Cost Analysis & Optimization of Repair Concepts and Spare Parts Using Marginal Analysis

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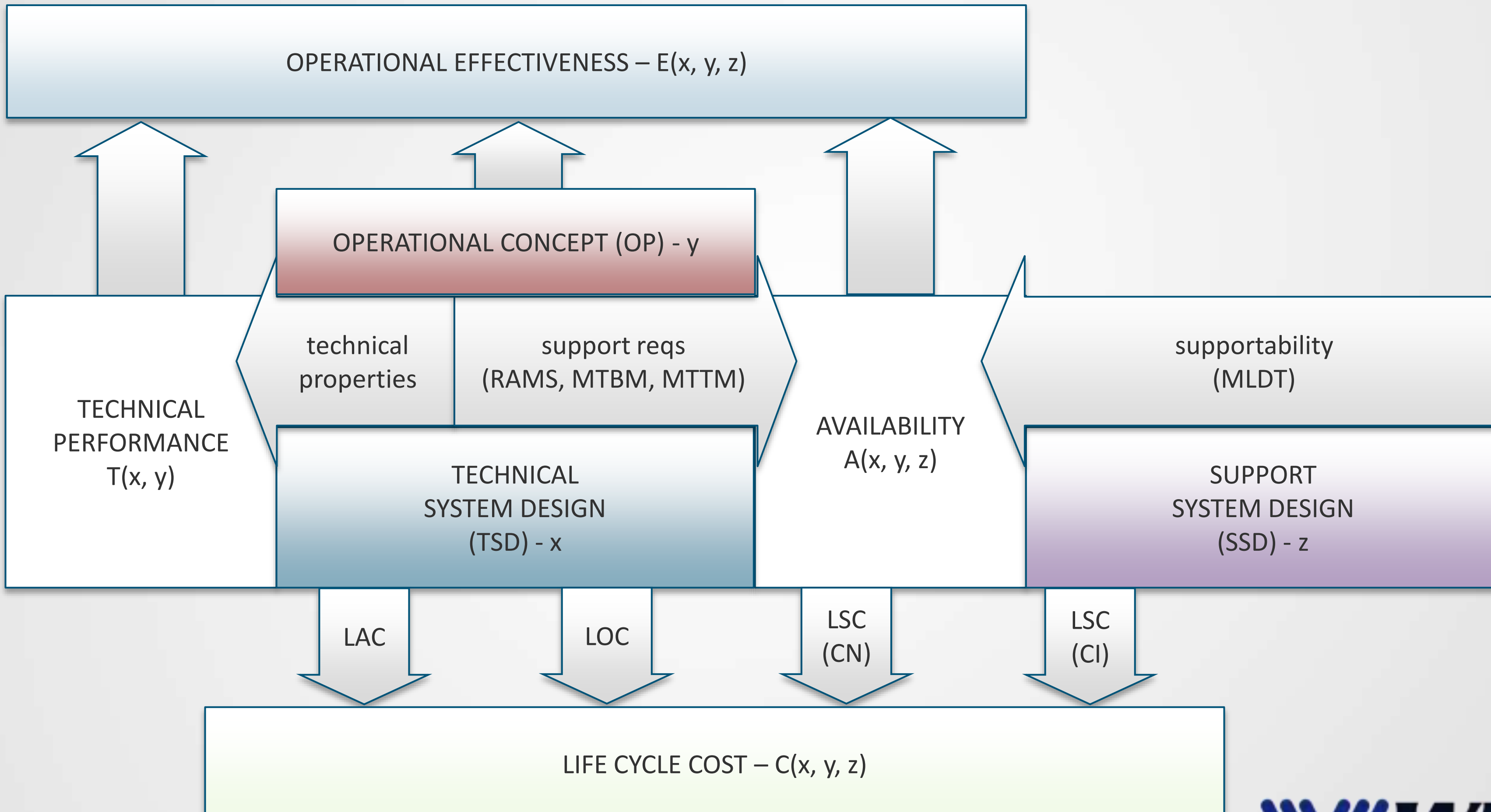
WPI Optimization

Introduction

- The fundamental property of cost and capability trade studies is that the model allows for a simultaneous optimization of two problems to achieve the highest performance at the lowest Life Cycle Cost:
- What is the most cost effective repair strategy?
- What is the optimal sparing strategy?
- The choice of repair strategy concerns:
  - Whether to discard or repair items
    - if the item is to be repaired, where the repair should take place
  - The sparing strategy optimizes the amount of spares at each location, when, and how much to reorder.

SYSTEMS AND LOGISTICS ENGINEERING (ILS)

THE BASICS – ALL IN ONE PICTURE



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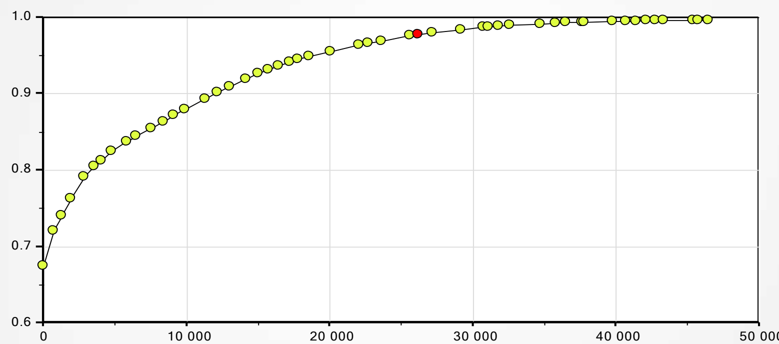
SYSTEMS AND LOGISTICS ENGINEERING (ILS)

PRIMARY OBJECTIVES

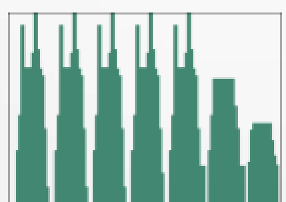
cost-effectiveness

MAXIMAL OPERATIONAL EFFECTIVENESS AT MINIMAL LCC

TECHNICAL SYSTEM (TSD) - x



SUPPORT SYSTEM (SSD) - z



OPERATIONAL CONCEPT (OP) - y

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OPTIMAL SUPPORT SYSTEM DESIGN

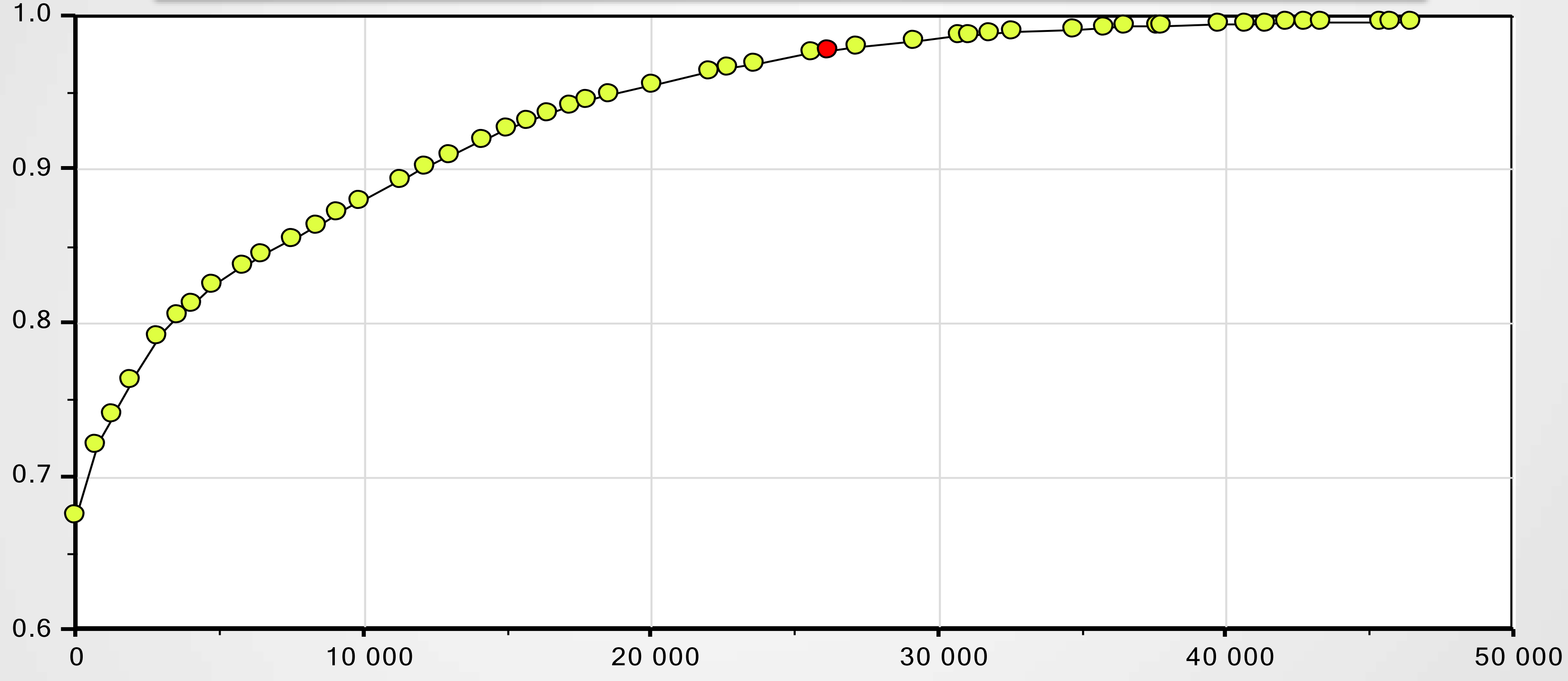
- given a technical system design (TSD) – x
  - incl. RAMS properties (support requirements)
- given an operational concept (OP) – y
- design an optimal support solution – choose z so as to
  - maximize A(x, y, z) and minimize LSC(x, y, z)
  - generate cost-effective support system designs – z*
- identify LSC-related cost drivers in x and y
  - feedback to TSD and operational ambition OP

