BEST PRACTICES FOR EMERGENCY RESPONSE PLANNING & DISTRIBUTION POWER GRID RESTORATION

FOLLOWING EXTREME WEATHER EVENTS

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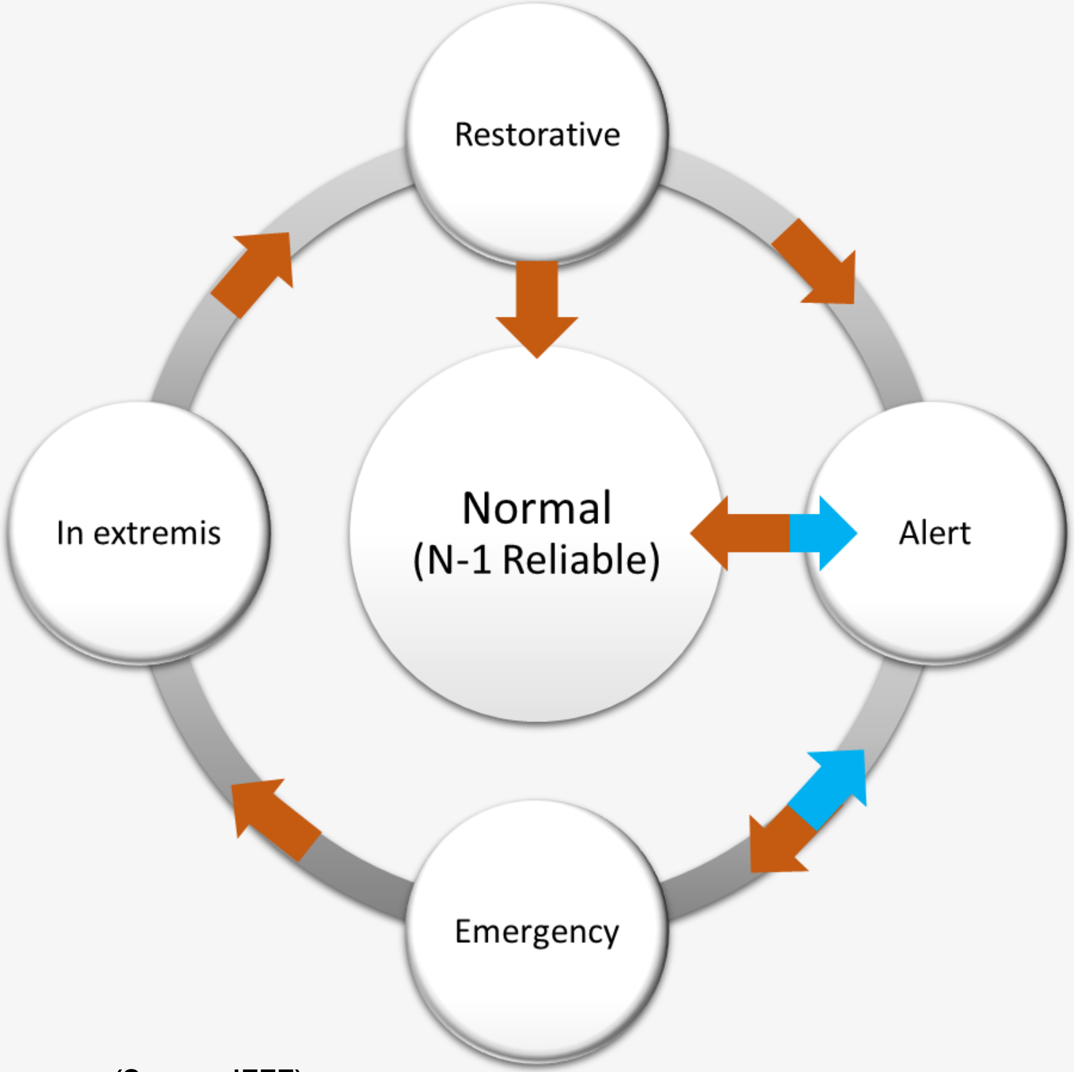
INTRODUCTION

Cases of Emergency Situations:

- Interruption of operation of critical network elements
- Interruption of operation of an extensive part of the network
- Shutdown of critical network monitoring & control systems
- Excess of the limits of acceptable operation of network elements
- Significant deviation of network operating characteristics from nominal values
- Force Majeure events or unpredictable incidents



(Source: IEEE)

POWER SYSTEM OPERATING STATES

- The “normal” condition, which meets the N-1 reliability criteria, is encountered most often.
- The system on occasions enters “alert”, “emergency”, “in extremis” and “restorative” states in various cases of emergency situations.

METHODOLOGY

Pre-crisis	Crisis Response	Post-crisis

Objective:

Pre-crisis	Crisis Response	Post-crisis
Prevention & Preparedness, i.e., reducing the known risks that can lead to a crisis	**Notification & Mobilization**, i.e., implementation of the Emergency Response Plan	**Recovery**, i.e., response assessment, adaptation & update for the future
Risk Management	***Crisis Management***	***Corrective Actions***

Key Considerations:

Pre-crisis

- Risk identification
- Network upgrades & maintenance
- Emergency Response Plan
- Crisis Management Structure
- Communication Channels
- Critical Stocks
- Training & Testing
- Warning System

Crisis Response

- Action Plan
- Emergency Response Teams
- Command Centre
- Emergency Shutdowns
- Restoration Prioritization Strategy
- Fault Announcement / Call Centre
- Crisis Management Application
- Security & Safety

Post-crisis

- Review
- Good Practices
- Lesson Learned
- Capability Upgrade
- Adaptation

Actions:

Pre-crisis

Routine Phase

- Guidelines to all Service Units based on Civil Protection General Plans
- Table-top Exercises / Emergency Drills
- Inspections & Preventive Maintenance
- Vegetation Management
- Network Hardening Initiatives
- Mutual Aid Agreements
- Updated List of Critical Customers
- Updated Contact List of third parties
- Crisis Playbook – Sharing of Best Practices

Alert Phase
(following a severe weather alert)

- Suspension of scheduled outages
- Staffing reinforcement (own & contracted)
- Standby Engineers in critical infrastructures
- Reinforcement of shifts in Control Centers
- Inspections in HV/MV substations
- Call Center reinforcement
- Complementary guidelines
- Coordination with warehouses
- Pre-staging of resources in areas that are expected to be affected
- Pre-loading of vans with materials
- Rapid Access Licenses for vehicles

Crisis Response

- Action planning based on the incident (type, extent and severity)
- Liaison in Civil Protection
- Information flow & escalation according to the established process
- Whatsapp / Viber teams
- Cooperation with third parties for preventive power outages, if required
- Preliminary onsite inspection, isolation of faults and re-electrification of health parts of the network, where possible
- Situation / damage assessment by inspection technical crews
- Power restoration prioritization – focus on critical loads
- Real-time data entry in the Fault Report software applications
- Crew capacity adjustment - contribution from other Service Units, if required

Post-crisis

- Assessment of crisis response records
- Collection of best practices
- Reporting to the Regulatory Authority for Energy, as defined in Code of Operation
- Resilience enhancement measures

Part I

PLANNING OF GRID FAILURE (PREVENTION & PREPAREDNESS)

