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Digital Risk Twin Driven Simheuristic for Maintenance Optimization

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09E Reliability Modelling III
Model-Based integrated prediction

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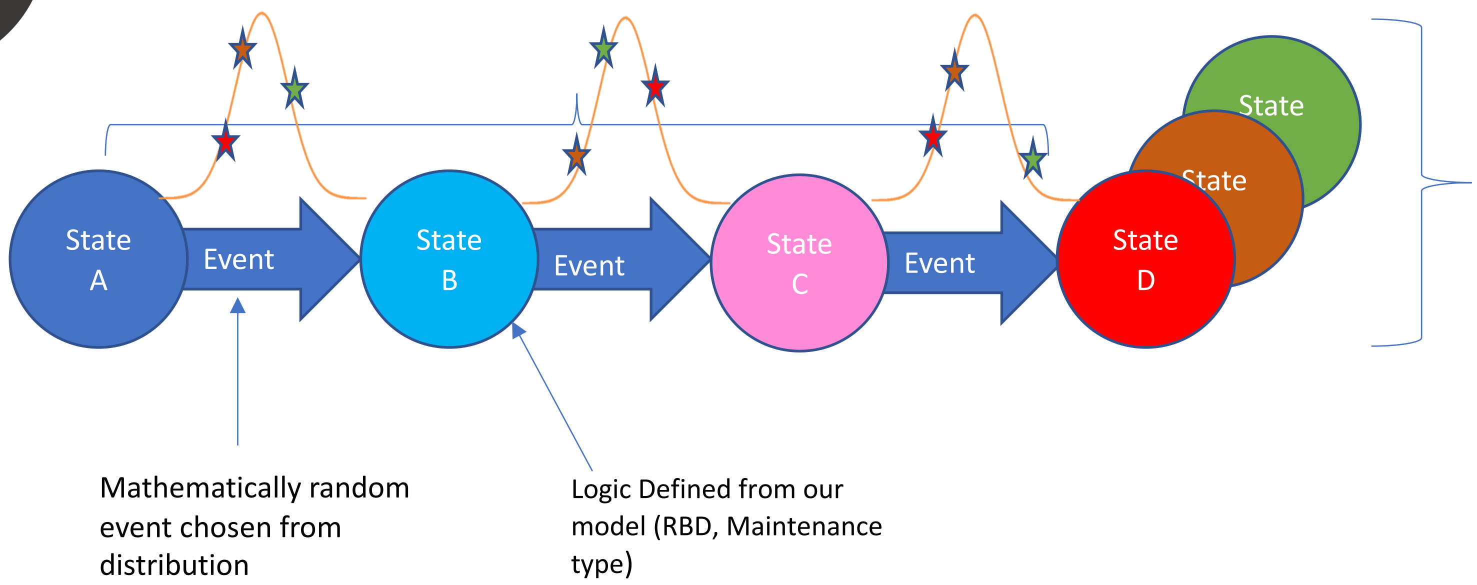
Overview and Outline

Why DES?

- A discrete-event simulation (DES) models the operation of a system as a (discrete) sequence of events in time
- DES is a digital test rig
- The quality of the output is based on the quality of the input and assumptions made.



Range of expected parameter(s) of interest over simulation period

(e.g., Cost, Availability)

Why Optimization + DES

DES

- User defined parameters
- Outcomes are dependent on these parameters
- Trade studies still require manual input (e.g. MA)

DES + Optimisation

Closes the loop between user-defined parameters and simulated outcomes

Finds a set of parameters (decision variables) that lead to a user defined optimal outcome

