879.2: Integration of Demand Planning and Manufacturing Planning

RESEARCH PERSONNEL:

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Primary Anticipated Results:

- A methodology for analyzing the capacity requirements of products and their groupings
- A risk model for capacity planning under uncertainty
- A methodology for optimal capacity allocation

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Task Description:

- **Year 1: Capacity requirement analysis at multiple levels of granularity**
  - Developed a method to analyze the capacity requirements of a hierarchy of products. (Products are first classified into a hierarchy of products and their families based on similarity in routing.)
  - Developed a risk model for capacity plans.
- **Year 2: Methodology of capacity planning under uncertainty**
  - Developed a framework of analysis for capacity requirement under uncertainty
  - Developed a model to optimize the risk of capacity plans
- **Year 3:**
  - Refine the algorithms
  - Demonstrate business planning applications, e.g., timing and sizing of plant investment or outsourcing

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Task Deliverables:

- Capacity analysis and aggregation method (Model, Report) (DEC-01)
- Integrated method for demand and capacity modeling (Model, Report) (DEC-02)
- A framework and methodologies of business and demand planning (Model, Report) (DEC-03)

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- **Executive Summary**:

During the second year we have

- developed a framework of analysis for capacity planning under uncertain product demands
- developed a method to optimize the risk of capacity plans

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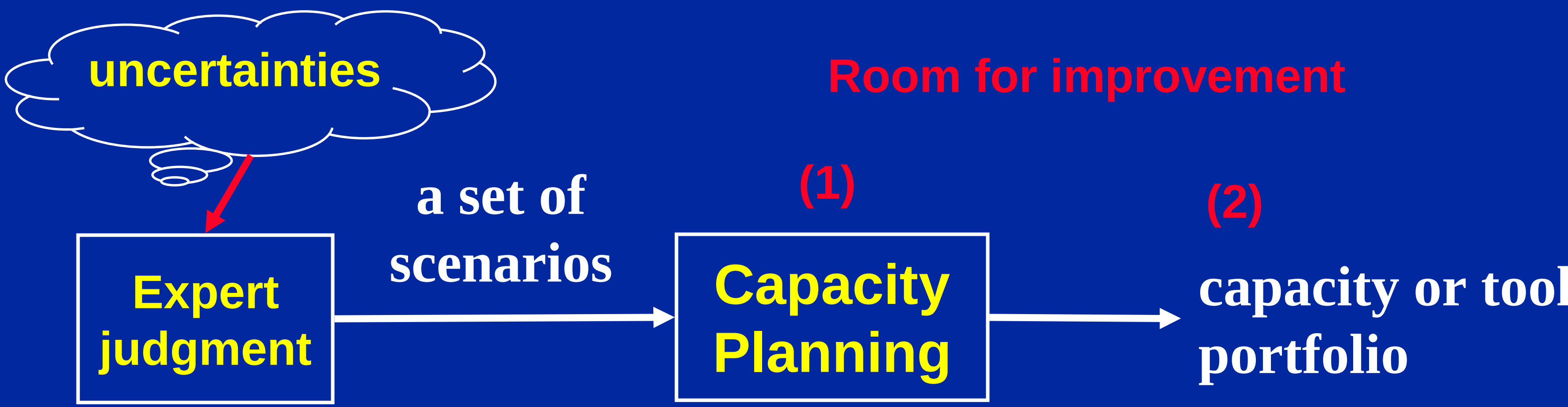
- **Conventional Mathematical Models**



- Objective function: to maximize the revenue (subtracted by penalty for lost-sales)

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- **Motivation**
  1. This representation of scenarios is crispy.

Scenario		A	B	C
weight		0.4	0.5	0.1
Product and demand	#1	23	26	30
	#2	12	15	14
	#3	10	11	16