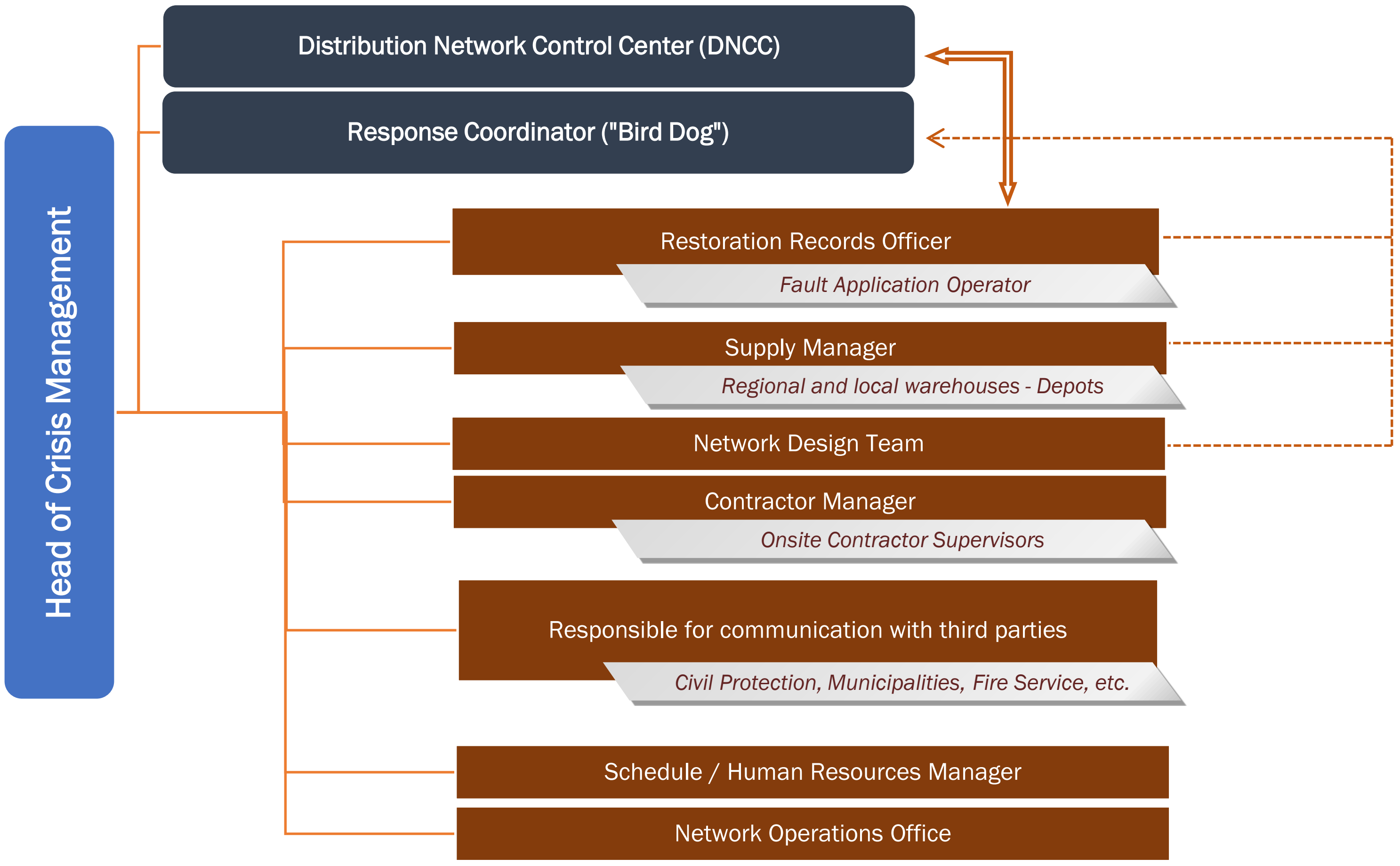
- Emergency Operations Centre
- Crisis Management Structure
- Vegetation Management, Inspection & Preventive Maintenance
- Network Hardening Initiatives
- Mutual Aid Agreements
- Fault Announcement / Call Centre
- Increased Preparedness Protocol

Emergency Operations Centre

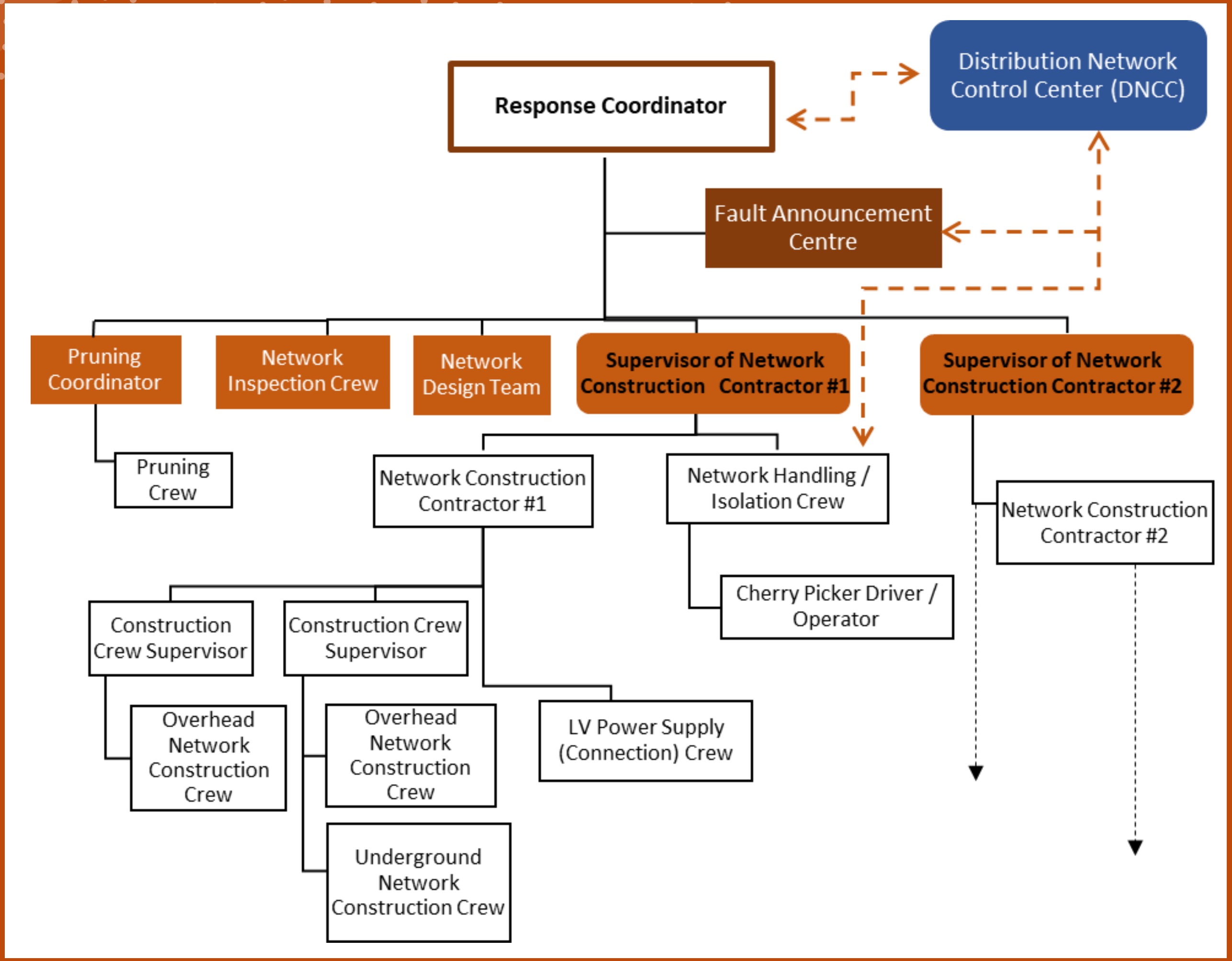
Command Centre

- An effective EOC with delegation of authority in the field and designated management roles is crucial.
- The EOC should be established, **fully equipped**, in a specific physical location close to the impacted areas (typically the headquarters of the Service Unit responsible for the network affected)
- The EOC is necessary to share and update **emergency contact details** with critical partners and stakeholders as well as keep an updated list of critical customers.

