Operational Resilience Metrics for a Complex Electrical Networks

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Operational Resilience Metrics

RESILIENCE

The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. [UNIDSR]

Resilience is the ability of the system to withstand a major disruption within acceptable degradation parameters and to recover within an acceptable time and composite costs and risks. (Haimes, 2009)

The ability of a CI system exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, for the preservation and restoration of essential societal services. [IMPROVER Project]*

Operational **METRICS** Strategic

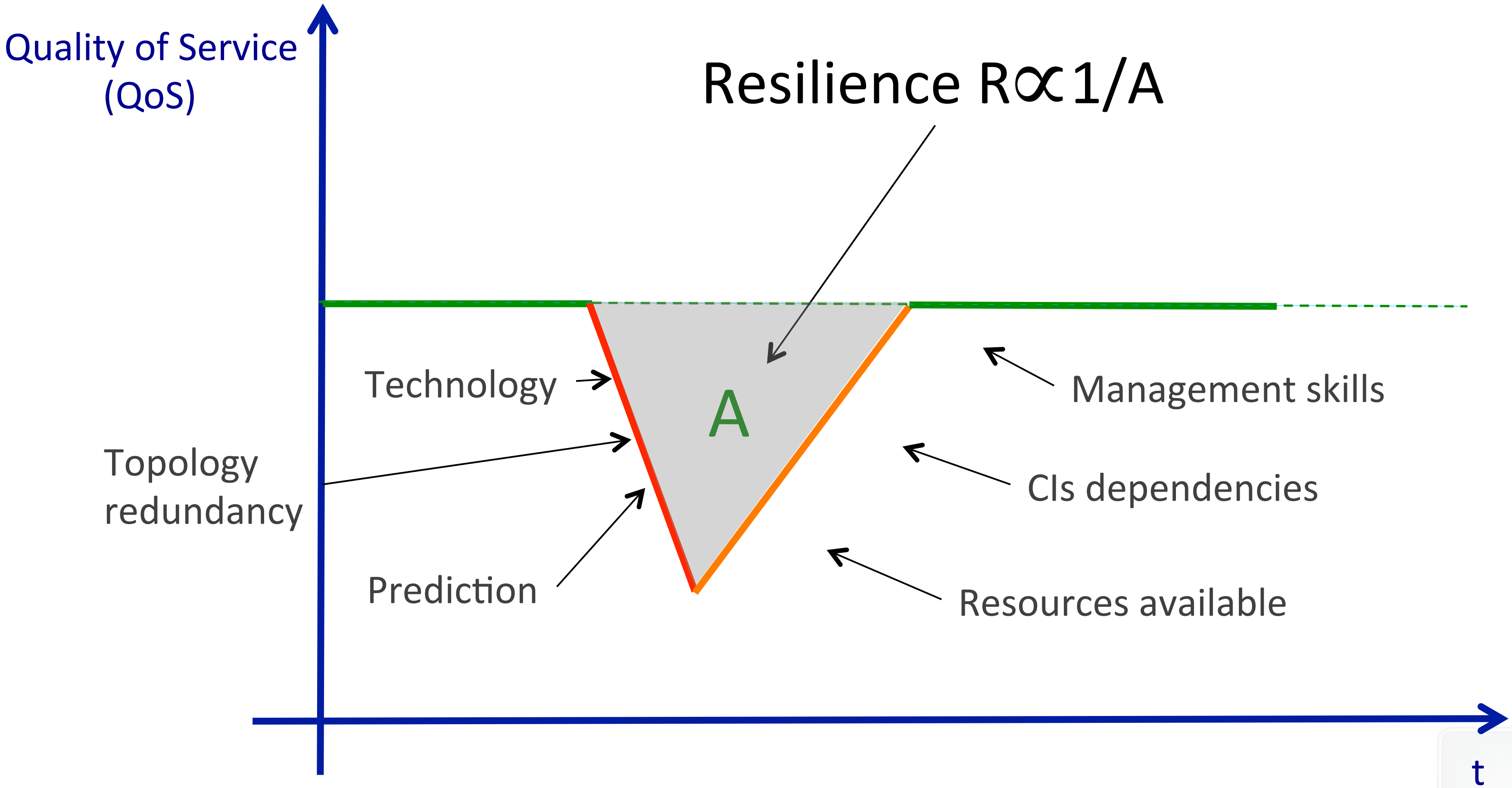
…how many spare parts are in stock and what options exist for backup power generation

...Measuring economic output or economic damage stemming from disasters at a national or regional level

