HIERARCHICAL MULTIPLE CRITERIA OPTIMIZATION OF MAINTENANCE ACTIVITIES ON POWER DISTRIBUTION NETWORKS

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Optimization of Maintenance Activities
- Models, Methods and Applications -
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Summary

- Motivation
- Problem Representation
- Mathematical Formulation for One Objective
- Main Data and Parameters
- Case Studies with a Reference Network
- Multiple Criteria Formulation
- Hierarchical Multiple Criteria
- Discussion

Motivation

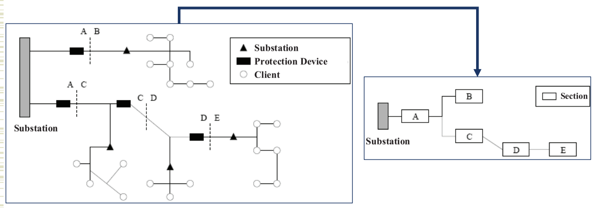
- Provide the best possiblie policies for maintenance activities at each local network of a large distribution company;
- Allow to define the best allocation of constrained maintenance budgets;
- Avoid fines associated to inadequate reliability indices for a group of networks;
- Allow to negociate and justify maintenance budgets at the various decision levels of a distribution company (including the board).

Problem Representation

- *EPDS comprising*:
  - Substations, primary networks, secondary, networks;
  - Feeders (cables, lines, poles, auxiliary structures);
  - Switching equipments;
  - Protection equipaments;
  - Correction equipments (voltage regulators, capacitor banks);
  - Tranformers.

Problem Representation

- *EPDS* divided in blocks connected by protection equipments



Problem Representation

- **Comments:**
  - A customer connected to any load point requires all componentes between himself and the substation to be operating;
  - Failures can occur due to ageing of components or due to external actions (tree branches touching the network, for instance);
  - Corrective maintenance is performed after the failure;
  - **Preventive maintenance** is performed before the failure (to avoid it).

Mathematical Formulation for One Objective

- Failure rate model:
  - Represents the ageing of network components and their change of state by the ***average failure rate*** of the components;
  - ***Failure rate multipliers*** operate on the average failure rate of network components to model different maintenance actions.

Mathematical Formulation for One Objective

- Minimize present value of costs s.t. reliability constraints:

$$MIN \quad \sum_{t=1}^{HP} \left\{ \left(\frac{1}{1+i} \right)^{t-1} \left[\sum_{e} \left(\sum_{n} p_{en} x_{en}^{t} + \lambda_e^t c_e \right) \right] \right\}$$

$$s.t. \quad SAIFI^t \leq SAIFI^{\max}$$

Mathematical Formulation for One Objective

- Failure rate model
  - The failure rate λ of a component e in period t, after receiving a maintenance procedure i is computed as follows:

$$\lambda_e^t = \delta_i \lambda_e^{t-1}$$

Main Data and Parameters

- λ_e^t, failure rate for component *e* in time *t*;
- p_{en}, cost of preventive maintenance actions of level *n* on components *e*;
- c_e, cost of corrective maintenance on components *e*;
- **Detailed information about the network topology and location of components.**

Mathematical Formulation for One Objective

- The reliability of the network is represented by the ***system average interruption frequence index*** - *SAIFI*

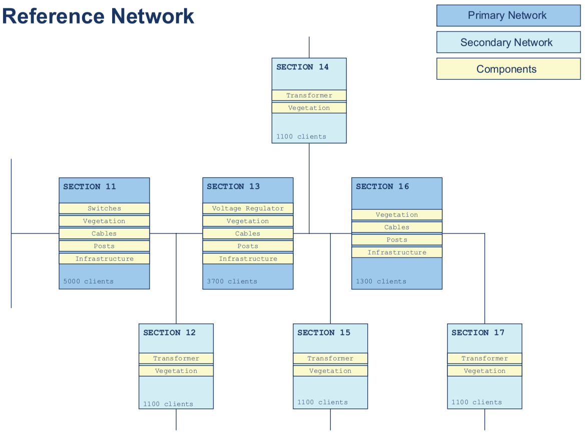
$$SAIFI^t = \frac{\sum_{s} \lambda_s^t N_s}{N_{TOTAL}}$$

- Where,
  - λ_s - average failure rate for section s,
  - N_s - number of customers in section s,
  - N_{TOTAL} - total number of custumers in the network.