  2. Over-capacity and under-capacity are equally detrimental.
  3. Risk information has been overlooked.

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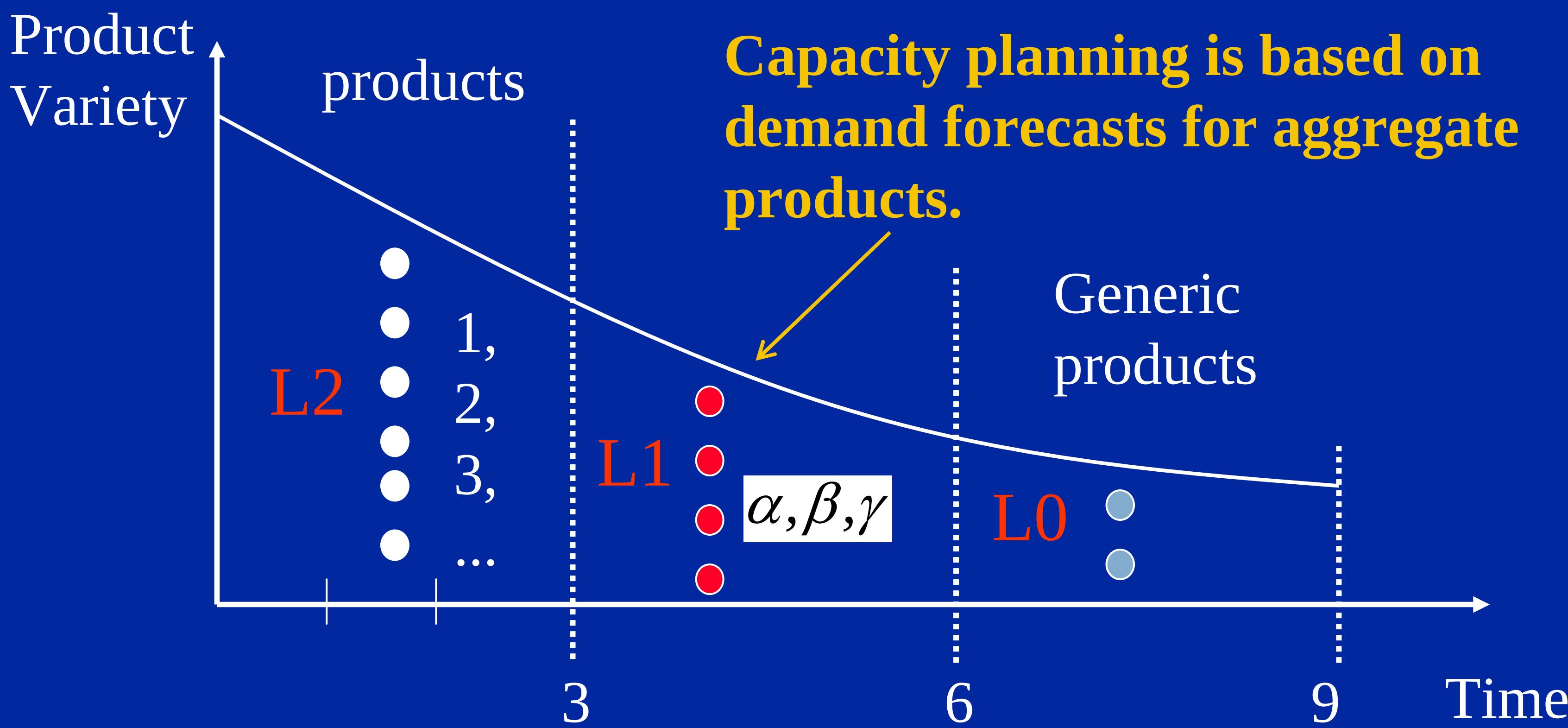
- **Product Variety Granularity**



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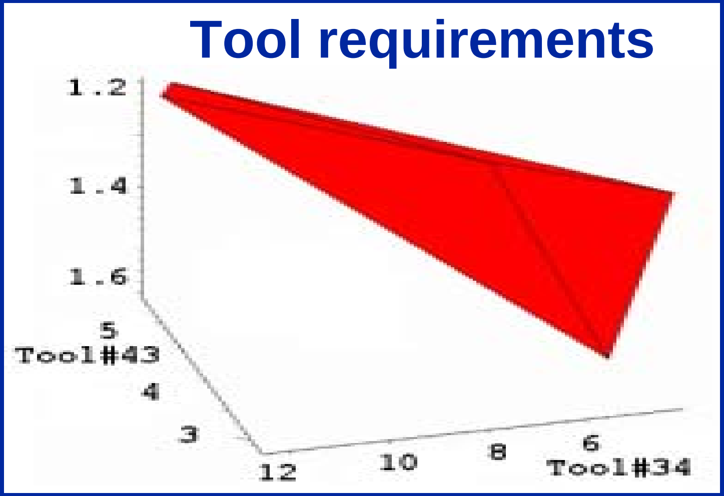
- **Tool Requirements**

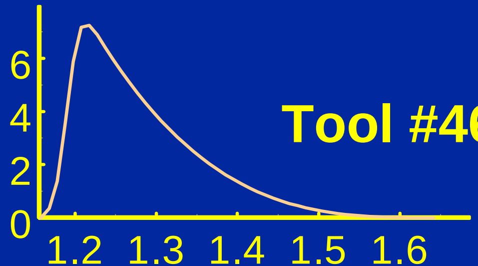
Suppose a product family β contains n products

$$\text{demand } D_\beta = \sum_{i=1}^{n} D_i = \sum_{i=1}^{n} a_i \cdot D_\beta$$

$$\text{product mix}: \sum_{i=1}^{n} a_i = 1$$

- Because the product mix (a_i) is uncertain, the tool requirements will be a convex hull.





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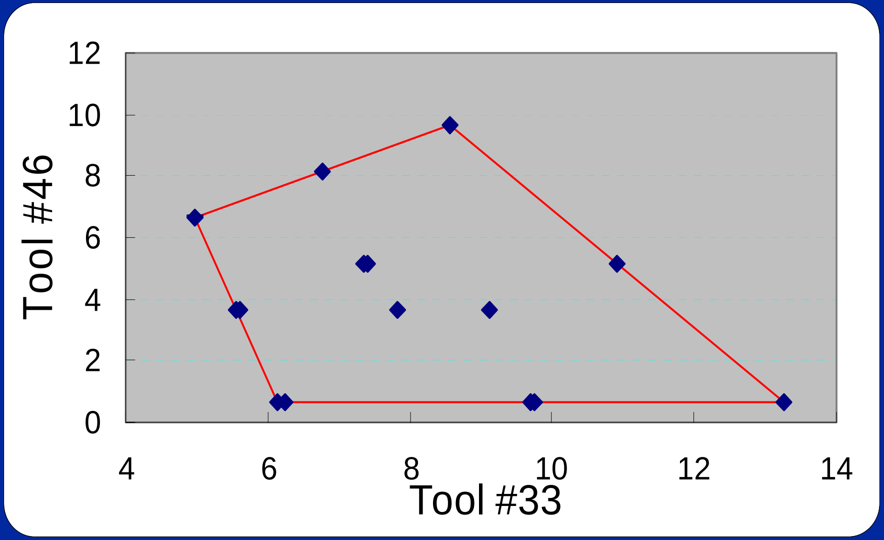
- **A discrete model of the convex hull**
  - Generate all scenarios of product demand mixes D_i