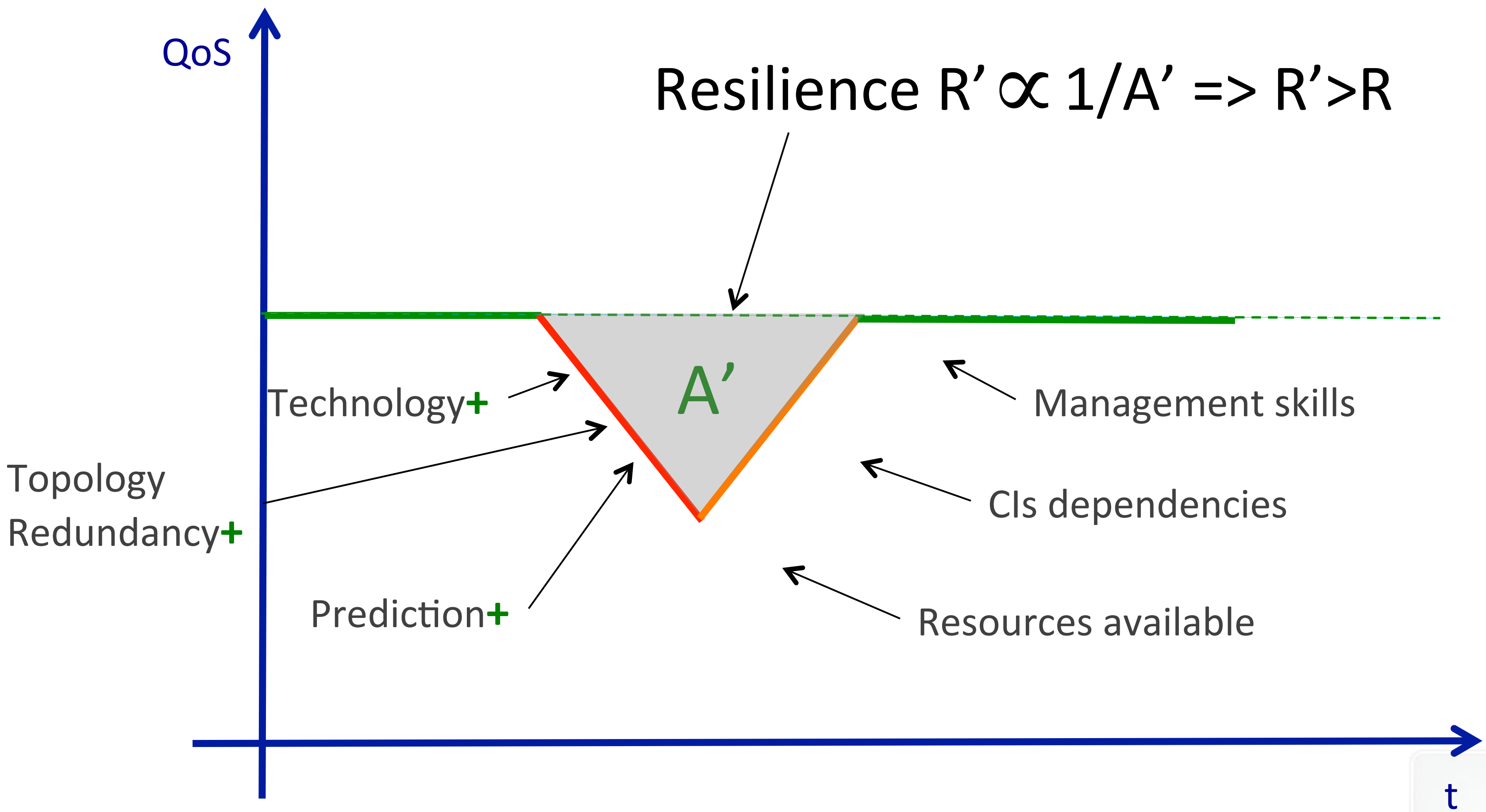
Measuring the Resilience of Energy Distribution Systems
by Henry H. Willis, Kathleen Loa
[https://www.rand.org/pubs/research_reports/RR883.html]

*CIPRNet CIPedia
[https://publicwiki-01.fraunhofer.de/CIPedia/index.php/]