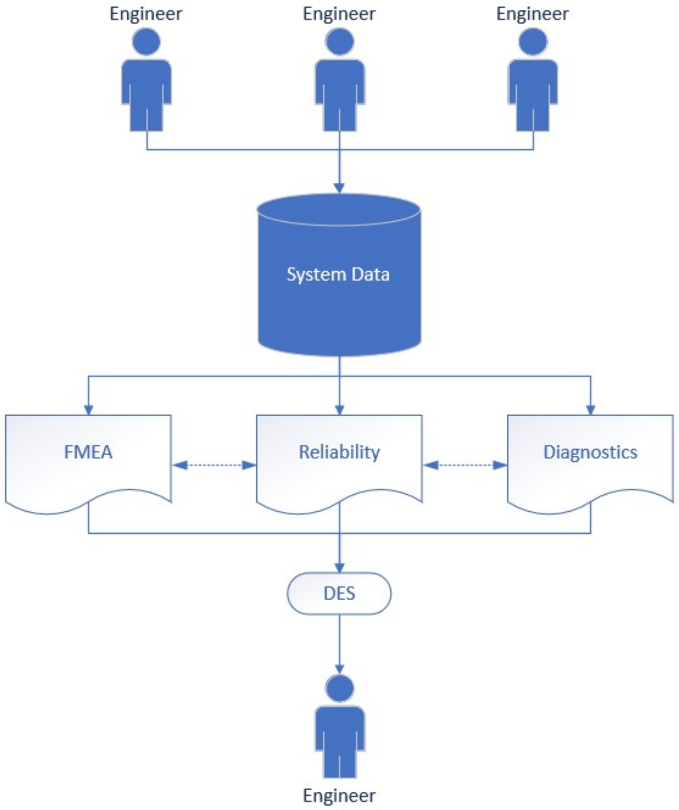
Enhances decision support capability of DES

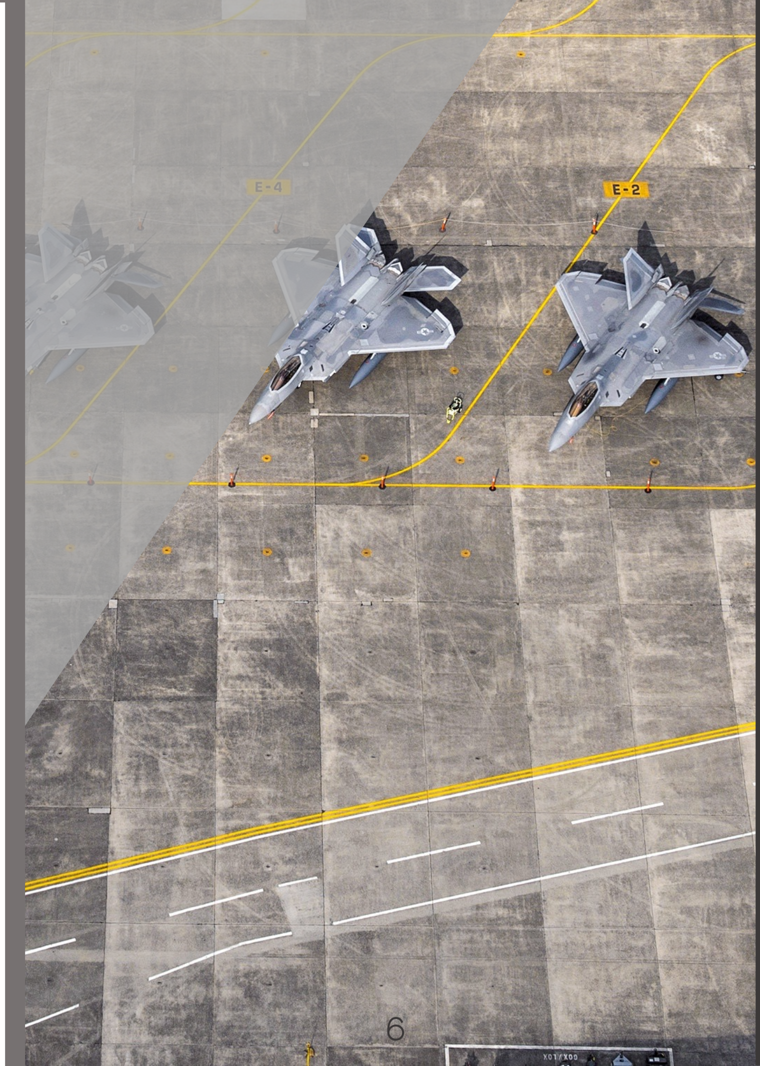
Problem: The key issue when applying metaheuristic approaches to Stochastic Combinatorial Optimization Problems (SCOP) is the computation of the objective function - how do we abstract the expected utility?