$$\sum_{i=1}^{n} D_i = D_\beta$$

  - Compute the tool requirements R_k

$$R_k = \sum_i W_{k,i} \cdot D_i$$



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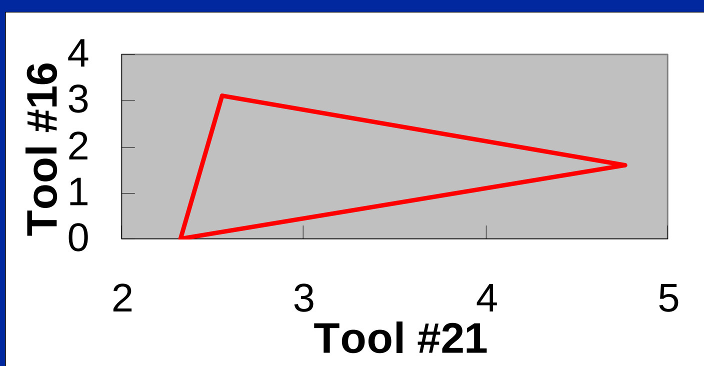
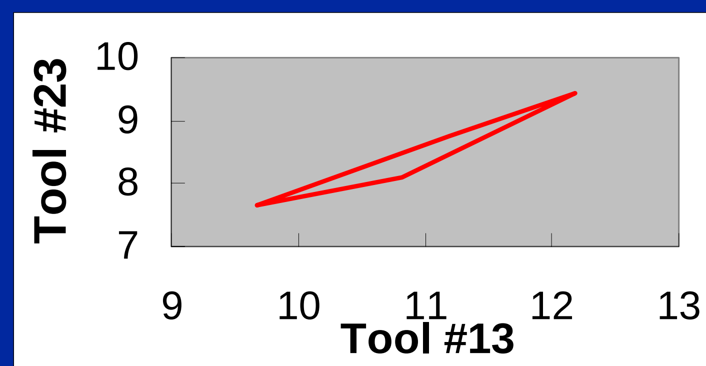
- **Correlation between tool requirements**

	Tool #13	Tool #16	Tool #21	Tool #23
Tool #13	**-**	**0.38**	**-0.43**	**0.97**
Tool #16		**-**	**0.1**	**0.50**
Tool #21			**-**	**-0.22**
Tool #23				**-**

- Low correlation



- High correlation



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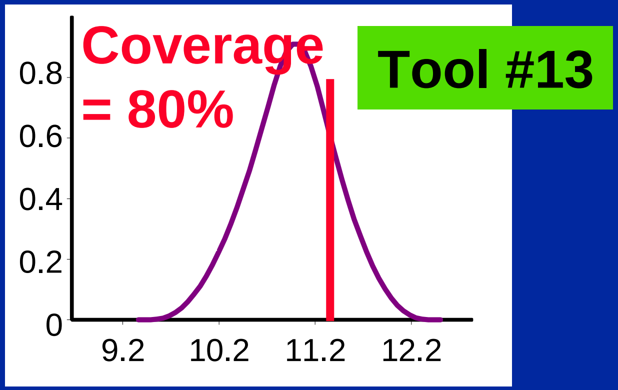
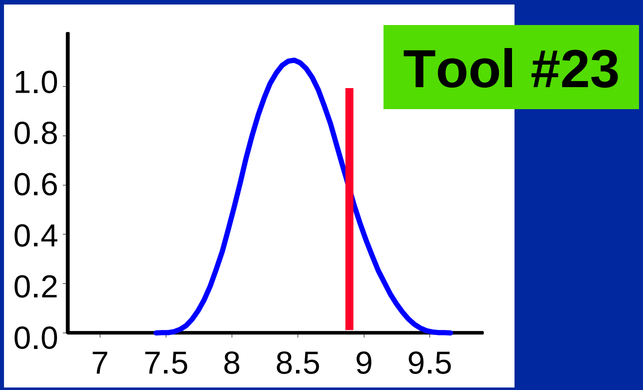
- Effect of correlation





11.34 ← **provisioned capacity** → 8.77

- How does the coverage improve if the quantity of a tool is increased by 0.1?

