Supply chain re-design: an industrial application case in the electric motors industry

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Main objective & Problem statement

- *Objective: Redesign an optimal supply chain for the electric motors industry minimizing costs and deciding where to place warehouses, which installed warehouses should be eliminated, what are the stock capacities and safety stocks required as well as how to connect the different echelons of the supply chain in order to satisfy uncertain demand of motors.*

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- Multiple-echelon supply chain with Multi-product Factories (F), Central Warehouses (CWH), Warehouses (WH) and Repair Work-shops (SC) and End Customers (EC)
- Challenges:
  - **Multiple products** to deliver
  - **Uncertain Demand** with known probability distribution due to **motor failure rate** in End Customer Plants
  - Demand can be partially satisfied with **repaired motors**
  - **End customers** could have **storage** capacities
  - End customers expect different **service level** for their product (guaranteed time)

Solution approach

- Two main approaches to address uncertainty
  - **Probabilistic model**: uncertainty is considered indirectly using safety stock and guaranteed service level to prepare for shortage in stock → **non linear model**

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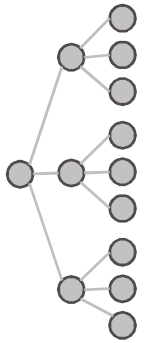

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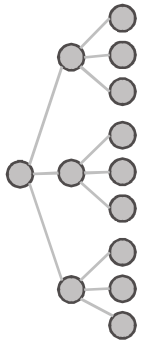

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Probabilistic Model

MINLP Model

Demand, Safety stock & Back-orders

- Uncertainty modeled with Poisson distribution
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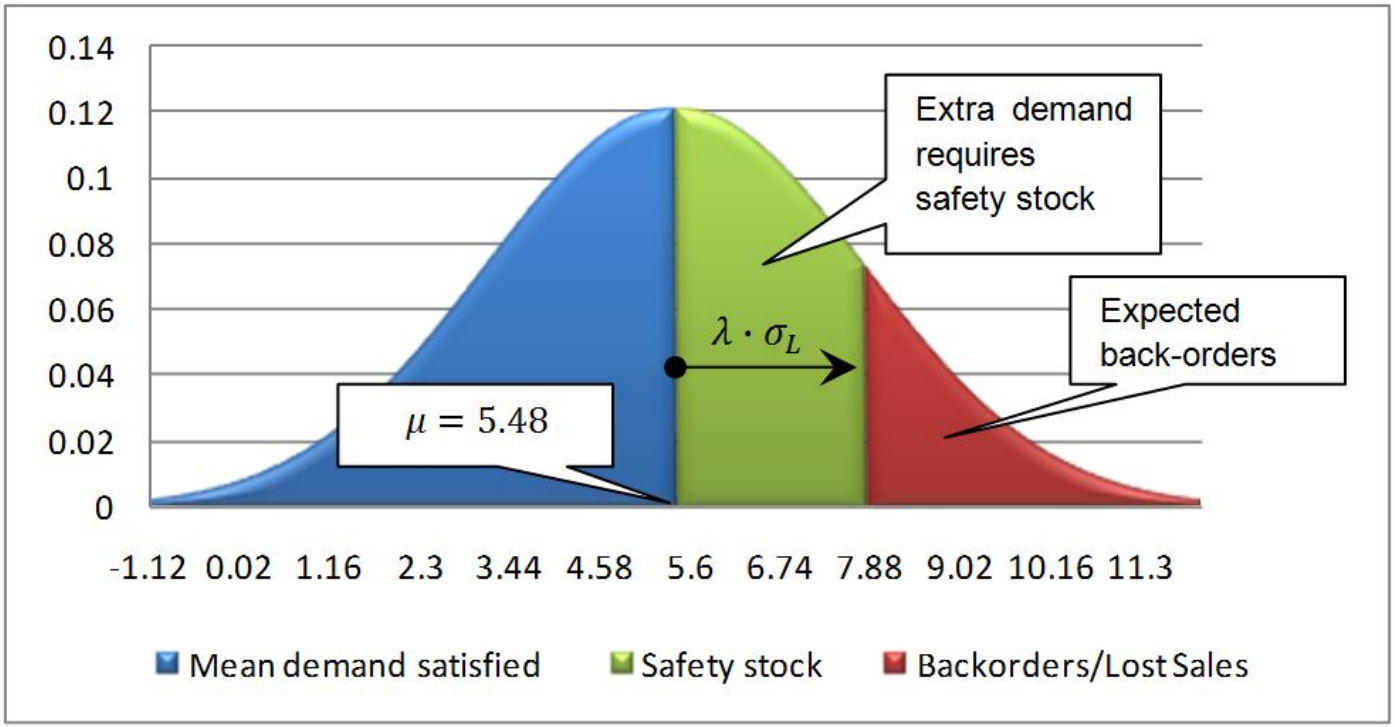