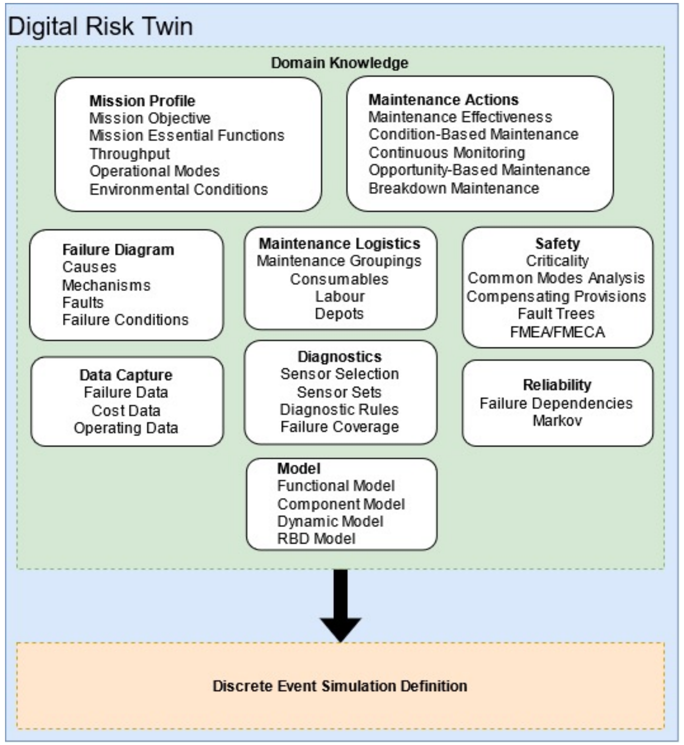
Solution: We estimate the objective function via simulation.