	False expectation	Realizable
Tool #13	5.58%	1.51 %
Tool #23	7.37%	2.11 %

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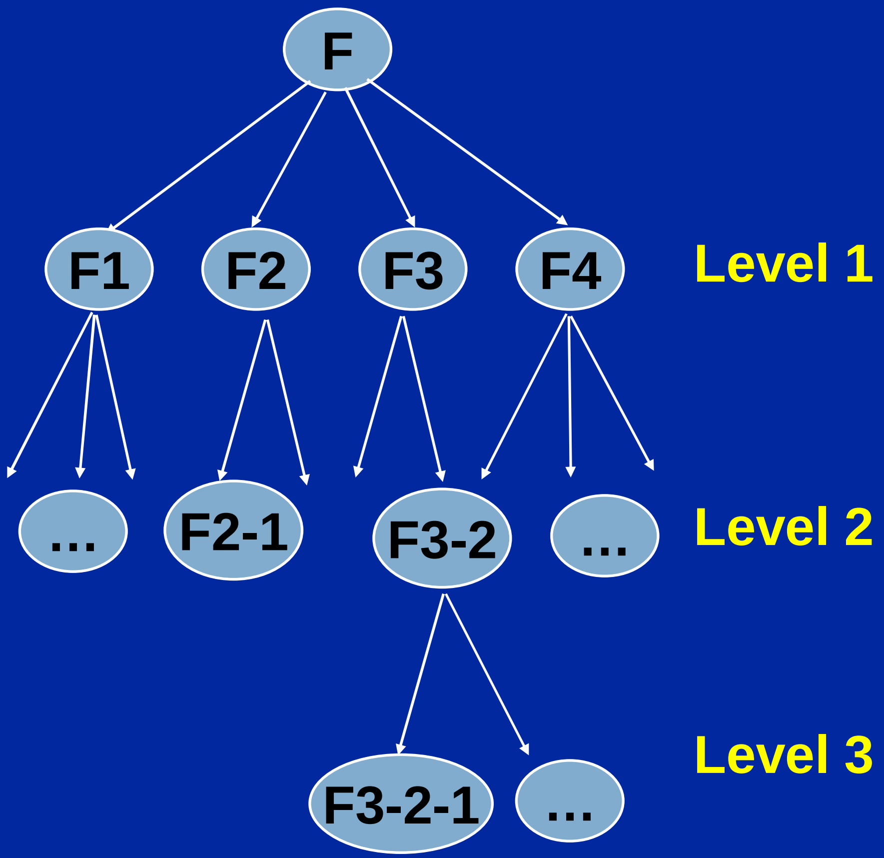
A Dataset

- 440 routings (F)
- Each routing has 6 to 12 critical tool groups.
- Total numbers of tool groups: 65



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- **Family Size: Level 1 & 2**

	Routes	Tools
F1	136	32
F2	135	12
F3	46	9
F4	123	12

	Routes	Tools
F1-1	32	13
F1-2	23	9
F1-3	60	10
F1-4	21	11

	Routes	Tools
F2-1	42	12
F2-2	8	10
F2-3	51	11
F2-4	23	11
F2-5	11	12

	Routes	Tools
F3-1	17	7
F3-2	10	8
F3-3	19	9

	Routes	Tools
F4-1	48	12
F4-2	20	12
F4-3	55	12

The 4 clusters are disjoint in tool groups.

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- **Family size: Level 3**

	# R	# T		# R	# T
F1-1	32	13	F1-1-1	20	13
			F1-1-2	12	7
F1-2	23	9			
F1-3	60	10	F1-3-1	33	10
			F1-3-2	27	10
F1-4	21	11			

	# R	# T		# R	# T
F4-1	48	12	F4-1-1	17	12
			F4-1-2	31	12
F4-2	20	12			
F4-3	55	12	F4-3-1	41	12
			F4-3-2	14	12

	# R	# T		# R	# T
F2-1	42	12	F2-1-1	30	12
			F2-1-2	12	12
F2-2	8	10			
F2-3	51	11	F2-3-1	37	11
			F2-3-2	14	11
F2-4	23	11			
F2-5	11	12			

