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Integer linear programming enables optimal decision making in supply chain management operations

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Matlab EXPO Poland 2020, Online Conference
June 24, 2020

Agenda

- Problem statement
- Scope and use cases
- Solution approach
- Optimization problem formulation
- Methods and implementation
- Summary

Problem statement and solution approach

1

Background

From time to time electronic components market faces shortages in standard components

Risk of penalties and missing revenue due to lack of hardware deliveries

2

Problem statement

Lack of systematic, analytical optimization process to determine the best possible allocation based on objective metrics (revenue, sales margin, etc.)

Limited possibilities to simulate the impact of new component purchases to cover the supply gap

3

Solution

Formulate the component-customer allocation problem as a multi-period integer linear optimization program to allow systematic allocation of components and products

Integrate data from various sources (supply, demand, commercial) to provide a holistic view on the supply chain optimization problem

The optimization problem is complex, we focus on 3 key questions

Optimization landscape is large, hence it is required to narrow down the scope

Main challenges

- Strong interdependency of levers at all levels of Nokia/ recursive problem
- High level of uncertainty: demand evolution, customer needs evolution, deal win / loss ratio
- Limited access to external information (esp. supply)
- Real world complications to factor in: e.g. lead-times in factories and logistics

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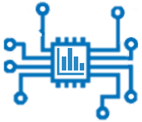
We worked on 2 parallel streams to build the optimization engine

Streams	Input data	Model outputs (use cases)
1 Dynamic intelligence to provide visibility 	• Demand forecast (regular updates on demand and minimum requirements with project pipeline view) • Supply intelligence (supplier confirmations, alternatives, inventory, long term outlook)	• Full transparency of demand and supply situation • Identification of component shortages and risk view for impacted items and customers
2 Optimization engine 	• Demand & supply data (as above) • Commercial factors (item level pricing, customer profitability and T&Cs, strategic considerations)	• Optimal allocation of products to customers with capability to change constraints (e.g. strategic customers, profit maximization) • Verify if open market component purchases make commercial sense

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We developed optimization engine as a daily tool for allocation decisions with automatic recommendations and capability for manual inputs

Dynamic intelligence
On component shortage

- Identified risk of component shortage in the future
  - Which items and in which quantity are impacted?
  - Which customers are impacted and when?

Option 1:
Close the component gap

1. Buy components from open market (distributors)
2. Use alternative suppliers

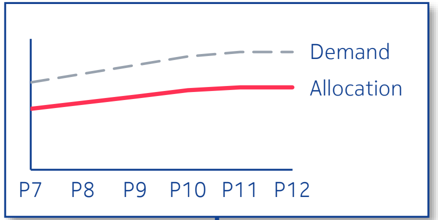
Option 2:
Reprioritize products and customers

- Optimization engine to propose allocation on commercial basis
- User can include manual constraints and the rest is allocated by the engine
- Re-run the optimization by considering the constraints

