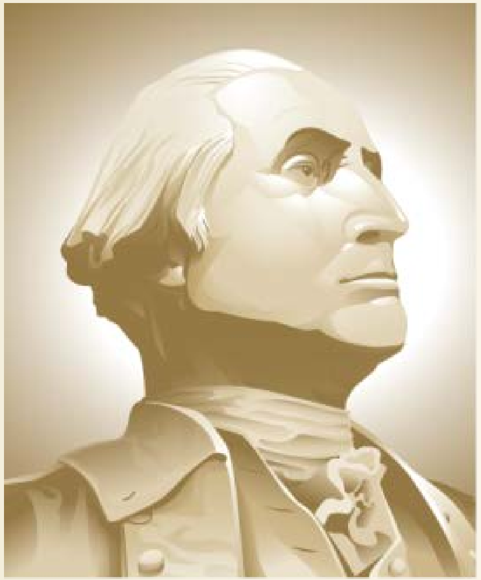
Monitoring Remaining Project Completion Uncertainty, a Bayes Network Approach



THE GEORGE WASHINGTON UNIVERSITY

WASHINGTON, DC

Johan Rene van Dorp and Ifechukwu Nduka

Department of Engineering Management and Systems Engineering

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INTERNATIONAL SOCIETY FOR BAYESIAN ANALYSIS

SYMPOSIUM

I²SDS - Decision Sciences

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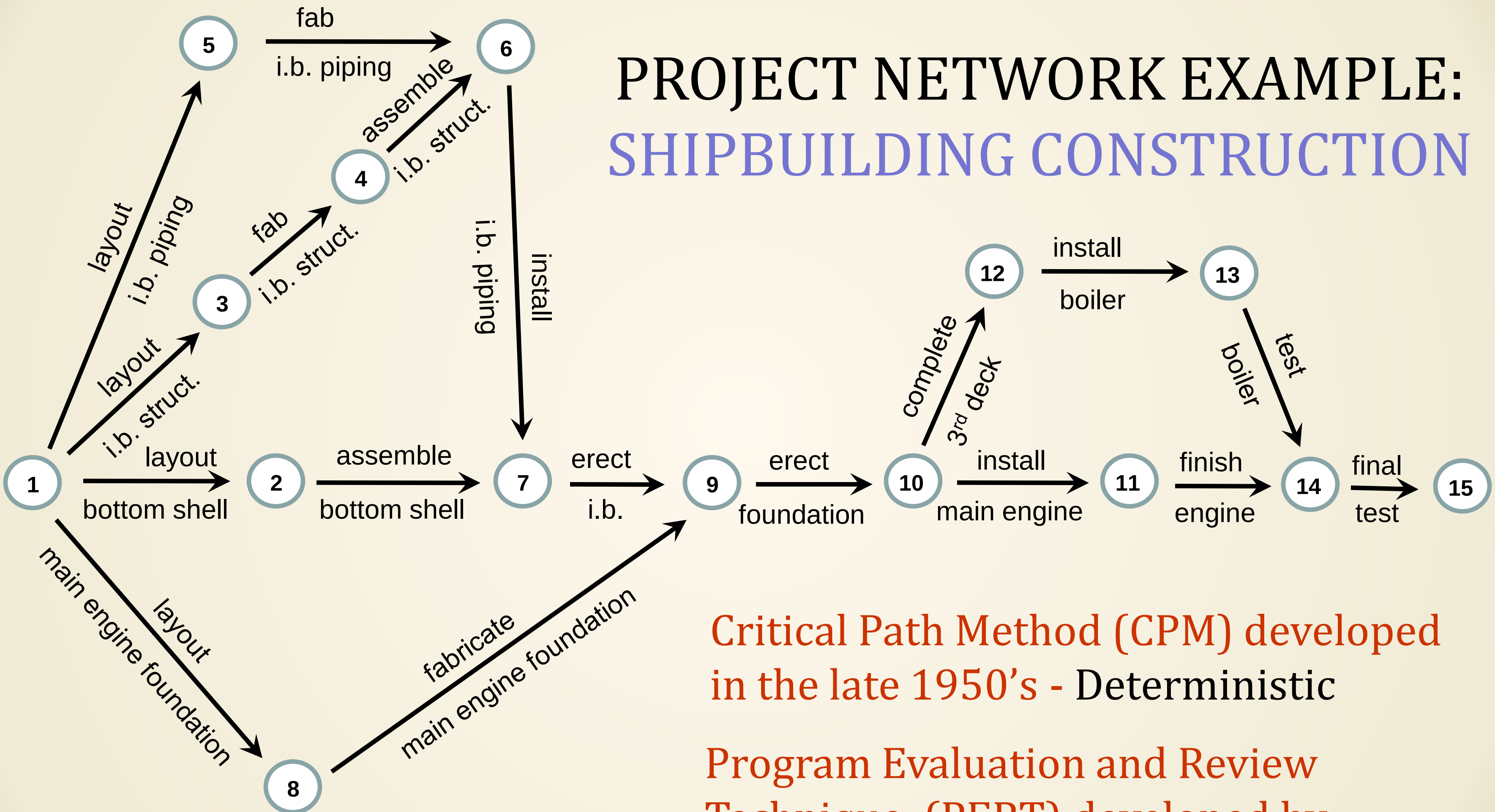
SCHOOL OF BUSINESS

- Case Study Description
- Bayesian Network Model
- Statistical Dependence Elicitation
- Uncertainty (n) and Dependence (β) Parameter Selection
- Prior Completion Time Uncertainty
- Posterior Analysis: Monitoring Uncertainty
- Conclusion