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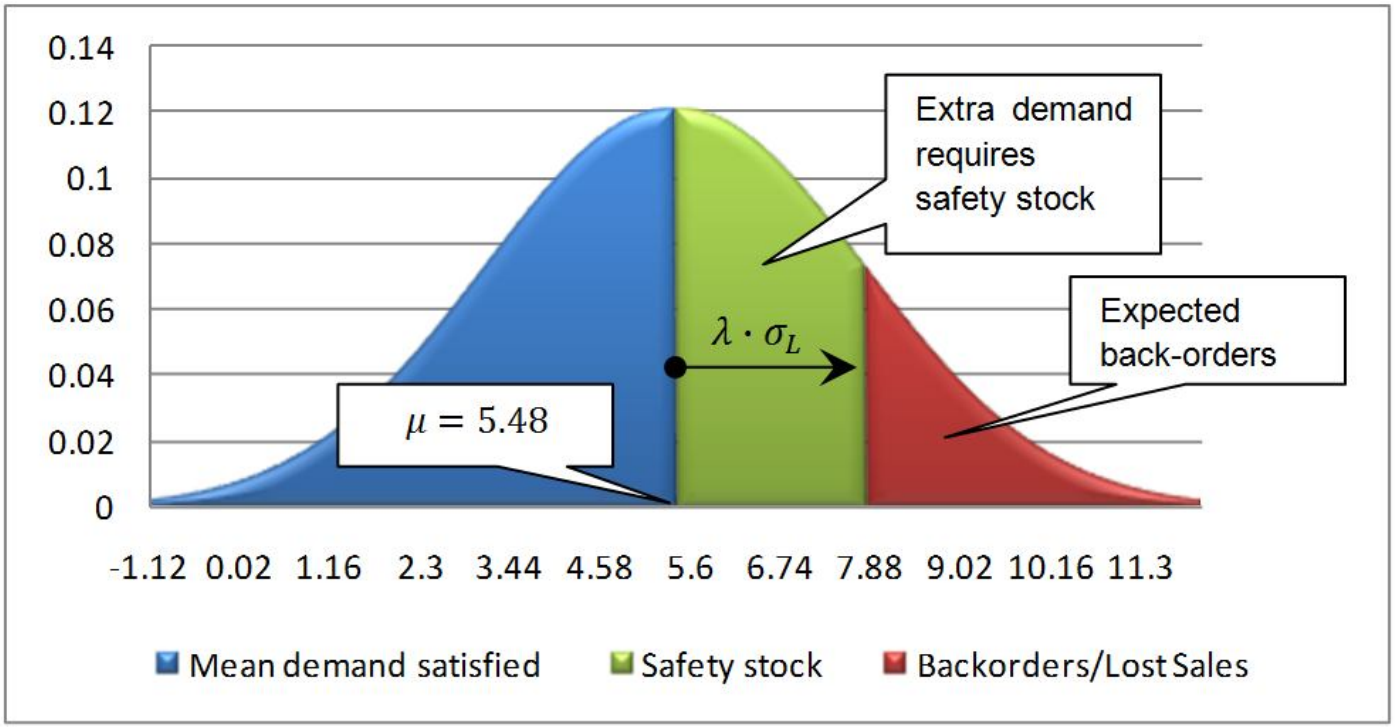
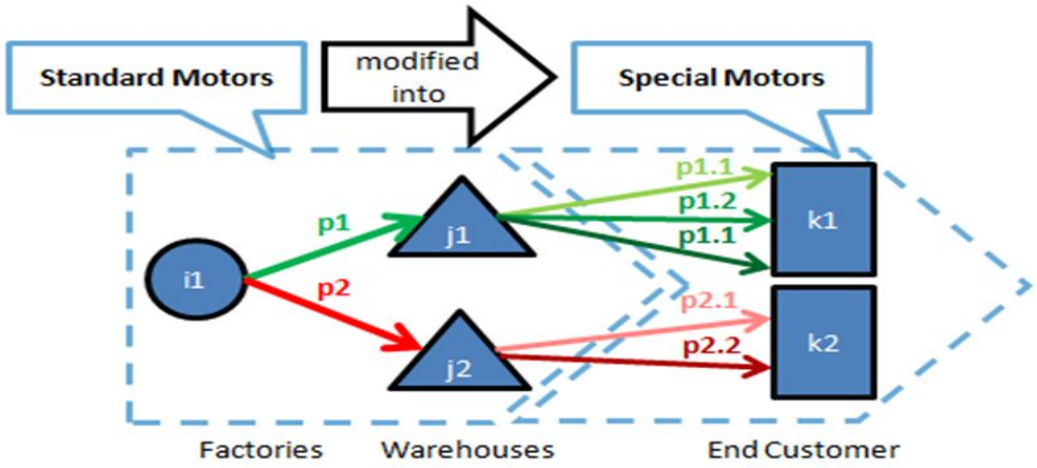