Reference Network

- A small network adapted from the literature (Sitthumwat et al., 2004), to allow sencitivity analysis with respect to initial conditions of components and different maintenance actions.
- 7 sections (3 primary, 4 secundary) and 22 network components .
- Planning horizon of 5 years.

Reference Network

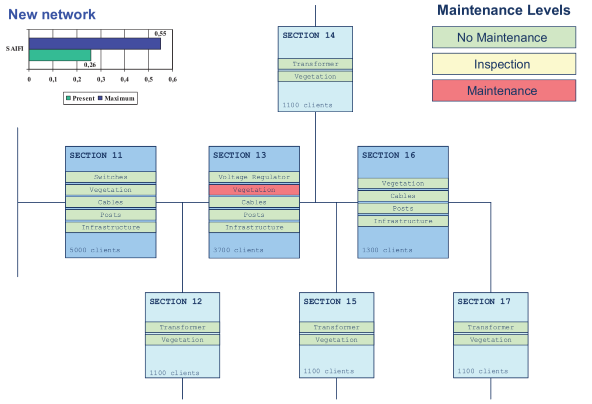


Multi-criteria Optimization

- Definition:
  - process of simultaneously optimizing two or more conflicting objectives subject to certain constraints.
- Characteristics:
  - The goal of multi-criteria optimization problem is searching for solutions in which each objective has been optimized to the extent that if we try to optimize it any further, then the other objective(s) will suffer as a result.

Year 1

New network



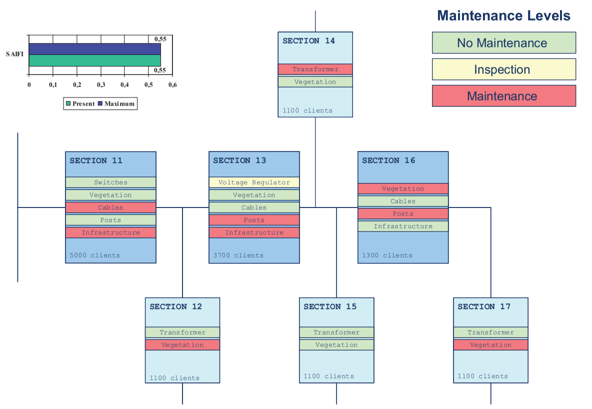
Preventive Maintenance cost = R$1.025,00

Corrective Maintenance Cost= R$3.475,00

Multiple Criteria Formulation

- Considers two objective functions:
  - Network reliability (maximize) and
  - Maintenance costs (minimize).
- Conflicting objectives: we must search non-dominated solutions (***efficient solutions***) and associated pareto frontier (***trade-off curves***).

Year 5



Preventive Maintenance Cost = R$5.680,00

Corrective Maintenance Cost = R$6.204,00

Multiple Criteria Formulation

Solve...

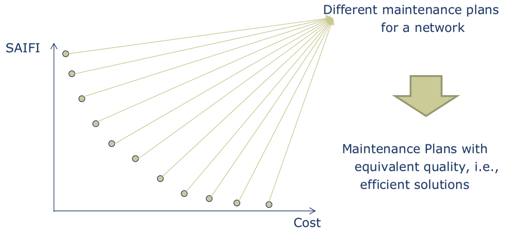
$$MIN \quad \sum_{t=1}^{HP} \left\{ \left(\frac{1}{1+i} \right)^{t-1} \left[\sum_e \left(\sum_n p_{en} x_{en}^t + \lambda_e^t c_e \right) \right] \right\}$$

$$MIN \quad SAIFI^{\max}$$

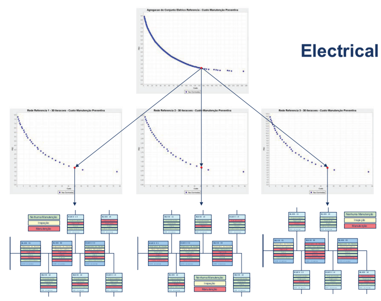
$$s.t. \quad SAIFI^t \le SAIFI^{\max}$$

Multiple Criteria Formulation

- Solution:



Hierarchical Multiple Criteria



Multiple Criteria Formulation

Solver:

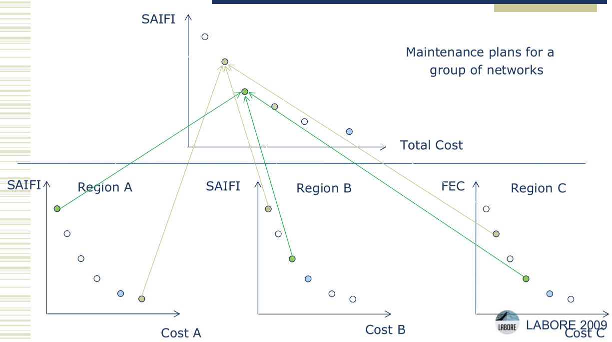
- **ε – Constraint Method** powered by a
- **Hybrid Genetic Algorithm** (Paulo Reis, 2007)
  - Electronic copy available (in portuguese): http://libdigi.unicamp.br/document/?code=000440731

Hierarchical Multiple Criteria

Two main properties:

- ***Efficient solutions*** at the upper level are composed of ***efficient solutions*** at the lower levels*;*
- Not all combinations of ***efficient solutions*** at the lower levels are ***efficient solutions*** at the upper levels.

Hierarchical Multiple Criteria



Hierarchical Multiple Criteria

Input:

- ***n pareto frontiers*** (one for each network)*;*
- each pareto frontier populated with ***p non-dominated solutions***.

Hierarchical Multiple Criteria

Compositions:

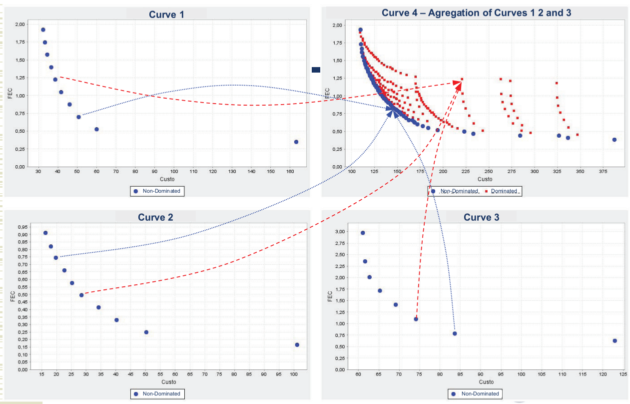
- calculate all possible solutions and filter ***p non-dominated*** compositions - p^n calculations; ex., p=20 and n=50, $p^n = 20^{50}$;
- Compound the pareto frontier two-by-two preserving at each stage ***p non-dominated*** solutions – $(n-1)p^2$ calculations.

Hierarchical Multiple Criteria

Execution times in a Pentium Quad-Core 3.0 GHz, 4 Gb RAM.

- Network A – 3m40s;
- Network B – 15m16s;
- Network C – 29m33s;
- Composition of ***pareto frontier*** – 2s.

Composition of pareto frontiers



Discussion

- Prototype well received by engineers and upper level decision makers (~ 13k lines of code in Java);
- Can provide information for negotiation of reliability indices with the regulatory agency (Aneel).

Hierarchical Multiple Criteria

Instance

- Set of three real power distributions networks in Brazil (48247 customers, 6314 equipments):
  - Network A (4513 customers, 765 equipments);
  - Network B (18268 customers, 2061 equipments);
  - Network C (25466 customers, 3488 equipments).

Discussion

- Is the methodology ready? No.
- What does it need?
  - Polish the model with input from field tests;
  - Implement procedures (better, a culture) dedicated to network maintenance data acquisition for engineering purposes (not only for accounting);
  - Develop specific data banks to keep track of equipment states and maintenance actions;
  - Develop specific interactive user interfaces.

Acknowledgement