The Role Of Model-based Domain Knowledge

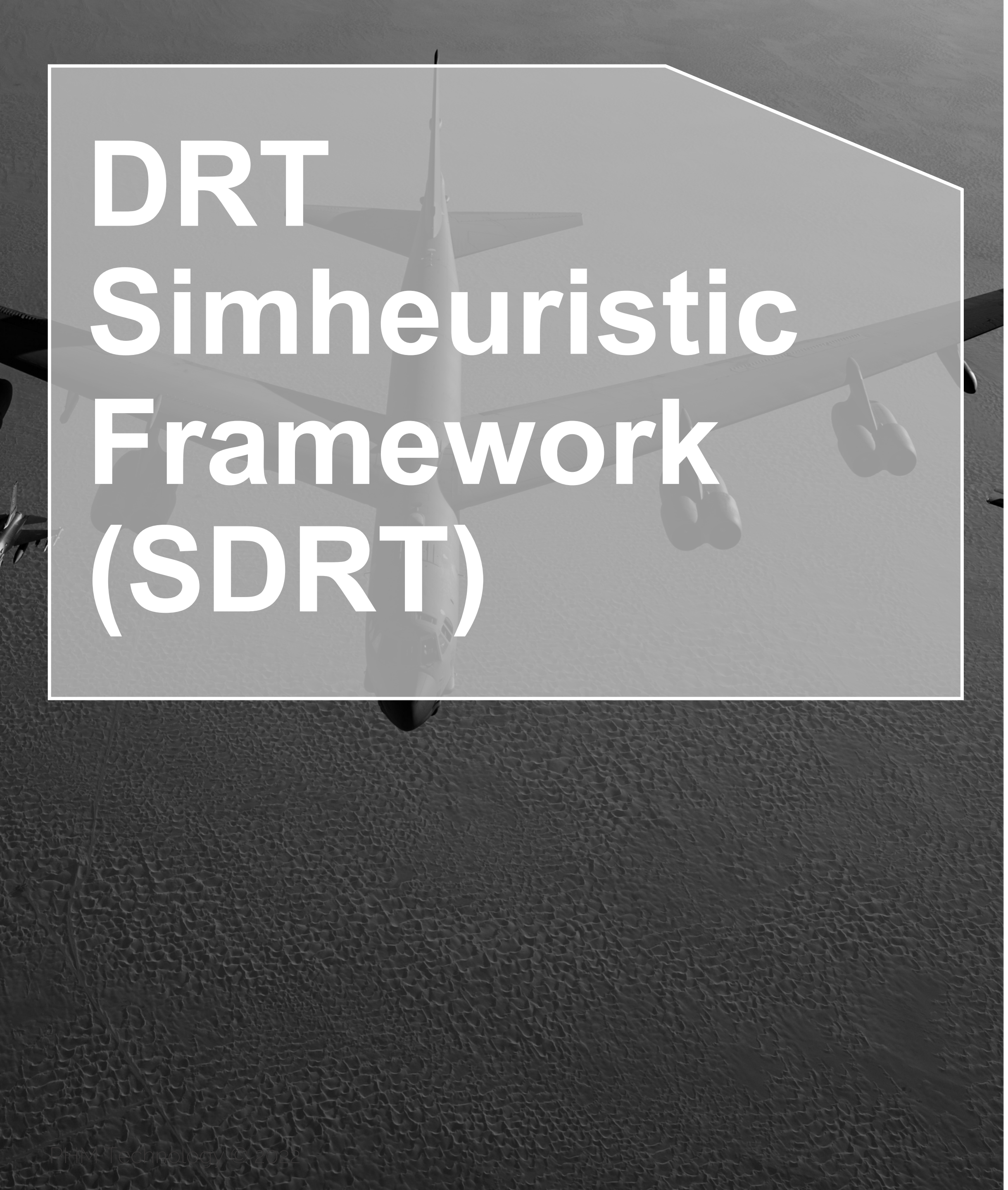
The model-based solution captures domain knowledge about the SUI