Crisis Management Organization Structure at EOC



Onsite Crisis Management Structure



Preparatory Actions

Vegetation Management

1. Extensive **tree pruning and logging**, where necessary.
2. **Critical MV lines** should be prioritized.

Network Inspections (thermal cameras / drones)

1. Check of **concrete poles** for cracks and of **wooden poles** for rot. Particular attention should be paid to the replacement of any discarded or dangerous poles.
2. Check of the robustness and good condition of the **electricity poles' support systems**.
3. Check of **electrical connections** at cable joints.
4. Inspection of **indoor substations** at regular intervals and in any case before autumn.
5. Periodic **load measurement** per distribution transformer's feeder.
6. Periodic inspection of existing **grounding systems, insulators**, etc.

Preventive Maintenance

Emphasis should be given to the **maintenance and/or replacement of equipment elements** and to the **permanent restoration of faults that affect the ability to handle the network** (i.e., maintenance / replacement of switches, etc.).

NETWORK HARDENING

- **Undergrounding** of sections of overhead networks
- **Structural reinforcement** of existing distribution lines
- **In forest areas,** upgrade of the overhead network or rerouting of existing lines to run in parallel to the road network, ensuring easier access or fire protection
- Network design upgrade by providing **alternative power network paths**
- Preparation of networks for **future connections of Distributed Energy Resources**
- **Network reconstruction with more resilient materials**
- **Reinforcement of structures with larger openings** in stormwater basins or redesign to ensure that no network infrastructure is placed in such locations.
- Implementation of **fire protection works** in HV/MV substations and regional warehouses.
- **Relocation** of critical facilities or network elements to less vulnerable areas.
- **Flood protection** of substations located in flood zones.

MUTUAL AID AGREEMENTS

Power utilities should establish contracts with suppliers and third parties to ensure sufficiency of critical equipment for:

- **Inspection** (thermal cameras, drones, helicopters, etc.)
- **Staff transport** (light, medium, and heavy-duty on-road vehicles, helicopters, high-speed boats, open type ferries, etc.)
- **Network construction** (cherry pickers, cranes, Grader type vehicles for road opening, etc.)
- **Special services** (snow trucks, water tankers, etc.)
- **Restorations** (equipment for fault location in underground networks, water pumps for indoor substations, mobile generators, etc.)

FAULT ANNOUNCEMENT / CALL CENTRE

- Having **robust telephony and web systems adequately resourced** is critical.
- The Fault Application Operator should have experience and knowledge of the geography of the area of interest to **group faults by possible cause and geographical location** and direct technical crews to the cause of the fault, if necessary.
- This is critical for **reducing outages** and **significantly saving time** for fault restorations.
- To keep consumers informed, the Application Operator must **record the estimated restoration time of faults.**
- This estimate is made through constant communication with the Response Coordinator and the technical crews.

INCREASED PREPAREDNESS PROTOCOL

Upon an extreme weather alert, **additional preparatory measures** should be taken by power utilities to ensure immediate and effective response, **depending on the anticipated level of risk.**

These actions include:

- Standby duty of all technical staff (own and contracted)
- Increased readiness of personnel in DNCCs and local Units
  During the fire season, technical workers should be alert in cases of high risk based on the Civil Protection’s Daily Fire Risk Forecast Map.
- Readiness to integrate contractors or third-party crews into the organization structure
- Emergency Response Teams with an appointed Response Coordinator
- Timely provision of sufficient materials, tools, and other equipment in the warehouses
- Readiness of fully and appropriately equipped vehicles and construction machinery
- Readiness of wireless and mechanical equipment
- Readiness of back-up generators and planning for their transport and installation
- Information to critical users about the appropriate safety measures in case of an unplanned power outage
- Additional preventive measures in cases of indoor substations with a history of water inflow during flooding incidents
- Necessary waivers and rapid transit permits for vehicles and construction machinery
- Pre-staging of resources

Part II

GRID FAILURE MANAGEMENT (RESPONSE & RECOVERY)

- Damage Assessment
- Severity and Criticality of Damage
- Crisis Management Application
- Transport of Technical Crews
- Depots
- Role of Distribution Network Control Centres
- Prioritization of Restorations
- Back-up Generation Units
- Focus on Safety
- Communications

