

Simulation based Optimization

About SimWell

- Delivering Decision Intelligence
- World leader in Simulation
- Team of 80 and growing
- Global footprint
 - USA, Canada, Australia, Netherlands, India
- We have worked with clients who are industry leaders
- Multi-disciplinary team built to deliver Digital Twins at scale



RioTinto

BHP

SIMWELL
Your Simulation Technology Partner



 **ABInBev**

amazon



NewmontTM

Johnson & Johnson

Google


BlueScope

 **BOEING**

Simulation

- Scenario, Capacity, & Master Planning
- Risk Analysis
- Facility Design

Digital Twin

- Plant Digital Twin
- Supply chain digital twin
- Resilient and Sustainable Production

Production Planning and Scheduling

- Dynamic Scheduling
- Scenario testing
- Risk Analysis and mitigation
- System integration

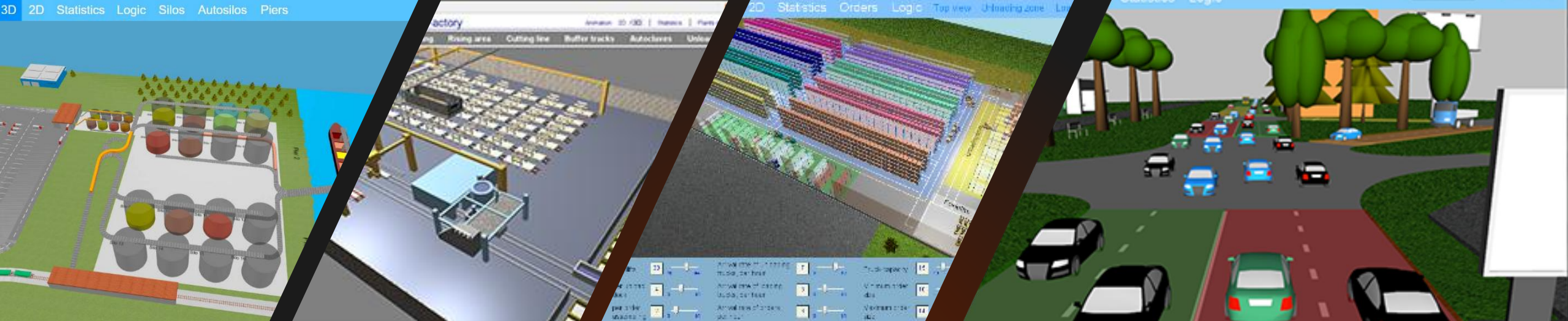
Optimization

- Strategic Network Design
- Transportation/Routing Optimization
- Inventory Optimization