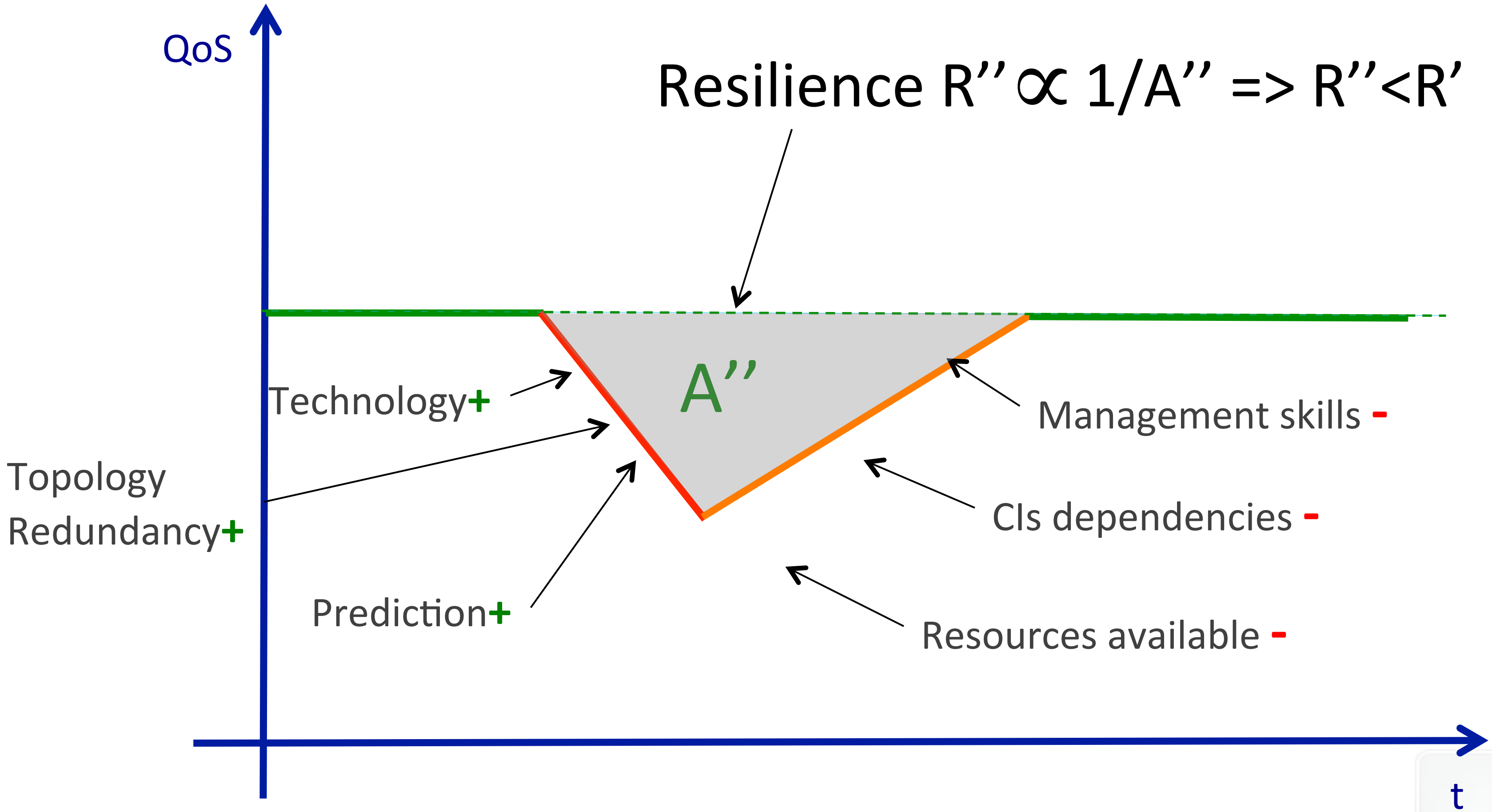
Operational Resilience Metrics



Operational Resilience Metrics



Operational Resilience Metrics



Our proposal

<u>A theory enabling to account for all these properties/characteristics when dealing with "resilience" estimates has not been formulated yet</u>.

This is a first attempt to provide an unifying model for estimating the resilience of a couple of dependent networks (electrical and telecommunication) by taking into account all of these factors.

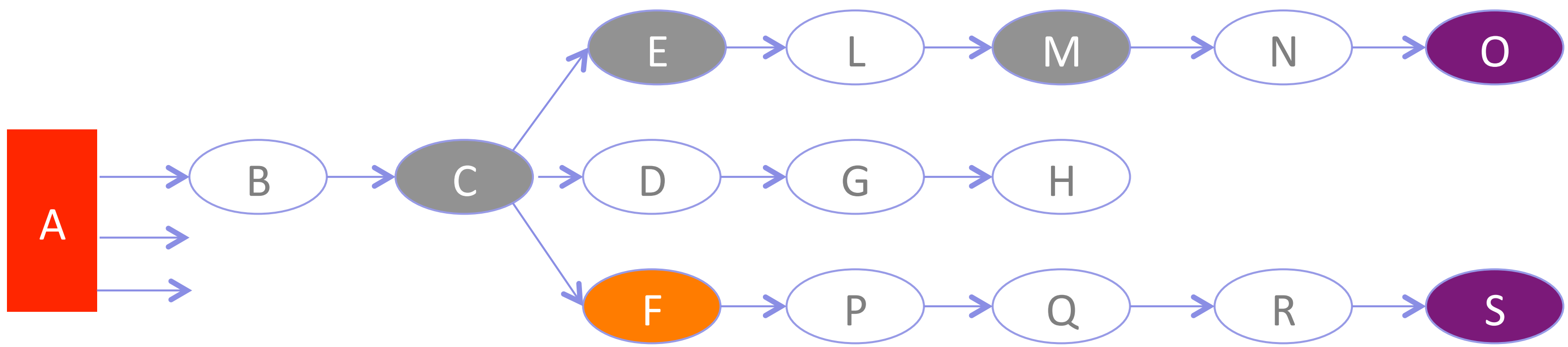
Our approach

1) Build up a model of an electro-telco inter-dependent system enabling the simultaneous consideration of all these properties <u>based on a model representing a real system</u>
2) Define an appropriate operational metric to estimate Resilience
3) Estimate the Resilience of an electrical network by measuring the consequences resulting from a perturbation consisting in the fault of one of its components (i.e. a Secondary Substation, SS hereafter).