SUPPORT SYSTEM DESIGN

PRIMARY OBJECTIVE

cost-effectiveness

MAXIMAL AVAILABILITY AT MINIMAL LSC



DESIGN VARIABLES

DEGREES OF FREEDOM IN z

- spares safety stocks
  - OPUS classic
- spares resupply strategy
  - OPUS discardables

SPARE PARTS OPTIMIZATION

- maintenance and support resources
- maintenance concept
  - what maintenance where
- plus many more
  - e,g., transportation policy

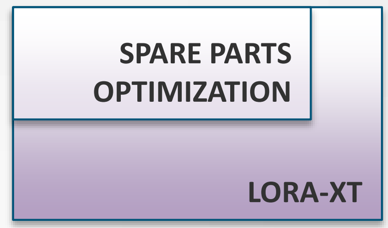
REPAIR CONCEPT OPTIMIZATION (LORA-XT)

WPI Optimization

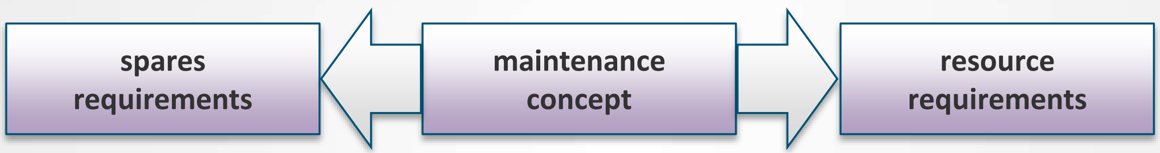
LORA-XT

THE BASICS

- extended scope compared to spare parts optimization



- necessary coordination



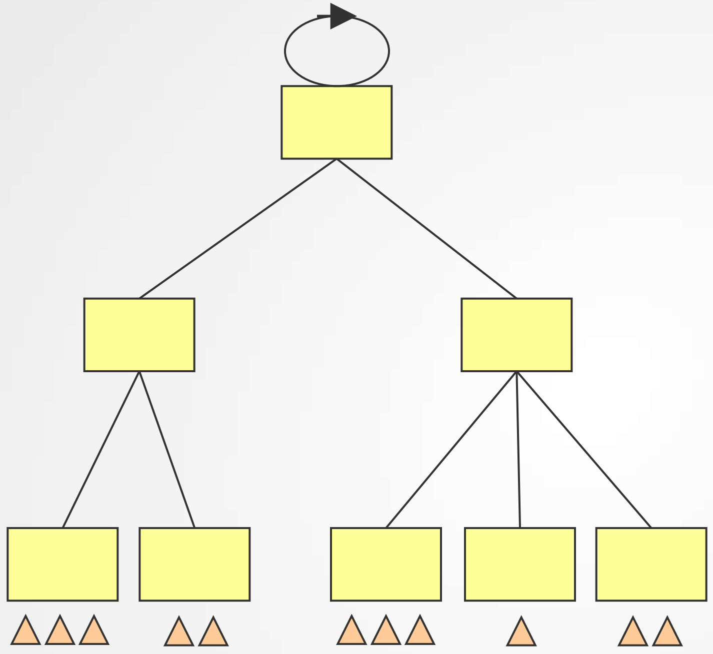
- the extended scope is the right step
  - towards total support system optimization
  - coordinated optimization over several design variables
  - power functionality

LORA-XT

- repair/discard decision per failure mode
  - not per item
- repair level (location) decision per task/failure mode
  - not per item
- maintenance level decision also includes preventive maintenance
  - not only repair (corrective maintenance)
- the output – cost effective allocation/definition of
  - maintenance concept
  - spares
  - resources

Calculation and optimization

The basic scenario



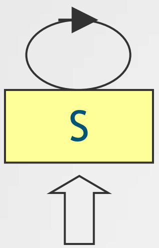
Support organization

(stores and workshops)

Systems in operation

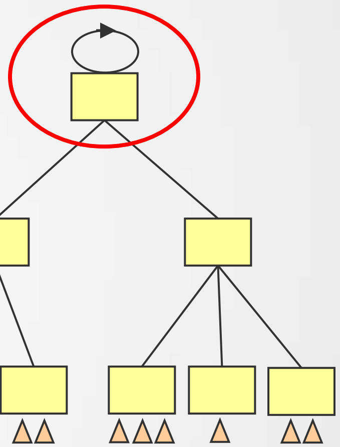
Calculation model (1 level)

Resupply time (T)



Stock level (S)

Demand rate (D)
Poisson process

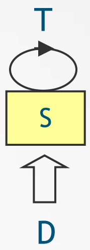


Stochastic variable X:

- Number of outstanding demands
- Steady-state distribution is Poisson (D·T)

$$P(X = k) = \frac{(DT)^k}{k!} e^{-DT}$$

Measure of efficiency:



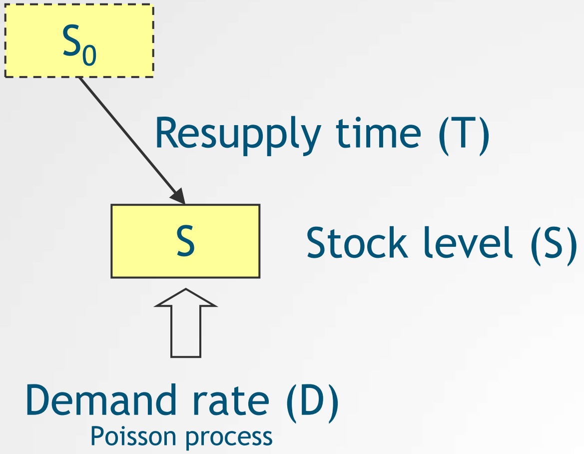
- X > S => Shortage !
- Risk of shortage (ROS)
  - Probability that the stock is empty
  - $P(X \geq S)$

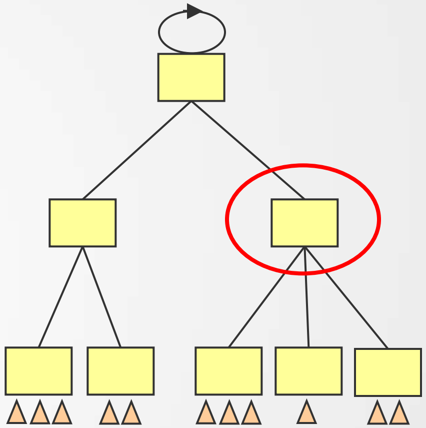
$$\sum_{k=S}^{\infty} P(X = k)$$

- Expected number of backorders (NBO)
  - Average queue
  - $E(X-S)^{+}$

$$\sum_{k=S}^{\infty} (k - S) P(X = k)$$

Calculation model (several levels)