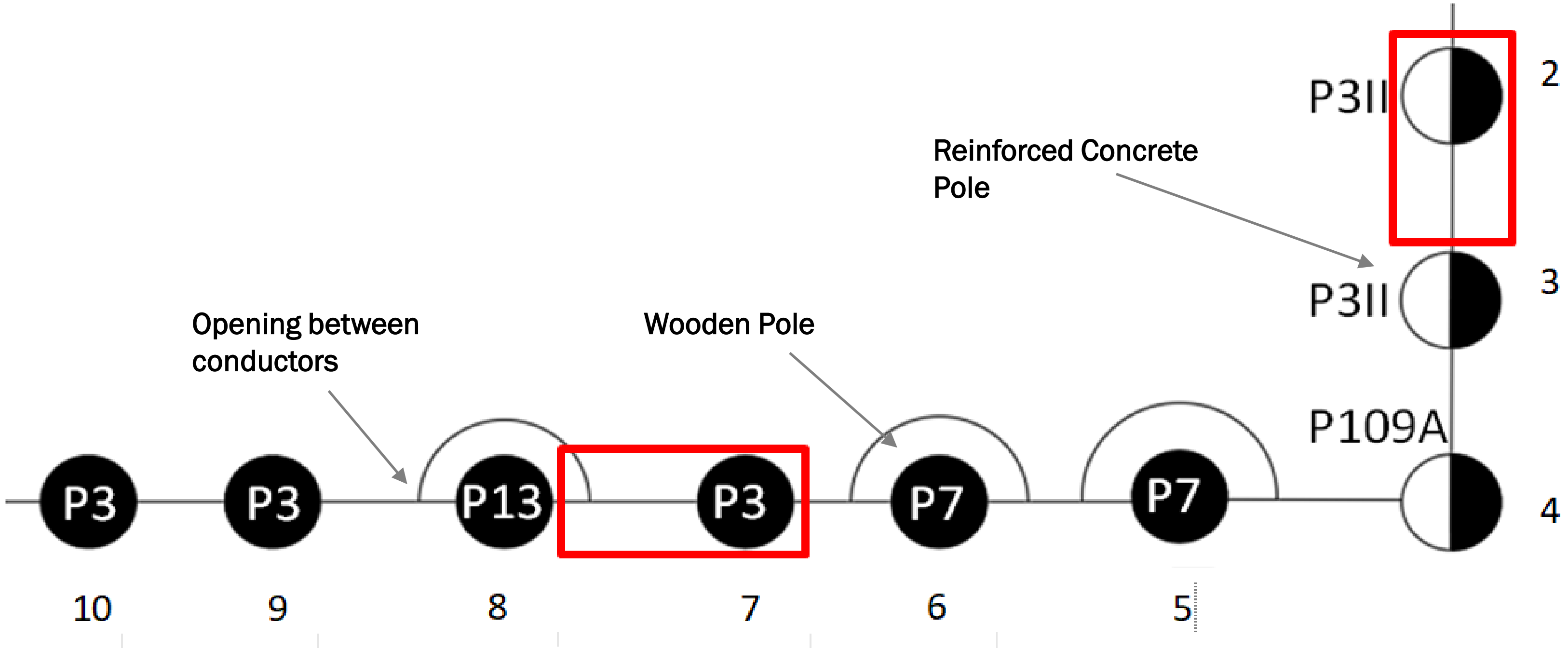
DAMAGE ASSESSMENT

- When a MV or LV line initially breaks down, the line's **protective mechanisms are automatically activated**, cutting off the electricity to that line.
- In certain situations (such as a wildfire), the DNCC of the respective Service Unit will, in coordination with the onsite technical crews that are monitoring the phenomenon from a safe location, **pre-emptively isolate the MV line(s) (or part of them such) for safety purposes.**
- A **preliminary assessment of the extent of the damage**, even as the phenomenon is in progress, can be conducted as follows:
  - MV network: from DNCC's data, through SCADA, the following are recorded:
    - **MV lines (or parts of them)** which have been damaged
    - **Distribution substations** which are out of operation
    - **Critical loads (customers)** which are left without electricity
  - LV network: from the Fault Announcement / Call Centre's data (i.e., calls, reports, incoming requests for power cuts from LV customers).

SEVERITY OF DAMAGE

The severity (S) of each damage depends mainly on the Restoration Difficulty Level (RDL) due to:

- The **nature of the damage (N),** i.e., the type and number of the affected components and their degree of wear (from negligible wear to entire destruction)
- The **location of the damage (L),** i.e., the geographical location of the affected network element, in terms of access by technical crews and the construction machinery required for its remediation



Depiction of a MV Network Segment – Poles and Conductors' Suspension

SEVERITY OF DAMAGE

Gradation of Restoration Difficulty per Network Construction & Type of Pole

Standard Distribution Network Structures

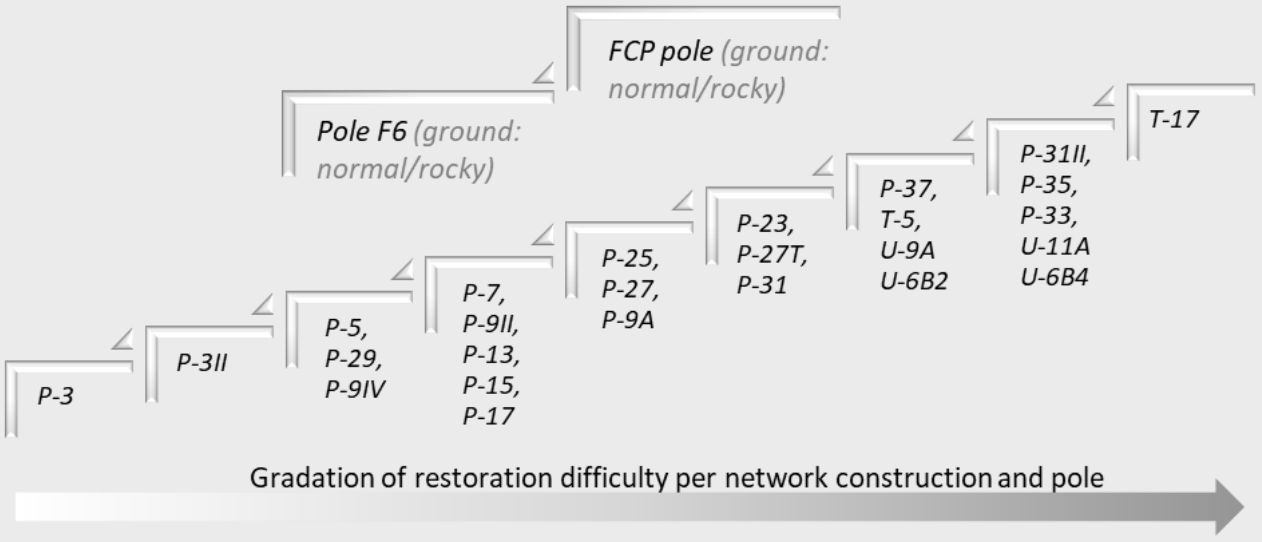
F6: Wooden pole

FCP: Reinforced concrete pole

P: MV overhead construction

T: Distribution substation construction

U: Underground Network Construction



$$S_j = L_j N_j \Rightarrow L_j \left[W_{Pj} + W_{Cj} + \left(\frac{n_{Lj} W_{Lj}}{2} \right) \right], \qquad 0 \le n_{Lj} \le 3$$

- W_P = restoration difficulty level for replacing poles
- W_C = restoration difficulty level for replacing the conductors’ suspension construction
- W_L = restoration difficulty level for tensioning the conductors supported
- n_L = number of damaged conductors

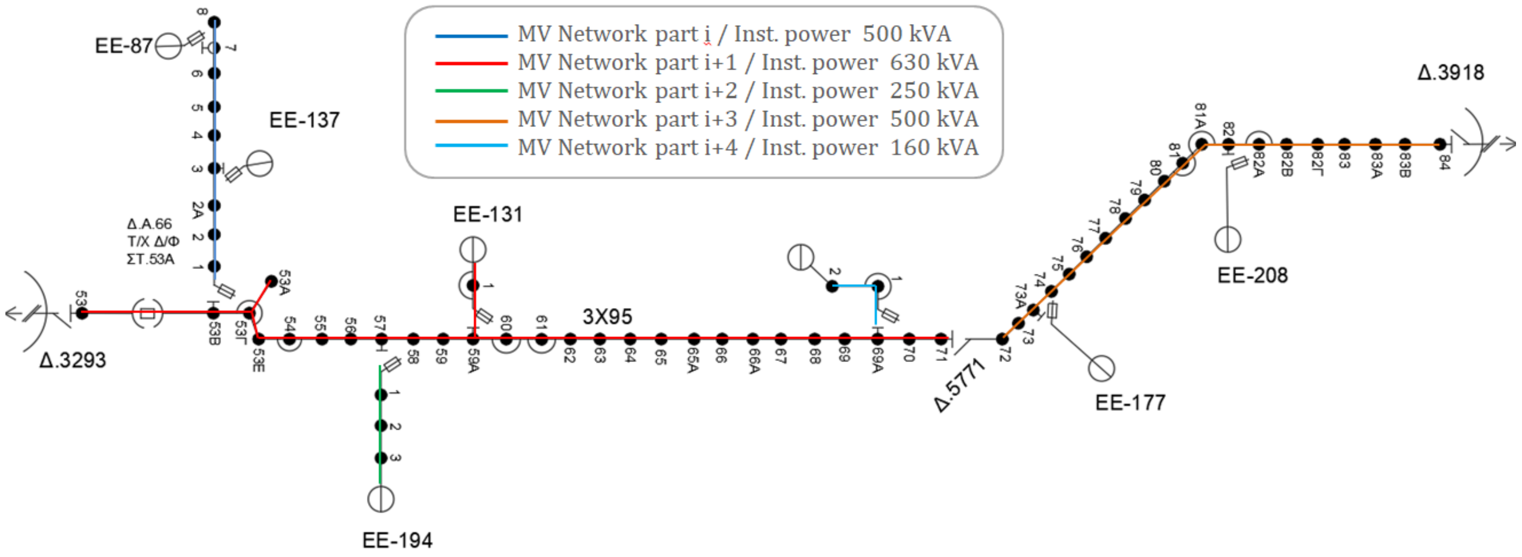
$$S_i = \sum_j S_j$$

$$S_{line} = \sum_{i=1}^{i=n} \sum_j S_j$$

CRITICALITY OF DAMAGE

The factors for calculating the degree of criticality in an MV network segment are:

- The **installed capacity** of the MV/LV substations and MV consumers supplied (or not supplied when there is a failure in at least one element) by that segment
- The **criticality of the non-electrified loads and consumers** that are installed on the segment



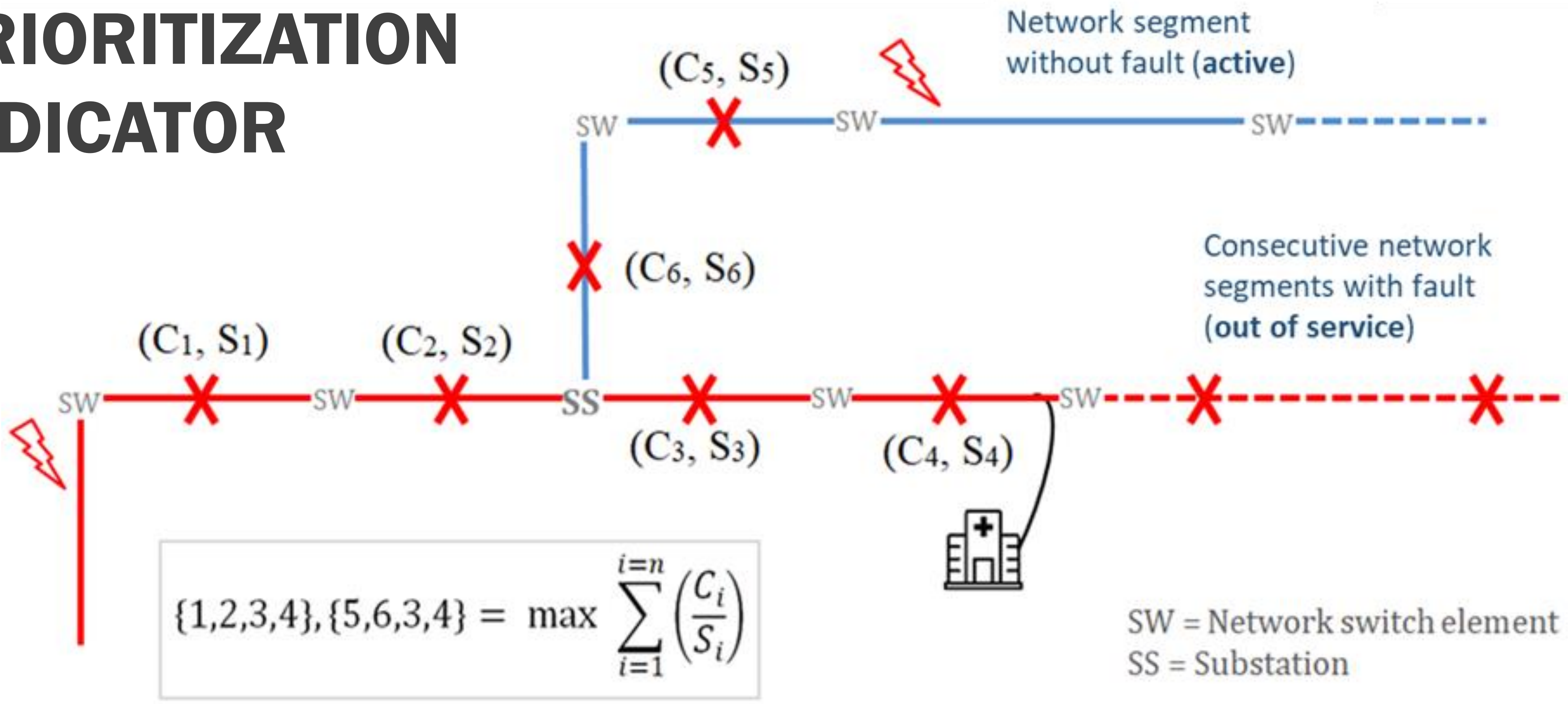
Order	Load Served
1	Substations that provide the system with the ability to switch and reroute power supply (i.e., HV/MV substations, coupling substations, three-loop indoor substations, etc.).
2	Public services and critical infrastructures including public safety and health buildings, such as hospitals, nursing homes, emergency shelters, fire brigade, water pumping stations, gas installations, telecommunication facilities (antennas, etc.)
3	Consumers (MV customers) whose activity is directly related to national security
4	Commercial spaces that provide basic necessities, such as food, etc.
5	Apartment buildings and small groups of consumers

CRITICALITY OF DAMAGE

PRIORITIZATION OF RESTORATIONS

- It might be possible to restore electricity to a large number of network users **by fixing targeted faults of low severity.** In these cases, the immediate restoration of damages is a priority.
- When the MV network has suffered severe damages and faults (thus power restoration will delay), **the loads of increased criticality are supplied by backup generators** which the DSO must have or need to be supplied**. Under these circumstances, the LV network is repaired by priority in order to be supplied by backup generator**. **Multiple scenarios are also assessed** so that, with the restoration of a MV and LV network of a short length, the power supply of several substations by the same backup generator becomes possible.
- Where the LV network segments are entirely destroyed but only a few consumers are connected to it, **then small-scale generators are placed in the electricity supply installations** of the customers.