- How to face and diminish the EFFECT of demand uncertainty? → SAFETY STOCK (additional stock to face extra demand)
- Any demand exceeding target demand → Lost sales

Type of motors considered

- Factories and Warehouses store and handle standard motors
- Standard motors are modified into special motors in Warehouses
- End customers store special motors
- Tailor made motors are delivered directly from factories to end customers



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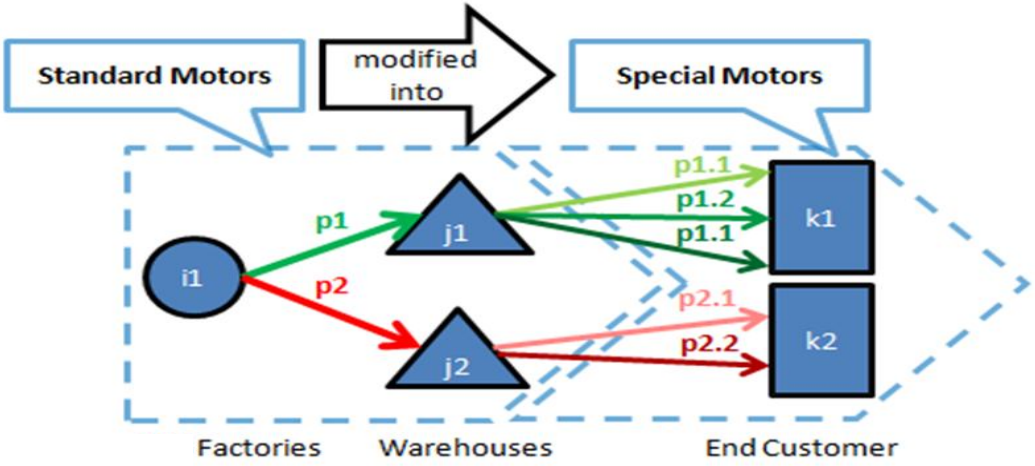
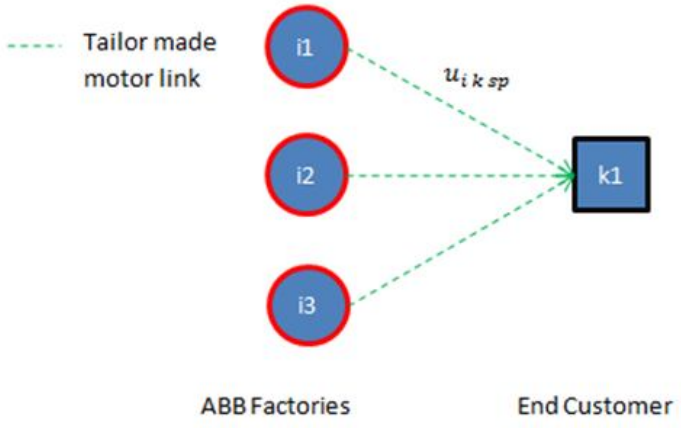
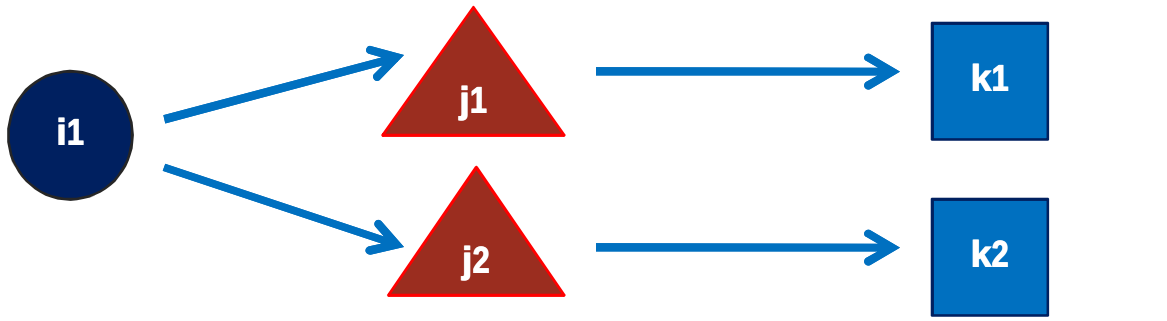