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- **Family Size: Level 4**

	# R	# T		# R	# T
F1-3-1	33	10	F1-3-1-1	13	10
			F1-3-1-2	18	10

	# R	# T		# R	# T
F4-1-2	31	12	F4-1-2-1	23	12
			F4-1-2-2	6	12
F4-3-1	41	12	F4-3-1-1	23	12
			F4-3-1-2	16	11

	# R	# T		# R	# T
F2-1-1	30	12	F2-1-1-1	18	12
			F2-1-1-2	10	11
F2-3-1	37	11	F2-3-1-1	17	11
			F2-3-1-2	18	11

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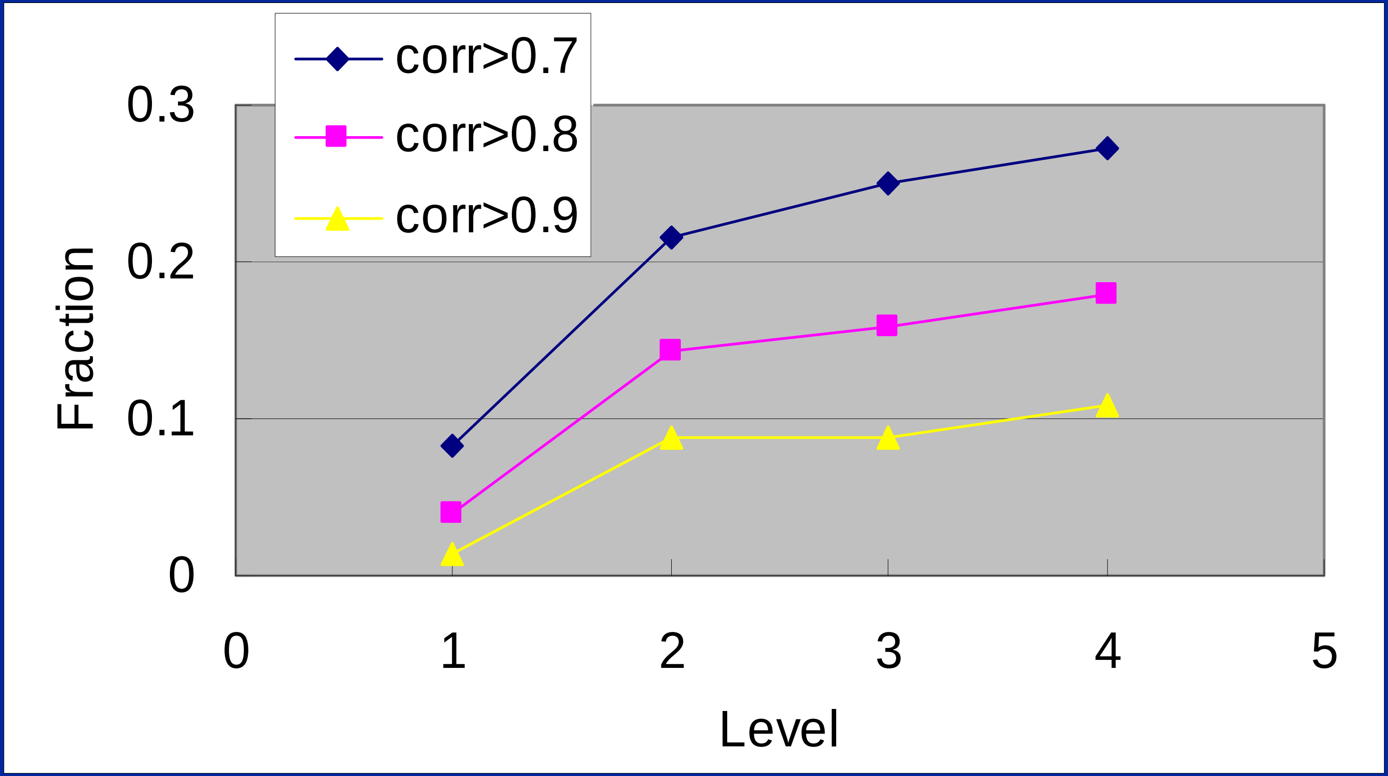
- How many tool pairs have high correlation?



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- **Error coverage for different tool pairs**

Tool	#39	#41	#42	#43	#44	#45
#39	-	0.78	-0.77	0.38	0.95	0.03
#41		-	-0.51	0.15	0.87	-0.13
#42			-	-0.72	-0.79	-0.44
#43				-	0.51	0.73
#44					-	0.14
#45						-

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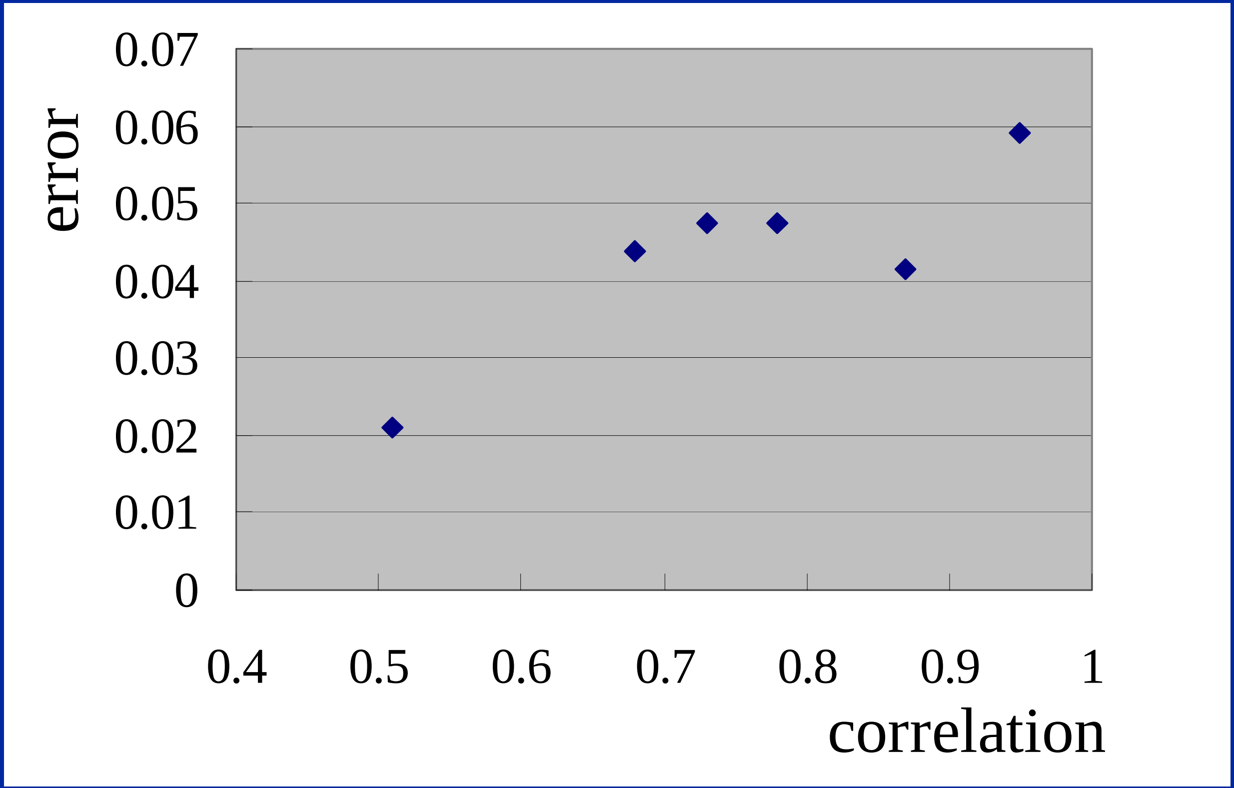
- Error of coverage estimation

$$F_{u,v}(Cu,Cv) - F_u(Cu) \cdot F_v(Cv)$$



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- **A Proposed Procedure of Capacity Planning**