EDN model

The electrical system is described at the level of MV lines

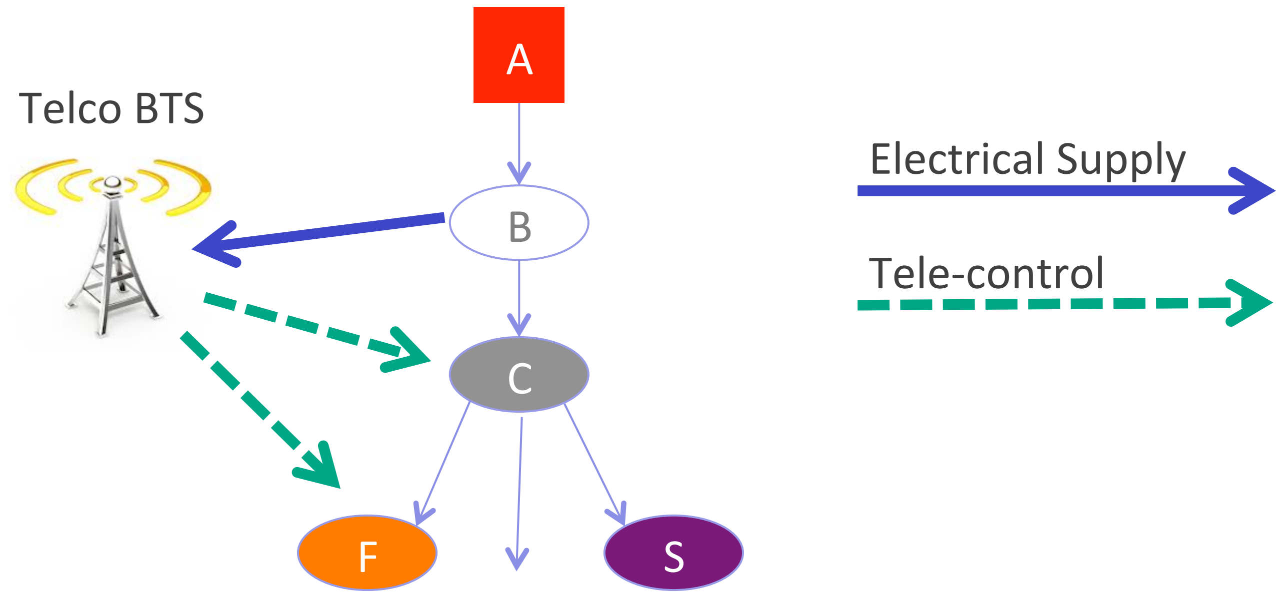
- Primary Substations (PS, e.g. node A) and Secondary Substations (SS)
  - Grey nodes: tele-controlled SS
  - Orange nodes: automated SS
  - Purple nodes: next-lines SS



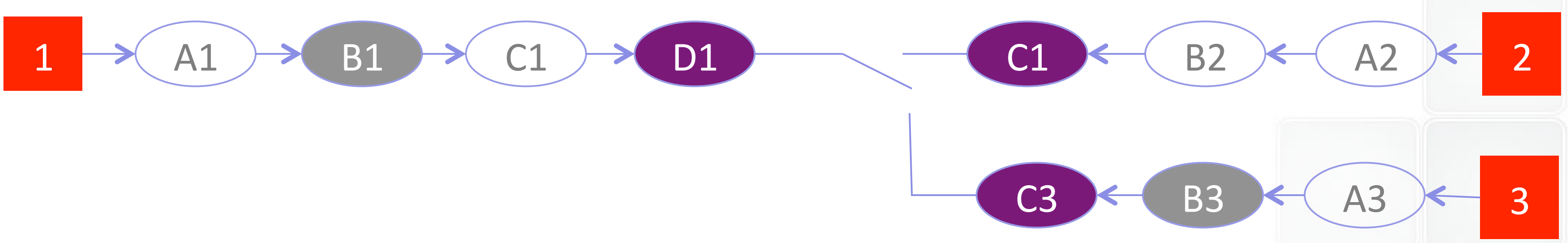
- Each element of the EDN can be on one of three functional status
  - *On* (Physically intact)
  - *Disconnected* (Physically intact but functionally unavailable)
  - *Damaged* (Physically unavailable)
- Each Secondary Substations has associated a number n of customers

EDN model

- We model the BTS allowing tele-control functionality to SS. Each BTS is also connected to a SS which ensures its electrical supply.



Electrical dorsal example



Electrical Distribution Network outage metric

Outage metric is expressed as the number of disconnected customers of a EDN SS times the duration of its disconnection

The damage on node *i* results in the disconnection of *m* nodes

KPI outage metric for a damage on node *i*

$$\Gamma_i = \sum_{j=1}^{m} n_j \tau_j$$

Single node KPI outage metric (kmin in the following)