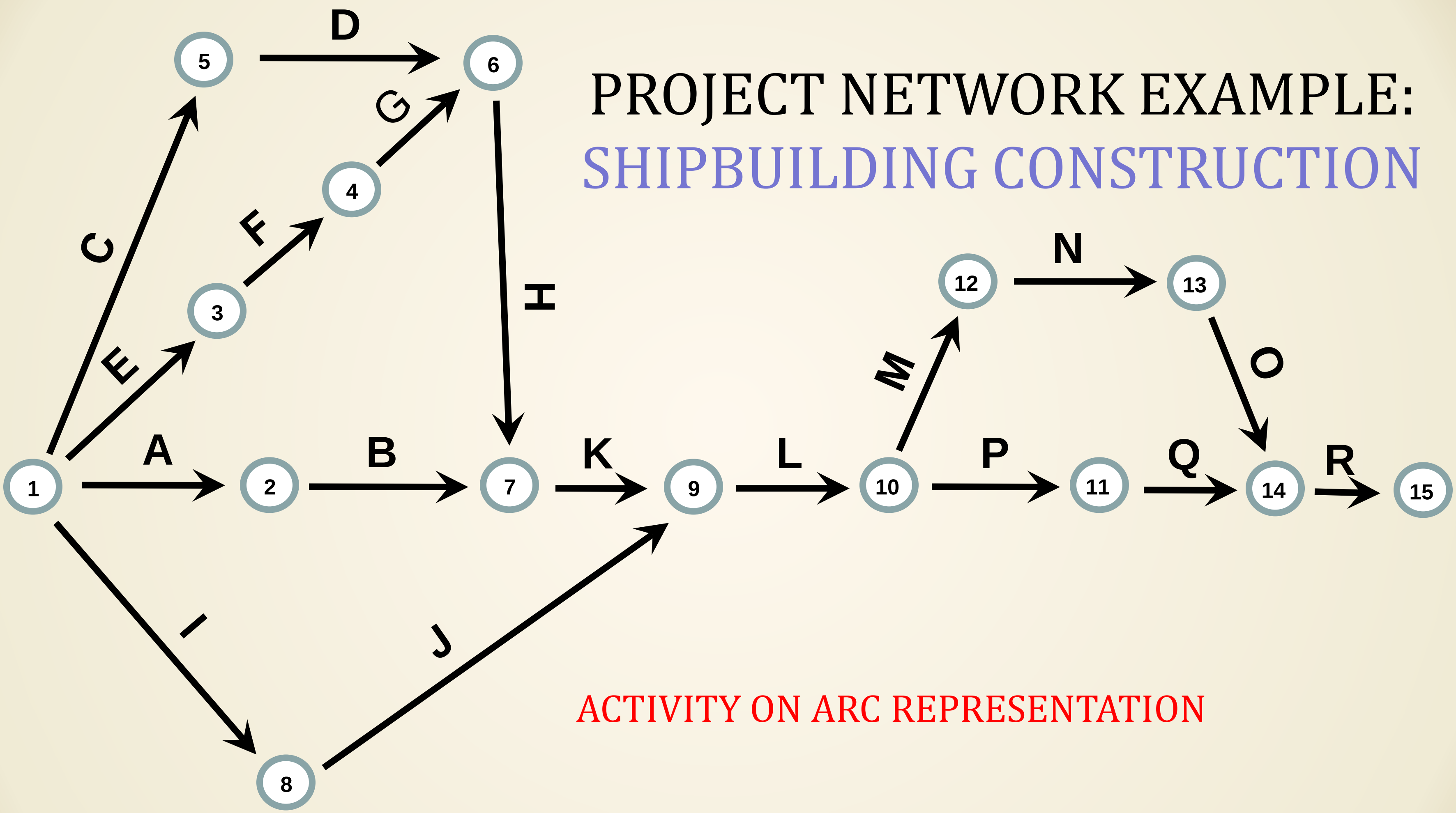
PROJECT NETWORK EXAMPLE: SHIPBUILDING CONSTRUCTION



Critical Path Method (CPM) developed in the late 1950's - Deterministic

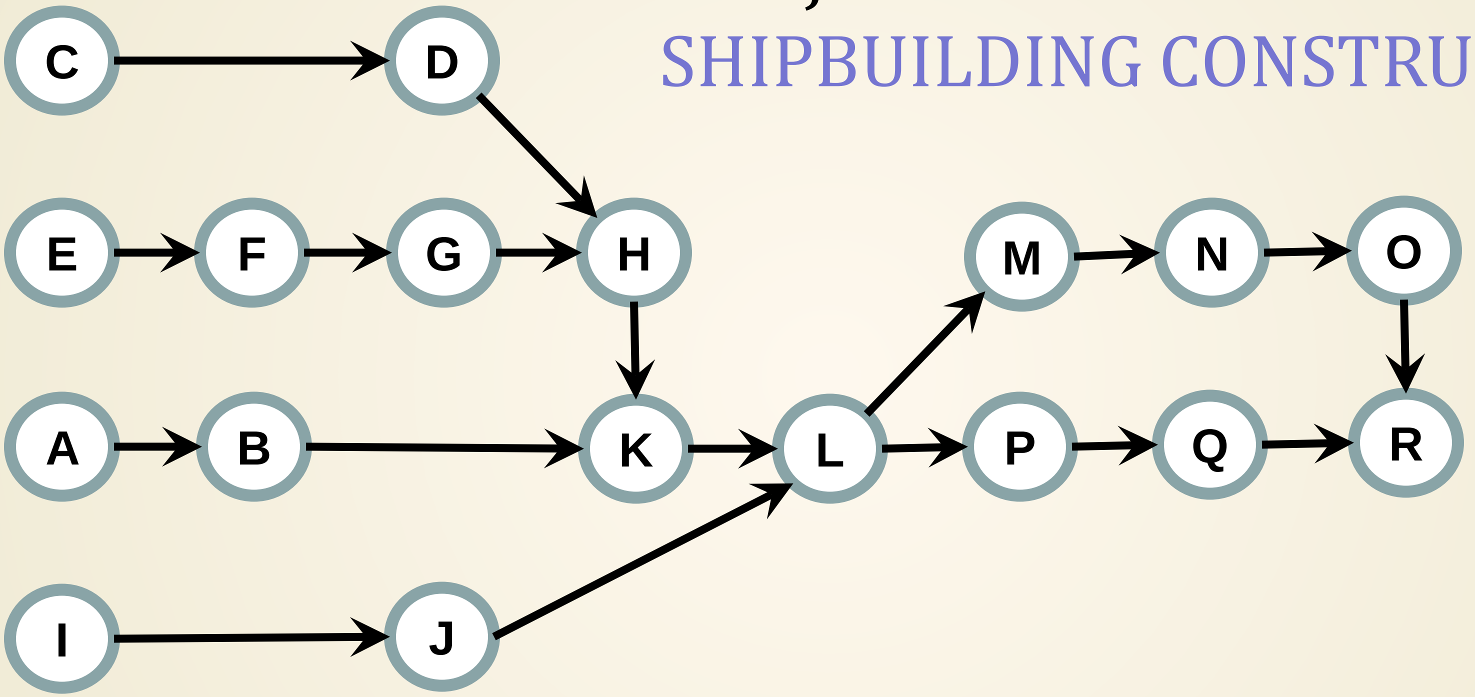
Program Evaluation and Review Technique (PERT) developed by Malcolm et al. (1959) – Stochastic CPM

PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION



ACTIVITY ON ARC REPRESENTATION

PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION



ACTIVITY ON NODE REPRESENTATION

PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION

ID	a	m	b	δ	C(δ)	PERT Variance	Modified PERT Variance
A	22	25	30	0.375	1.250	1.778	2.222
B	35	37	43	0.250	1.143	1.778	2.032
C	19	22	29	0.300	1.194	2.778	3.317
D	4	5	10	0.167	1.032	1.000	1.032
E	23	26	31	0.375	1.250	1.778	2.222
F	16	18	24	0.250	1.143	1.778	2.032
G	11	14	20	0.333	1.222	2.250	2.750
H	6	7	12	0.167	1.032	1.000	1.032
I	25	28	33	0.375	1.250	1.778	2.222
J	33	35	40	0.286	1.181	1.361	1.607
K	27	30	37	0.300	1.194	2.778	3.317
L	6	7	11	0.200	1.080	0.694	0.750
M	4	5	9	0.200	1.080	0.694	0.750
N	6	7	10	0.250	1.143	0.444	0.508
O	9	10	15	0.167	1.032	1.000	1.032
P	6	7	12	0.167	1.032	1.000	1.032
Q	17	20	26	0.333	1.222	2.250	2.750
R	13	15	20	0.286	1.181	1.361	1.607
						Average Variance	1.790

Malcolm et al. 1959

Traditional Activity Estimates

$$\text{PERT MEAN} = \frac{a+4m+b}{6}$$

$$\text{PERT VARIANCE} = \frac{(b-a)^2}{36}$$

Herrerias et al. 2011

$$\text{MOD. PERT VARIANCE} = C(\delta)\times\frac{(b-a)^2}{36}$$

$$\delta = \frac{m-a}{b-a}, C(\delta) = \frac{5}{7}+\frac{16}{7}\times\delta(1-\delta)$$

PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION

Malcolm et al. (1959) assumed statistical independence between activity durations

This is a specious assumption however!

- Imagine activities that have to be completed under the open sky
  Imagine activities that require the use of a single crane
  Imagine activities completed by the same subcontractor
- Approaches thus far that have tried to relax the independence assumption unfortunately suffer from high parameter specification burden in a problem context that already suffers from that “ailment”
- Looking to relax that independence assumption in a “pragmatic” manner that builds on Malcolm’s et al. (1959) work