Data Science

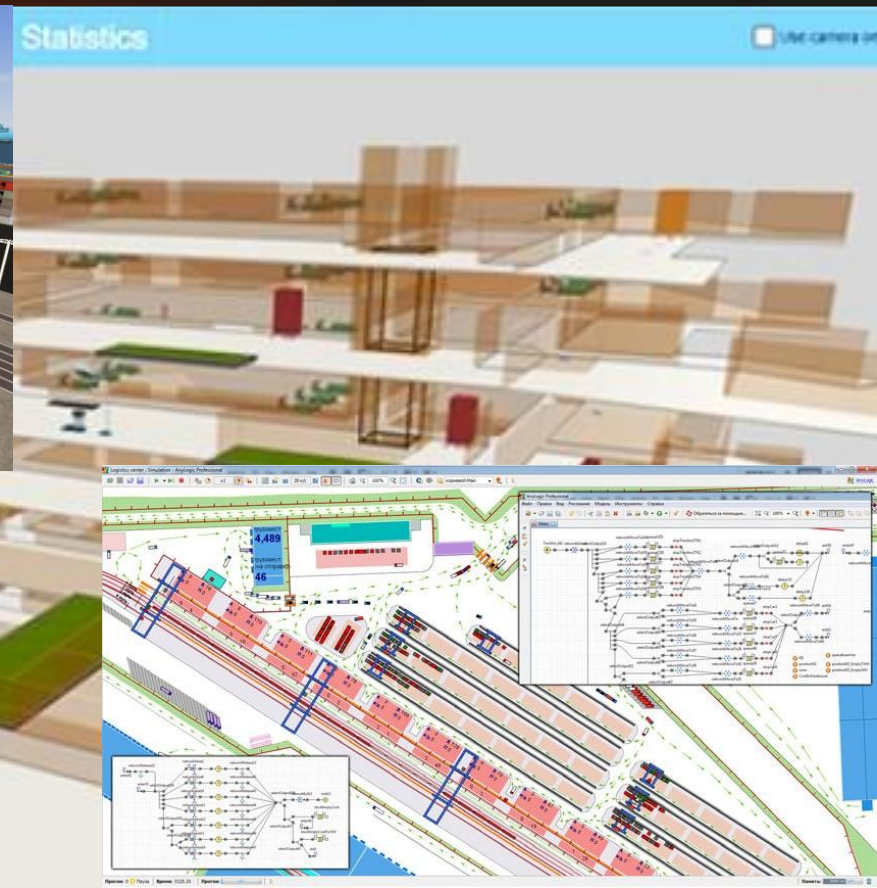
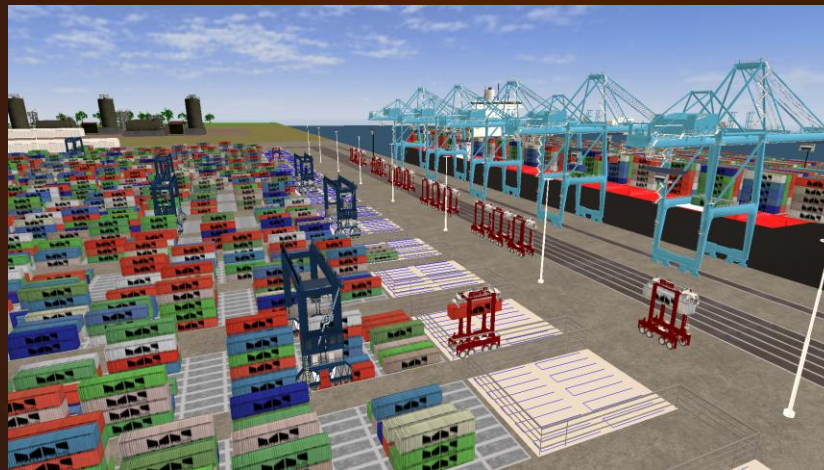
- Big Data & Transformation
- Data Pipeline and BI Dashboarding
- Machine learning and analytics

Your Decision
Intelligence Partner



Industries

- Manufacturing
- Food and Beverage
- Supply Chain
- Warehouse Operations
- Rail
- Mining
- Oil and Gas
- Public Transportation
- Healthcare
- People flow



Type of Analytics

Descriptive	Predictive	Prescriptive
• Exploratory Data Analysis such as Mean, median, mode, histograms, box plots • Run charts, control charts • Statistical tests such as t-test, anova, chi sq etc Simulation	• All machine learning and deep learning models are predictive model, examples: regression, logistic regression, classification trees, random forest and neural network based models • Time series forecasting • The “learning” in ML/DL is actually happening using optimization techniques + some randomness in the model Simulation (Digital Twin)	• Optimization models are prescriptive • Prescriptive methods always answer the questions “what is the best option/action?” • Such as supply chain network optimization, bin packing optimization etc. Analyse multiple simulation runs and then recommend

Where does Simulation as a tool fit?