Motors Route

- **New motors**



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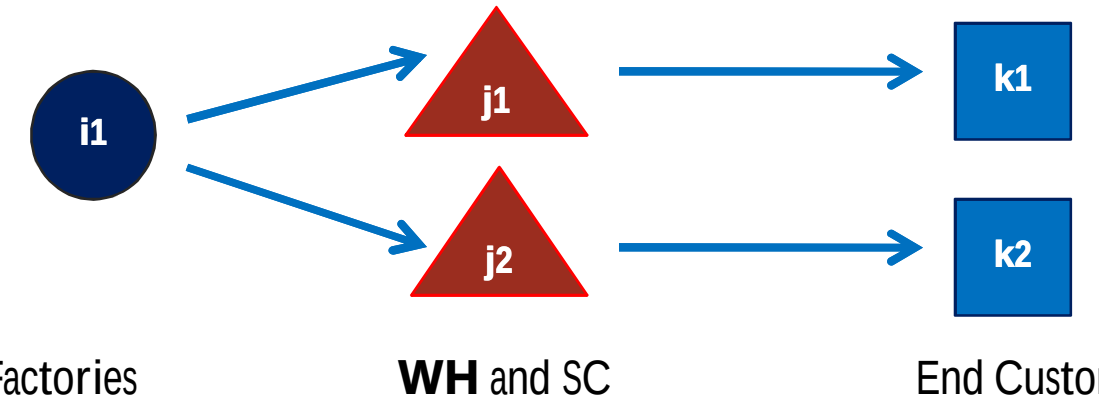
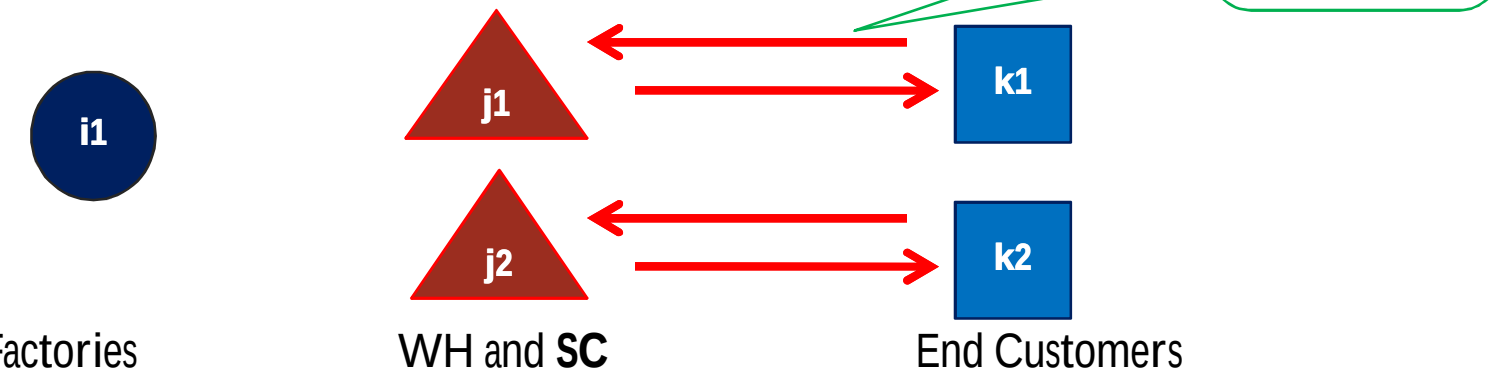


- **Used motors**



Objective Function & Constraints

- Costs in the objective function:
  - Installation / Rent / Expansion of Warehouses and Repair work-shops
  - Operating Fixed Costs of installed warehouses
  - Elimination Cost of installed Warehouses
  - Processing and repairing Costs
  - Inventory handling Costs of new motors and repaired motors
  - Transportation Costs
  - Safety stock Costs
  - Backorder Costs due to Stock shortage

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  - Reformulation constraints of bilinear products and square root function