1. Use a mathematical model to optimize the revenue and lost-sales penalty. (e.g., stochastic program)
2. Adjust the resultant portfolio solution to improve the coverage

Adjustment $\leqq$ capital increment

x_k : tool quantity of tool group k

Δx_k : adjustment

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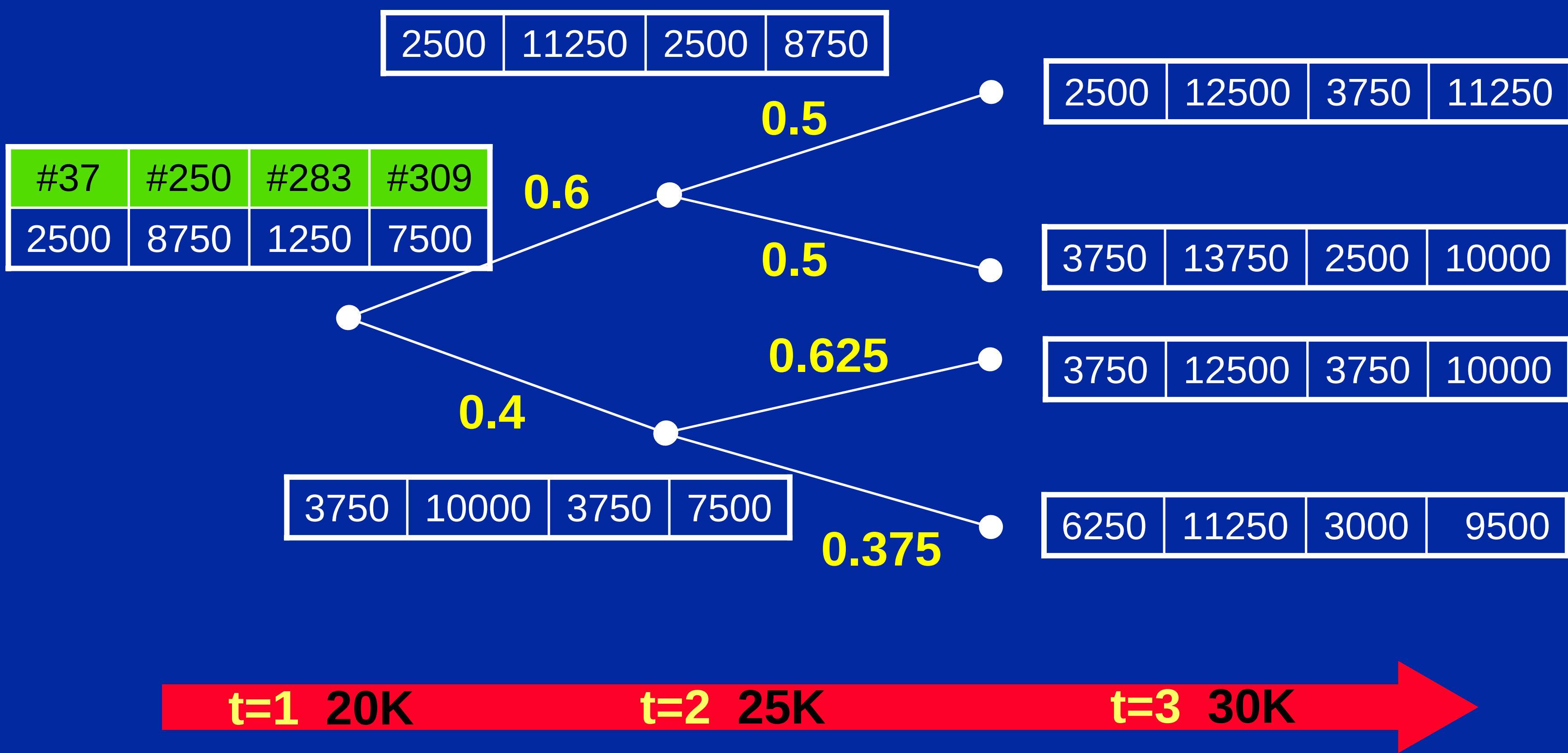
- **An Example of demand scenarios**



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- A stochastic program

$P_{s,t}$: prob. of occurence of scenario s

$d_{i,s,t}$: demand of product i in scenario s

β_i : penalty of prodution shortage

$$Min \quad \sum_t \sum_k \alpha_k \cdot x_{k,t} + \sum_t \sum_s \sum_i P_{s,t} \cdot \beta_i \cdot u_{i,s,t}$$

Tool cost

Shortage penalty

s.t.

