Mixed-Assets Optimization Using DOT™ (Decision Optimization Technology)

The information contained in these documents is confidential, privileged and only for the information of the intended recipient and may not be used, published, or redistributed without the prior written consent.

DOT

What is Mathematical Optimization?

Mathematical Optimization is a branch of science in Operations Research (OR). OR provides a scientific approach to decision making that seeks to optimize the performance of a system, usually under conditions requiring the allocation of scarce resources. OR originated during World War II when the British government recruited scientists from different disciplines to solve the operational problems of the war, such as the deployment of radar and the management of convoy, bombing, anti-submarine, and mining operations, which coined the term Operations Research. In the context of optimization, a system can be a collection of interdependent entities that work together to accomplish the goal of the system. For example, a corporation can be thought of as a system whose goal is to maximize its profit, while subjected to resource constraints and regulations governing its business activities. The focus of optimization is, therefore, to understand the complex operations of any system so as to predict its behavior over time and to identify the best course of action that leads to an ideal level of performance, or in other words, an 'optimal' solution. This scientific approach to decision making usually involves the use of mathematical models to represent the system's behavior in terms of objective functions, decision variables, and constraints.

In the context of asset management and investment planning, the term optimization has been used rather loosely for methods such as cost-benefit analysis or priority ranking. These methods, however, cannot be categorized as formal mathematical optimization and are far less effective as compared to true optimization methods. Optimization, or prescriptive modeling "prescribes" a detailed course of action for an organization to best meet its goals. The ideal course of actions, or the "optimal" solution, is determined as a result of rigorous mathematical assessment of the optimization model, rather than using intuitive processes or on an ad hoc basis. Optimization models seek to find the value of decision variables that either maximize or minimize (i.e., optimize) an objective function under certain constraints that must be satisfied. Accordingly, optimization models have three main components:

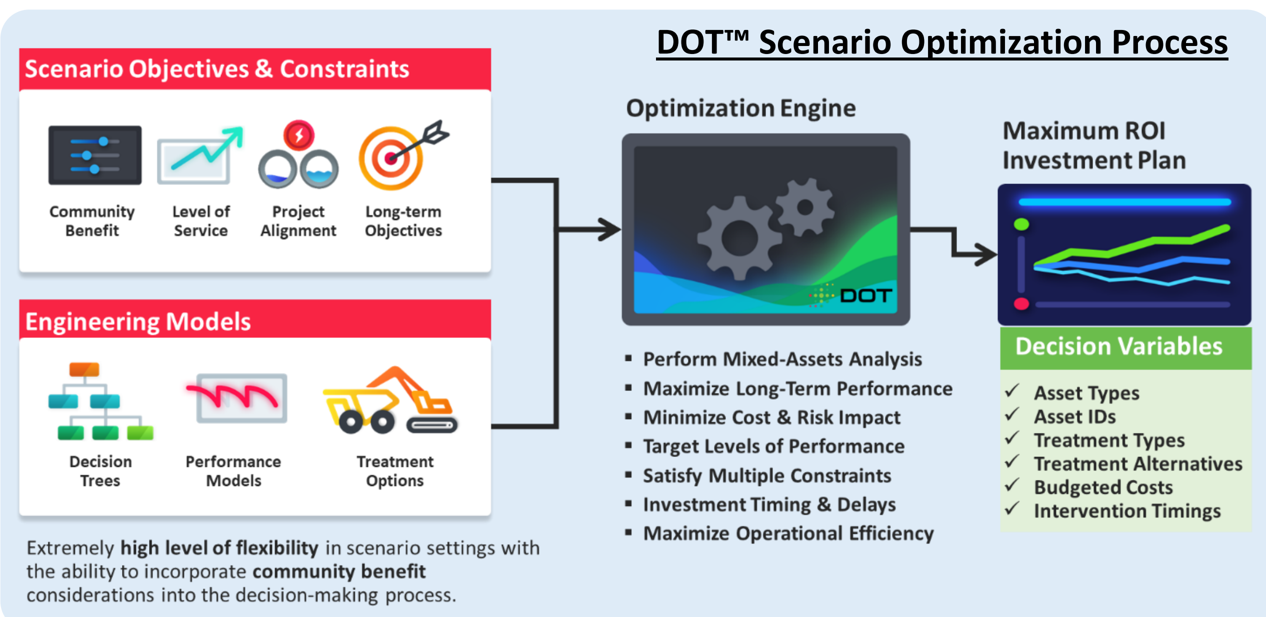
- **Objective Function:** In the case of asset management and investment planning, the objective function is typically defined as maximizing the overall network performance or condition projection over the planning horizon. Other examples of objective functions are minimizing cost, minimizing network risk level, or maximizing return on investment. It is important to note that the objective functions can be combined to represent a multi-objective optimization process.