Dynamic intelligence

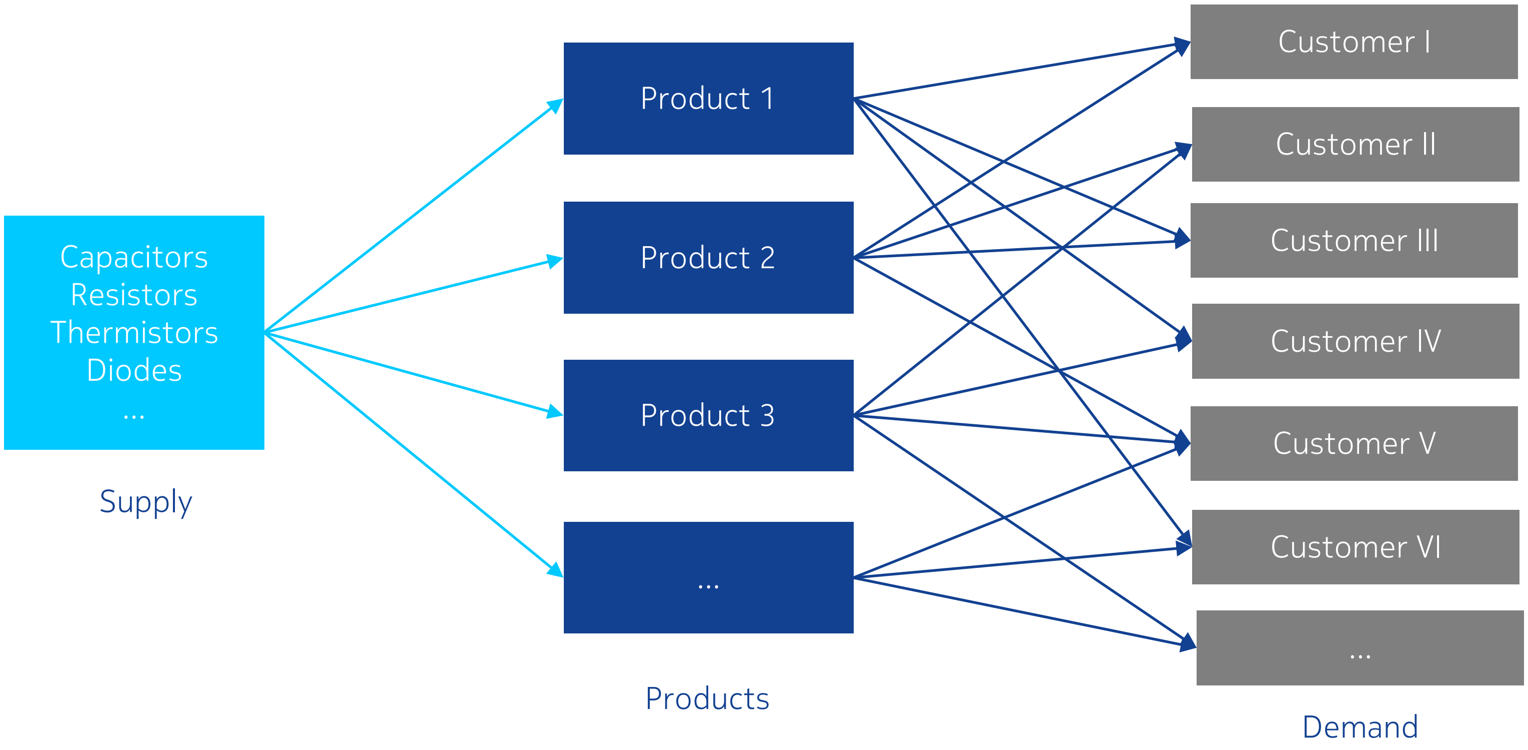
Identified component shortages

Products allocation



Updated view on shortages after prioritization

Schematic representation of the optimization problem



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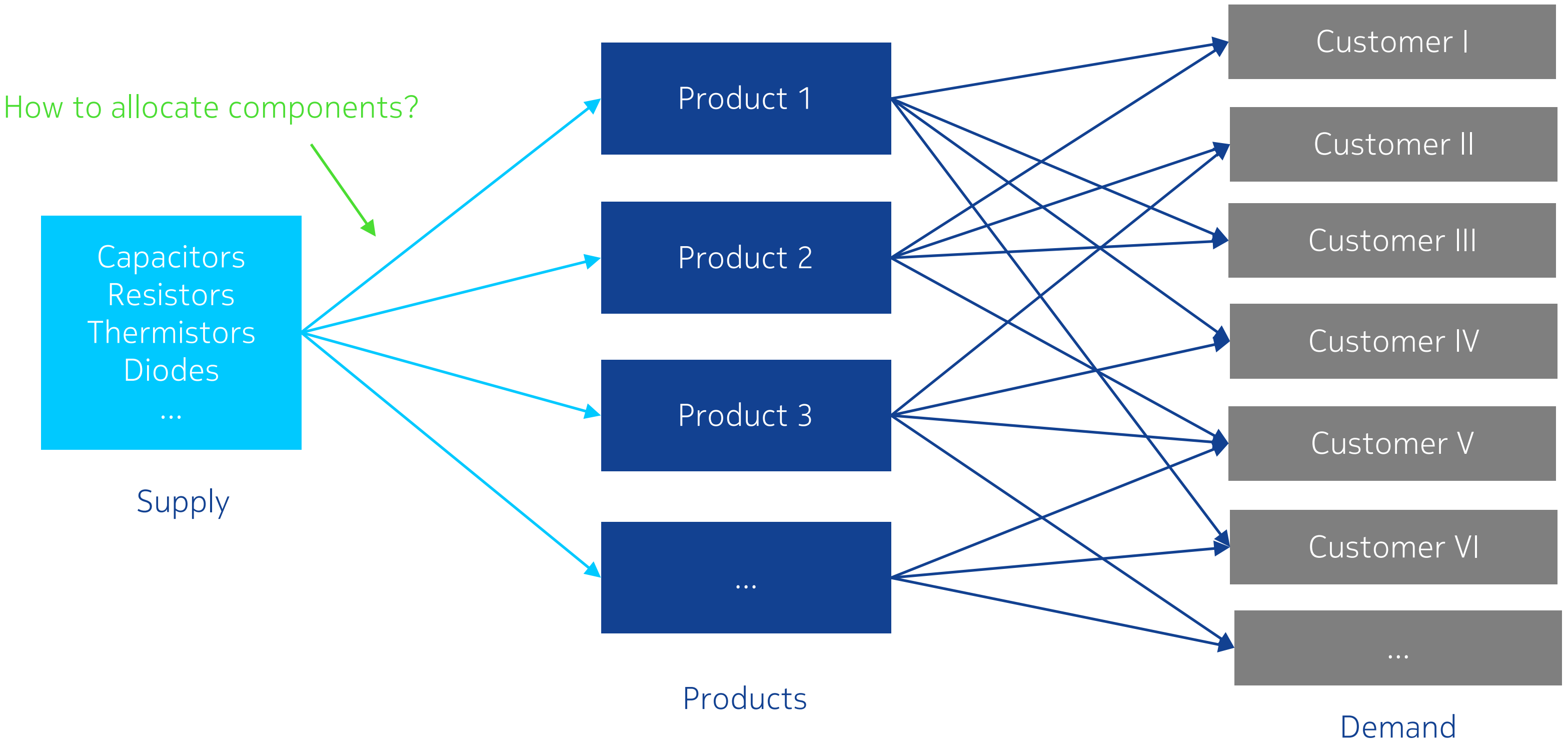