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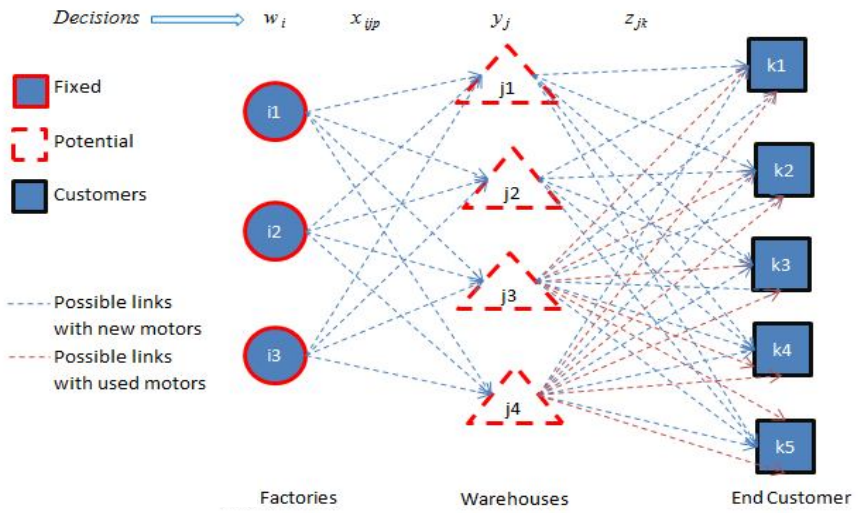
Remarks:

Original problem formulated as MINLP problem

Non-linearities in safety stock costs

Original formulation relaxed as a linear model applying piece wise linearization of the square roots that appear in the objective function

Three vs. Four level supply chains



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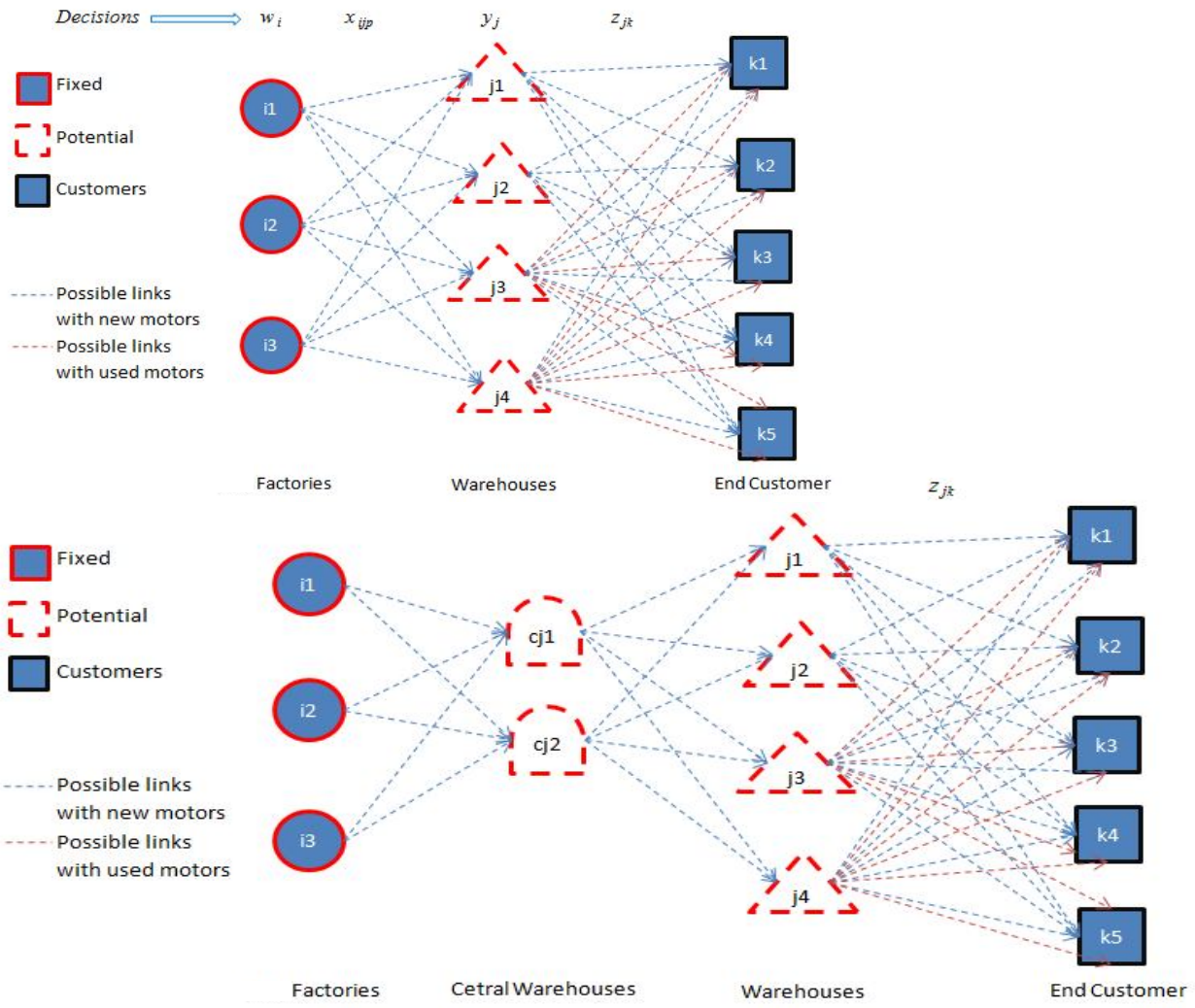

