Optimizing Electricity Distribution System Maintenance and Distribution Upgrades

2021 CIGRE USNC GOTF Symposium

BURNS McDONNELL

October 18, 2021

UNIVERSAL ELECTRIFICATION

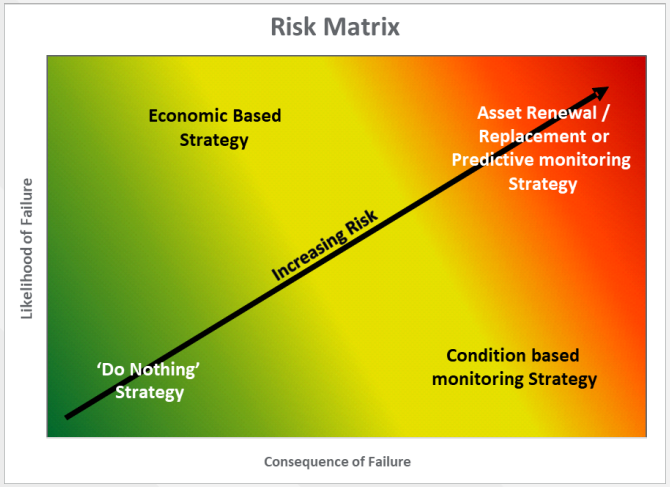
- Prior to World War II, the U.S. set out to achieve universal electrification
  - Tennessee Valley Authority Act of 1933
  - Rural Electrification Act of 1936
- Following World War II, remarkable growth
  - Connected millions to power systems
  - Created net-new systems with little required maintenance

Image: FDR Presidential Library & Museum / Wikimedia Commons

CURRENT TRENDS

Aging Infrastructure is Driving Strategic Asset Replacement

- Do-Nothing (run-to-failure) worked when poles and lines were mostly new
- Now a wall of aging infrastructure is approaching
- Investing in Asset Renewal / Replacement can avoid failures and their associated costs
- Earlier replacement offers more avoidance



KEY FACTORS AND OPTIONS

- Multiple obligations to
  - Customers
  - Members
  - Shareholders
  - Others
- Providing good stewardship
  - Resources
  - Environment

- Net-new, built-from-scratch
  - Greatest potential reliability
  - Prohibitively expensive & wasteful
- Affordable strategies can minimize risk while
  - Providing reliable power
  - Complying with budget limits
  - Reducing environmental impacts

A SCHEDULING USE CASE

So, our client has:

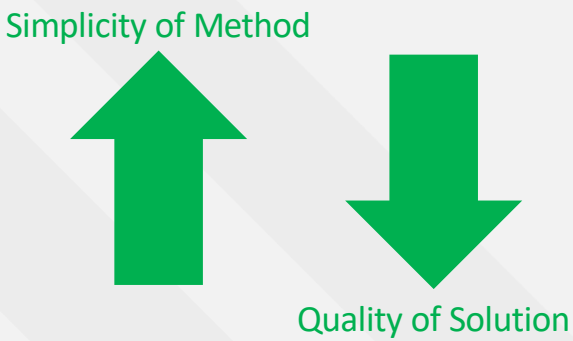
- 85,000 distribution projects to consider
  - 2/3 overhead
  - 1/3 underground
- Total, ten-year budget of $700M
  - 85% overhead
  - 15% underground

Our overall approach:

- *Situation*: Reduce overall system risk with strategic replacement
- *Task*: Identify the affordable replacement schedule that reduces the most risk
- *Action*: Design and develop a method that considers trillions of schedules to find the one that reduces the most risk
- *Result*: Provide a schedule that provides the most bang for the client's buck

Potential methods:

1. Simple Prioritization – Replace the assets most-likely to fail first
2. Smart Prioritization Heuristic – Each year, replace the assets with best risk reduction per dollar first
3. Optimization – Create a ten-year schedule that reduces maximum risk



MATHEMATICAL FORMULATION

Variables: $x_{p,y} = 1$ if we do project p in year y, and 0 otherwise

1. Maximize total risk reduction

Subject to:

2. Annual overhead budgets
3. Annual underground budgets
4. Minimum risk-reduction to cost ratio (rcr)
5. No repeated projects

$$\max_{x \in X} z^* = \sum_{p \in P, y \in Y} r_{p,y} x_{p,y} \quad (1)$$

$$s.t. \sum_{p \in \overline{P}, y \in Y} c_p x_{p,y} \leq \overline{b}_y \quad (2)$$

$$\sum_{p \in \underline{P}, y \in Y} c_p x_{p,y} \leq \underline{b}_y \quad (3)$$