Various Optimization Techniques

Analytical Optimization:

- Use high school calculus, BFGS etc.
- Work on unconstrained problems
- Not too useful for solving business problems

Linear Programming(LP):

- Decision variables are continuous
- Objective function is linear
- constraints are linear
- We Model the problem and give it to a solver

Mixed Integer LP (MILP):

- Decision variables are continuous and/or discrete
- Objective function is linear
- constraints are linear
- We Model the problem and give it to a solver

Others:

- Constraint Programming
- Dynamic programming

Classical Optimization

Heuristics:

- An algorithm that can solve a particular class of problems
- Example: Dijktras, bellman-ford, Johnsons, prims, kruskals
- Some are proved to be optimal
- Most get stuck in local optima – greedy algos like NNH

+ randomness

Meta-Heuristics:

- It's an outline for a heuristic
- Needs to be adapted for the problem type
- Does not guarantee optimality
- Uses much less time and space resource

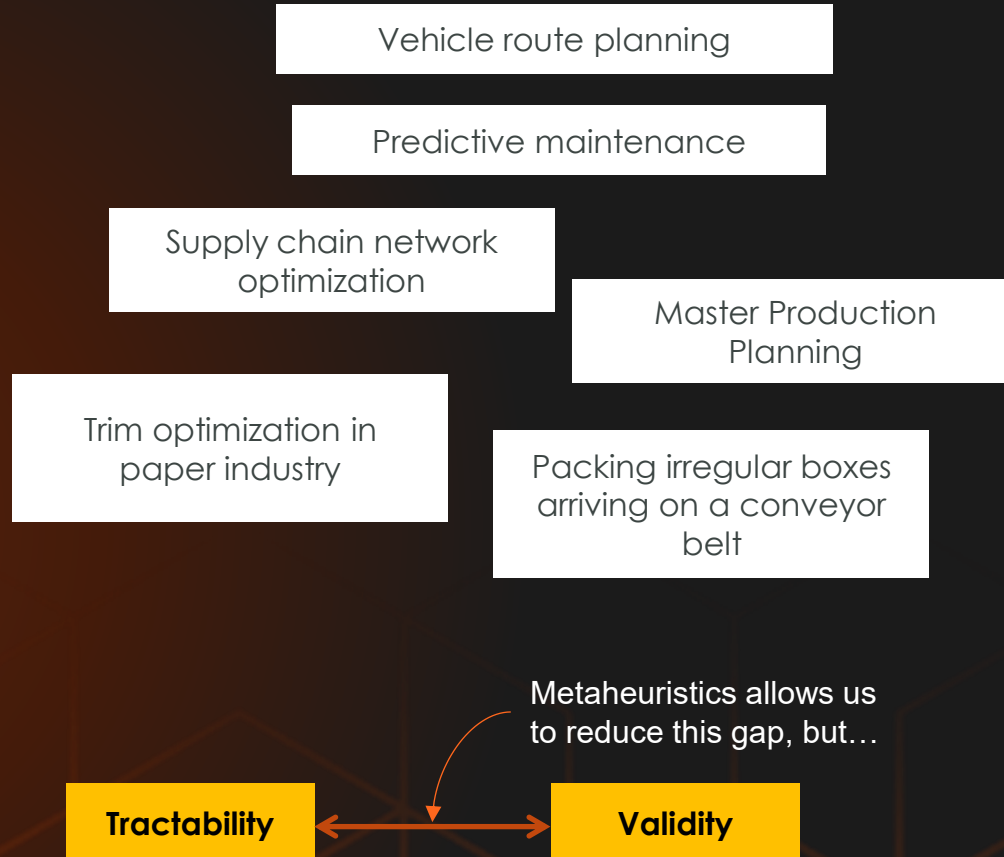
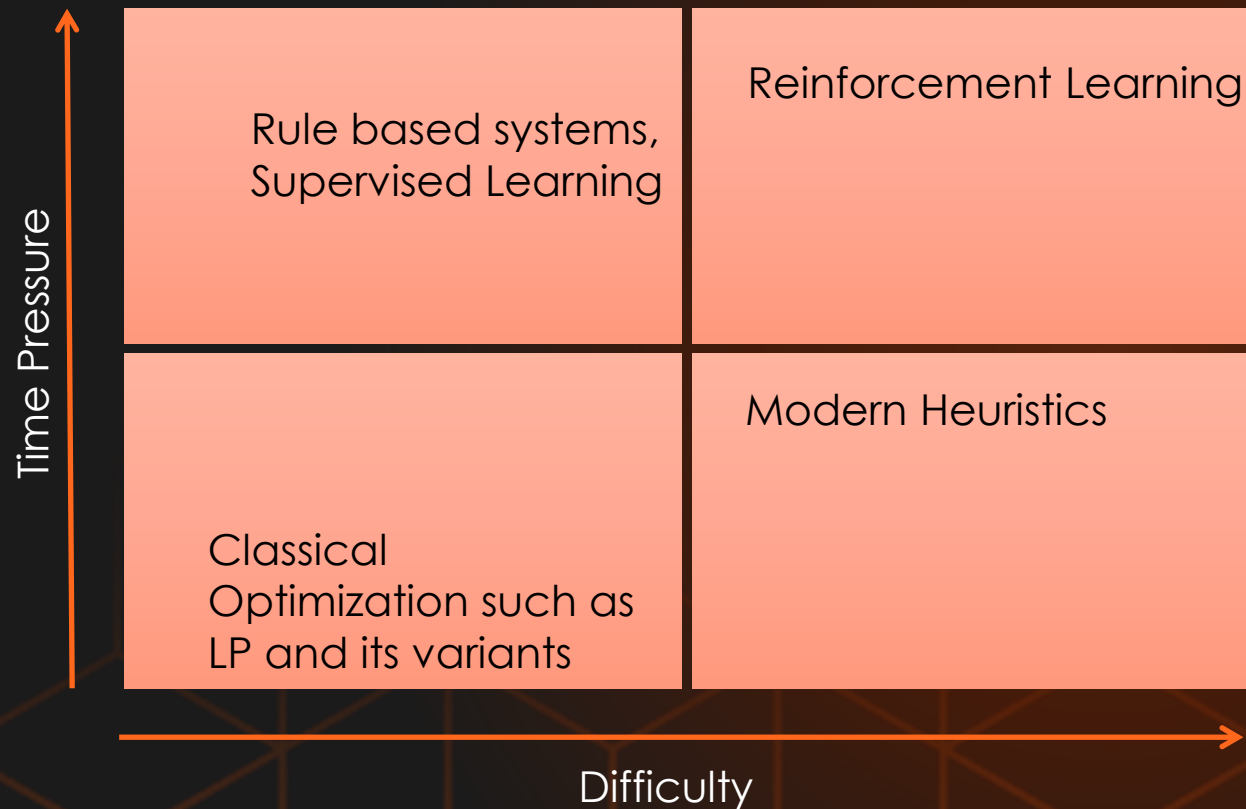
- Meta-Heuristics are also known as Modern heuristics
- Modern heuristic researchers argue that once a problem is NP hard, modern heuristics should be the method of choice
- They are not aware that for many NP hard problems there are classical optimization methods that are also fast
- On the other hand, researchers working on classical optimization methods are often sceptical of heuristics which do not guarantee finding optimal solutions
- They are not aware that meta-heuristics can generate good usable solutions in very short time (relatively)