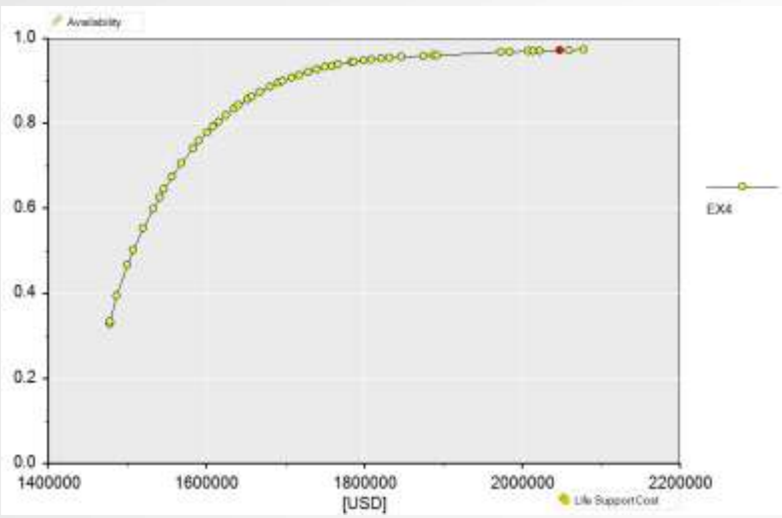


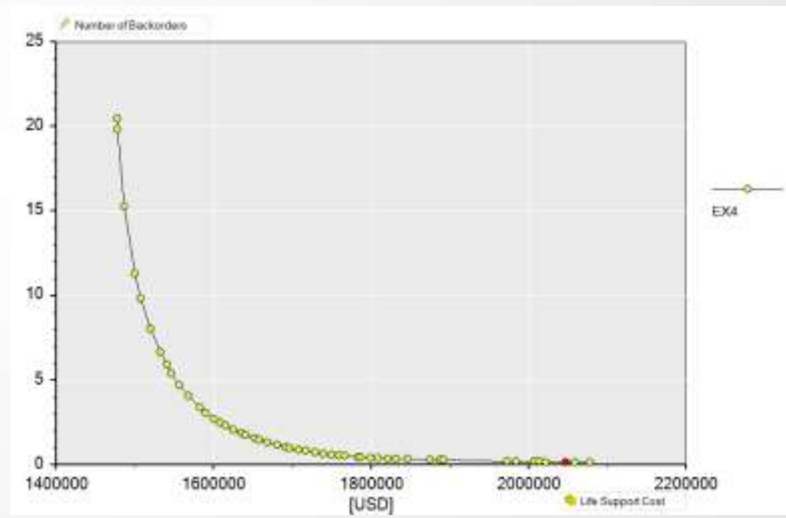


- T now depends on supporting stock
- Steady-state distribution of X more complex
- Approximate X with negative binomial
  - Select parameters to match of EX and VX
  - Known as Varimetric approximation (Sherbrooke)

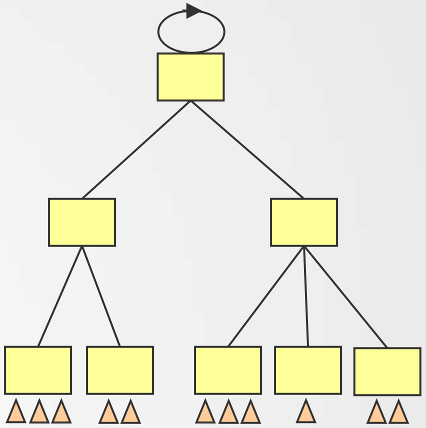
Availability vs NBO

- System availability (A) calculated from NBO: $A = \frac{1}{1+\frac{NBO}{NS}}$





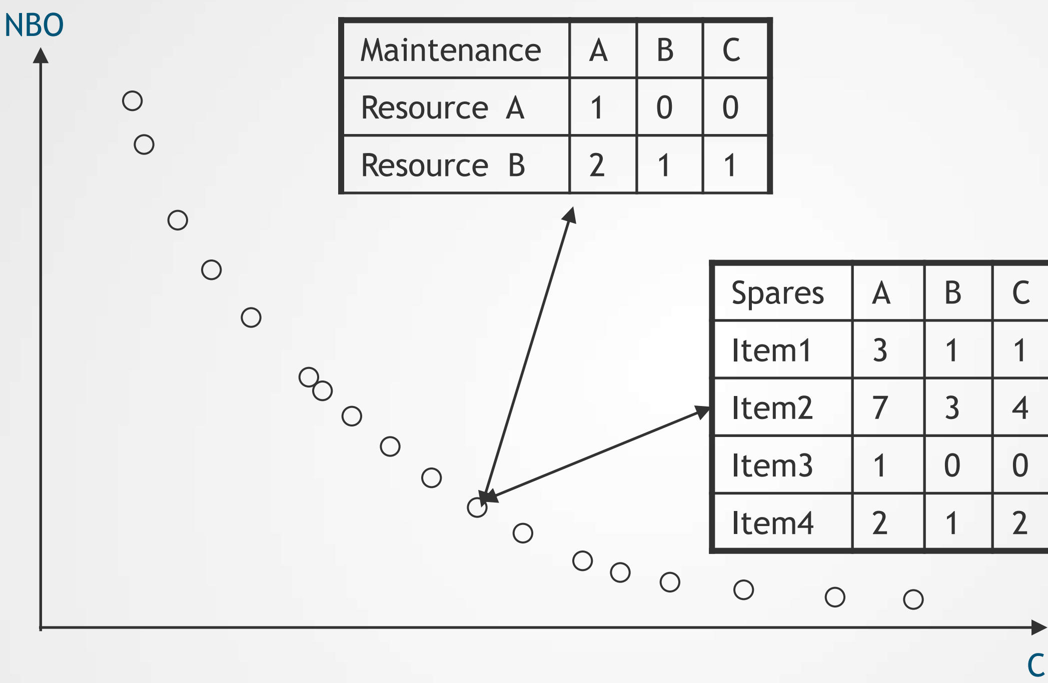
Optimization



- Objective: Total NBO
  - Minimize NBO ⇔ Maximize A
- Decision variables: Stock levels S
  - Per item and location
  - Non-linear integer problem
- Minimize total NBO for different values on total cost (LSC)

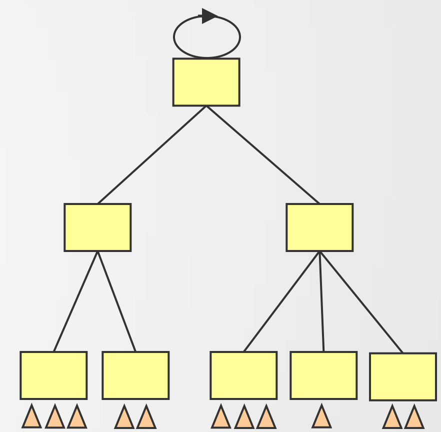
  =>
- Not only ONE optimal point but a set of points (curve)

Optimization



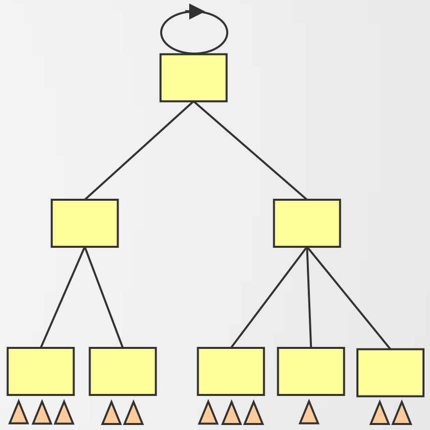
Maintenance	A	B	C
Resource A	1	0	0
Resource B	2	1	1

Spares	A	B	C
Item1	3	1	1
Item2	7	3	4
Item3	1	0	0
Item4	2	1	2



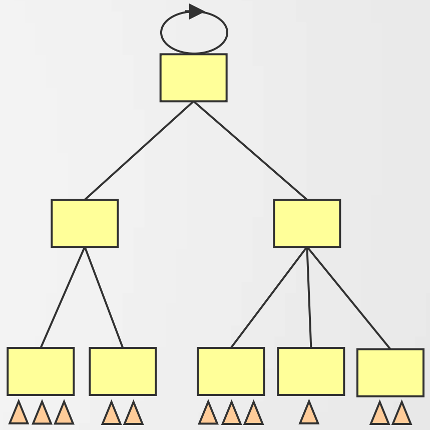
Optimization:

- Fast and efficient
- Problem with 10000 variables only takes a few seconds on an ordinary PC
- Simplifies analysis of alternative scenarios and sensitivity analysis



Optimization

- Marginal allocation
  - Increase stock at location/item that gives best improvement per dollar
  - Calculate marginal effectiveness *mbc* at all locations/items
  - Easy to calculate and update



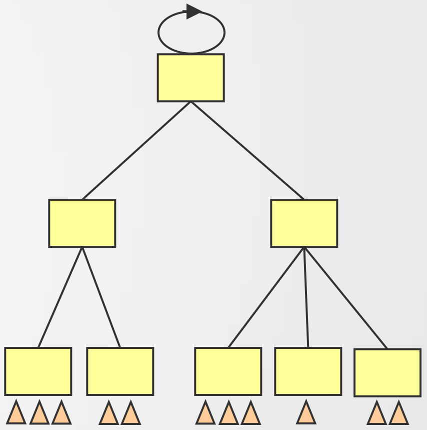
$$mbc = \frac{\Delta NBO}{\Delta C}$$

$$\Delta NBO = NBO(s+1) - NBO(s) = \ldots = ROS(s+1)$$

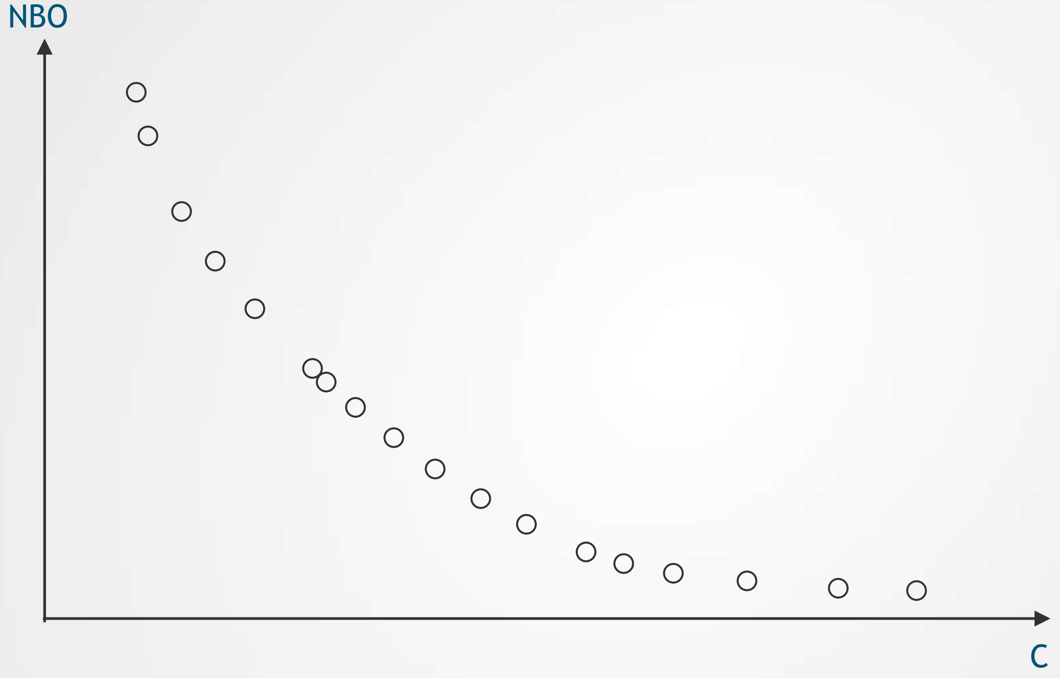
$$\Delta ROS = ROS(s+1) - ROS(s) = -P(X = s)$$

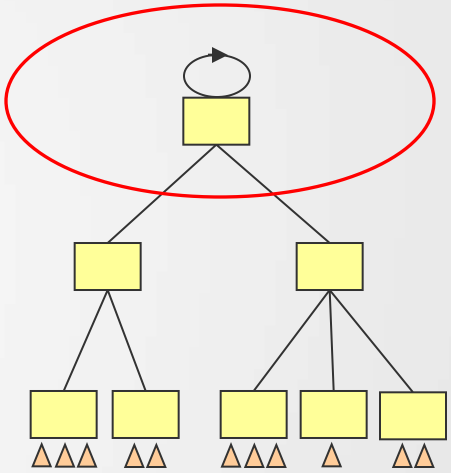
Optimization several levels

- Start at the ”far end” (least important)
- Minimize NBO locally
  - Generate a local solution curve
- Proceed to next level with a selected subset of solution points
  - Perform a local optimization for each solution point on the previous level
  - Form the convex hull over all local curves
- Heuristic approach that turns out to work very well
  - Constraints (min/max stock) can cause some problems