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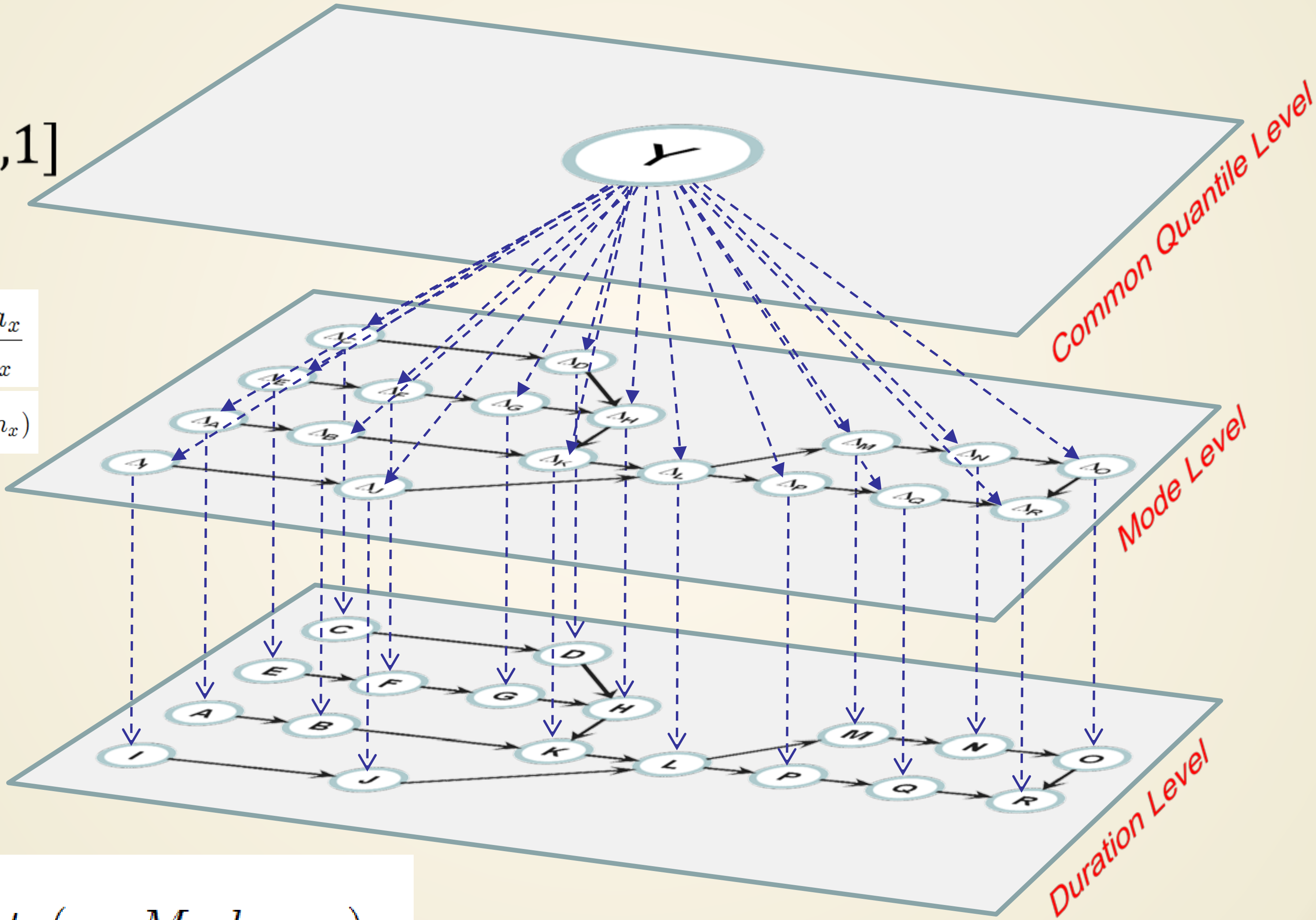
Bayesian Network Dependence Model for Project Risk Analysis

$Y \sim U[0,1]$

$$\Delta_x = \frac{M_x - a_x}{b_x - a_x}$$

$\Delta_x \sim TSP(\delta_x, n_x)$



$$X \sim Beta(a_x, M_x, b_x, \gamma_x)$$

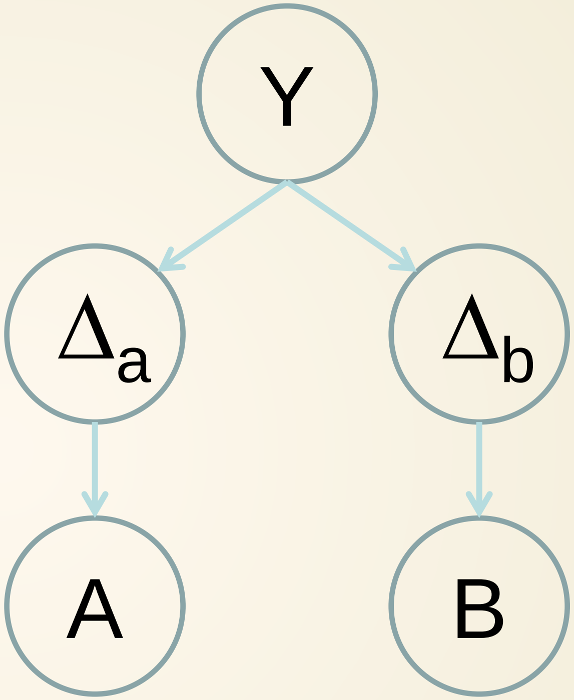
How does dependence materialize throughout the Bayesian Network?

$$Y \sim U[0,1]$$

$$\Delta_x = \frac{M_x - a_x}{b_x - a_x}$$

$$\Delta_x \sim TSP(\delta_x, n_x)$$

$$X \sim Beta(\Delta_x, \gamma_x)$$



Mode parameterization of Beta Distribution

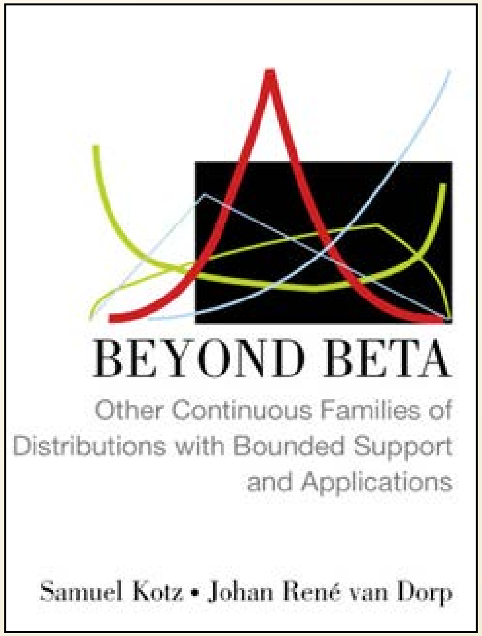
$$g_X(x|\Delta_x, \gamma_x) = \frac{x^{\gamma_x \Delta_x}(1-x)^{\gamma_x(1-\Delta_x)}}{\mathbb{B}(\gamma_x \Delta_x + 1, \gamma_x(1-\Delta_x)+1)}$$

How does dependence materialize throughout the Bayesian Network?

Two Sided Power Density of Mode Relative Distance Δ_x

$$f_{\Delta_x}(u|\delta_x, n_x) = n_x \times \begin{cases} \left(\frac{u}{\delta_x}\right)^{n_x - 1}, & 0 \leq u \leq \delta_x, \\ \left(\frac{1-u}{1-\delta_x}\right)^{n_x - 1}, & \delta_x \leq u \leq 1. \end{cases}$$

S. Kotz 1930 – 2010



2004

Some Two-Sided Power Distribution Properties

Cumulative Distribution Function:

$$F_{\Delta_x}(u|\delta_x, n_x) = \begin{cases} \delta_x\left(\frac{u}{\delta_x}\right)^{n_x}, & 0 \le u \le \delta_x, \\ 1 - (1-\delta_x)\left(\frac{1-u}{1-\delta_x}\right)^{n_x}, & \delta_x \le u \le 1, \end{cases}$$

Quantile Function:

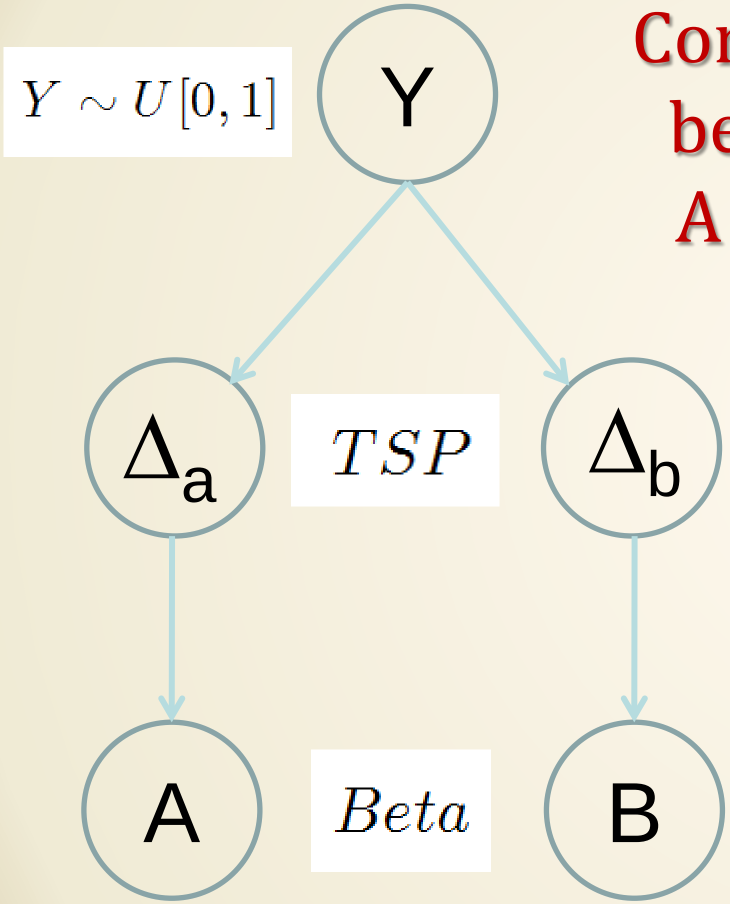
$$F_{\Delta_x}^{-1}(y|\delta_x, n_x) = \begin{cases} \delta_x\left(\frac{y}{\delta_x}\right)^{1/n_x}, & 0 \le y \le \delta_x, \\ 1 - (1-\delta_x)\left(\frac{1-y}{1-\delta_x}\right)^{1/n_x}, & \delta_x \le y \le 1. \end{cases}$$