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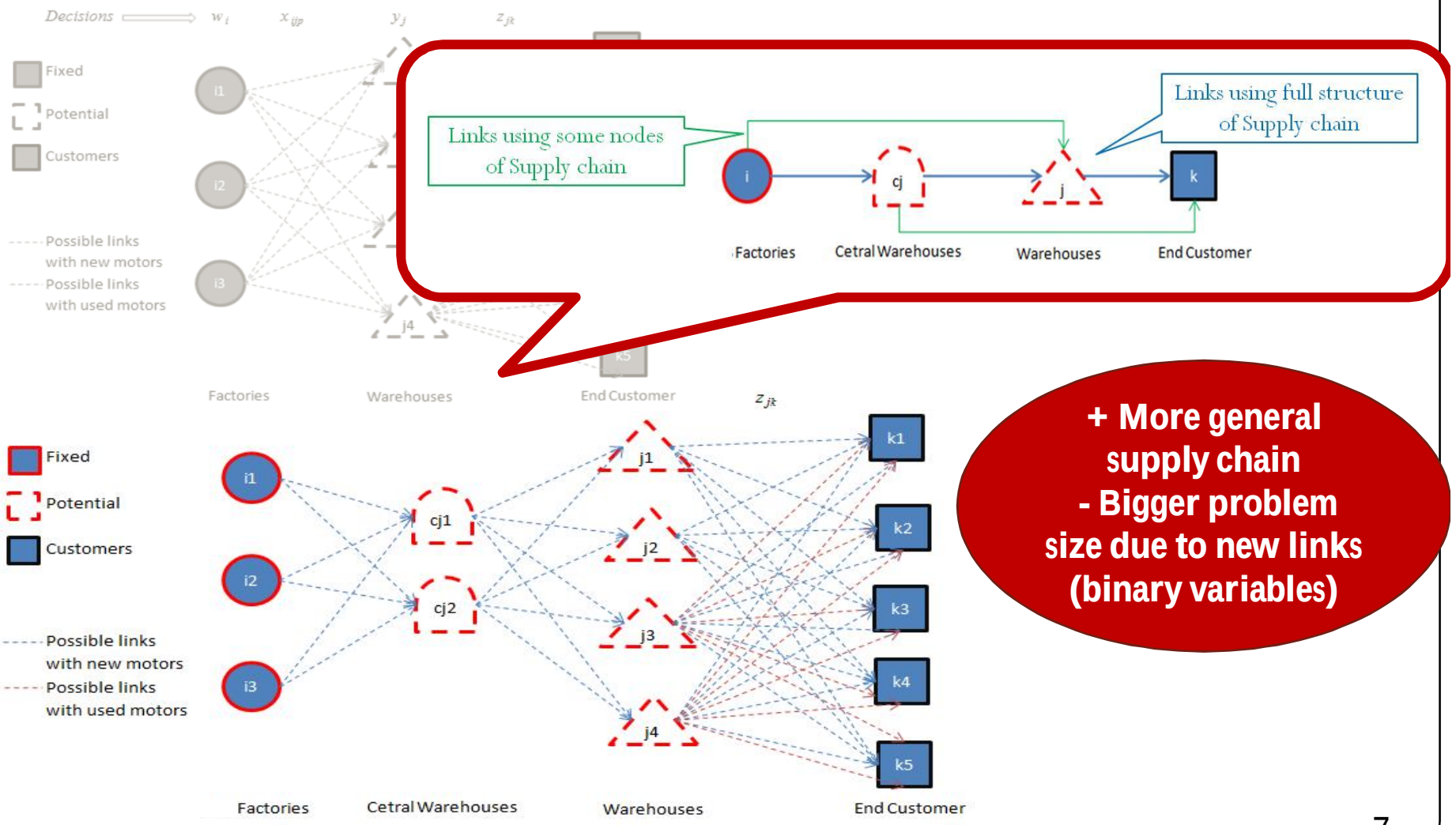