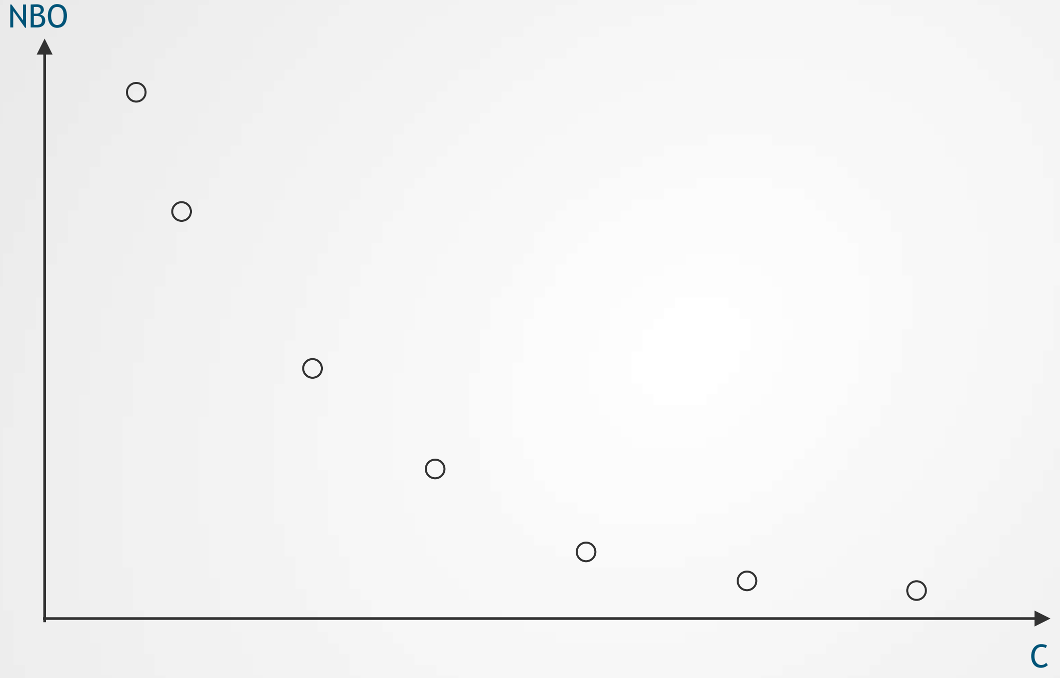


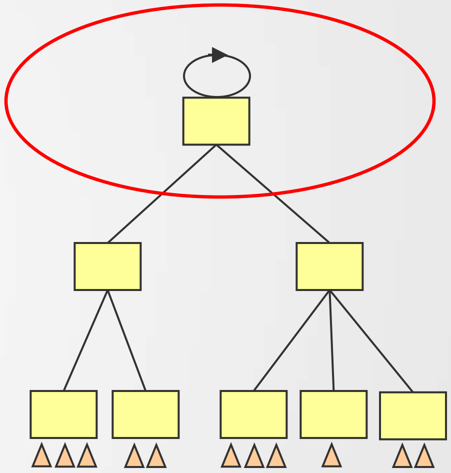
Optimization several levels



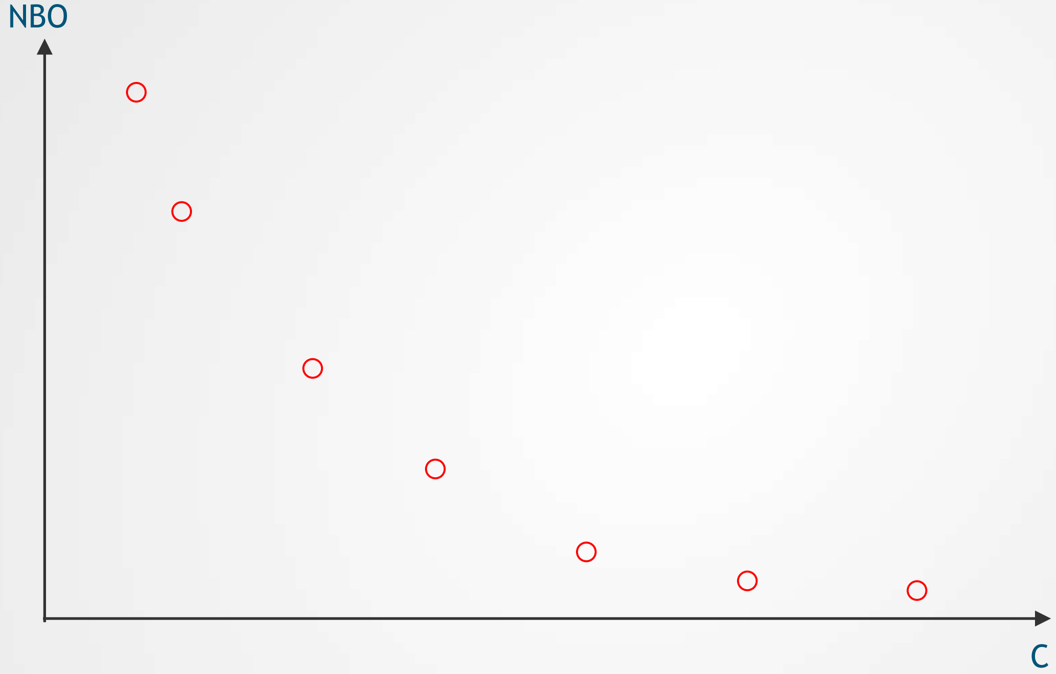


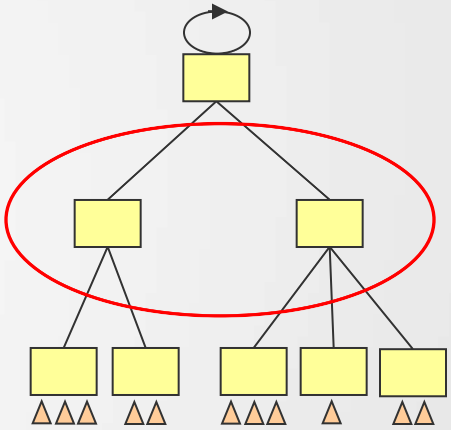
Optimization several levels





Optimization several levels





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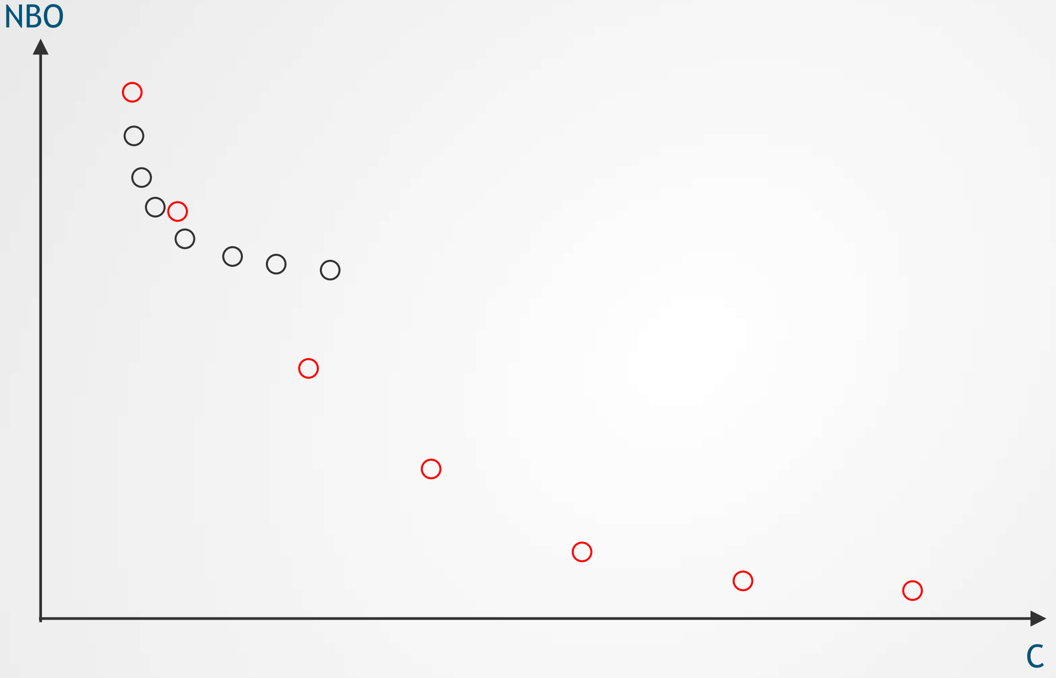
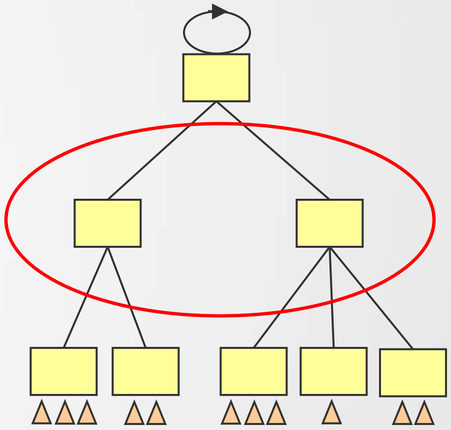
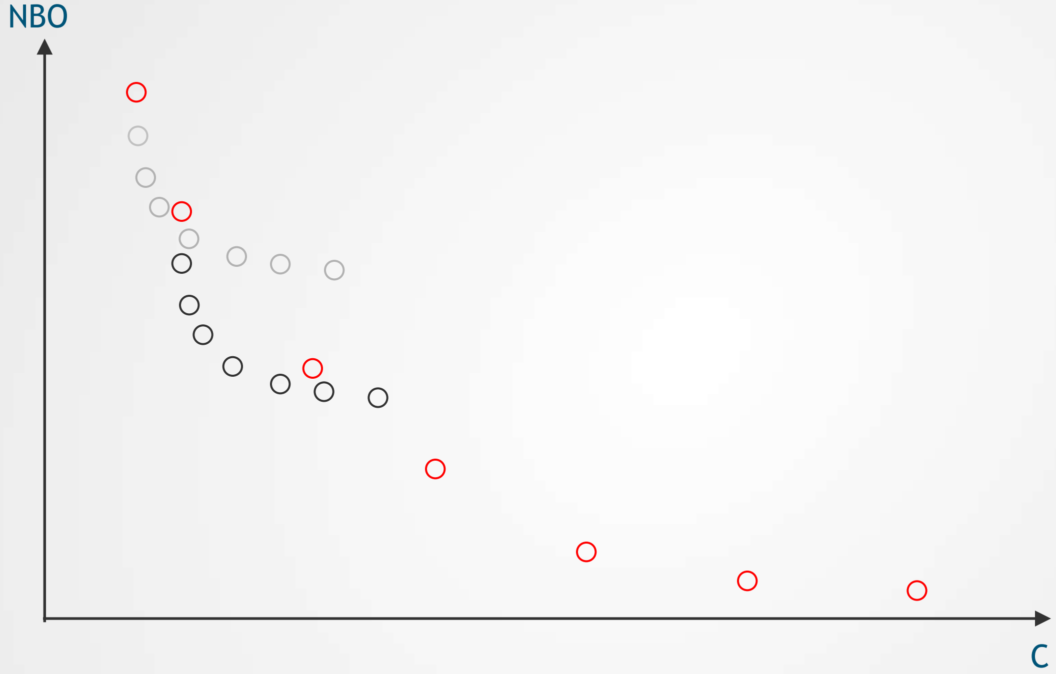
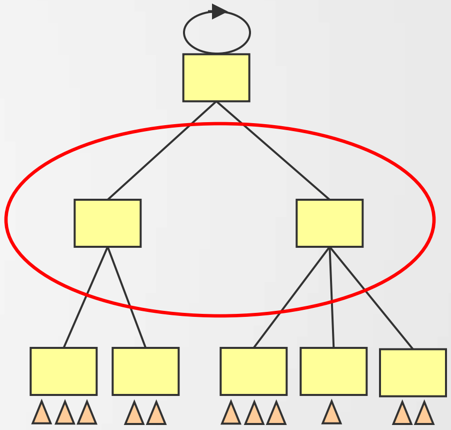
Optimization several levels