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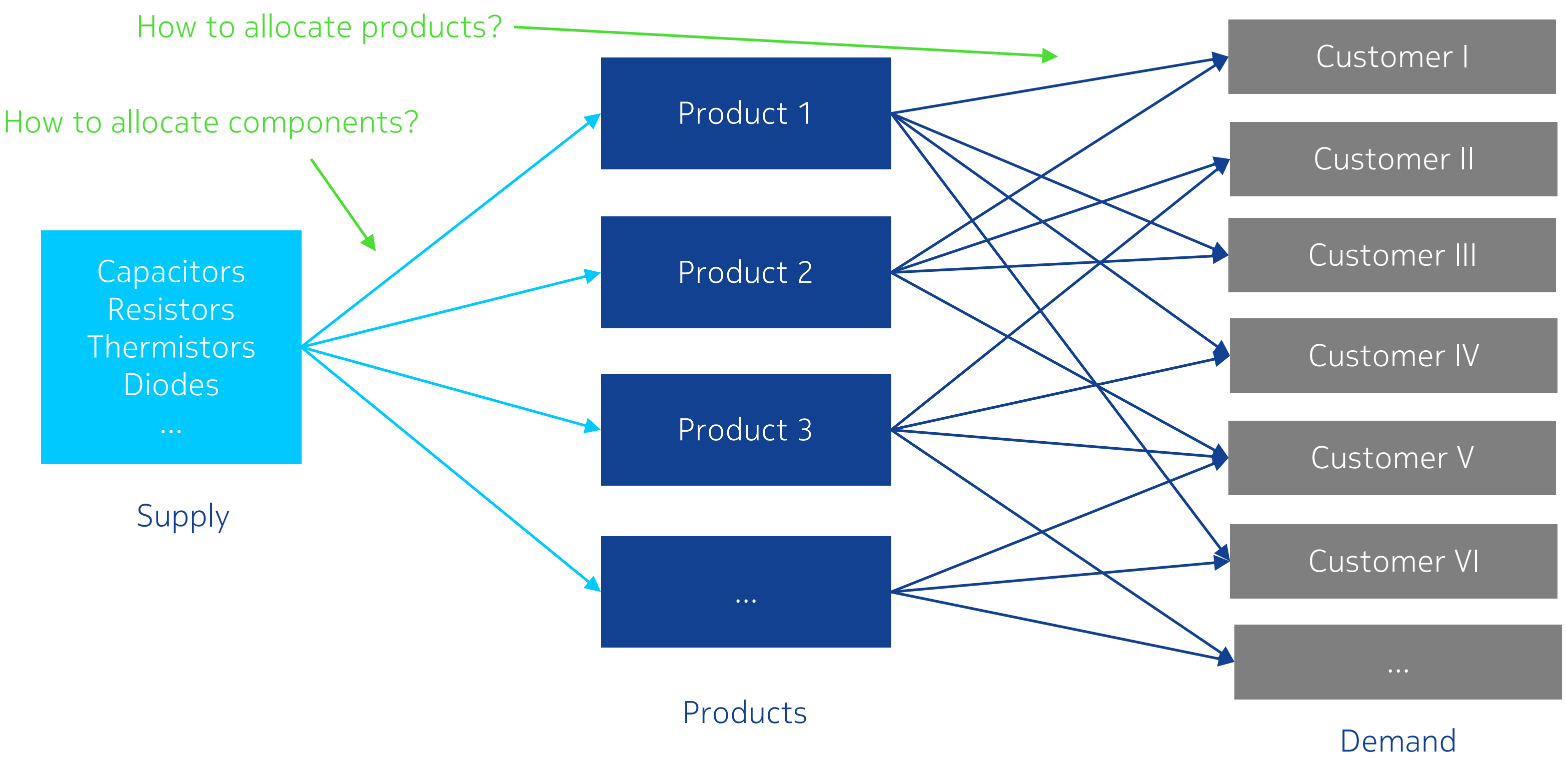