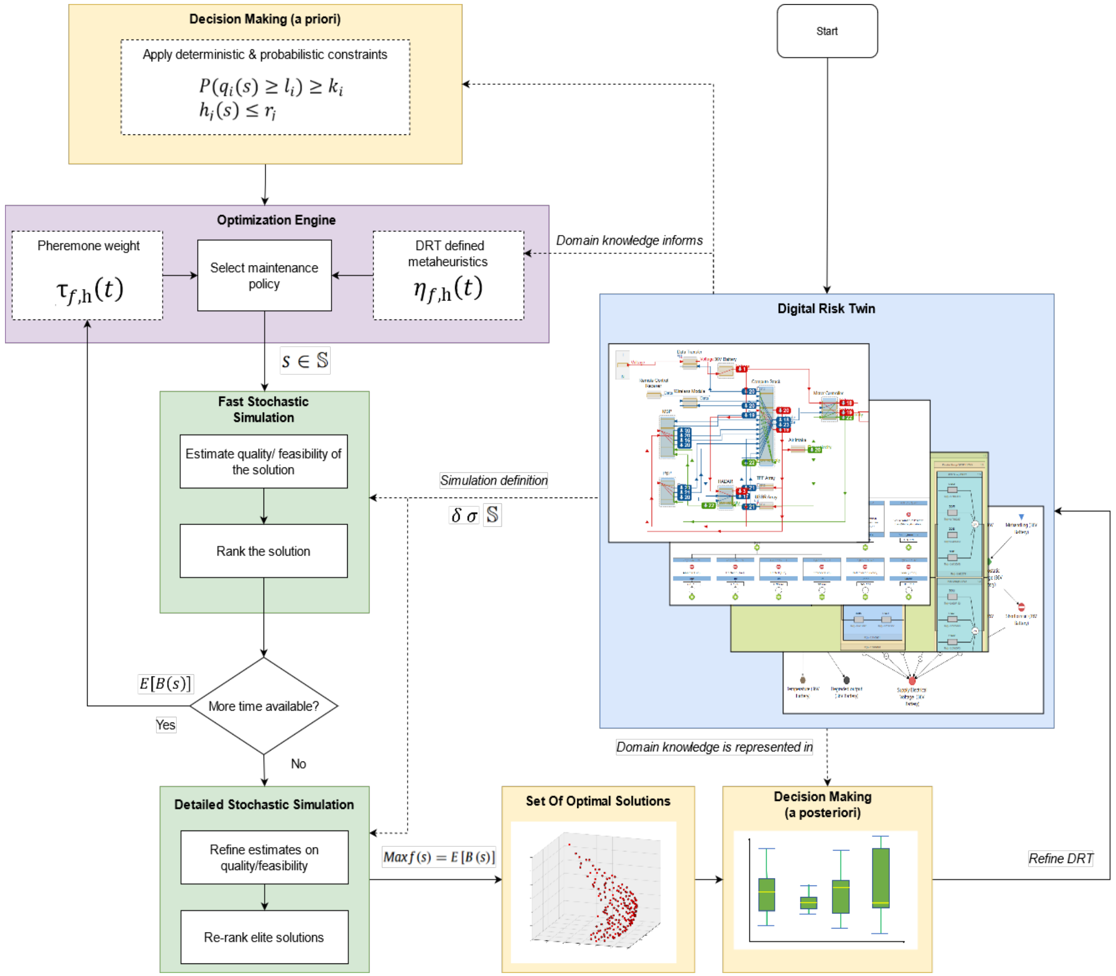




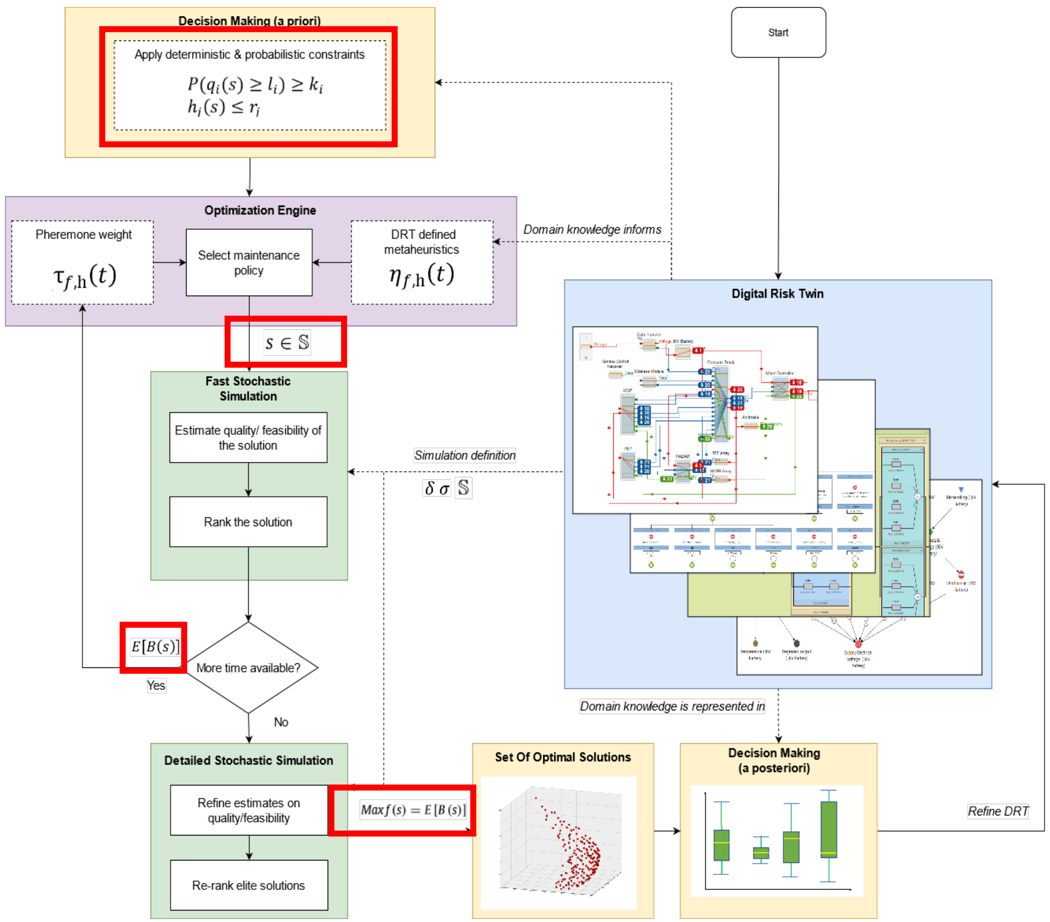
The model defines the structure, behaviour, and key input parameters of the DES