+ More general supply chain
- Bigger problem size due to new links (binary variables)

Illustrative example 4-level SC

- 4 Factories
- 2 Central warehouses
- 10 Warehouses
- 20 Customers
- 5 Standard motors
- 11 Special motors, one of them is tailor made
- 4 Service levels
- 8 Warehouses that can be repair work-shops
- Full structure of the supply chain must be used in this example

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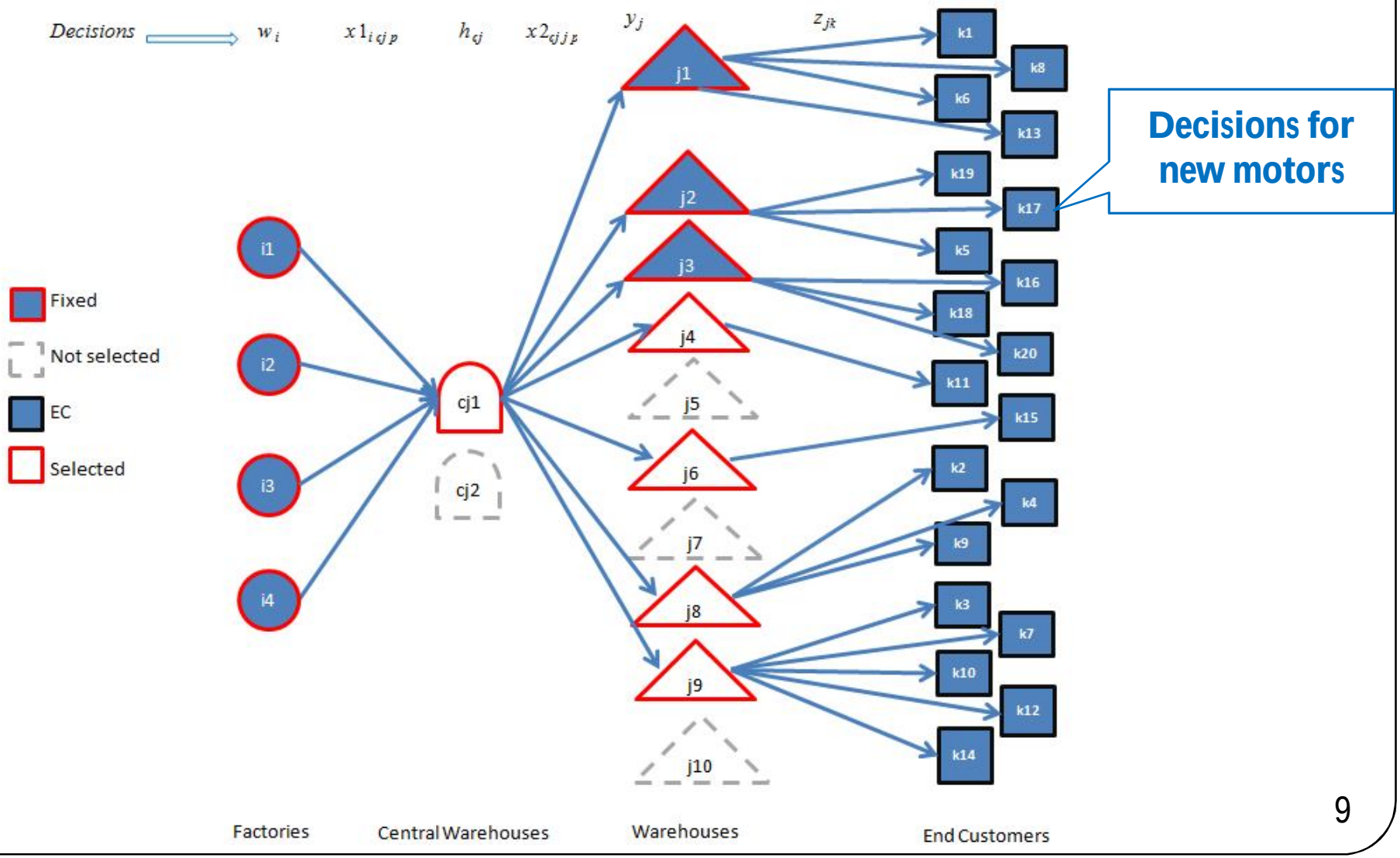
- MODEL PERFORMANCE

Objective Function (Costs)	Equations	Positive Variables	Discrete Variables	CPUs (MILP)
8827973.22	58559	25310	801	20.16