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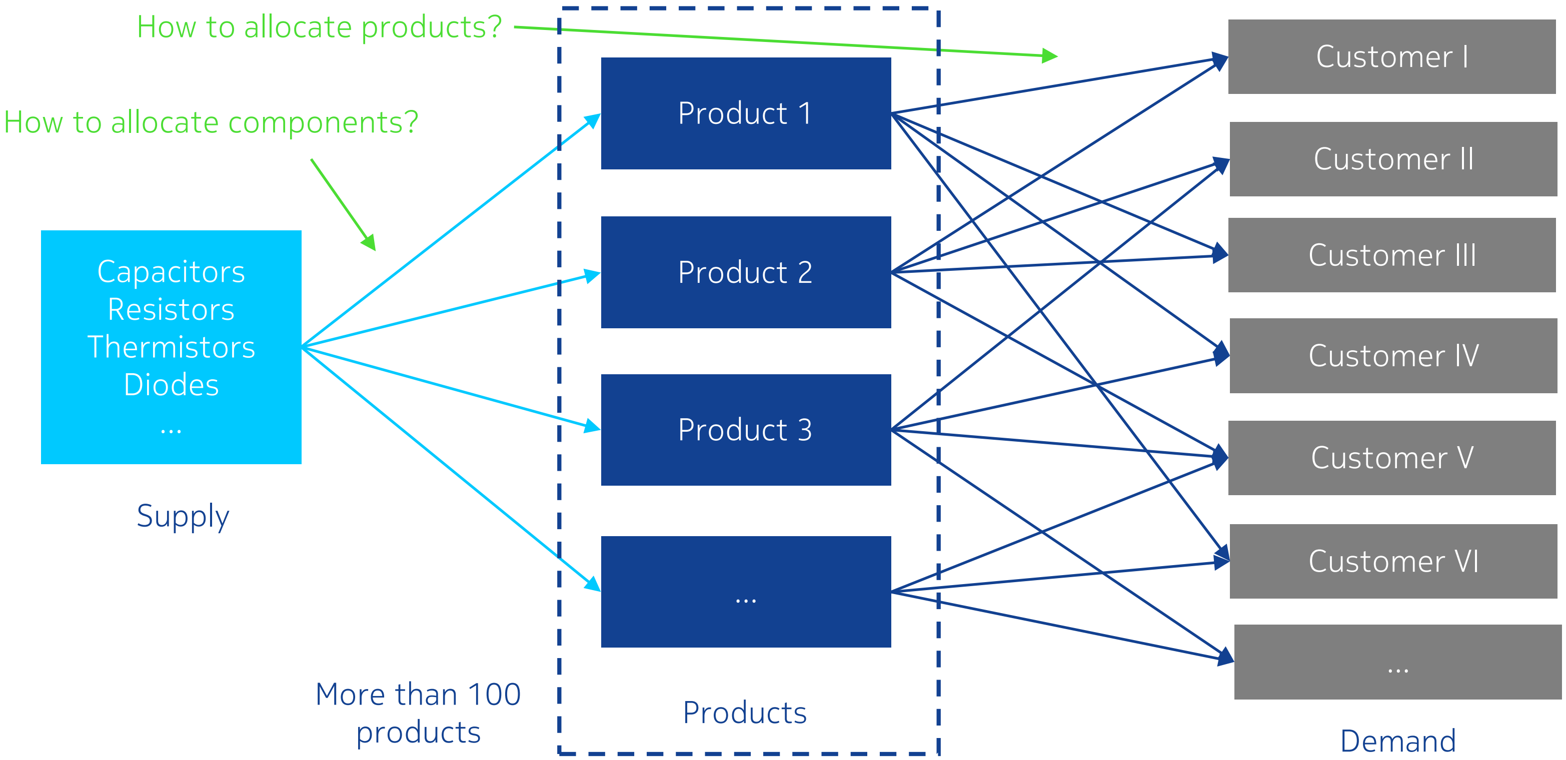
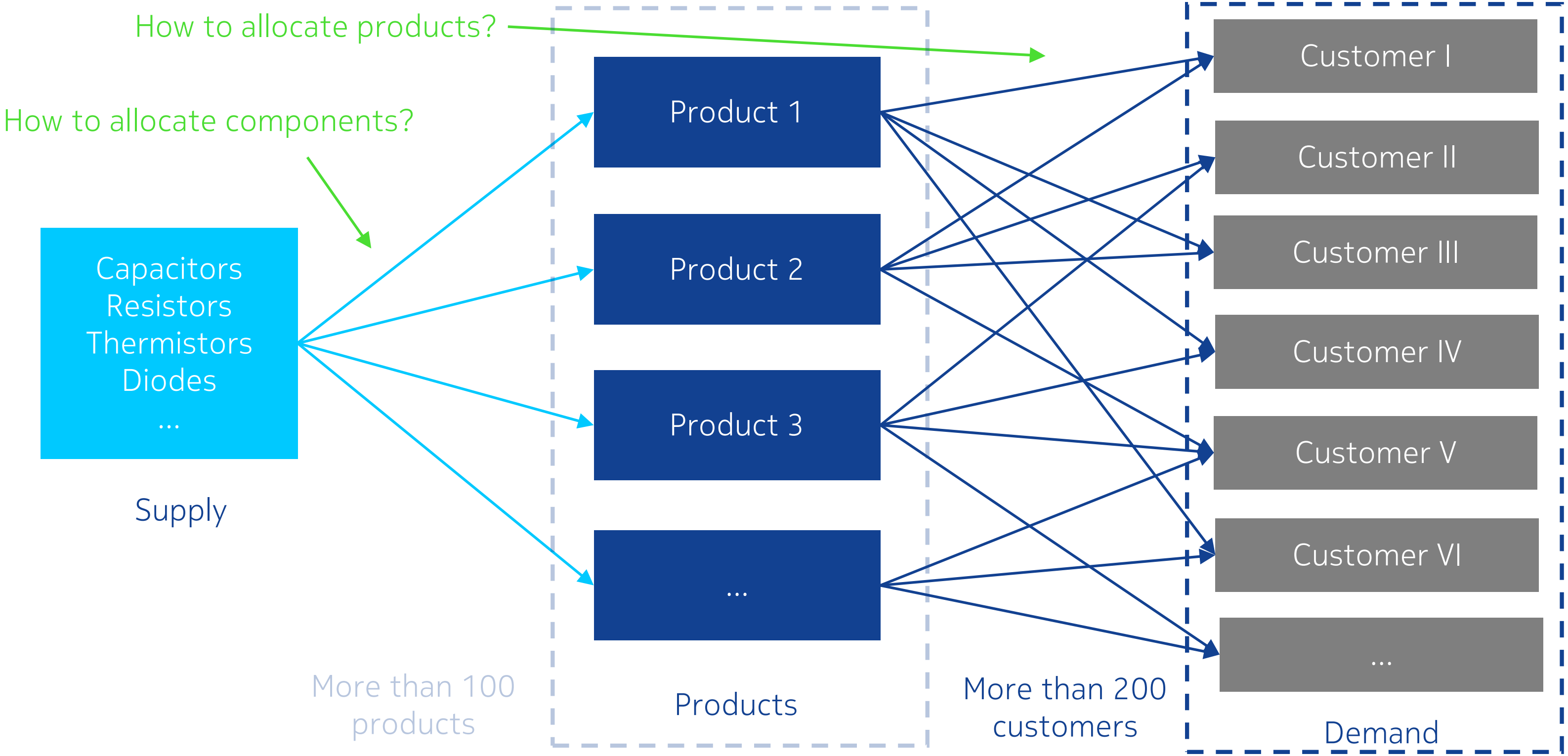