- **Decision Variables:** Represent variables that affect the performance of the system. In the case of asset management and investment planning, decision variables are typically defined at network-level as the timing of interventions and selection of individual assets for maintenance, rehabilitation, or full reconstruction. At the project-level, decision variables are concerned with selecting a detailed treatment option among various possible alternatives, such as a two-lift overlay for a road segment, replacement of a watermain, or joint sealing on a bridge deck. The optimized values of these decision variables answer the key questions about which asset to be repaired, with what treatment, and at what time.

- **Constraints:** In real life, only certain values for a decision variable represent a practical solution. Public and private asset owners operate within a multitude of restrictions when planning future investments. These restrictions represent optimization constraints. In the case of asset management and investment planning, restrictions such as annual budget limits, minimum level of service requirements, risk tolerance, operational considerations, resource and manpower limitations, and political requirements are examples of optimization constraints.

Asset renewal and investment planning problems represent a special category of optimization problems called ‘Combinatorial Optimization’. In simple terms, combinatorial optimization seeks to find the best possible combination of a number of alternatives, amongst all the possible combinations (called the search space). These types of problems are difficult to solve, especially due to the nonlinear nature of the problem and the exponential growth in complexity (i.e., number of possible combinations) as the problem size (e.g., number of assets) grows. A real-life asset management optimization problem involves thousands of assets (e.g., road segments, watermains, bridges, facility elements, etc.) leading to substantial combinatorial complexity and prohibitively large processing time. In most large-scale problems, traditional optimization methods cannot convergence to an optimum solution.

Decision Optimization Technology (DOT)™ provides a true mathematical optimization algorithm that calculates a multi-year and multi-constraint investment plan for the entire asset portfolio across various departments, such as Transportation, Water, Bridges, Facilities, etc. As shown in the figure below, the scenario optimization process finds an optimal budget allocation plan by considering various objective functions defined by the user, while also considering a wide range of ancillary requirements such as budget constraints, treatments and costs, level of service objectives, risk tolerance, operational requirements, and alignment with other departments. It finds the best possible investment plan to maximize ROI in terms of a combination of actions, including the selection of asset types, asset ids, treatment types, detailed treatment alternatives, budgeted costs, and the timing of all recommended interventions. DOT™ uses one of the most advanced large-scale optimization systems, based on over 10 years of doctoral-level research and development to arrive at an optimal solution within a very efficient processing time. The outcome of the optimization considers the trade-offs between delaying and accelerating interventions or alternative ways of allocating budget across all available options. The resulting plan is hence defensible as it is mathematically guaranteed to be the best possible solution and results in a much more efficient investment strategy.