Conclusion:

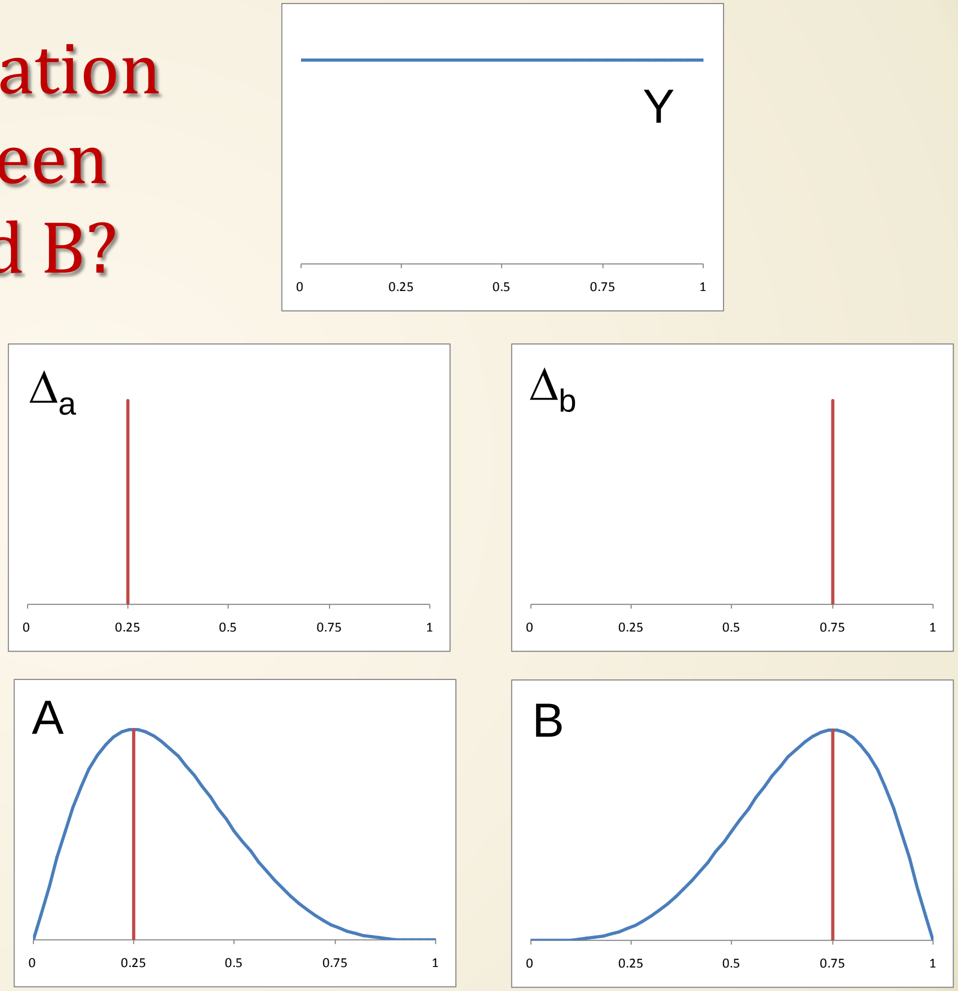
$$F_{\Delta_x}^{-1}(y|\delta_x, n_x) = F_{\Delta_x}(y|\delta_x, 1/n_x).$$

QF and CDF are of the same functional form!

How does dependence materialize throughout this Bayesian Network?



Correlation between A and B?



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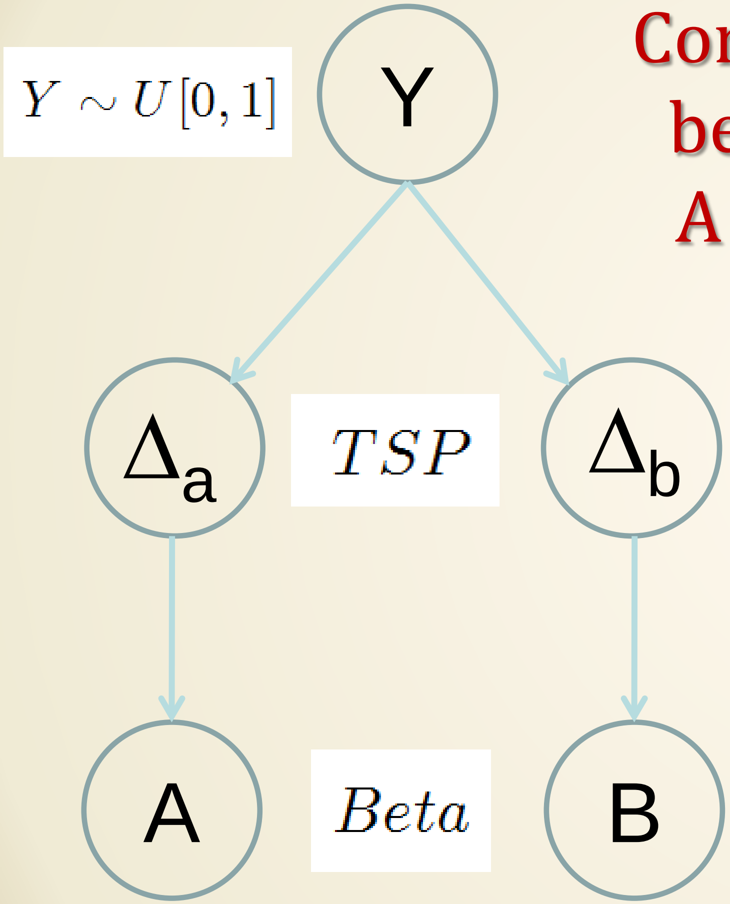

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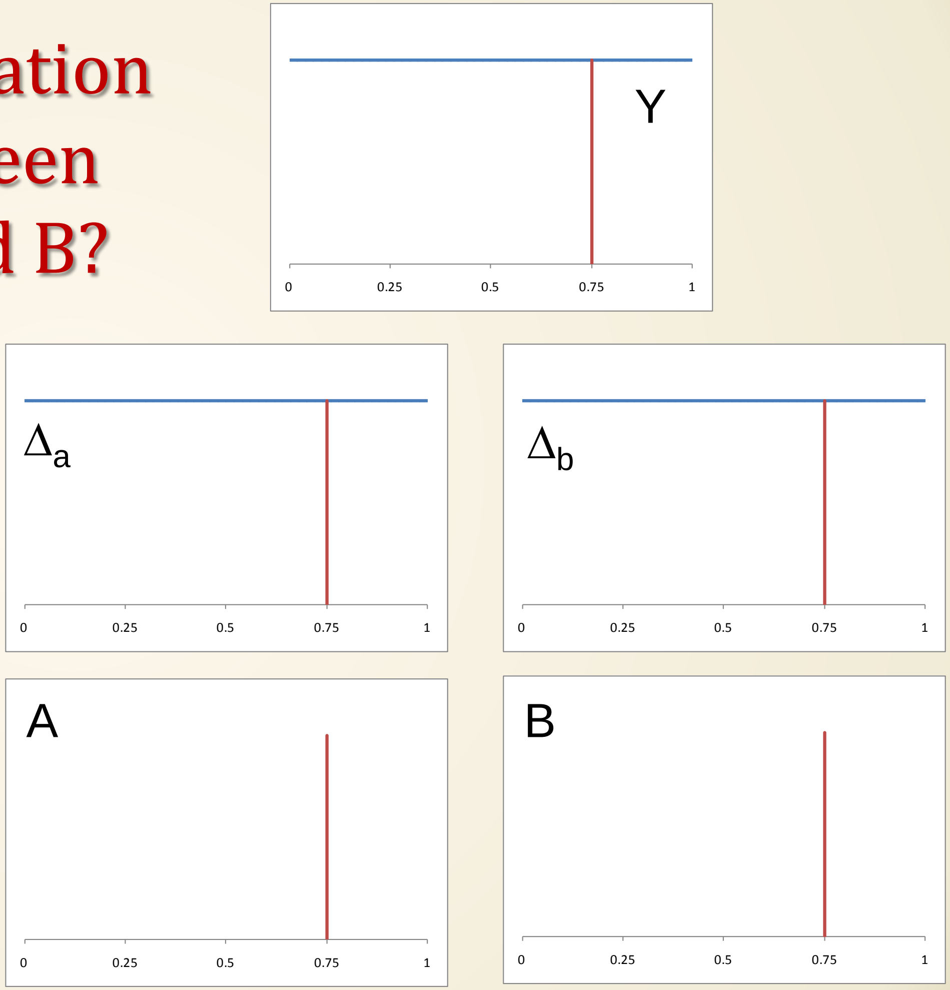