Reinforcement Learning:

- Setup environment (Simulation)
- Define the states (observations) and rewards
- Allow agent to learn strategy or policy by interaction with environment

AI based

When to use which technique?



Simulation based Optimization



- The Simulation model is parameterized based on the parameters in control that we want to optimize
- The optimizer changes the values of these parameters (based on an input range and step size provided), We refer to each selection of a set of parameters as an **Iteration**
- Quality(performance and robustness) of the output KPI (objective value) is evaluated by the simulation model. For each Iteration, the model is run multiple times (multiple **replications**)
- The optimizer receives this feedback from the model and over several iterations can converge to the optimal(actually near optimal) settings for the parameters

Classical Optimization

Decision Variables (We call them Parameters):

dv1 : Integer

dv2 : Continuous and > 0

Constraints:

$$2 * dv1 + 5 * dv2 \leq 100$$

Objective Function:

Maximize a Profit Function $f(dv1, dv2)$

Demo Model and Problem

- We have a Job shop with 4 types of workstations : WC_A, WC_B, WC_C and WC_D
- It manufactures 4 Products: Prd_1, Prd_2, Prd_3 and Prd_4
- Each Product has a unique routing
 - Prd1 [WC_A -> WC_B -> WC_C -> WC_D]; Prd2 [WC_D -> WC_B -> WC_C] etc.
- Sources of stochasticity:
 - We know the order arrival rate but not the exact arrival time
 - We know the order mix (proportion of Prd_1 from past data) but not the exact sequence in which orders will come
 - Processing time at the workstations for each task
 - Order completion promised datetime
 - We could have added planned and unplanned downtimes
- Parameters or Decision Variables:
 - The number of machines in the various Workstations
 - For example: if I buy 5 machines in WC_A then it can process 5 tasks in parallel
 - Scheduling Rule
- KPIs : Service Level and Total Investment or cost

Scheduling Rules

Which Job to start?



Server

Static Rules

- First Come First Serve (FCFS) : The task which arrives first gets serviced first. Default behaviour in Anylogic Queue Object
- Earliest Due Date (EDD): Each task is linked to an order and order has a due date

Dynamic Rules

- Least Slack Time (LST): $Slack = (Due_Time - Current_Time) - Remaining_Processing_Time$
- Critical Ratio (CR): $CR = (Due_Time - Current_Time) / Remaining_Processing_Time$
 - Smaller CR has higher priority

Problem Formulation

Formulation 1:

Objective: *Minimize Total Investment Cost*

Parameters to optimize: *Number of machines in each workstation and Scheduling Rule*

Constraints or Requirement: *Service level should be greater than 90%*

Formulation 2:

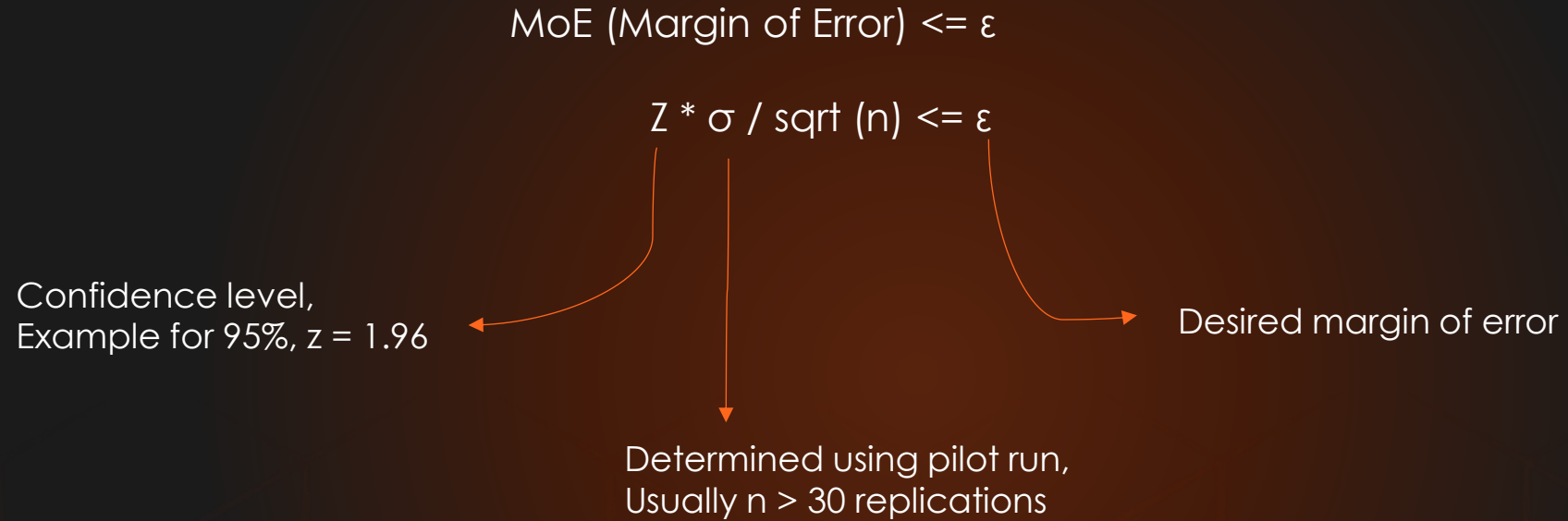
Objective: *Maximize Service Level*

Parameters to optimize: *Number of machines in each workstation and Scheduling Rule*

Constraints or Requirement: *Total Investment Cost should be less than some Amount*

Simulation based Optimization - Demo

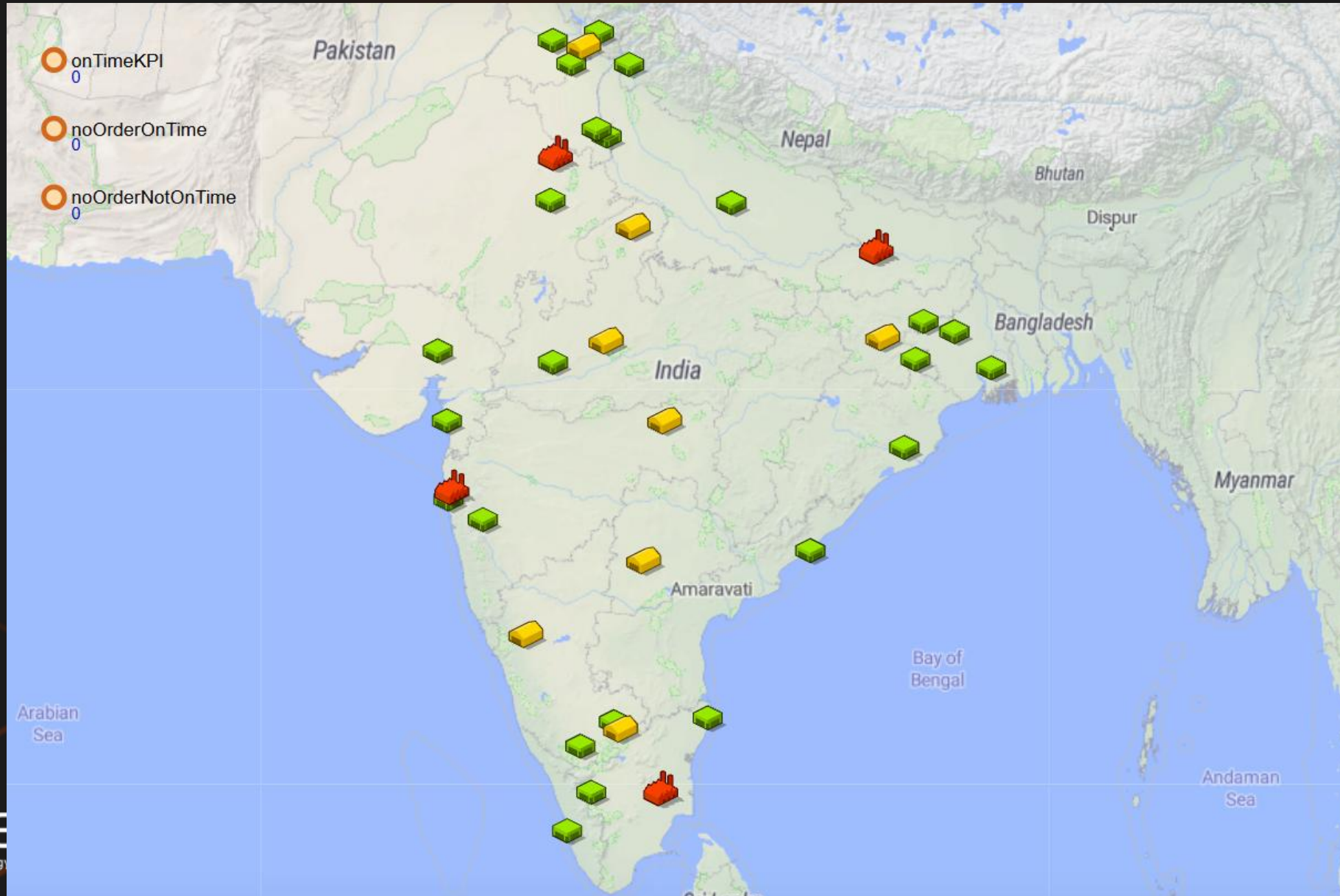
Determine appropriate number of Replications