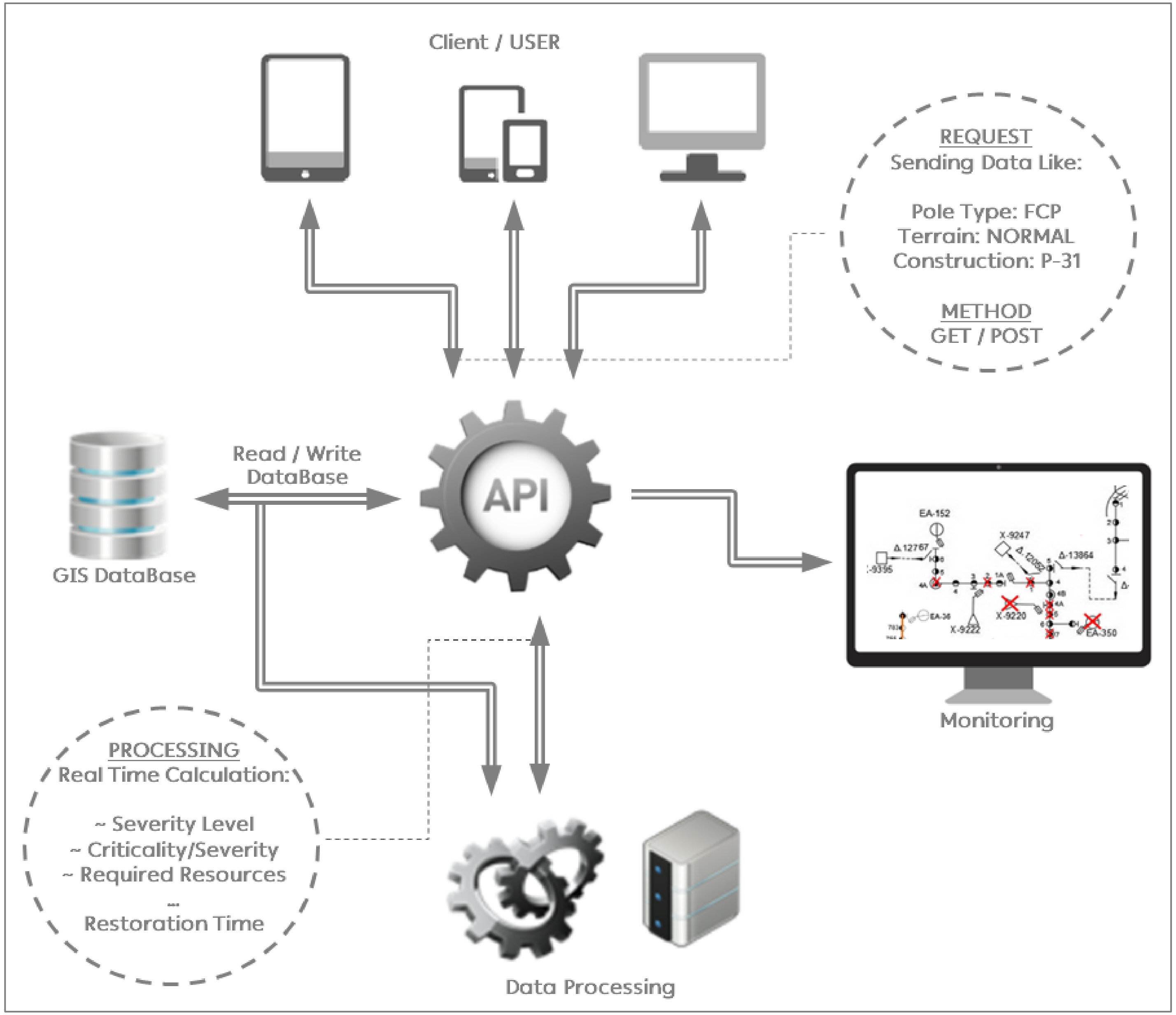
PRIORITIZATION INDICATOR



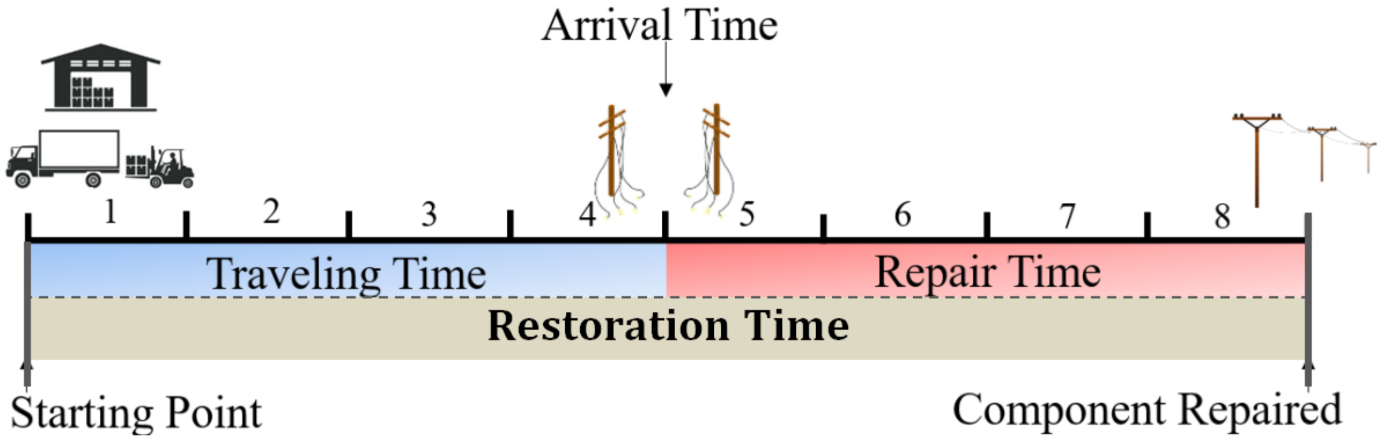
$$PI_{max} = \max \sum_{i=1}^{i=n} PI_i = \max \sum_{i=1}^{i=n} \left(\frac{C_i}{S_i}\right), \qquad \forall\, i \in G, F$$

Crisis Management Application

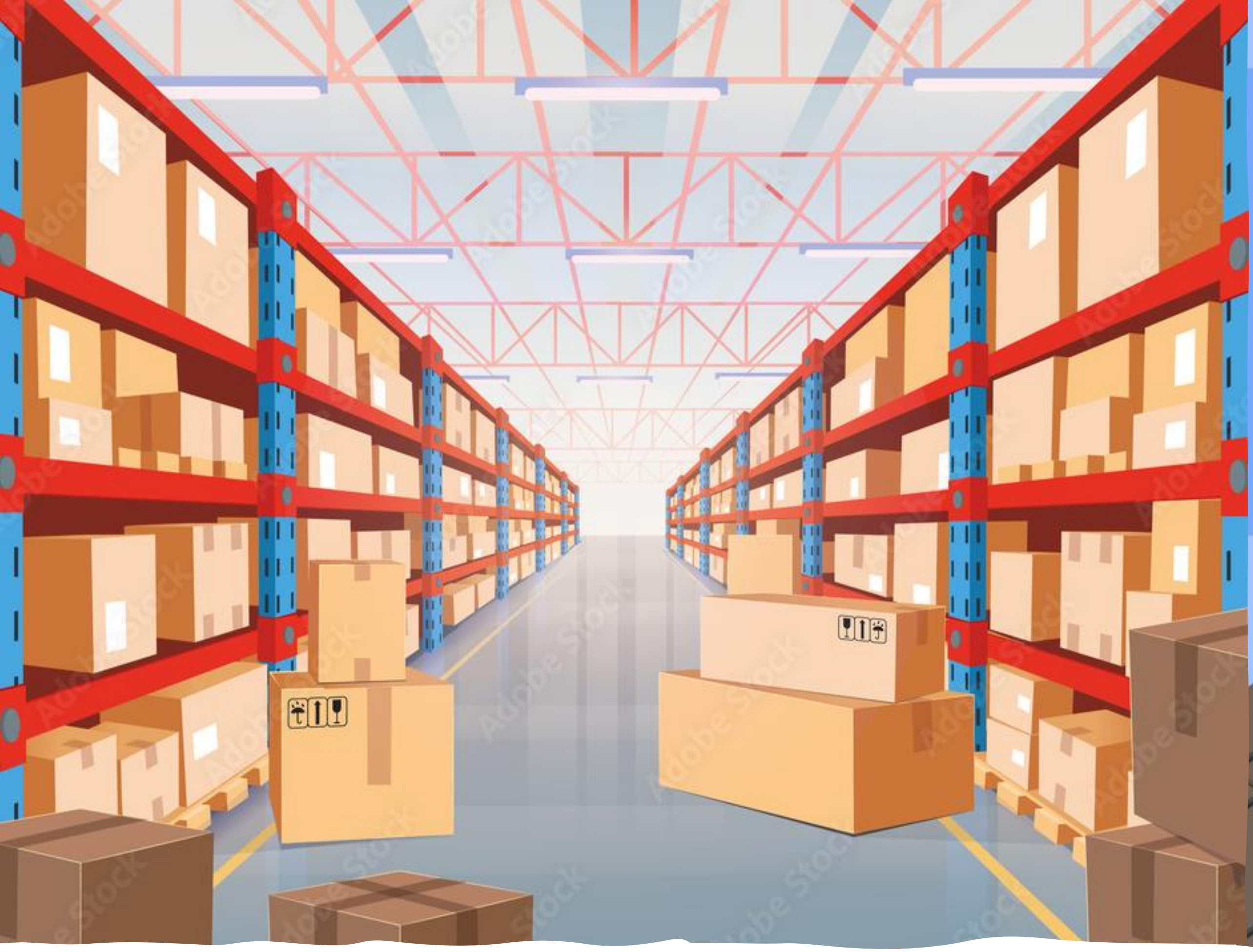
- **Digital display of monolinear diagrams** during inspection
- Ability to **automatically locate** (via the device's GPS) **and display** the affected network segment
- **Simple data verification by the user**, since the conductors' suspension construction, the height and category of the pole are already registered in the GIS database
- **Simple and user-friendly interface** to enter the type of damage by selecting checkboxes
- Ability to **evaluate and enter any additional information**
- **Rapid dissemination of findings** to the EOC

