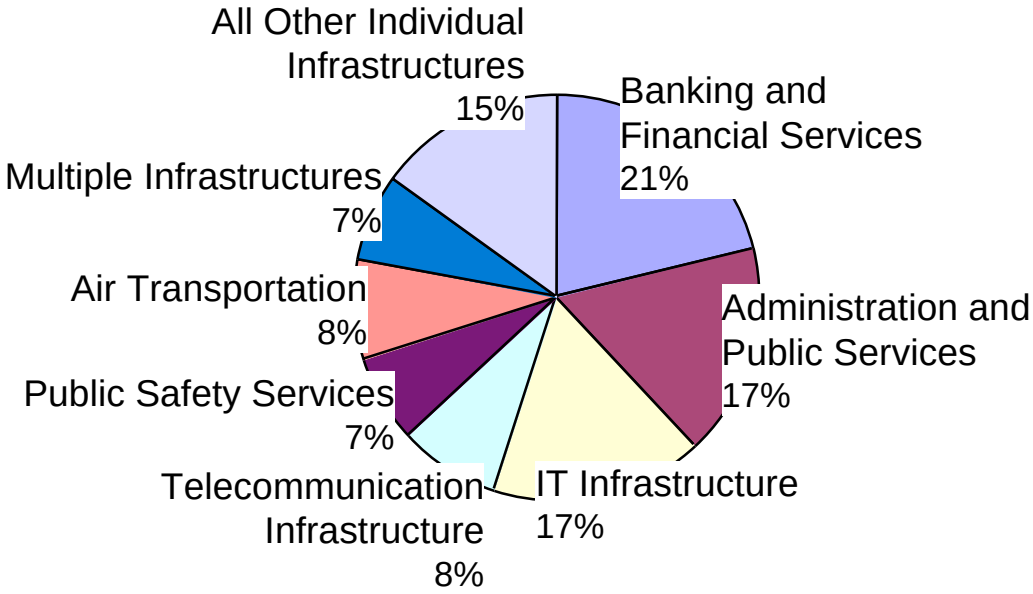
Faults that lead to infrastructure failure



Localities affected by infrastructure failures



Infrastructure failure source that affect IT infrastructure



Infrastructures affected due to IT infrastructure failure