$$\sum_i w_{i,k} \cdot y_{i,s,t} \le C_k \left(\sum_{\tau=0}^{t} x_{k,t} \right) \quad \forall k, (s,t)$$

$$y_{i,s,t} + u_{i,s,t} \ge d_{i,s,t} \quad \forall i, (s,t)$$

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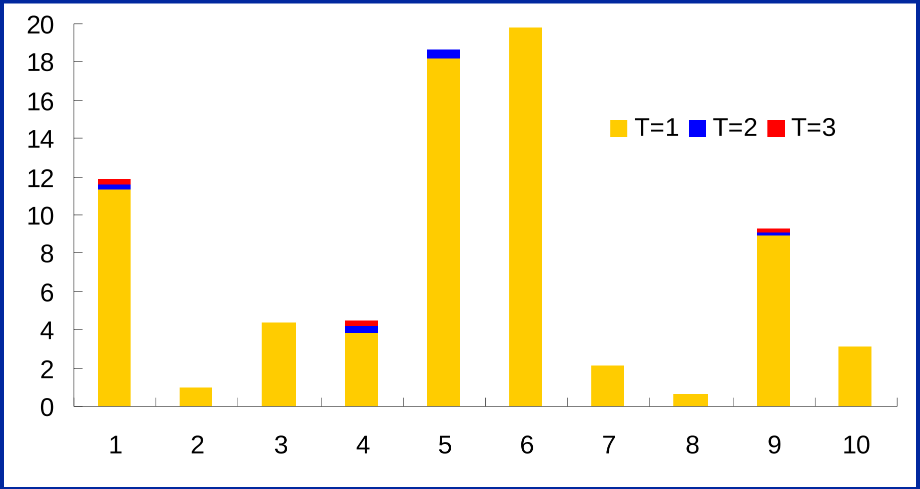
- Resultant Tool Portfolio (tool quantity)

	#13	#14	#15	#16	#17	#20	#21	#22	#23	#24
T=1	11.37	0.98	4.4	3.83	18.22	19.78	2.18	0.63	8.89	3.14
T=2	0.27	0	0	0.37	0.45	0.04	0	0	0.23	0
T=3	0.20	0	0	0.3	0.01	0	0	0	0.14	0



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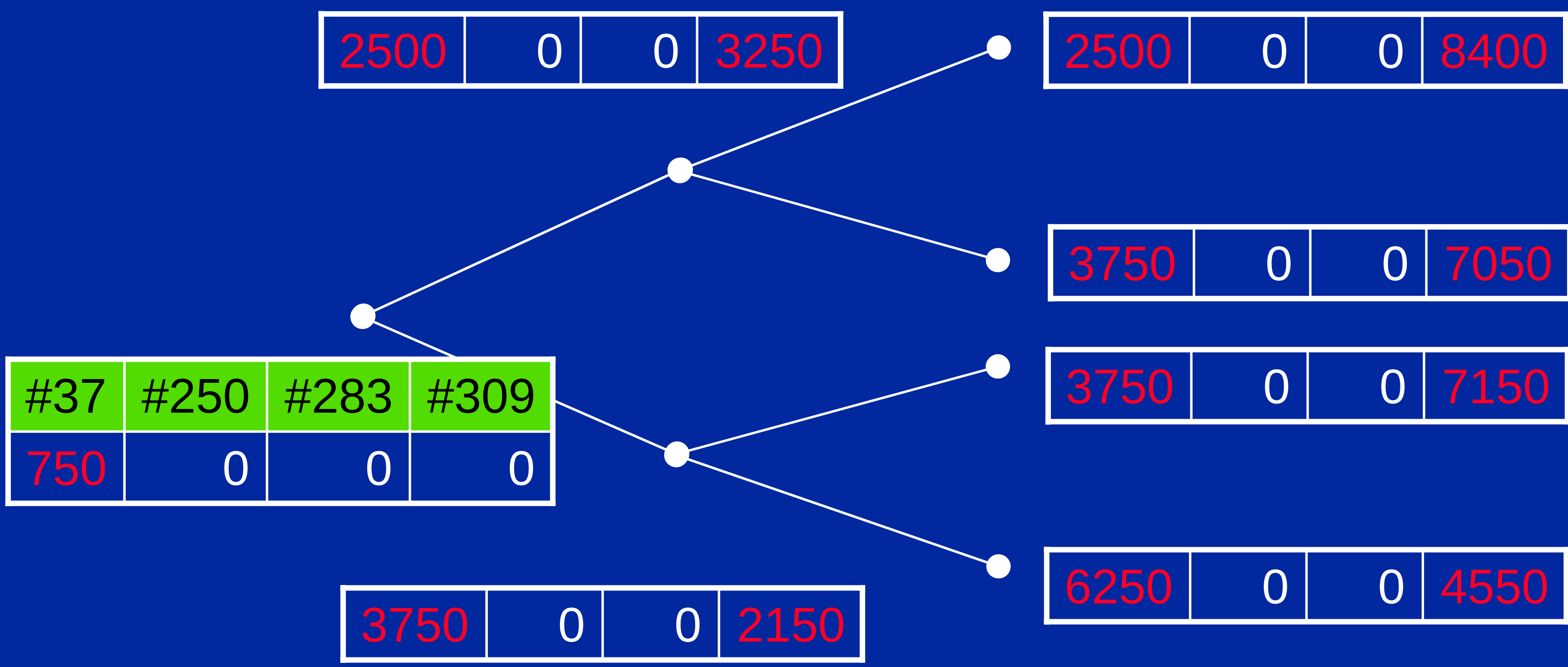
- **Shortage of production**