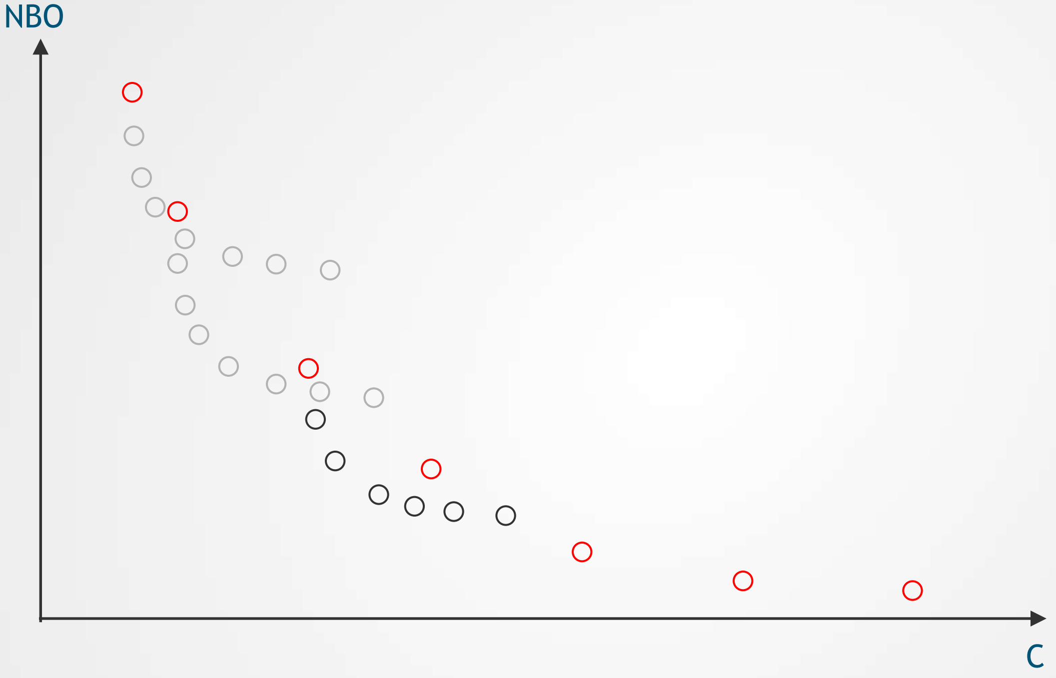


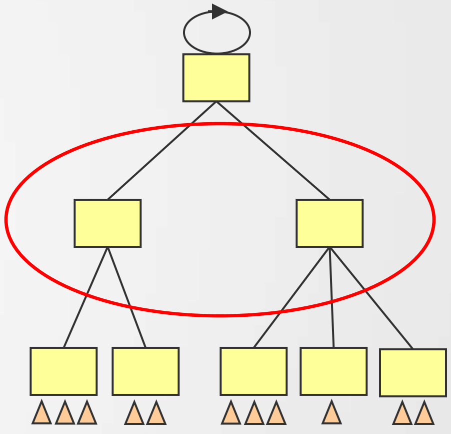
Optimization several levels



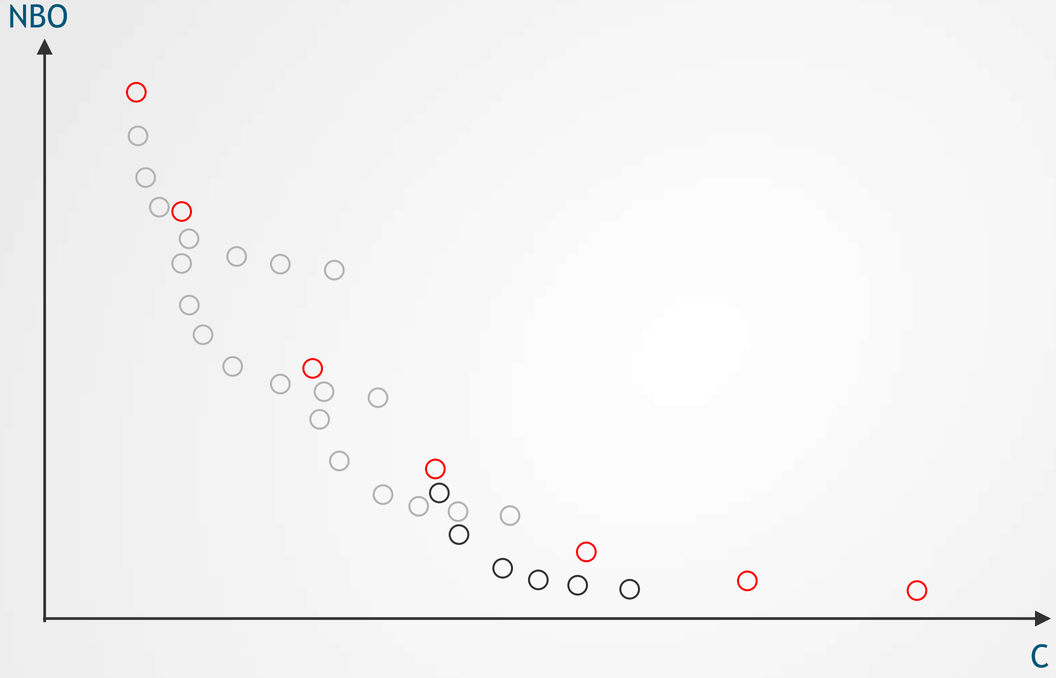


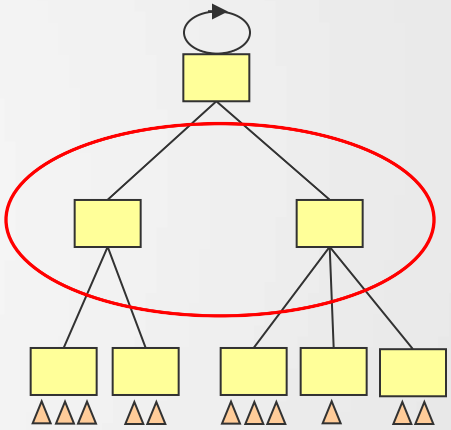
Optimization several levels





Optimization several levels





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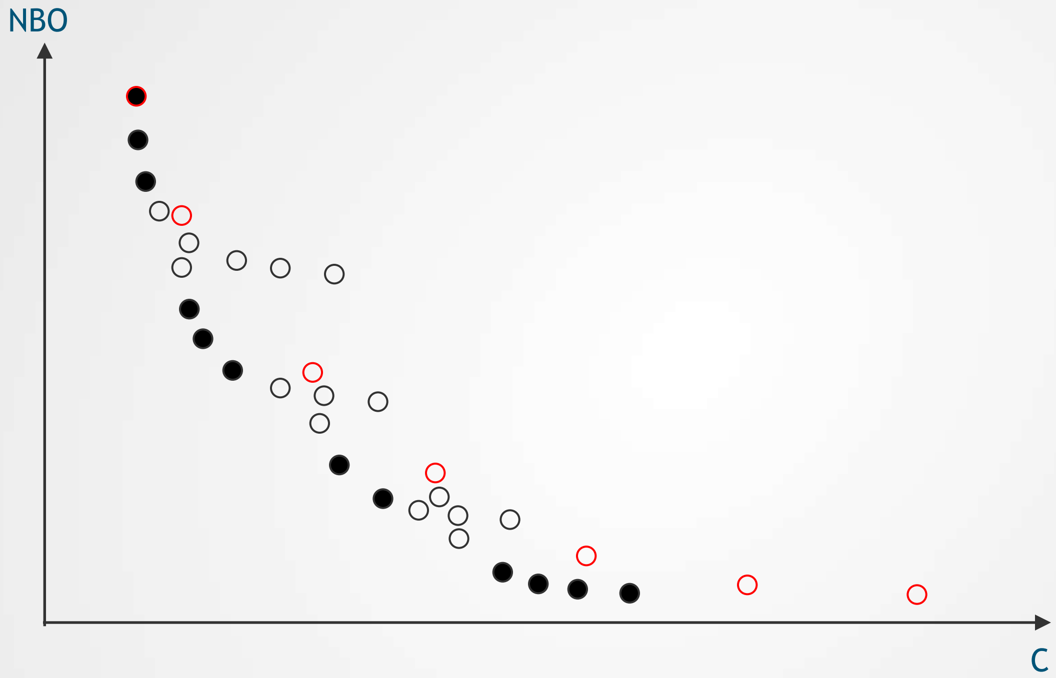