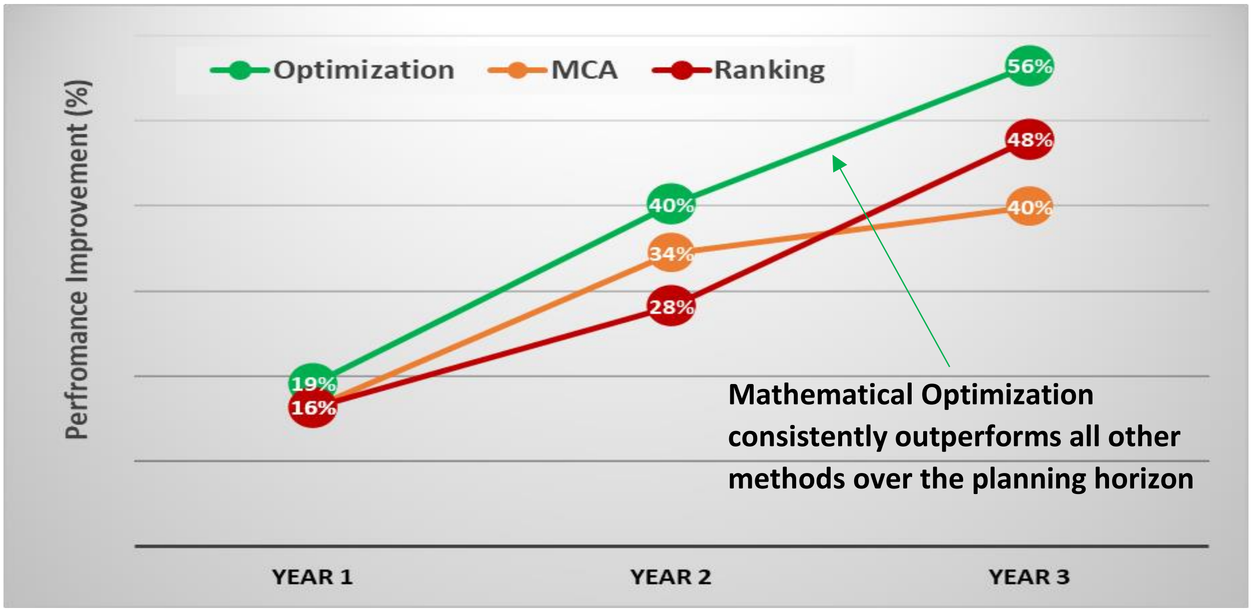


Benefits of True Mathematical Optimization

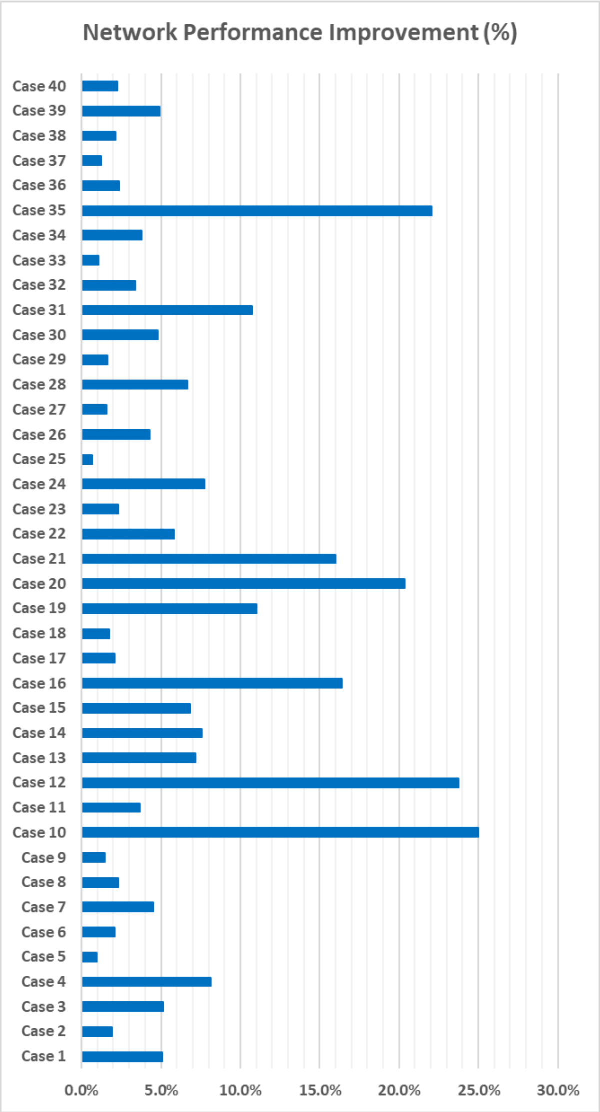
Due to the complexities and difficulties in optimizing large-size problems, the vast majority of capital planning solutions do not use true optimization and use prioritization methods instead. Traditional decision-making methods range from simple condition-based ranking, to multi-criteria prioritization, to cost-benefit analysis. None of these methods, however, represent an actual multi-constraint multi-year optimization and do not result in finding the best possible solution. Some of the more advanced software solutions use incremental cost-benefit analysis, which is a variation of the cost-benefit analysis and claim to have an optimization solution. This, however, is still far from a true optimization in terms of solution quality.

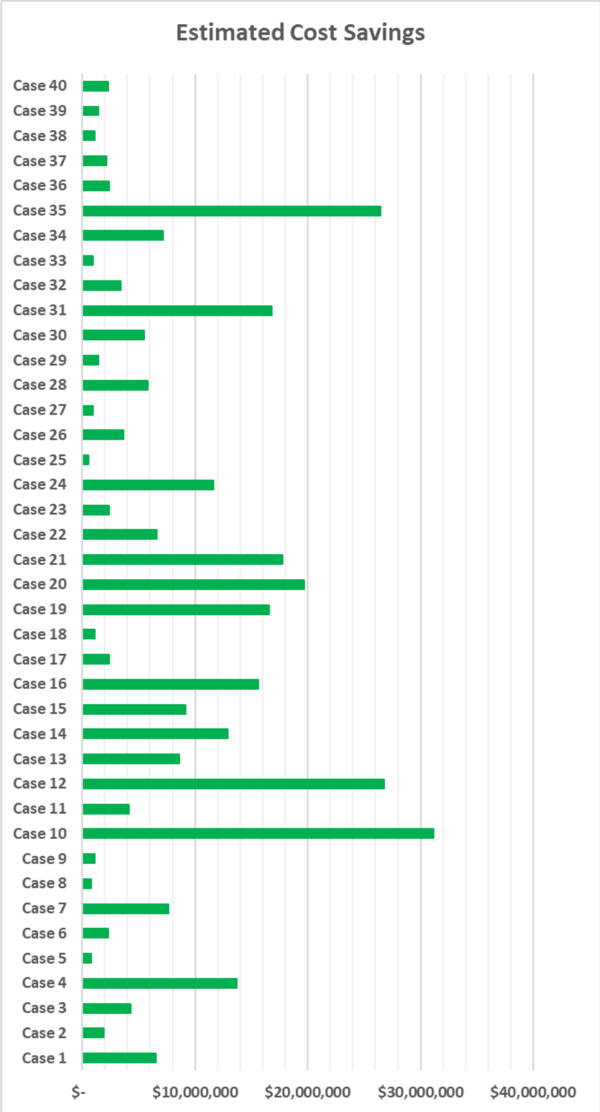
Summary of Various Decision-Making Methods