$$\frac{r_{p,y}}{c_p} x_{p,y} \geq \underline{rcr} \quad (4)$$

$$\sum_{y \in Y} x_{p,y} \leq 1 \; \forall \, p \in P \quad (5)$$

Total Problem Size

- 2.28 million variables
- 1.08 million constraints

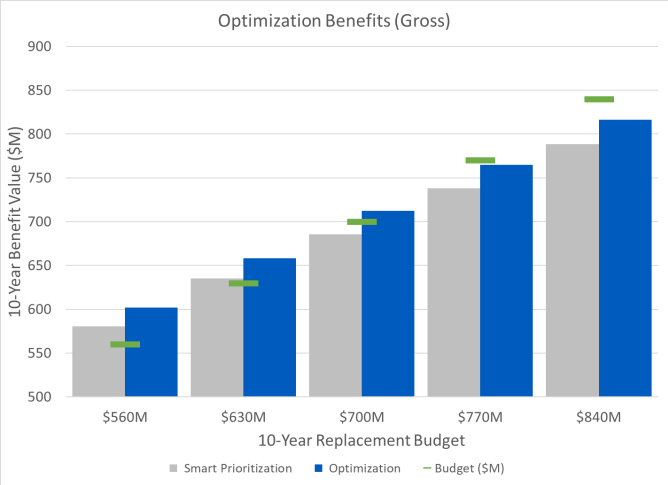
INITIAL INSIGHTS

We begin by considering

- Client's base budget of $700M
- Set a minimum risk-reduction to cost ratio of 0
  - Our client would spend entire budget, even if some projects yielded only negligible risk reduction
- Budget excursions +/- 10% and +/- 20%
- Compare to a previous heuristic method's results

Ten-Year Budget ($M)	Ten-Year Risk Reduction $(M)		Optimization % Improvement
	Optimization	Heuristic	
560	601.66	580.60	3.63%
630	657.91	634.87	3.63%
700	712.32	685.31	3.94%
770	765.08	737.89	3.68%
840	816.25	788.18	3.56%

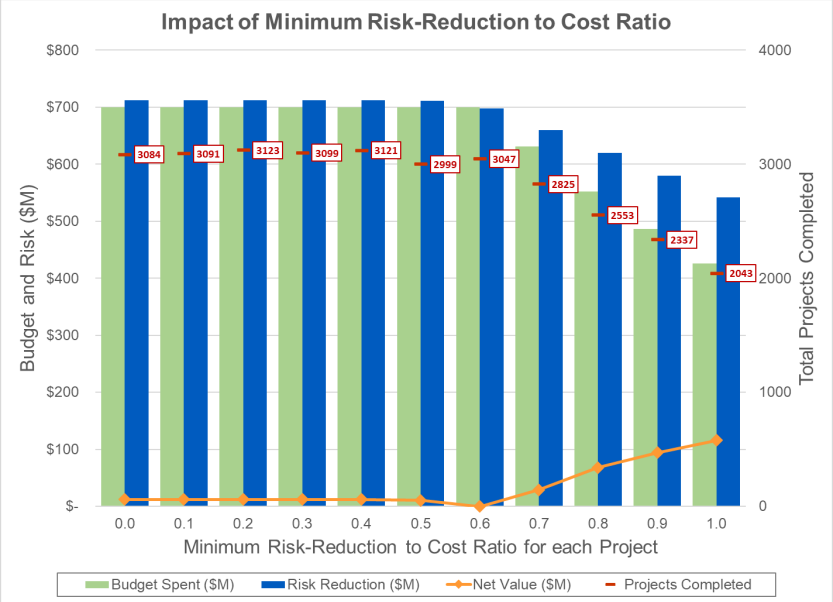
3-4% Improvement Over Heuristic → $2M Per Year in Added Value



SENSITIVITY ANALYSIS

We consider how much the minimum risk-reduction to cost ratio (RCR) drives results

- What happens when each project must reduce risk equal to some portion of its cost
- For example, with a minimum RCR of 1, the project's risk reduction would need to equal its cost
- With minimum RCR of 0.0 to 0.6
  - We expend the entire budget
  - And, we schedule approximately 3000 projects
- With minimum RCR above 0.7
  - Fewer projects exceed the minimum RCR
  - So, we schedule fewer projects and reduce less risk
- With minimum RCR of 1.0
  - We retain $273M of the budget
  - And, this retention yields **net** benefit of $115M



NEXT STEPS

- We continue supporting clients with optimization insights to support capital planning and scheduling
- Current and planned extensions to the scheduling model include:
  - Enforcing budget caps within a utility's individual regions and districts
  - Scheduling groups of related projects within specified windows of time
  - Fixing individual projects in particular years
  - Scheduling multi-year project
  - Enforcing prerequisite projects

ACKNOWLEDGEMENTS

- This presentation represents the work of an entire team of utility experts and data scientists.
- Special thanks to
  - Carol Bogacz
  - Jeff Casey
  - Arlin Mire
  - Jason De Stigter

QUESTIONS


BURNS McDONNELL