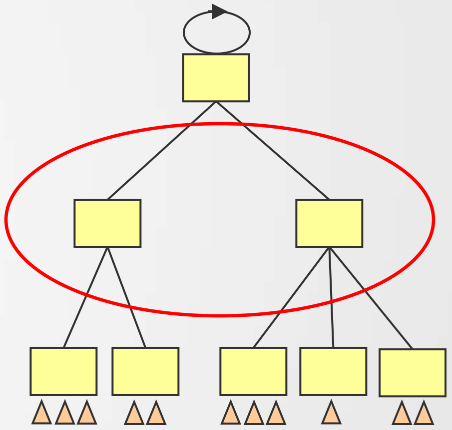
Optimization several levels





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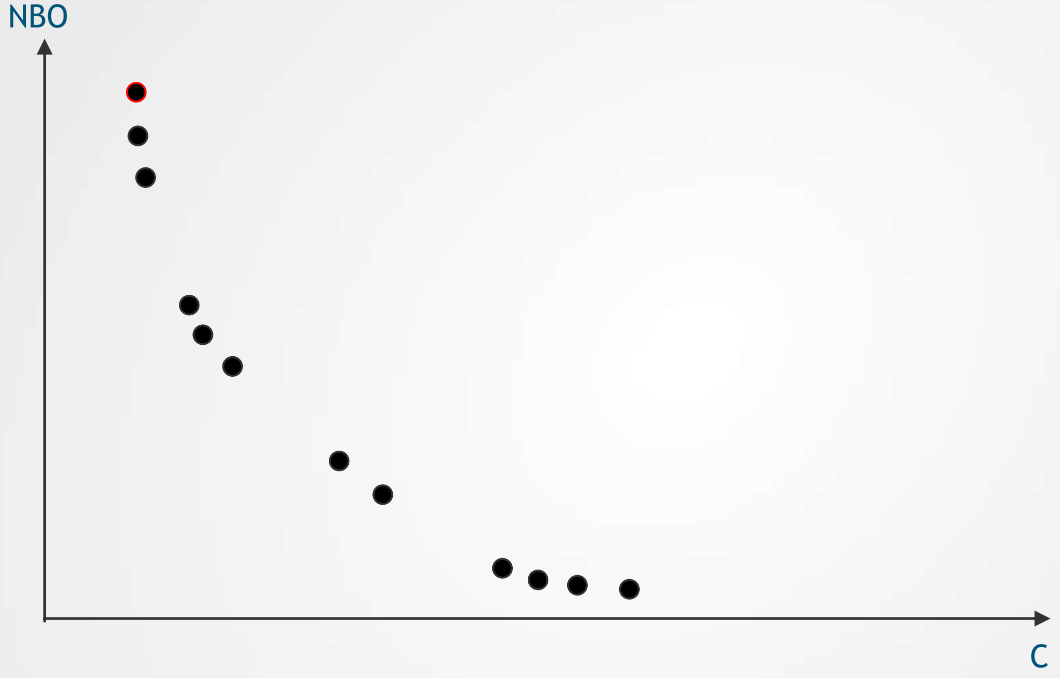

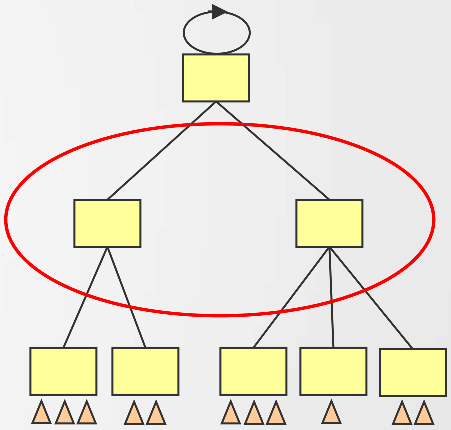

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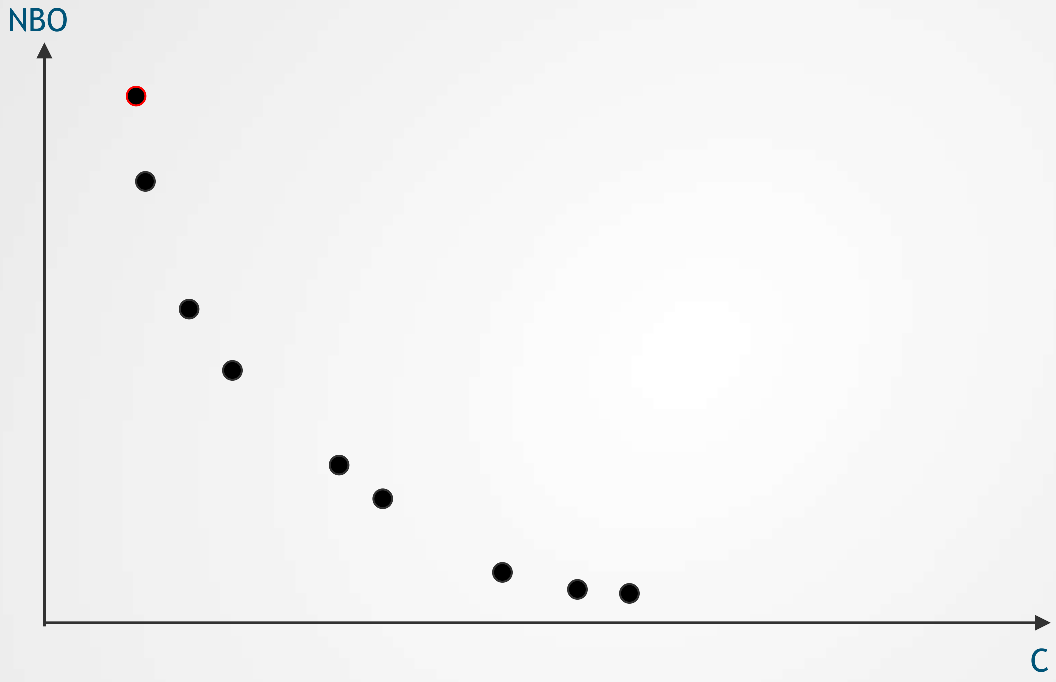
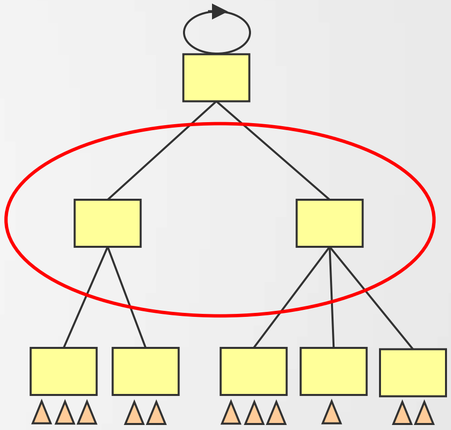
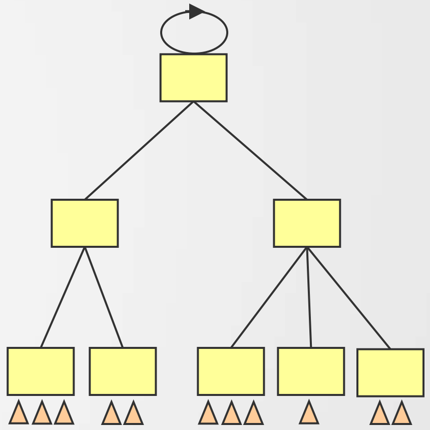