Simple Ranking	Prioritization & CBA	True Optimization
Sections are ranked and investments are determined based on current asset condition (worst-first). Budget is used until it is fully exhausted. This results in the lowest level of investment efficiency.	Sections are Prioritized using multiple criteria, such as condition or risk, or based on a cost-benefit analysis. The analysis is performed on a year-by-year basis to identify projects.	A true multi-constraint multi-year analysis that results in a scientifically proven and mathematically guaranteed best possible solution.
✗ Multi-Criteria Analysis	✓ Multi-Criteria Analysis	✓ Multi-Criteria Analysis
✗ Guaranteed Best Performance	✗ Guaranteed Best Performance	✓ Guaranteed Best Performance
✗ Target Level of Performance	✗ Target Level of Performance	✓ Target Level of Performance
✗ Considering Multiple Constraint	✗ Considering Multiple Constraint	✓ Considering Multiple Constraint
✗ Investment Timing & Delay	✗ Investment Timing & Delay	✓ Investment Timing & Delay



Truly optimized decision support systems result in a **scientifically proven and mathematically guaranteed best possible solution** that results in significant cost savings and added performance as compared to conventional capital planning methods. Following results show a summary of 40 optimization comparison cases for various real-life municipal datasets with different network sizes, populations, and a wide range of annual budget limits. Similar to previous tests, under all cases optimization outperformed other solutions and **Performance improvement of up to 25%** was observed as shown in the results. To determine cost savings, the additional investment required to improve network performance to the optimized level was calculated for each comparison case. As shown in the results the expected cost savings over the 10-year planning horizon is significant in most cases. Even under small improvements, cost savings can be translated into millions of dollars.





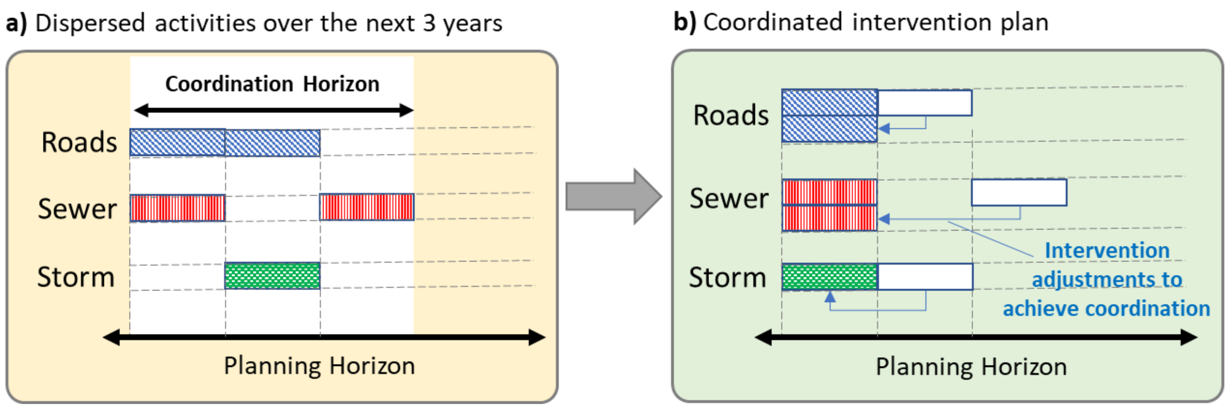
Performance improvements and associated cost savings using DOT™'s True Optimization

Mixed-Assets Optimization

The ability to analyze multiple asset types and competing projects is a requirement for a more holistic analysis of an agency's infrastructure portfolio and investment planning. Shared sources of funding, departmental requirements, and cross-departmental alignments are some of the reasons an agency might need to analyze multiple asset types at the same time. Coordinating the rehabilitation of co-located assets is also of importance to improve the operational efficiencies by minimizing construction disruptions, bundling projects for more cost-effective tendering, and considering infrastructure dependencies in the decision-making process.