Some tips – How to make problem tractable?

- Can the problem can be decomposed into 2 or more independent problems? Optimize for each problem separately
- Use 80/20 rule to optimize in detail for the parameters responsible for highest impact
- Multi step optimization - When the range in which optimal value of a parameter may lie is large, start by a coarse search using larger step size and make the search finer in the nest step
 - If the optimizer suggests optimal value as the lowest or highest value of range then increase the range in that direction and perform another optimization run

Case 1: E-Commerce – Truck Schedule



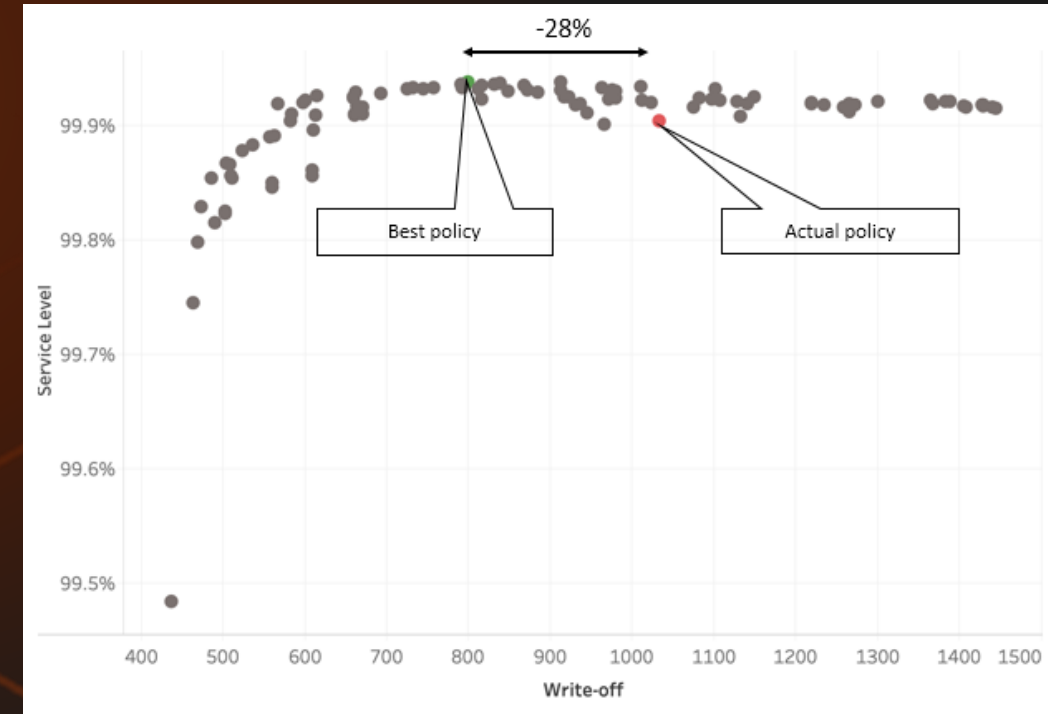
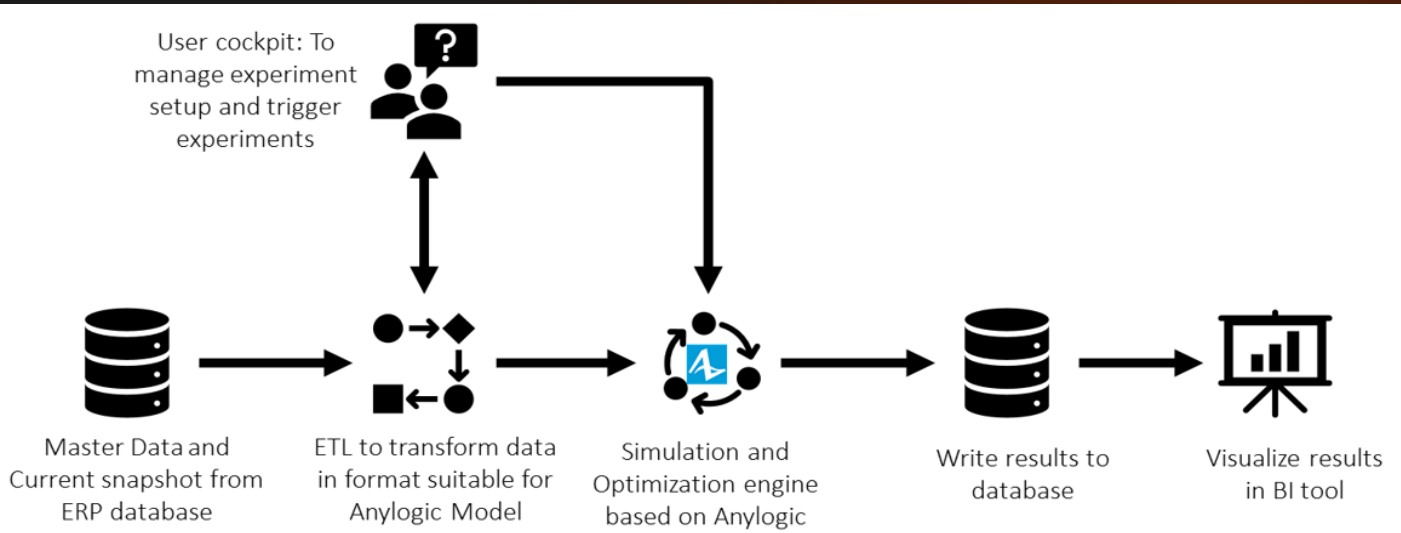
Case 2: Staffing Optimization in a QSR