Supply chain selected



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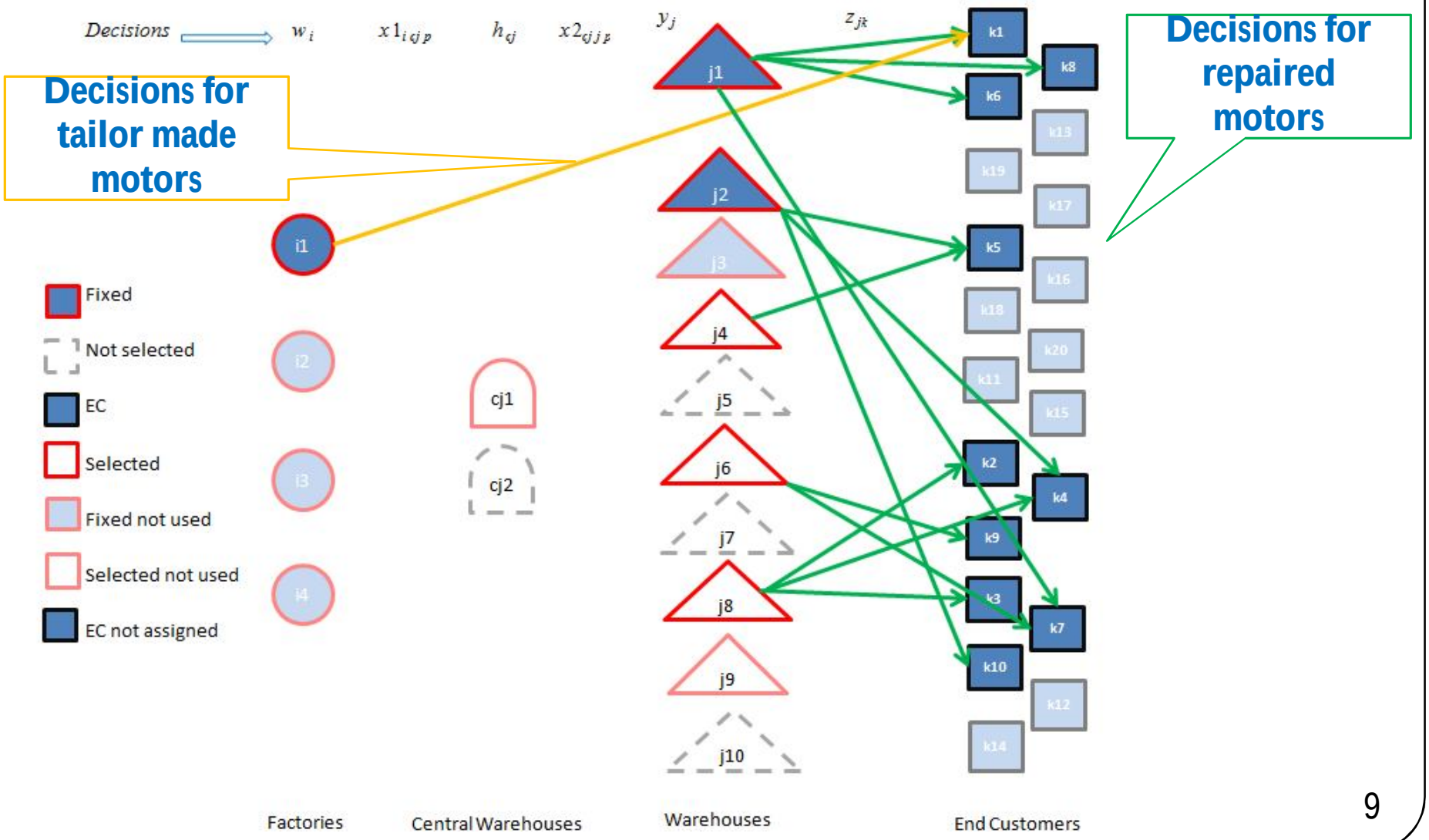

Safety stock

- Standard motors in warehouses

Standard motors

Warehouses	p_1	p_2	p_3	p_4	p_5
j_1	28	50	46	75	52
j_2		38	41	18	33
j_3	16	26		27	
j_4	19	4	17	14	
j_5	26	27	15	37	50

- Special motors in end customers

Special motors

End customers	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9	s_{10}	s_{11}
k_1				2							
k_2							1	1			
k_3						1					
k_4	1	1									
k_5			1								
k_7						1					
k_8							1				
k_9								1			
k_{10}										1	
k_{11}						1					
k_{15}								1			

Small amounts comparing to warehouses due to risk pooling effect!

Thanks for your attention!

Questions?