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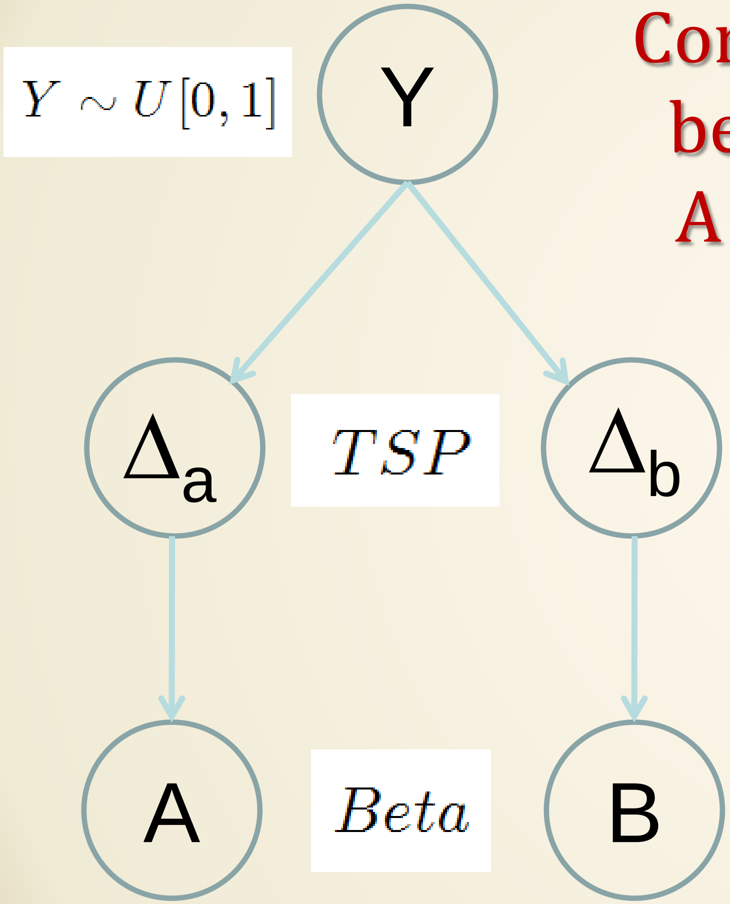

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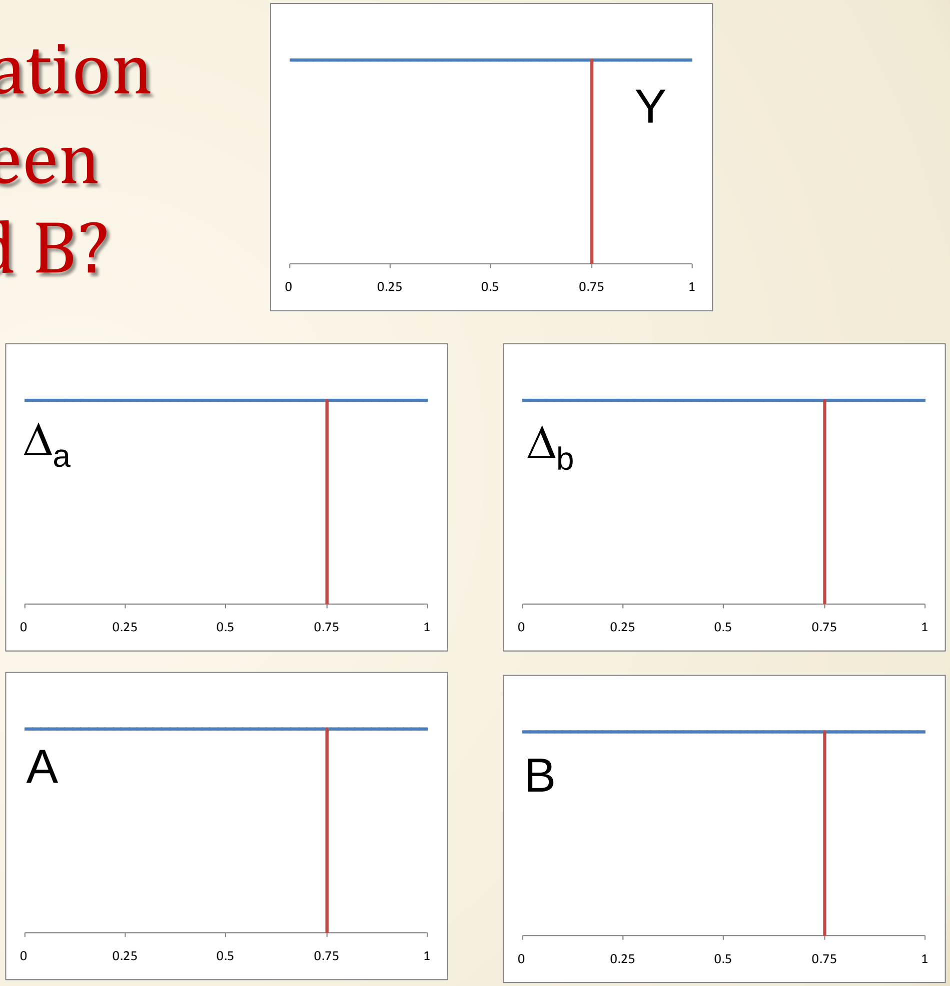

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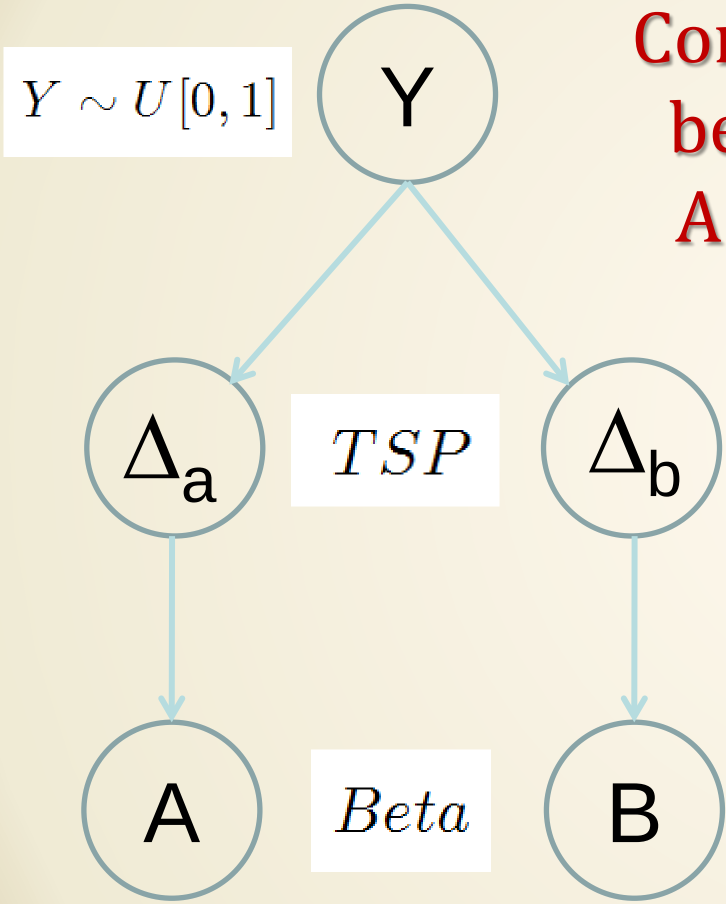