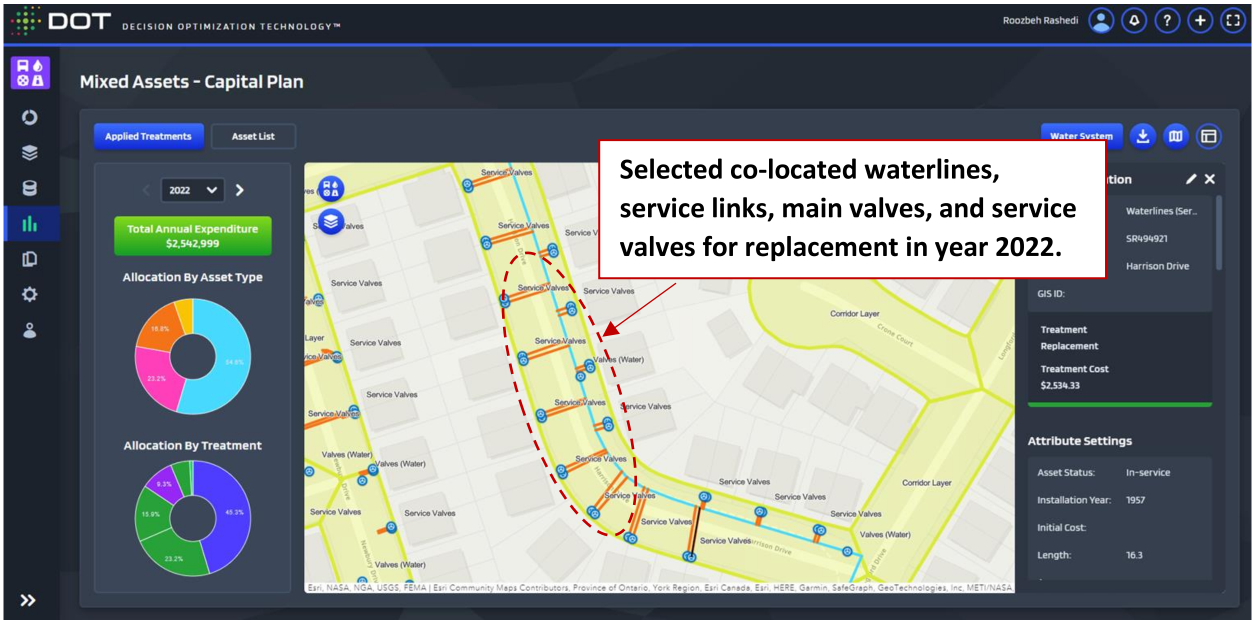
DOT™ provides the ability to analyze multiple asset types at the same time using our 'Mixed-Assets Optimization' engine. The mixed-assets scenarios enable users to analyze multiple assets from the same system/category (e.g., Water System) or across multiple categories (e.g., Storm, Sewer, and Roads), while providing mixed-assets criteria such as system-wide budget limits. The mixed-assets features also enable users to visualize different aspects of mixed-assets results and export them into various report types. Unique to DOT™ software, the 'Mixed-Assets Optimization' enables users to consider the timing of interventions for a group of assets based on various information and asset characteristics to find the optimal coordinated timing for the interventions. This enables users to perform a variety of analyses such as 'Corridor Rehabilitation' or synchronizing the renewal of multiple elements of a parent asset to improve efficiency.

When enabling the Intervention Coordination analysis, DOT™ considers the possibility of fully, or partially, coordinating interventions for all assets belonging to the same Group (e.g., same utility corridor). While doing so, DOT™ considers all the objectives and constraints involved in a mixed-assets scenario and finds an optimal timing of coordinated interventions for all asset types involved in the analysis that satisfies all the decision criteria, simultaneously. While performing the intervention coordination analysis, the system searches over a predefined 'Coordination Horizon' to find possibilities for coordination. The optimal timing of coordinated interventions, therefore, minimizes the deviations from an uncoordinated solution, while delaying or accelerating certain interventions to achieve full or partial coordination.



DOT™ Intervention Coordination Analysis under Mixed-Assets Optimization

Example of coordinated corridor renewal for water system including waterlines, service links, main valves, and service valves.



Example of cross-departmental corridor rehabilitation planning for Roads, Storm, and Sewer assets.