Significance levels:

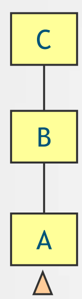
- A way to organize positions according to importance
  - Level 1 contains the most far away positions
  - Level N contains the system positions
- Calculation are performed level by level starting from level 1
- Positions at level k depend on positions at level k-1 only
- Positions that are equally “important” are optimized against each other



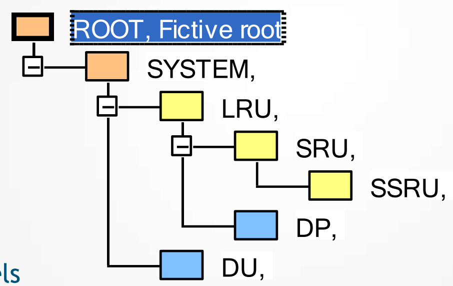
Significance levels:
multi echelon and multi indenture

- Significance refers both to station distance and indenture distance
- Only positions with demand are included

Stations



Materiel

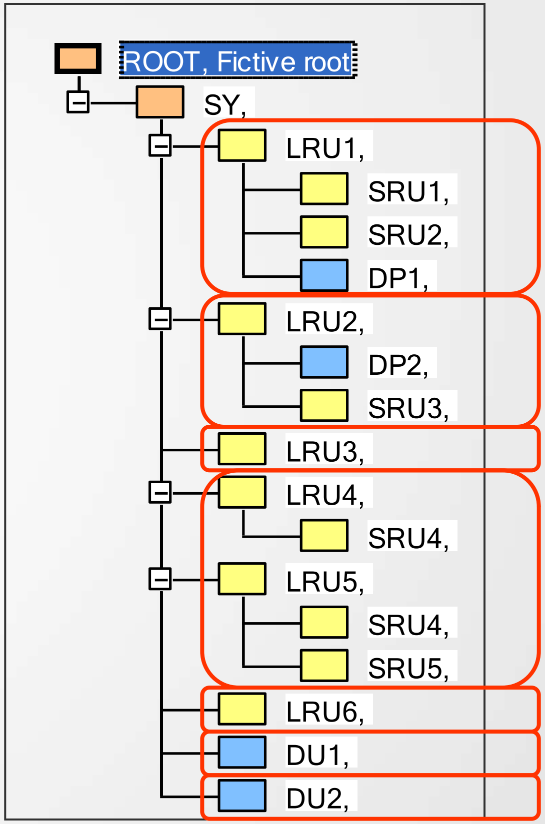


Sign levels

	C	B	A
SSRU	1	2	3
SRU/DP	2	3	4
LRU/DU	3	4	5
System			6

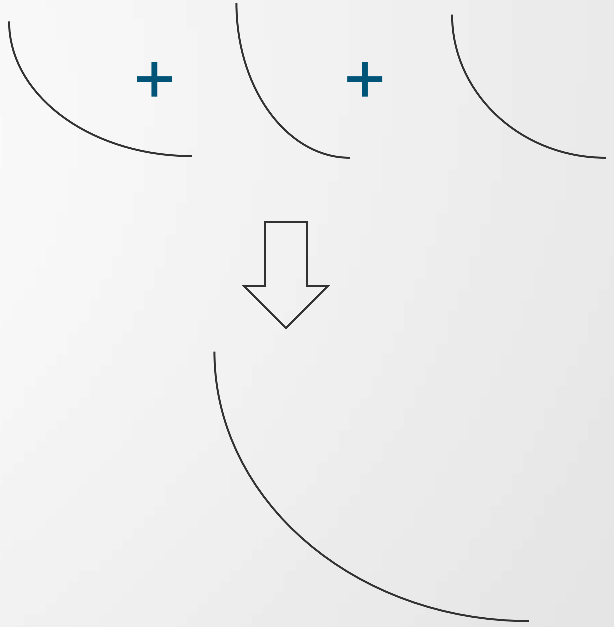
Subproblems:

- Items are split into independent subproblems
- Maximal split based on primary items
- Items with common subitems must belong to the same subproblem



Subproblems:

- A separate C/E-curve is created for each subproblem
- The different subproblem are combined by use of marginal allocation
- Faster and “better”



Different steps in the optimization:

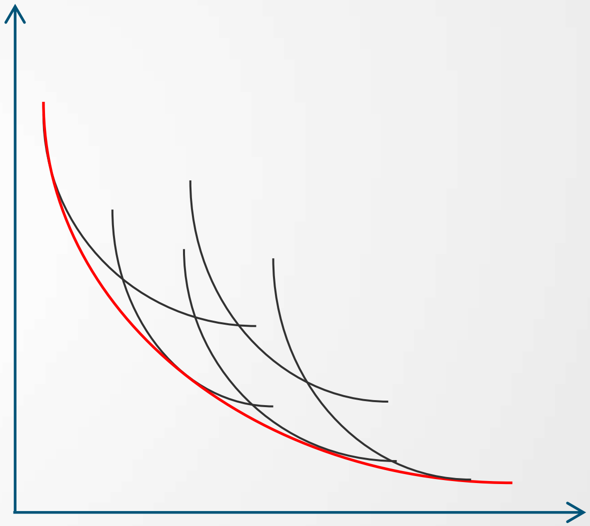
- Position
  - A C/E-curve to describe Cost/Moe per position
  - Implicit recursion formulas except for reorder positions
- Subproblem
  - Traditional optimization based on significance levels
- Total
  - Combining subproblems into total C/E-curve

Optimization of Maintenance Concepts (LORA):

- Split into subproblems based on task category
  - Related tasks needing same type of repair resources
- For each task category
  - Evaluate different maintenance concepts (resource allocations)
  - Include discard option (no resources)
  - Identify convex hull to find optimal solutions (C/E-curve)
- Master problem
  - combine subproblems using marginal allocation
  - generates (total) C/E-curve

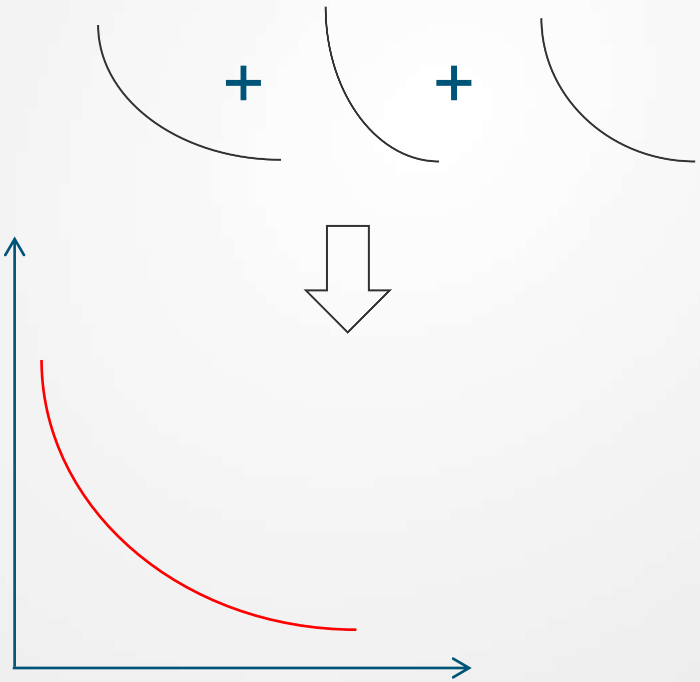
Task category subproblem:

- Evaluate different maintenance concepts
  - Solve different spares problems
- Identify convex hull
  - optimal solution for this subproblem



Master problem:

- Given optimal C/E-curves for each task category subproblem
- Combine to total C/E-curve by use of marginal allocation



Conclusion

- Through Marginal Analysis we are able to optimize:
  - Repair Concepts
  - Spare Parts Requirements
- We can model the actual system and it's environment in a highly accurate way
- Find the lowest possible cost solution to met availability and KPP requirements
- By modeling reality and being able to quickly provide solutions for rapid sensitivity and what if analysis, this method gives the analyst the ability to provide highly defensible results seconds rather than days