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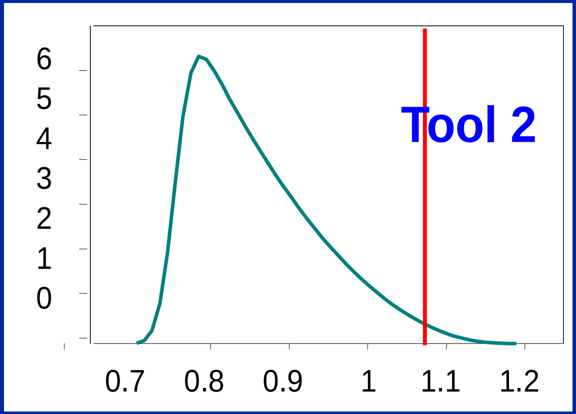
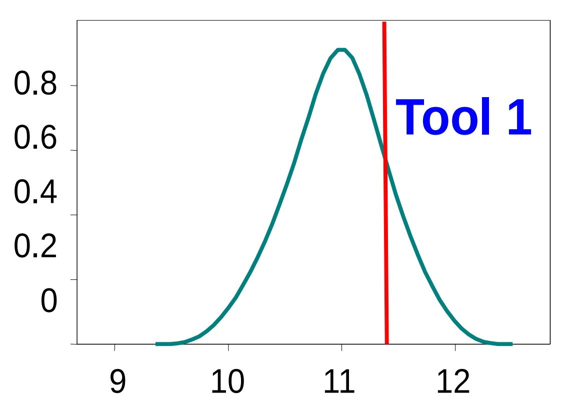
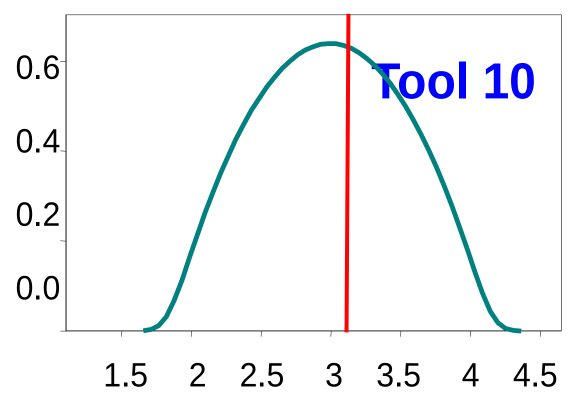
- The coverages of 10 tool groups are not balanced.







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- **Boundary of the convex hull**
  - **Total demand = d**
  - **The number of products = n**

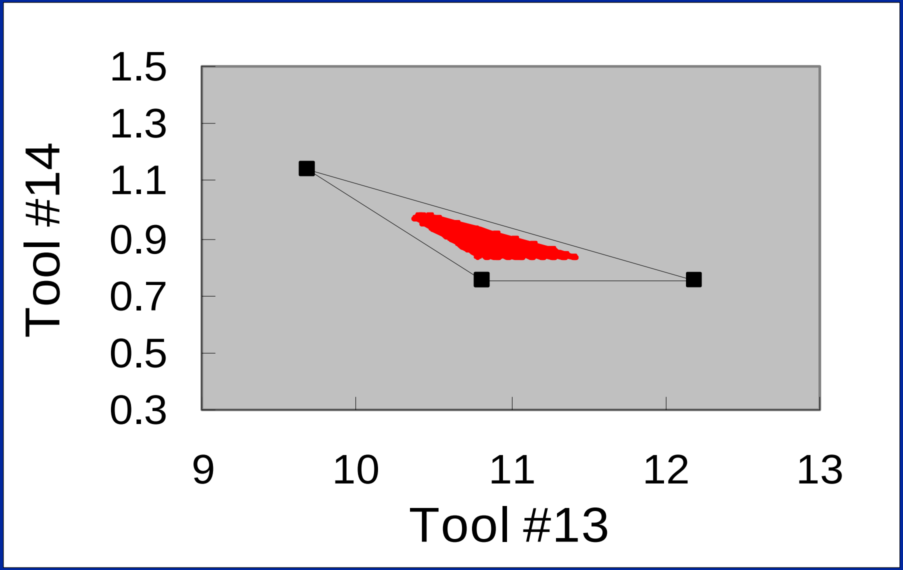
$$d_1+d_2+\ldots+d_n = d$$

$$d_{1(min)} < d_1 < d_{1(max)}$$

$$d_{2(min)} < d_2 < d_{2(max)}$$

$$\vdots$$

$$d_{n(min)} < d_n < d_{n(max)}$$



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- To Optimize the coverage
  1. *Generate the convex hull (a discrete representation)*
  2. *Analyze the correlation between tool requirements*
  3. *Identify the tool pairs with high correlation*
  4. Compute the density functions from the convex hull

x_k : tool quantity

Δx_k : adjustment to tool quantity

β : additional capital investment

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- **Optimization of the coverage**

	Tool Groups									
	#13	#14	#15	#16	#17	#20	#21	#22	#23	#24
X_k	11.37	0.98	4.4	3.83	18.22	19.78	2.18	0.63	8.89	3.14
coverage	0.82	0.91	0.36	0.89	0.93	0.99	0.86	1	0.88	0.6
$\Delta X_k(\beta=100)$	0.13	0.02	0.6	0.17	-0.19	-0.28	--	--	0.11	0.36
coverage	0.88	0.93	0.9	0.93	0.89	0.94	0.86	1	0.93	0.79
$\Delta X_k(\beta=500)$	0.18	0.12	0.6	0.17	-0.22	-0.28	0.32	--	0.11	0.86
coverage	0.9	0.99	0.9	0.93	0.88	0.94	0.96	1	0.93	0.99

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Conclusions

- Developed a framework to represent the uncertainty in tool requirements.
- Showed that the correlation between tool requirements is significant.
- Improvements on capacity planning
  - Robust tool portfolio
  - Risk information

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- **Future Plan and Directions**
  - Scenario modeling
  - Modeling lead-time in capacity planning: correlation between demand scenarios in multiple time periods