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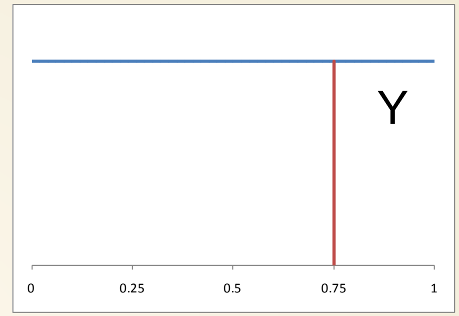
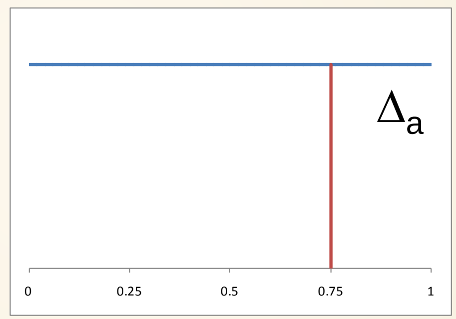
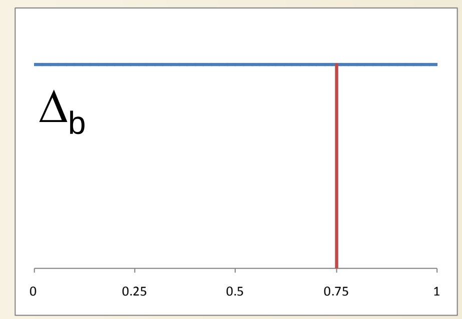
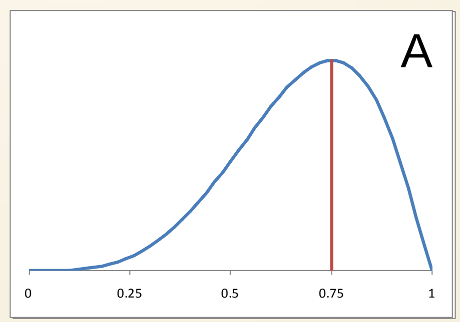
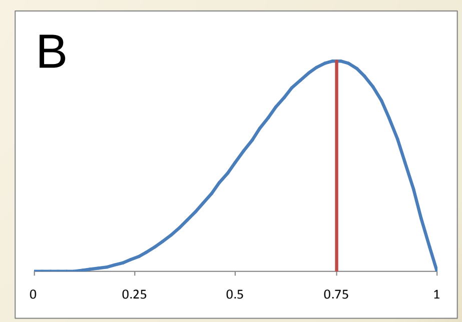


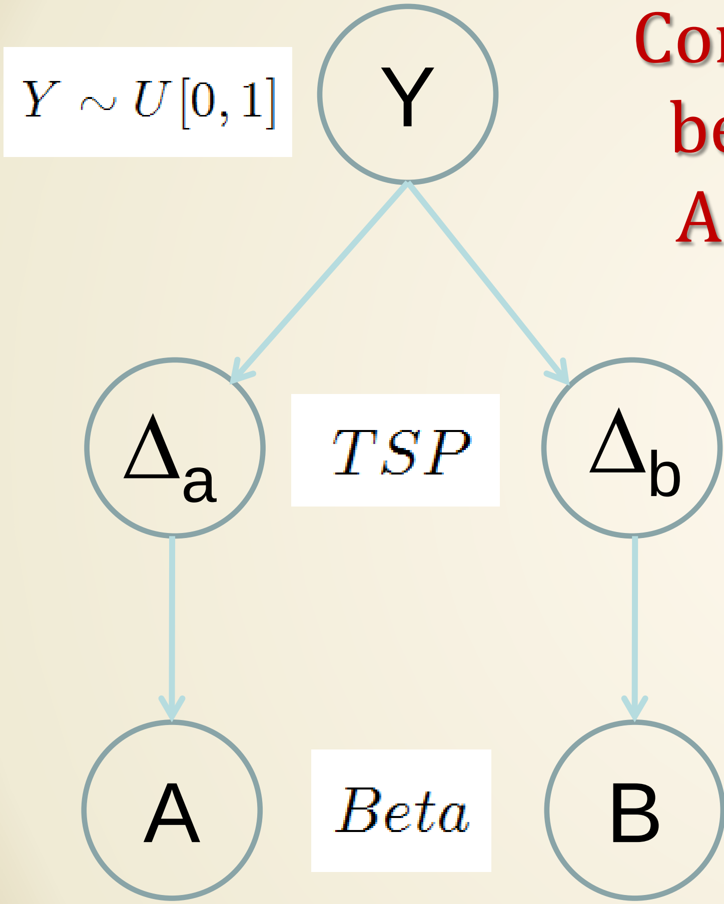








How does dependence materialize throughout this Bayesian Network?



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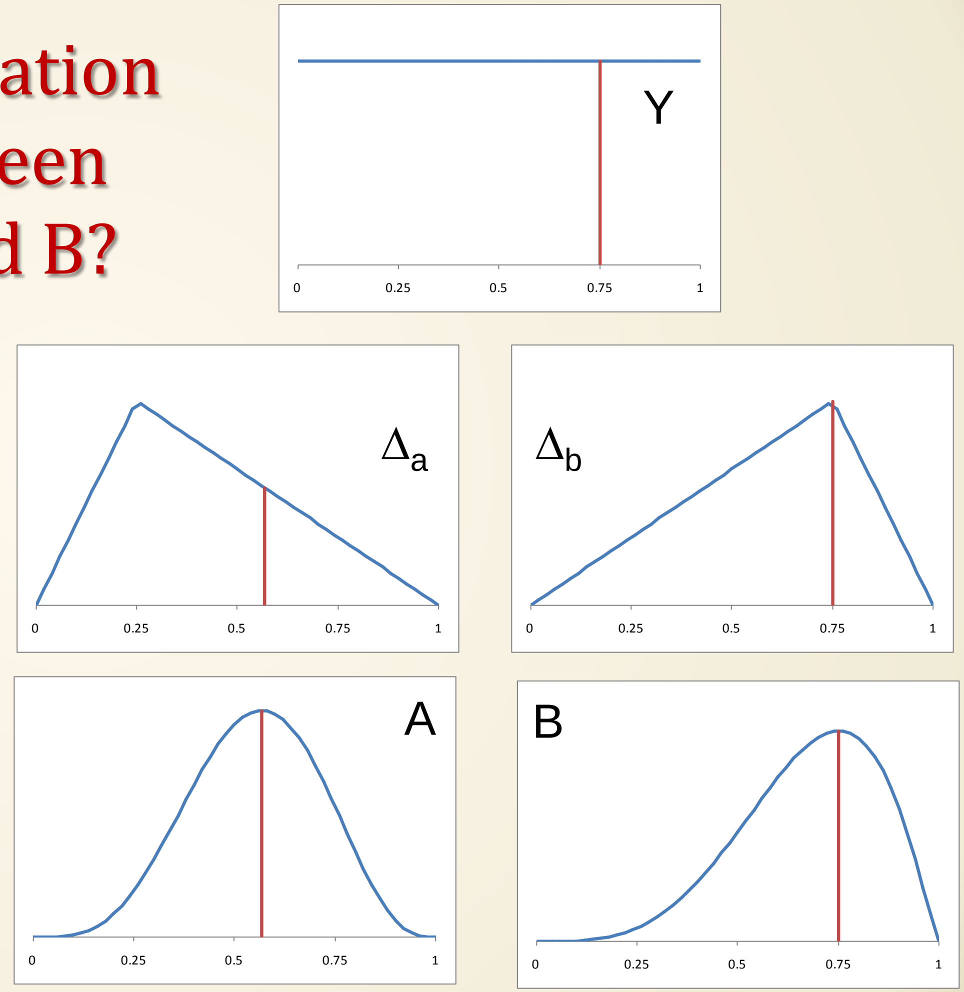
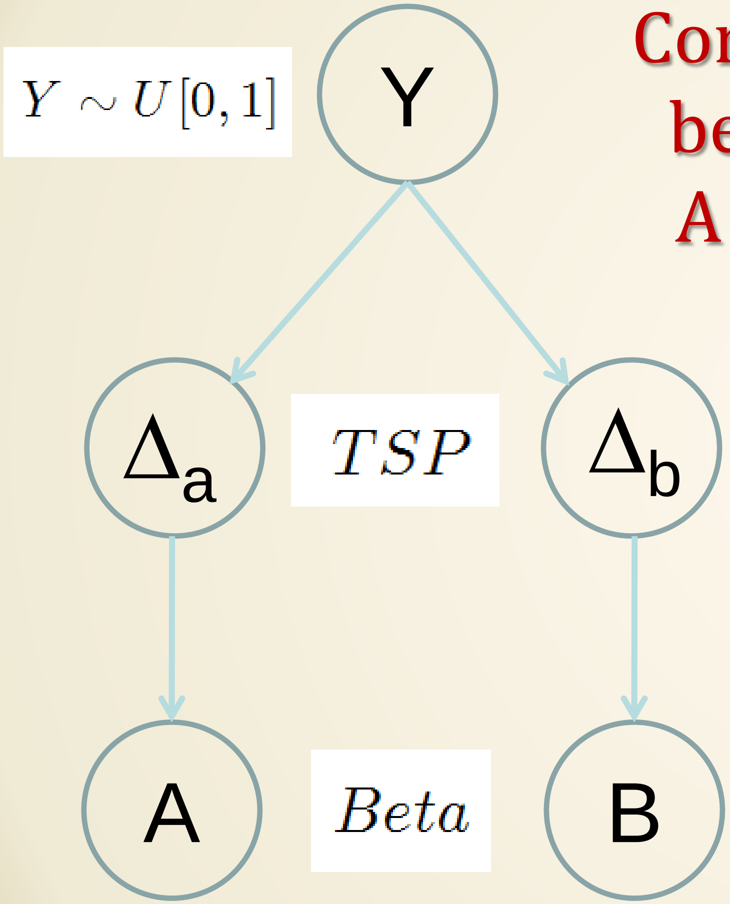