Schematic representation of the optimization problem



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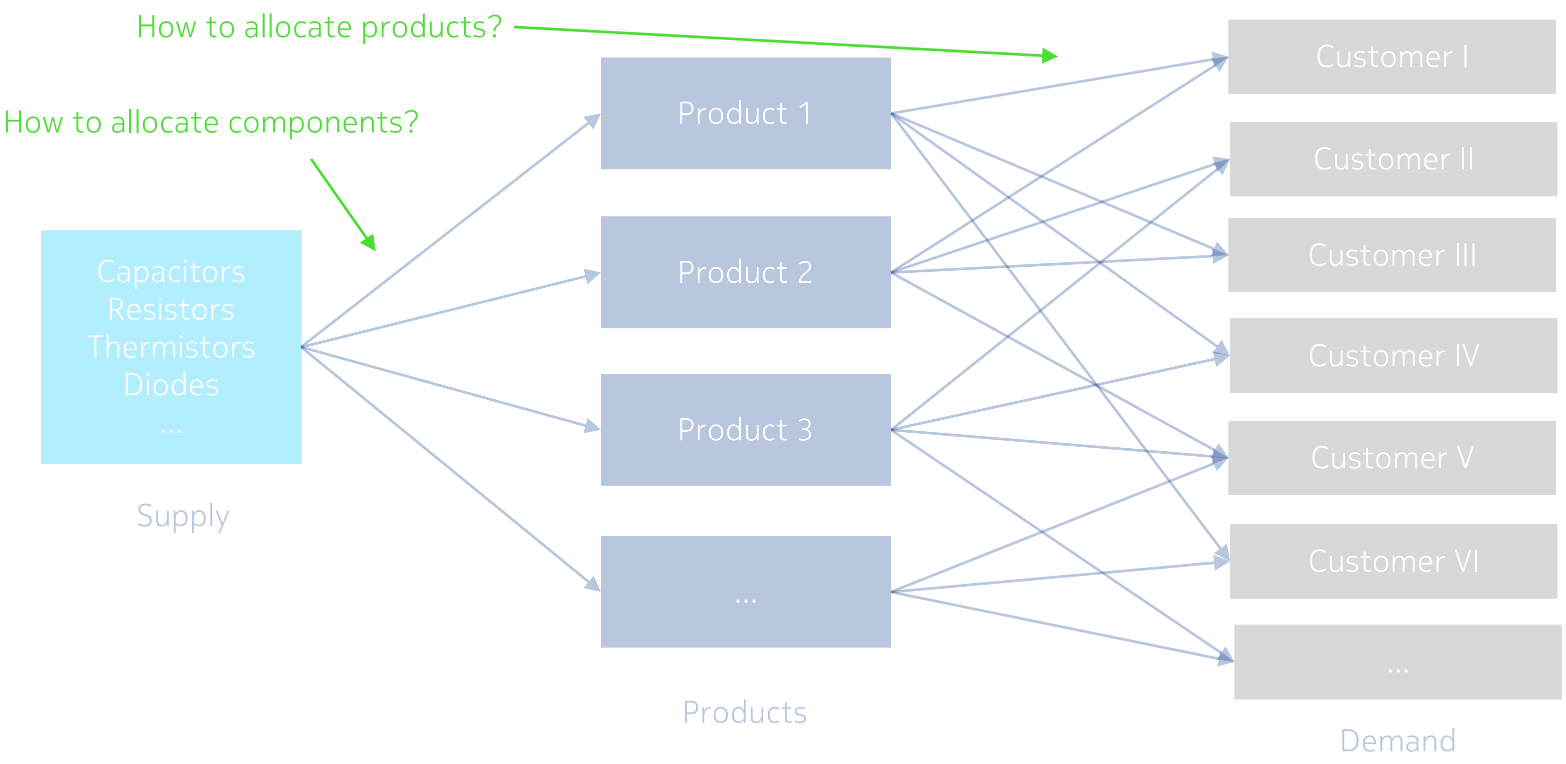