EDN Operational Resilience Metric

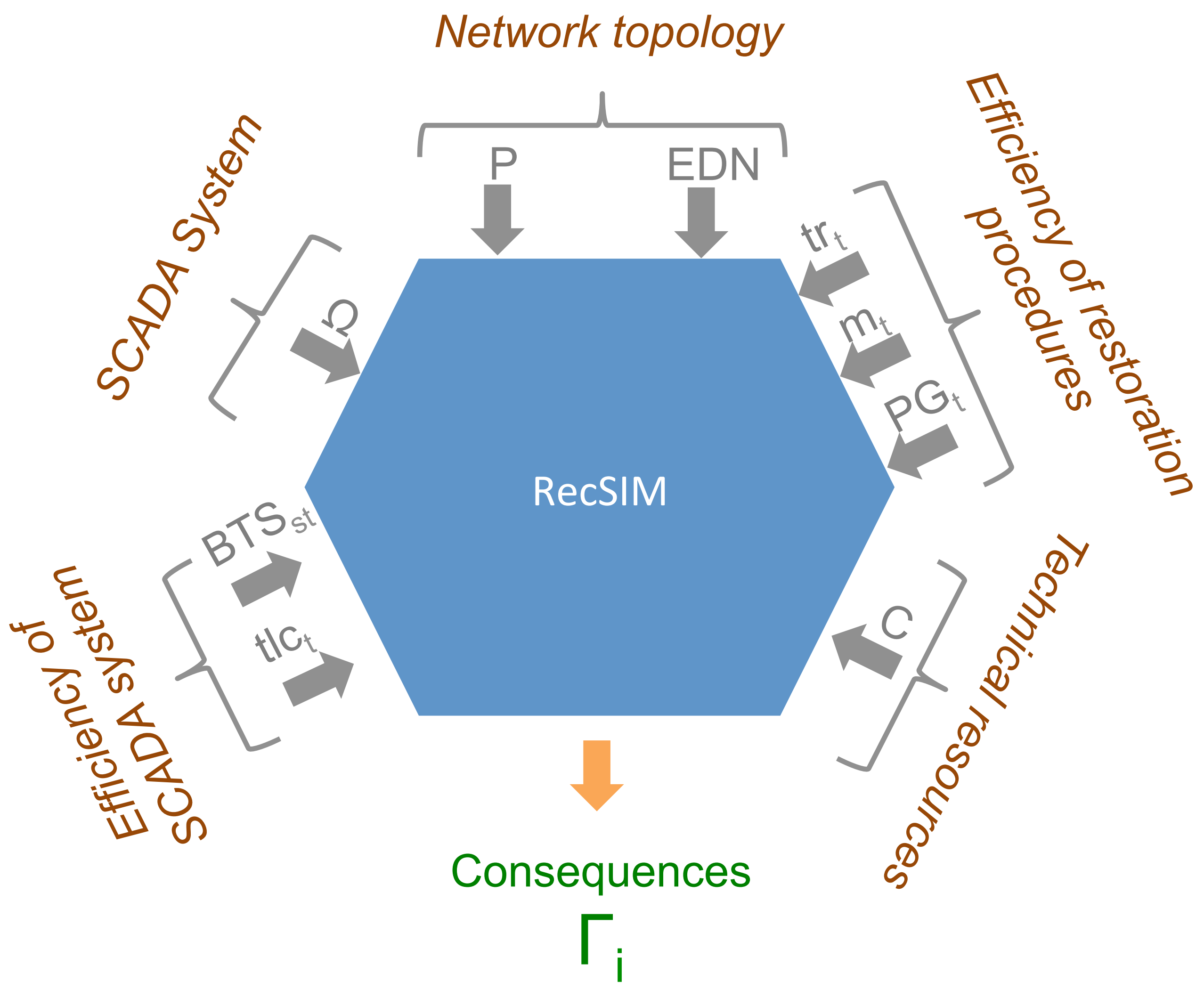
- As the value of the KPI outage metric depends on the *Resilience factors* (e.g. network topology, SCADA system, efficiency of SCADA system, efficiency of crisis management, number of technical resources), it would not be inappropriate to correlate the value of the KPI outage metric (Γi) with the inverse of the Resilience concept **R**. In other terms

$$\mathbf{R}^{-1} \propto \Gamma_i$$

- The overall operational network Resilience will be thus associated to the value of the integral of the distribution function of all the Γi values (D(Γ)) resulting to the failure of each one of the N nodes of the EDN (normalized with respect to the total number of nodes N):

$$\mathbf{R}^{-1} \propto \frac{\int D(\Gamma)d\Gamma}{N}$$

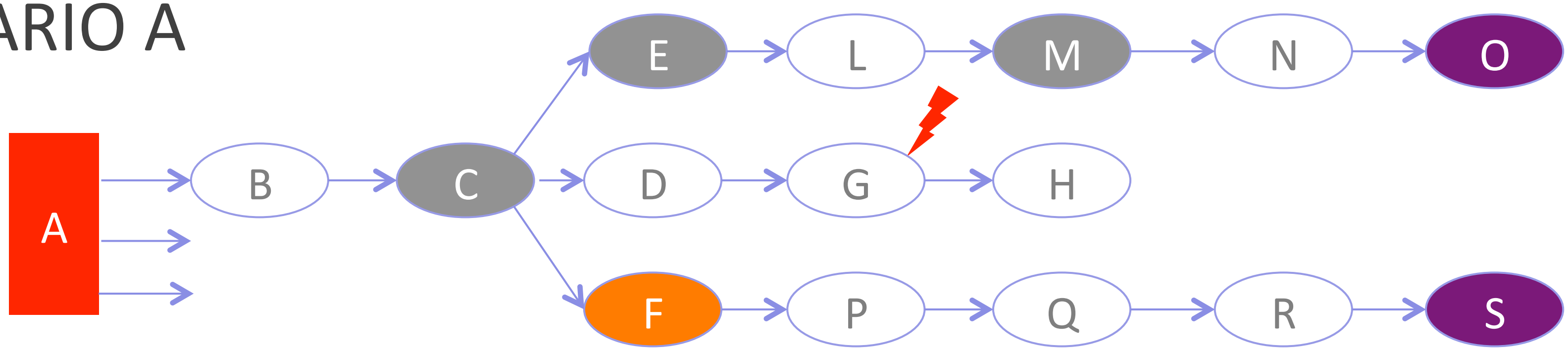
RecSIM



Network topology
P
EDN
SCADA System
Ω
Efficiency of restoration procedures
tr_t
m_t
PG_t
Efficiency of SCADA system
BTS_{st}
tlc_t
Technical resources
C
RecSIM
Consequences
Γ_i

RecSIM – reconfiguration procedures

SCENARIO A



T=0 Severe failure on SS G → T=0 All nodes on line will be disconnected

T ≈ 5 mins the Operator open the switch C-D using the SCADA System

T ≈ 45 mins the emergency team open the switch D-G. Customers of SS D feed after 45 mins