DRT Simheuristic Framework (SDRT)



DRT Simheuristic Framework (SDRT)



$$\mathrm{Max}(f(s)) = E[B(s)]$$

$$P(q_i(s) \geq l_i) \geq k_i$$

$$h_i(s) \leq r_i$$

$$s \in S$$

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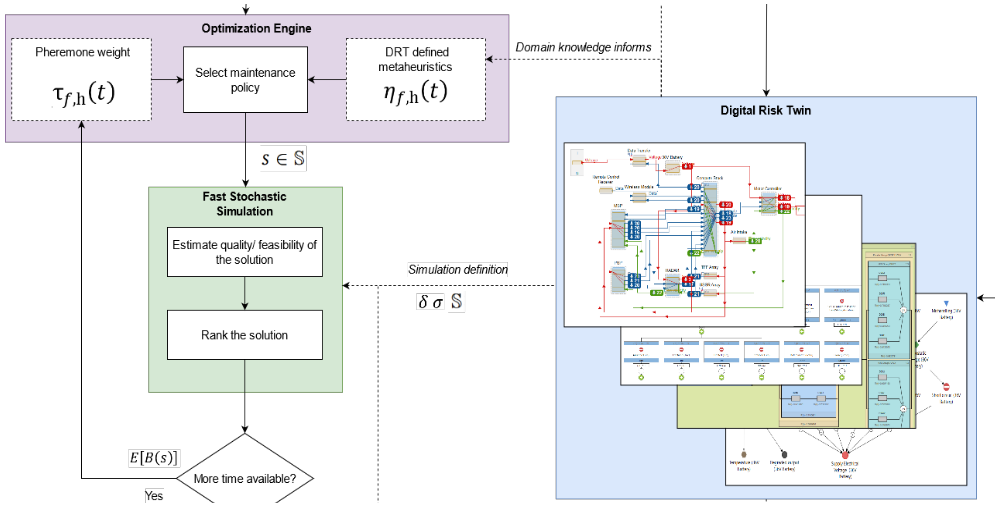
SDRT
Ant Colony Optimization Engine

Digital Risk Twin

- The ACO metaheuristic is then the family of algorithms inspired by the ant foraging pattern.
- Effective in solving combinatorial optimisation problems
- The **configuration** of the ACO directly influences the behaviour of the ant agents and subsequently the output of the SDRT