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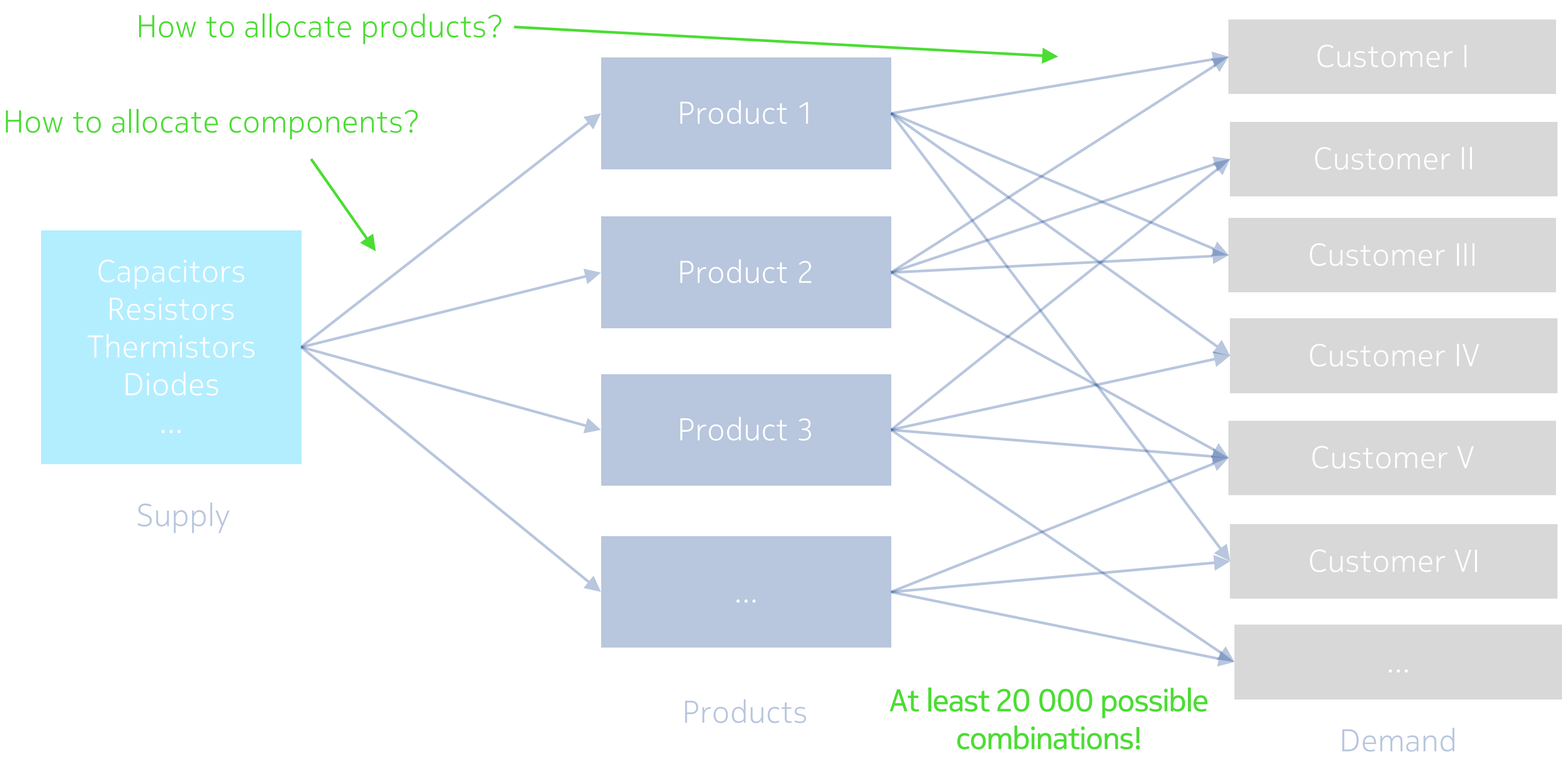
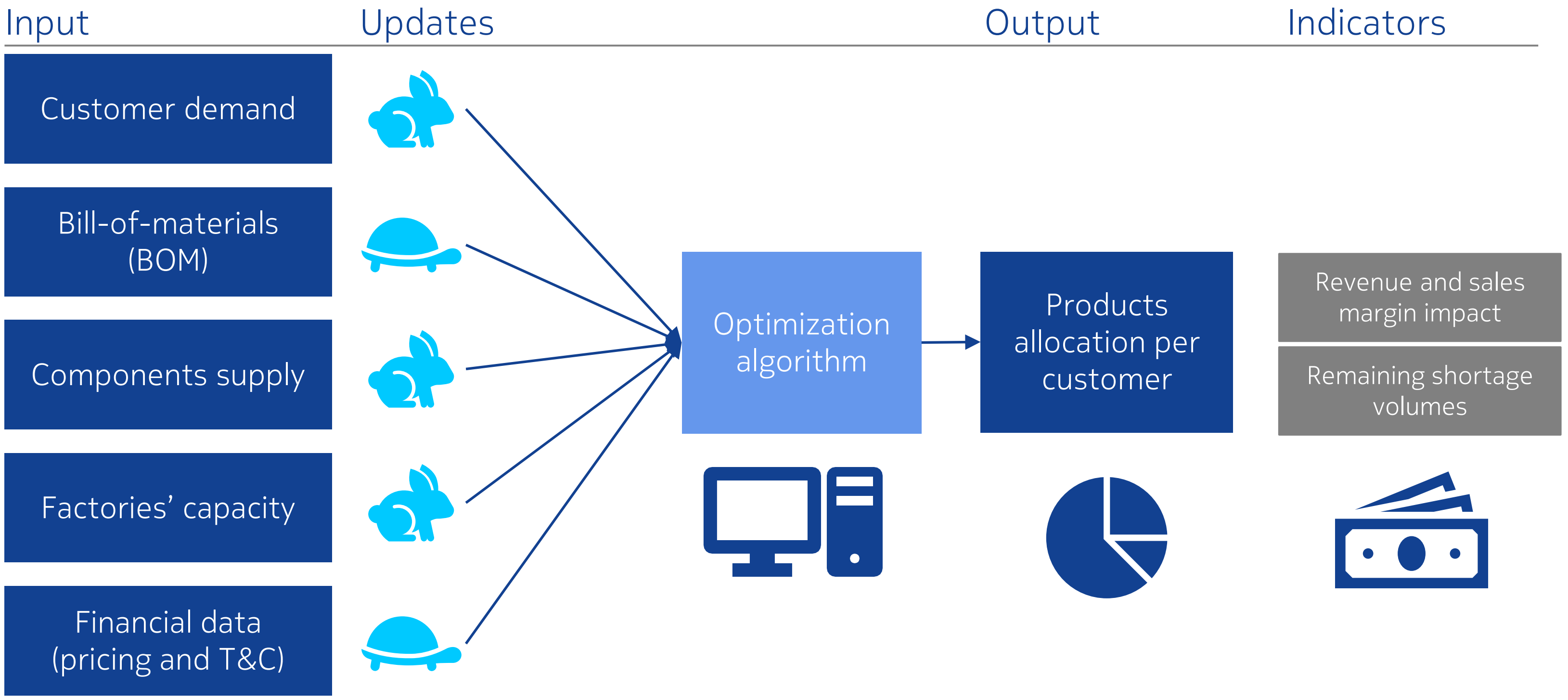