- In a Quick Service restaurant, there are various types of tasks customer facing as well as Kitchen tasks
- Each Role can handle some tasks with defined priorities
- Based on the customer arrival and items orders, how many staff of each role should be employed such that 90% of orders are delivered within 10 minutes?
- How can we stagger the shifts (start time) of each staff to optimize this service metric and minimize staffing costs?

Case3: Service Level vs Obsolescence tradeoff

- For a particular medicine with low shelf life, client was facing high write offs and low service levels
- Simulation was used to model the entire supply chain for this product (with country specific SKUs) and arrive at the appropriate production policy
- Multiple production policies were tried and finally the one with lowest write offs and a good service level was chosen
- The simulation in Anylogic was fully integrated with multiple data tables and simulation options in excel. The output exported in excel format for further analysis and visualization
- The best production policy with optimized parameters (coverage days for various SKUs) could be selected and put into production



Critique

- When using BlackBox Optimizers, as the problem gets larger (and more realistic), performance degrades. To increase performance, we must design the meta-heuristic in a more problem specific way
- Hence, researchers recommend that modern heuristics should not be applied out of the box as black-box optimization algorithms but adapted to the problem at hand

OptQuest as well as the Genetic Optimization Engine are Black-box optimizer

- Black-box optimization methods are algorithms that need no additional information about the structure of a problem but are able to reliably and efficiently return high-quality solutions for a large variety of different optimization problems
- **No Free Lunch Theorem** : The design of a general black-box optimization methods is not possible

However, in practice we have seen that this Simulation based optimization approach is useful and powerful tool

Q and A



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