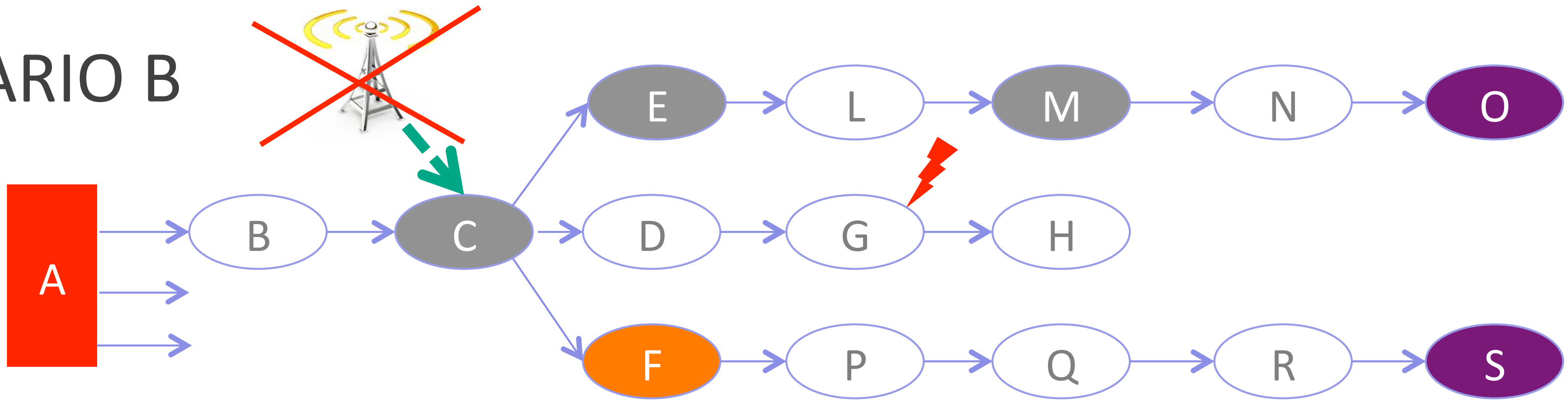
T ≈ 180 emergency crews install power generators in nodes G and H.
No other options available

T ≈ 180 mins the customers of SS G, H are feed trough power generators

Then, RecSIM computes the outage associated to the scenario (KPI_A)

RecSIM – reconfiguration procedures

SCENARIO B



T=0 Severe failure on SS G → T=0 All nodes on line will be disconnected

T ≈ 45 mins the emergency team opens the switch D-G (Fault isolated)

T ≈ 180 the emergency teams install power generators on node G and H.
No other options available

T ≈ 180 mins the customers of SS G, H are feed trough power generators

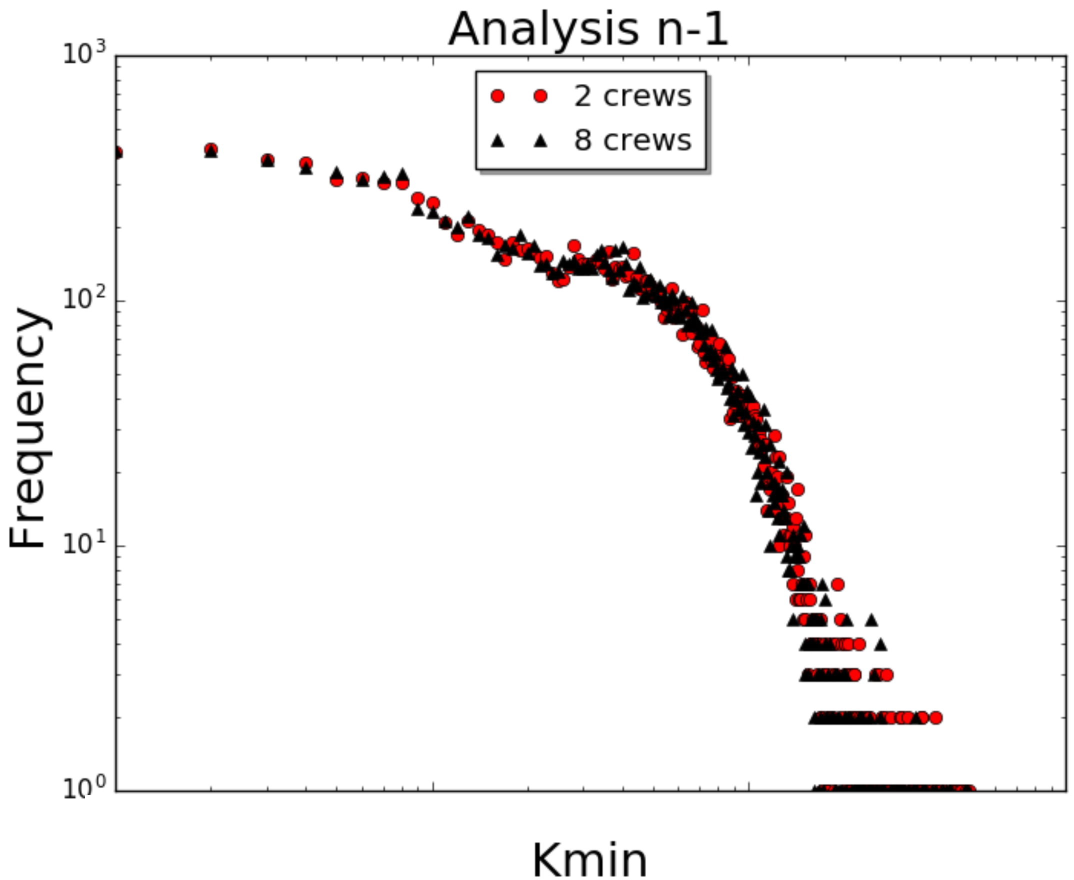
Then, RecSIM computes the outage metric associated to the scenario (KPI_B)