The optimization engine uses mix of dynamic and static inputs



The problem is formulated as an integer programming problem

Data analysis

Step 1: Data preparation

- Supply and demand
- BOM
- Capacity
- Pricing and TnC
- …

Step 2: Data import

- Consistent structure
- More "machine-friendly" form
- Modular approach

Optimization

Step 3: Declaration of variables

- Example: *y(i, j)* stands for the number of sales items *i* delivered to customer *j*

Step 4: Objective function

- Maximize revenue
- Minimize number of missing products
- Prioritize customer X
- …

Step 5: Constraints definition

- Do not exceed the available supply
- Meet demand
- Manufacture complete products

Step 6: Solution

- Find optimal mix of components
- Determine optimal products allocation

Data extraction

Step 7: Post-processing

- Export data for analysis

Step 8: Visualization

- Prepare results for displaying in PowerBI

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Integer linear programming problem definition 1/2

Input variables

- $A_{(M \times K)}$ – bill of material
- $S_{(1 \times K)}$ – component supply
- $D_{(M \times N)}$ – demand for products per customer
- $C_{(M \times 1)}$ – factories capacities
- $I_{(M \times M \times N)}$ – products' interdependencies
- $P_{(M \times N)}$ – net unit price of each product

Decision variables

- Y – fulfilled demand, i.e. quantities of each product allocated to each customer in a given period, M x N
- Y^C – unsatisfied demand per customer for each product in a given period, M x N
- X – quantities of components allocated to manufacture products in Y, K x 1

Objective

$$\underset{x}{Maximize} \sum_{i=1}^{M} \sum_{j=1}^{N} (P \circ Y)_{i,j}$$

- Maximize revenue over all M products and all N customers
- Revenue is given by an element-wise multiplication of net price P and product allocation Y

Integer linear programming problem definition 1/2

Constraints

- Component allocation cannot exceed supply

$$X - S \geq 0$$

- Number of allocated products cannot exceed demand

$$Y - D \geq 0$$

- Sum of allocated and unallocated products is at least equal to the demand

$$D - (Y + Y^C) \geq 0$$

- Sum of allocated products cannot exceed factories capacities

$$\sum_{j=1}^{N} Y_{\cdot,j} - C \geq 0$$

- Interdependencies between products are respected

$$\forall_{i,j \in \{1,\ldots,M\}} \forall_{k \in \{1,\ldots,N\}} : I_{i,j,k} \neq 0$$
$$\Rightarrow Y_{j,k} - Y_{i,k} \cdot I_{i,j,k} = 0$$

- Non-negativity of variables

$$X \geq 0$$

$$Y \geq 0$$

$$Y^C \geq 0$$

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State-of-the-art data science tools are integrated with the Azure development framework