How does dependence materialize throughout the Bayesian Network?



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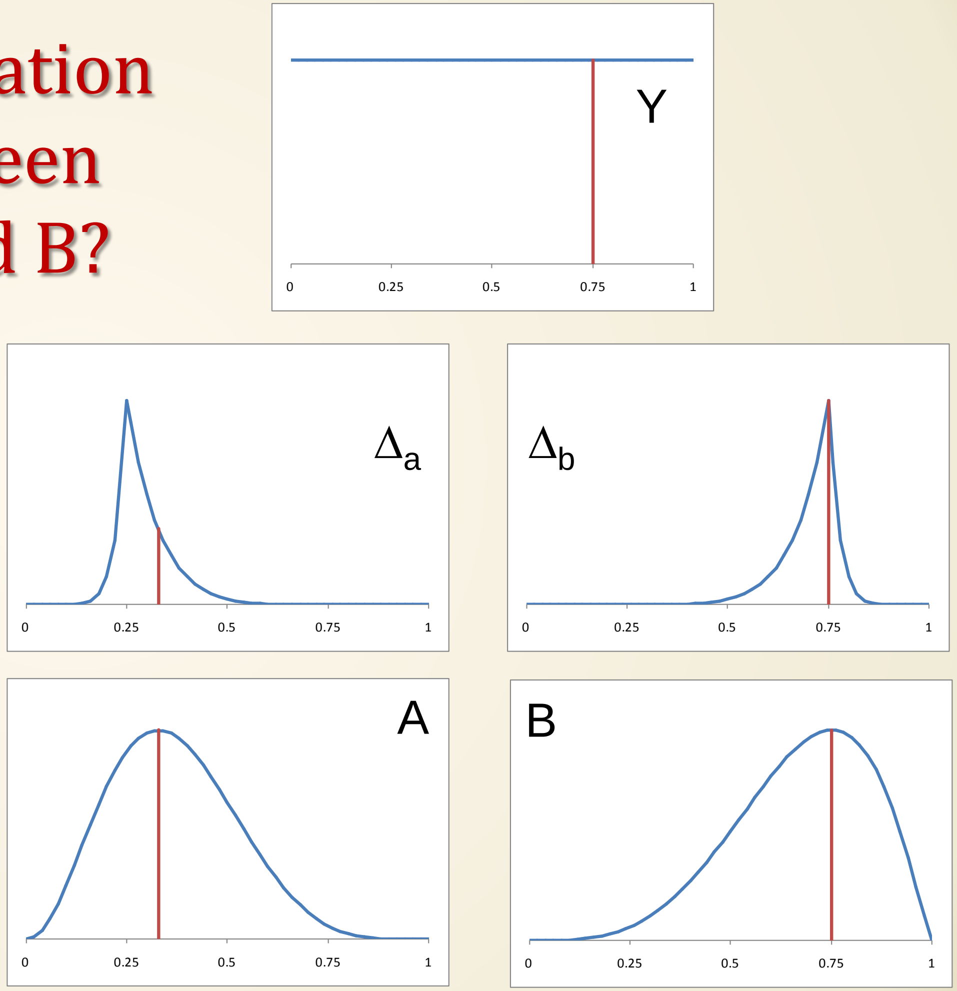
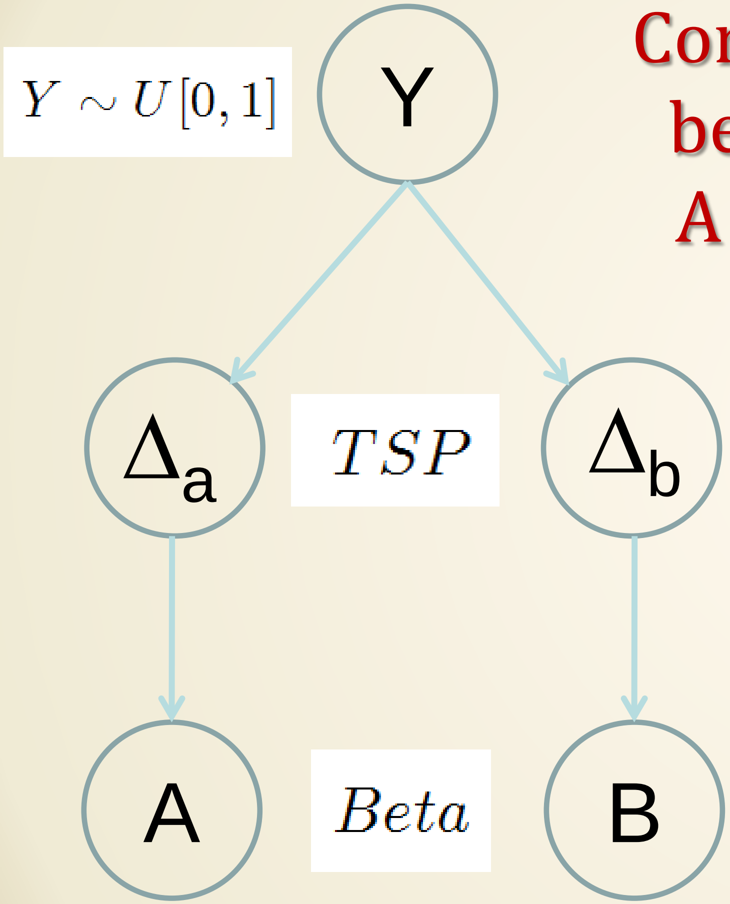
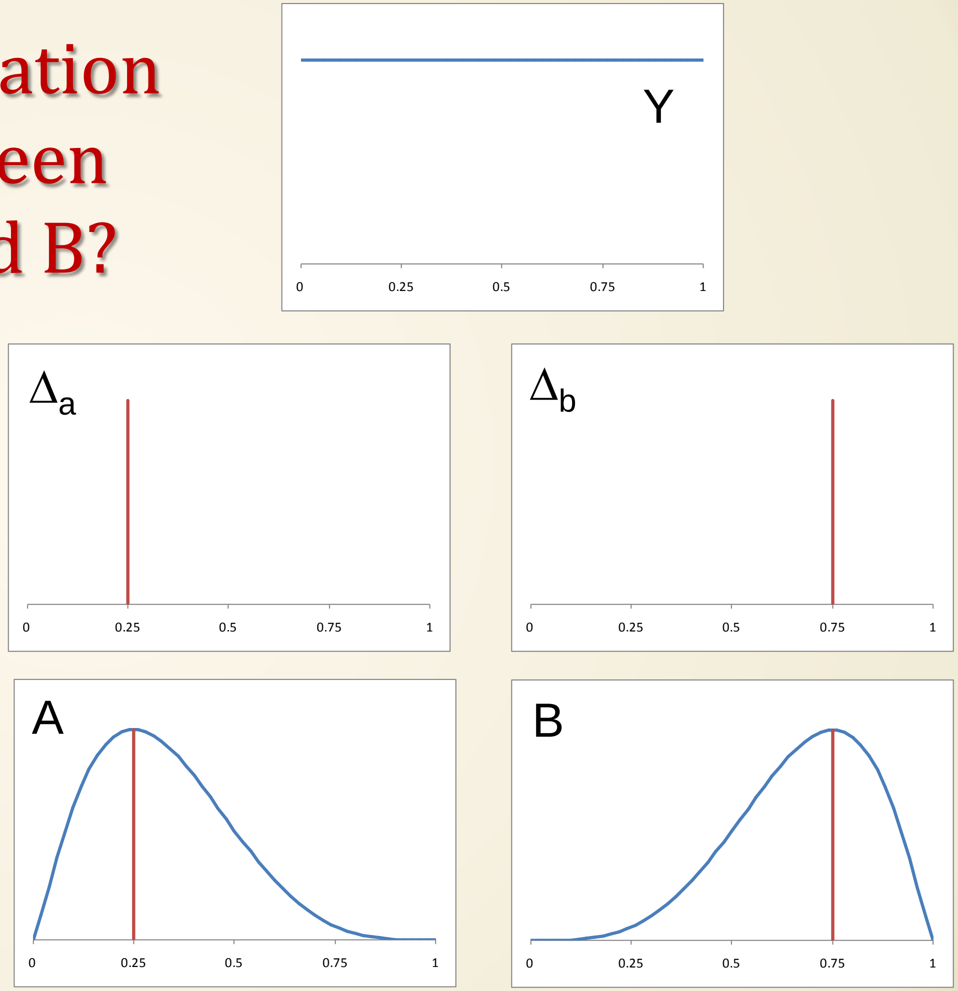