$$KPI_B > KPI_A$$

Results: N-1 analysis

Model parameters S1 Simulations	
Network topology	Normal configuration (30-03-2017)
# of technical crews	2, 4, 6, 8
Time for tele-controlled operations	5±2 mins
Time for technical intervention on site	45 ± 10 mins
Time for installing an electrical generator	180 ±20 mins
Fraction of tele-controlled SS being not tele-controllable	0.4 %

Results: N-1 analysis



# of technical crews	R^{-1}
2	X ~ + 2,2%
4	X (41,74)
6	X ~ - 0,2%
8	X ~ - 0,4%

Results: N-1 analysis

Model parameters S2 Simulations (low traffic)	
Network topology	Normal configuration (30-03-2017)
# of technical crews	4
Time for tele-controlled operations	5±2 mins
Tome for technical intervention on site	35 ± 10 mins
Time for installing an electrical generator	160 ±20 mins
Fraction of tele-controlled SS being not tele-controllable	0.4 %

$$R^{-1} \cong X \sim -13\,\%$$

Results: N-1 analysis

Model parameters S3 Simulations (high traffic)	
Network topology	Normal configuration (30-03-2017)
# of technical crews	4
Time for tele-controlled operations	5±2 mins
Tome for technical intervention on site	60 ± 10 mins
Time for installing an electrical generator	220±20 mins
Fraction of tele-controlled SS being not tele-controllable	0.4 %

$$R^{-1} \cong X \sim + 19\ \%$$

Results: N-1 analysis

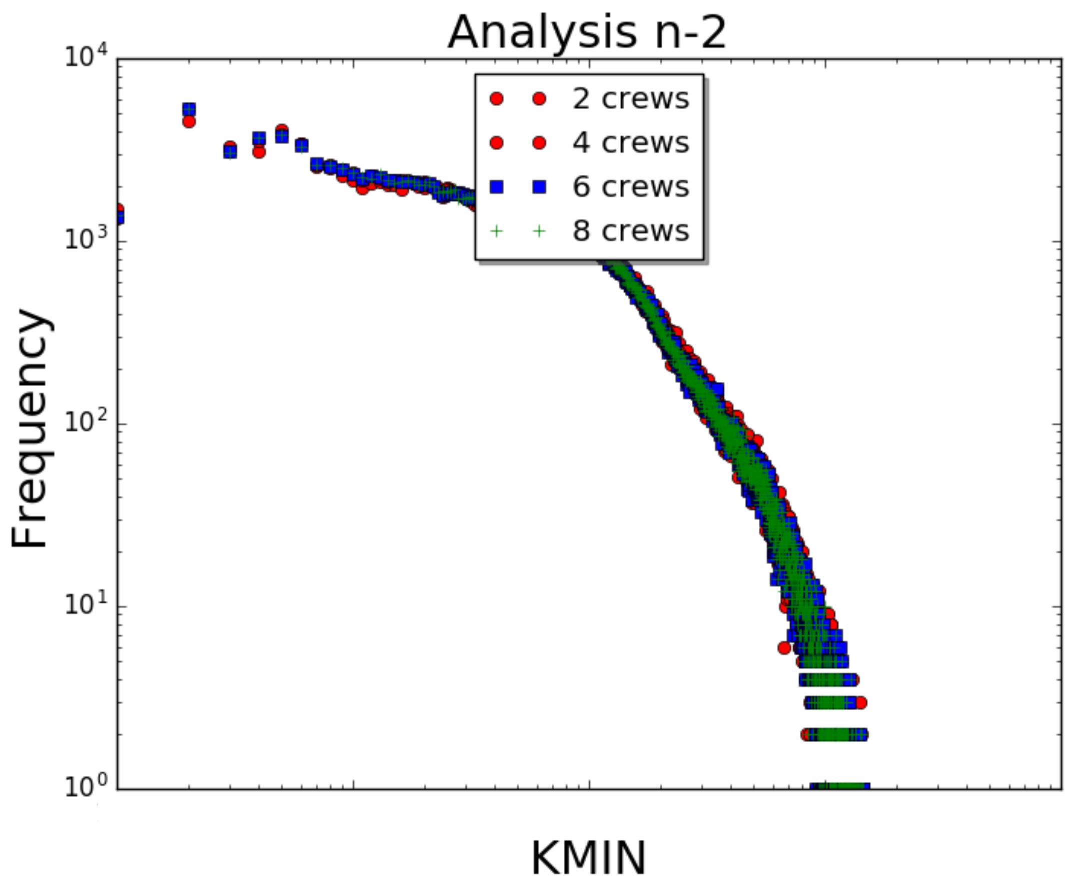
Model parameters S4 Simulations (low SCADA system availability)	
Network topology	Normal configuration (30-03-2017)
# of technical crews	4
Time for tele-controlled operations	5±2 mins
Time for technical intervention on site	45± 10 mins
Time for installing an electrical generator	180±20 mins
Fraction of tele-controlled SS being not tele-controllable	0.8 %

$$R^{-1} \cong X \sim + 20\ \%$$

Results N-2 analysis

Model parameters S1 Simulations	
Network topology	Normal configuration (30-03-2017)
# of technical crews	2, 4, 6, 8
Time for tele-controlled operations	5±2 mins
Tome for technical intervantion on site	45 ± 10 mins
Time for installing an electrical generator	180 ±20 mins
Fraction of tele-controlled SS being not telecontrollable	0.4 %