Matlab

- Formulation of an optimization problem

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State-of-the-art data science tools are integrated with the Azure development framework

Matlab

- Formulation of an optimization problem

Solver

- “Heart” of optimization
- Computes optimal solution

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Matlab

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IBM

Solver

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Objectives:

1. Maximize revenue/sales margin from delivered products
2. Prioritize customers and/or products

State-of-the-art data science tools are integrated with the Azure development framework

Matlab

- Formulation of an optimization problem

Solver

- “Heart” of optimization
- Computes optimal solution

Objectives:

1. Maximize revenue/sales margin from delivered products
2. Prioritize customers and/or products

Constraints:

1. Components supply
2. Bill of materials
3. Production capacity
4. Interdependencies among products
5. Customers demand

State-of-the-art data science tools are integrated with the Azure development framework

Matlab

- Formulation of an optimization problem

Solver

- "Heart" of optimization
- Computes optimal solution

Power BI

- Results visualization

Azure

- Web application / User interface
- Data integration

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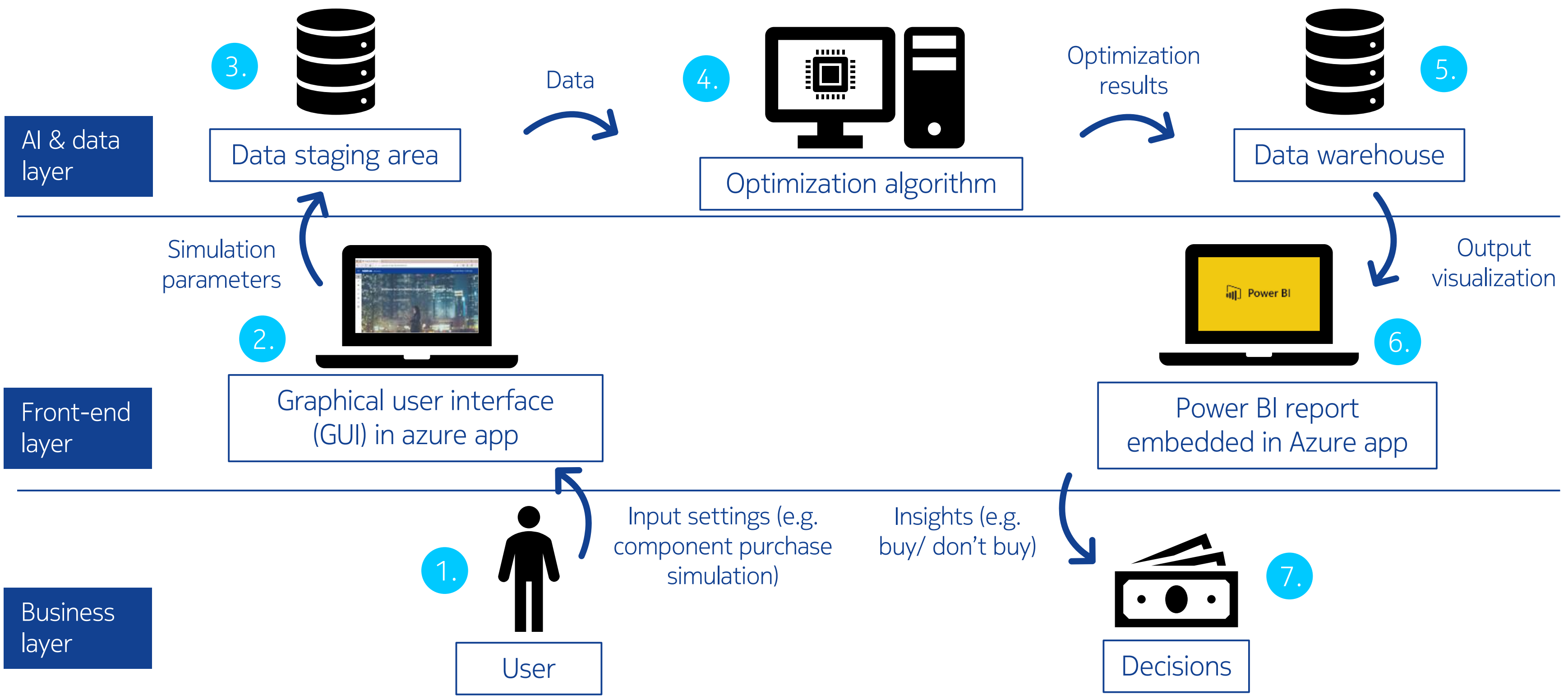
We developed an end-to-end AI-based online optimization tool



The developed tool helps to secure tangible business impact and further improves the existing supply chain management system

Feature	Traditional commercially available solutions	Optimization engine
Objective function/allocation principle	Lead time minimization only	Full spectrum of choices available: 1) Revenue/SM maximization 2) Customers and/or products prioritization
Open market purchase simulation & recommendation	✗	✓
Optimal allocation of components and products at the same time	✗	✓
Commercial data considered in decision-making	✗	✓
Top missing components (i.e. the first to run out of) identification	✗	✓
Financial risk assessment of components shortage	✗	✓
Comparative analysis of impact of allocation scenarios	✗	✓

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