SDRT
Ant Colony Optimization Engine



- The DRT influences this behavior through encoded domain knowledge to support the search of analyst preferable solutions
- Represented in the heuristic value, $\eta\_(f,h)\ (t)$,

$$w_{f,h}(t) = \frac{[\tau_{f,h}(t)]^{\alpha} \cdot [\eta_{f,h}(t)]^{\beta}}{\sum_{k=1}^{N} [\tau_{f,k}(t)]^{\alpha} \cdot [\eta_{f,k}(t)]^{\beta}}$$

SDRT
Heuristic Design

Extracting Domain Knowledge

User inputs

Criticality, maintenance costs, labor requirements

Model Structure

RBD, failure modes, failure dependencies

Analysis

FMECA, diagnostic analysis, common-mode analysis, RCM

SDRT Heuristic Design

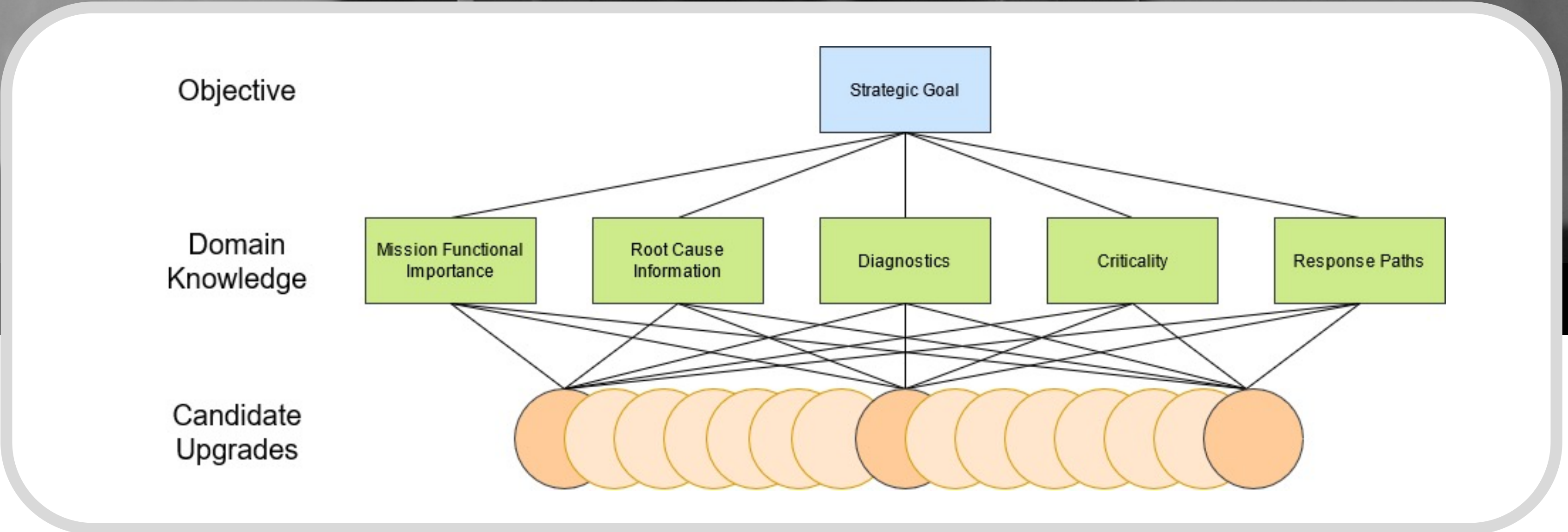
Effect Domain Knowledge

Informs optimization procedure to effectively explore the search space by defining the metaheuristic.

Reduces the search space size by ignoring infeasible options.

Maps causes to effect to inform where computational resources should be spent during simulation.

Optimal Policy Evaluation



- Decision maker requires a range of potential approaches that can be contrastively assessed.
- Each solutions can be explained in terms of the domain knowledge that informs the metaheuristic.

Summary & Conclusion

- Simheuristics are a promising approach to solving complex, stochastic problems

- Incorporating domain knowledge into the simulation and metaheuristic definition improves optimization performance and decision-making capabilities for the user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Thank you