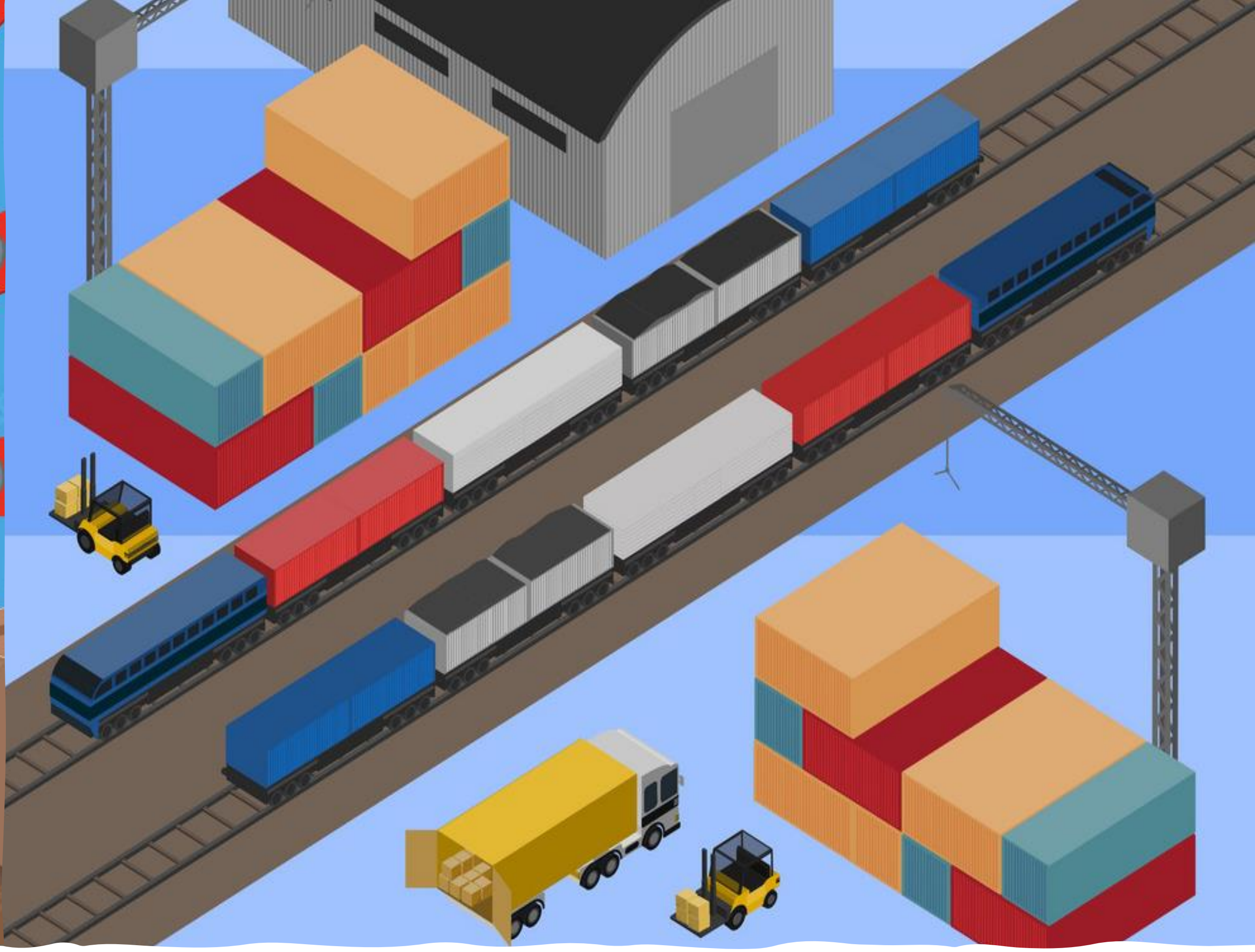


TRANSPORT OF TECHNICAL CREWS



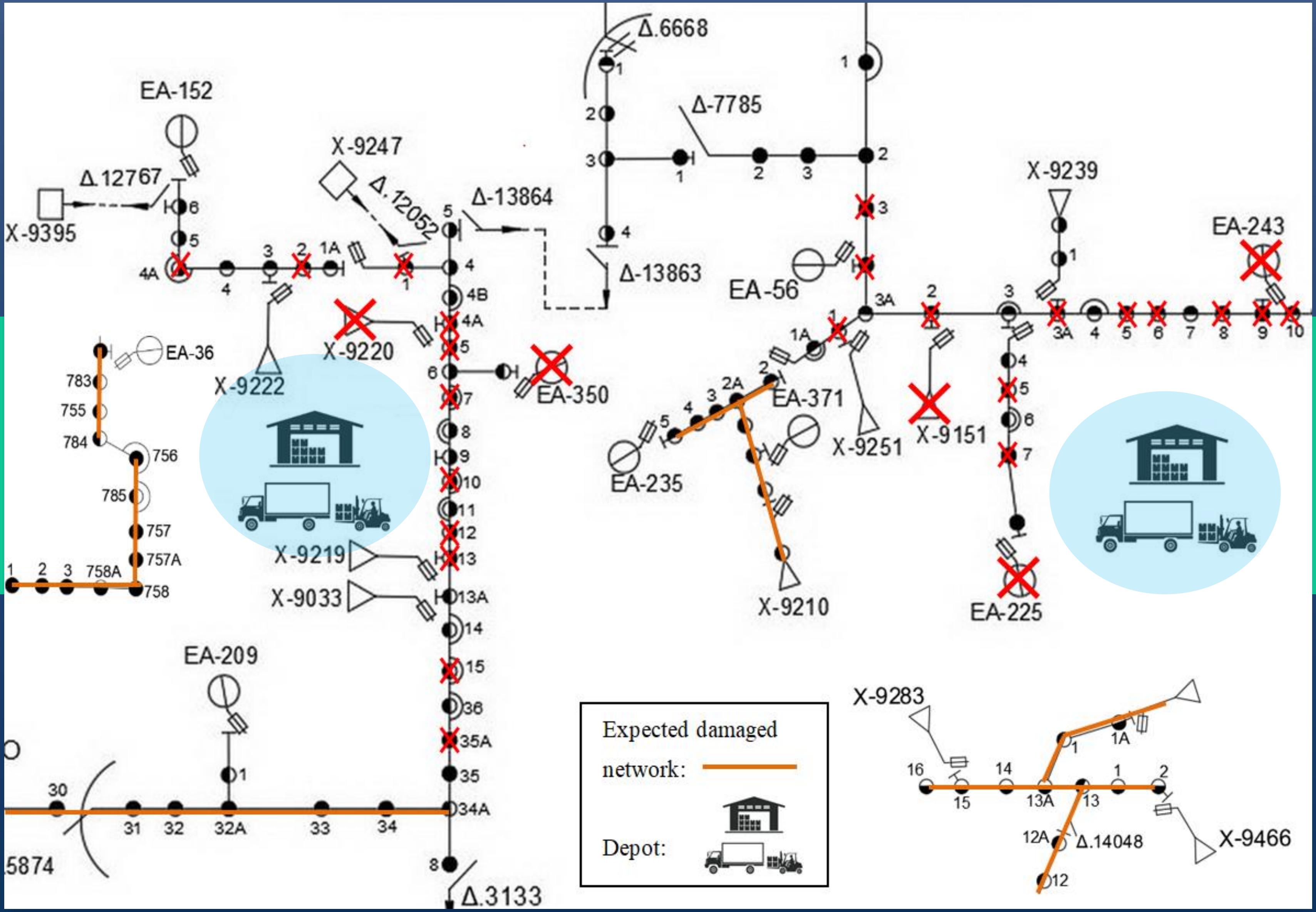
- The **pre-staging of resources close to the area** where damages are expected to occur is crucial during the preparedness stage.
- Furthermore, in the phase of response, crews should move in **manageably sized groups** and **as minimal as possible.**
- **Unnecessary relocations should be avoided** because the time required for the relocation of crews, vehicles, and construction machinery can cause considerable delays in restorations.