Results N-2 analysis



# of technical crews	R^{-1}
2	X ~ + 5%
4	X (125,95)
6	X ~ - 0,5%
8	X ~ - 0,7%

Conclusions

- The RecSim algorithm reproduces the cascade of failures following the sudden unavailability of one (or more) active elements of the electrical grid, its spread on the telecommunication network and the subsequent management activities carried out by the operator to restore the grid normal functions;

- RecSim operates on the whole MV network of the city of Roma (<14.000 electrical cabins and >500 telecommunication antennas)

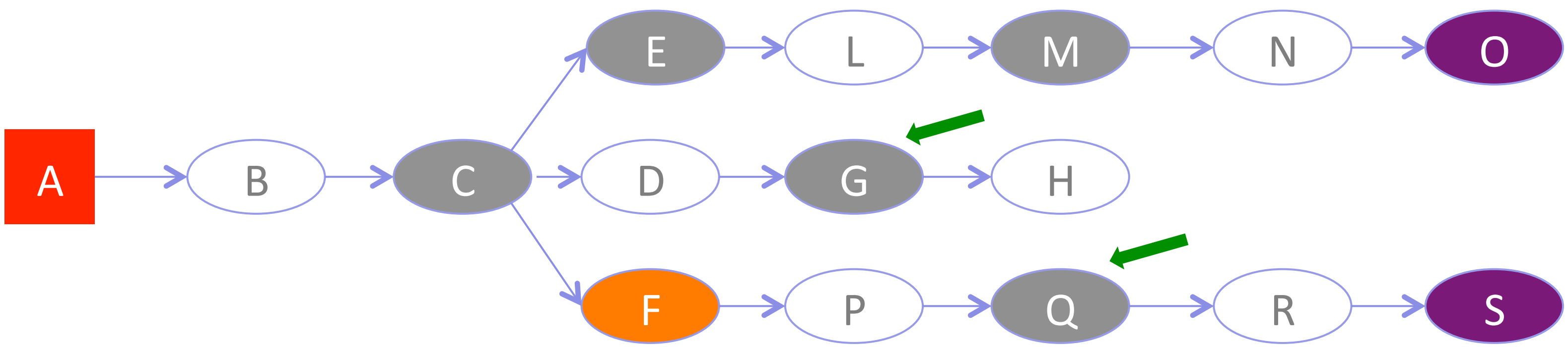
Conclusions

- The "intrinsic" operational resilience (OR) of the MT network decreases/increases by varying the fraction of not functioning SCADA system devices and/or BTS (i.e. the operational resilience decrease of the 20% if the number of not available tele-controlled devices are duplicated with respect to the normal condition setting);

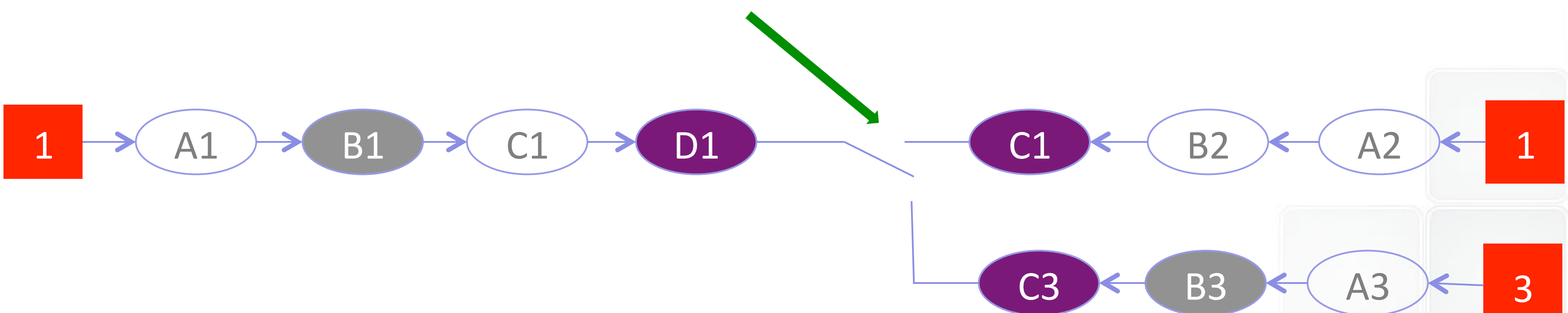
- The ~20% decrease of the mean time needed by a response team to reconnect a disconnected SS, allows a 13% OR increase;
- The ~20% increase of the mean time needed by a response team to reconnect a disconnected SS allows a 19% decrease;

Future work

- Simulations will be performed to assess the OR variation wrt
    - Fraction of tele-controlled SS in the network



- Position of the switches along the MT lines



Thanks for your attention

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