DEPOTS

- In cooperation with the Response Coordinator, temporary depots are selected in the field, **close to the locations where restoration works are expected to take place (or are already being carried out)**
- In general, **locations of depots should be selected as follows**:
  - They are geographically dispersed so that material supply on all response fronts is uninterrupted.
  - Vehicle transit routes are not hindered, and general traffic is not obstructed.
  - Materials, workers, and vehicles are kept safe from the effects of the extreme event
  - There is enough space for materials to be deposited and for vehicles / construction machines to move around (maneuvers)



INDICATIVE SELECTION OF LOCATIONS FOR DEPOTS

ROLE OF DISTRIBUTION NETWORK CONTROL CENTRES (DNCC)

- DNCCs are **involved in the prioritization of the MV network restoration works**, since they have a real-time visualization of the grid (using a map board), the supervision and control of the loads, the power flow, the switching means and protection equipment of all MV power lines in real-time.
- DNCCs are staffed with system operators **24x7**.
- DNCC's personnel **may be reinforced during emergencies** in order to ensure that their contribution to restoration efforts is effective.
- The system operators **are assigned specific roles** and are in constant communication with the Head of Crisis Management, the Response Coordinator and the technical crews that they **direct to perform activities (i.e., use/manipulation of switches) based on clear instructions.**

BACK-UP GENERATION UNITS

- The incentive to become resilient is evident in the substantial investments that some network users make in obtaining backup supplies.
- However, installing backup power systems alone is insufficient. **These systems must be regularly tested and maintained to ensure their reliable operation during a major outage.**
- Power utilities should evaluate and recommend the best approach for getting critical facility managers to **pre-register information about emergency power supply needs and available resources.**
- Collecting this information in a **centralized, accessible database** will expedite provision of emergency power to critical facilities and help set priorities for allocating resources.
- It is also a good practice that some utilities use **appropriately sized batteries to provide power for a longer time (i.e., 24 hours).**
- Furthermore, **portable batteries and generators** can be used to supply station power if needed during restoration.

FOCUS ON SAFETY

- **The safety of workers in the terrain is the preeminent operational concern.**
- **Working conditions are challenging and increase the risk** which must be evaluated and minimized in each task.
- Integrating and managing **safety standards and cultures** from multiple organizations during restoration operations is therefore a high priority.
- Providing technical crews with **extra Personal Protective Equipment**, as well as **sanitation and hygiene material** is also of major importance.
- It is also a good practice to **staff a Safety Officer** within high places of command to ensure the safety of all response personnel, inclusive of **responsibility for the overall operational safety**.

COMMUNICATIONS

Situation Awareness Meetings

During a major disruption, short **situation awareness meetings / emergency workshops** should be organized **every 1-3 days** depending on the severity of the situation.

In these meetings, the Crisis Management Team should go through any **safety issues**, discuss on the **response organization** and should agree on the **necessary measures.**

Sharing of Network Faults Records

Updates regarding open MV faults should be sent via e-mail or through the respective Crisis Management Application as follows:

Ad-hoc, to announce a new fault, or inform about the partial or final restoration of a damage

On a daily basis, to provide a detailed report with all MV faults (critical and non-critical) of the previous 24 hours.

Social Media, Website Updates and Press Releases

Network Operators should use a **variety of communication methods** to contact their customers.

They should also issue **official press releases** aiming to inform the relevant Ministry, authorities, agencies, and consumers affected about the measures taken for the management of the crisis and the progress of restoration efforts.

Part III

DISCUSSION & CONCLUSIONS

Resilience Metrics

Innovative Technology Solutions

RESILIENCE METRICS

- Power utilities should consider and evaluate resilience by setting **specific resilience metrics.**

Hard Resilience

Focus on Resistance (coping capability)

"**Fail-safe**" – building single infrastructures to withstand sudden impact. Looks to strengthen individual infrastructures and single assets.

Soft Resilience

Focus on Absorption (recovery)

"**Safe-fail**" – building infrastructures that recover quickly from sudden impacts. Looks to reduce impact of disruption by taking a systemic view.

Example Grid Resilience Metrics

(Source: Sandia National Laboratories)

Consequence Category	Resilience Metric
	Direct Consequences
Electrical service	• Cumulative customer-hours of outages • Cumulative customer energy demand not served • Average number (or percentage) of customers experience an outage during a specified time period
Critical electrical service	• Cumulative critical customer-hours of outages • Critical customer energy demand not served • Average number (or %) of critical loads that experience an outage
Restoration	• Time to recovery • Cost of recovery
Monetary	• Loss of utility revenue • Cost of network damages (i.e., repair or replace lines, transformers) • Cost of recovery • Avoided outage cost
	Indirect Consequences
Community function	• Critical services without power (i.e., hospitals, fire stations, police stations) • Critical services without power for more than N hours (i.e., N > hours of back-up fuel requirement)
Monetary	• Loss of assets and perishables • Business interruption costs • Impact on Gross Municipal Product or Gross Regional Product
Other critical assets	• Key production facilities without power • Key military facilities without power

INNOVATIVE TECHNOLOGY SOLUTIONS

- **Digital twin models.** The creation of a digital twin model of the network allows its digital representation and therefore the simulation of various scenarios, recovery strategies, impact assessment and optimization before the event.
- **Augmented Reality and Virtual Reality systems** to train and even support crews in the near future through instructions, thus enhancing business operations at local level, the promotion of safety practices and the efficiency of field personnel.
- **Blockchain technologies** for smart grids and supply chain management. This technology offers efficient tracking, verification and certification of critical equipment and spare parts inventory, enhancing logistics and automating emergency management.
- **Artificial Intelligence decision systems** which collect all above information and, combined with historical data, can propose solutions for the most appropriate strategy, depending on the situation or action during emergencies.

- As the impacts of climate change continue to intensify, it is crucial for power utilities to **prioritize effective emergency management** as a key component of climate resilience.
- By revising emergency management protocols, electric utilities industry can **enhance ability to adapt, safeguard both human and natural systems**, **minimize material damages**, and ensure the safe and uninterruptible power supply to the customers in crises.
- Efforts should focus on establishing a reliable load prioritization strategy for restorations, **considering the severity and criticality of damages** in the wake of an incident.
- An estimate of the degrees of severity and criticality of damages at the early stages of crisis response, when combined with the respective indicators of past incidents, **can lead to useful conclusions with regard to restoration times, the resources required and the total cost for recovery**.
- In this context, utilities must **work closely with government, academic and business organizations** to develop formalized public-private practices, operational models and joint communication platforms in order to manage new crisis management requirements.

CONCLUSION

Thank you for your attention!