How does dependence materialize throughout the Bayesian Network?



Correlation between A and B?



How does dependence materialize throughout the Bayesian Network?

Conclusion: Assuming Activities share a common *TSP* shape paramer *n* and a common *Beta* shape parameter g we have:

- Keeping *n* constant the correlation increases with increasing γ
- Keeping γ constant the correlation decreases with increasing *n*

Assuming **common TSP shape parameter *n*** and **common Beta shape parameter** γ amongst activities, how does one specify them using expert elicitation **building on** Malcolm's et al. (1959) PERT method?

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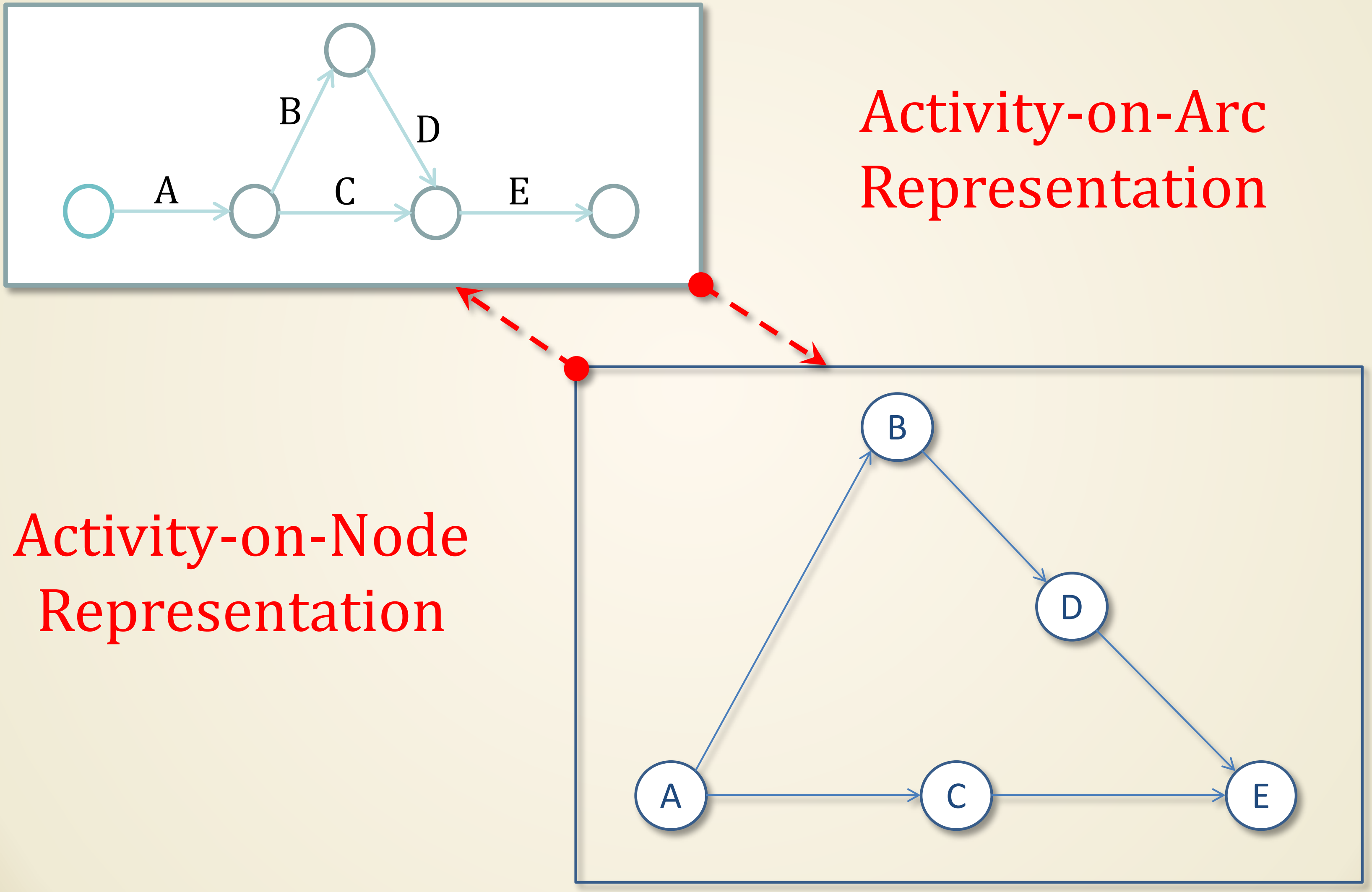
Small Activity Network Example



Activity-on-Arc Representation

Activity-on-Node Representation

Eliciting Conditional Medians

"Suppose Activity A has finished above its median value $a_{0.5}$, what is the probability that Activity B finishes above its median value $b_{0.5}$?"

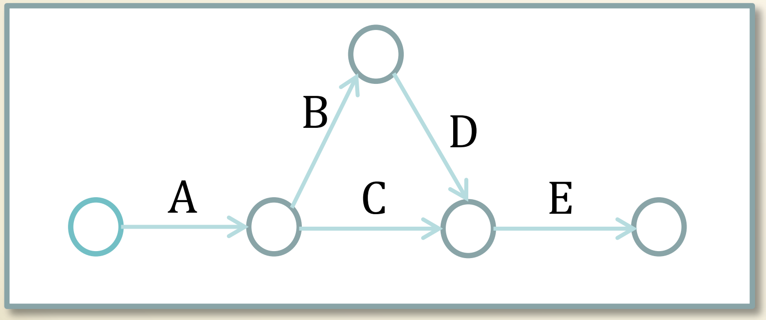
If answer is " = 0.50" , knowledge of A **does not** influence B

If answer is "> 0.50" , knowledge of A **does** influence B

If answer is "= 1.00" , knowledge of A **influences** B **"the most"**

Elicit activity conditional medians that are directly path-connected

1. $\Pr\{B > b_{0.5} | A > a_{0.5}\}$
2. $\Pr\{C > c_{0.5} | A > a_{0.5}\}$
3. $\Pr\{D > d_{0.5} | B > b_{0.5}\}$
4. $\Pr\{E > e_{0.5} | C > c_{0.5}\}$
5. $\Pr\{E > e_{0.5} | D > d_{0.5}\}$



Conditional Median Matrix

Notation: $\Pr\{ Y > y_{0.5} \mid X > x_{0.5} \} = \mathrm{Med}(Y|X)$

	A	B	C	D	E
A	1	Med(B|A)	Med(C|A)	Med(D|A)	Med(E|A)
B	Med(A|B)	1	Med(C|B)	Med(D|B)	Med(E|B)
C	Med(A|C)	Med(B|C)	1	Med(D|C)	Med(E|C)
D	Med(A|D)	Med(B|D)	Med(C|D)	1	Med(E|D)
E	Med(A|E)	Med(B|E)	Med(C|E)	Med(D|E)	1

Conditional Median Matrix is Symmetric:

$$\mathrm{Med}(X|Y) = \Pr\{ X > x_{0.5} \mid Y > y_{0.5} \} = \frac{\Pr\{ Y > y_{0.5} \mid X > x_{0.5} \} \Pr\{ X > x_{0.5} \}}{\Pr\{ Y > y_{0.5} \}}$$

$$= \frac{\Pr\{ Y > y_{0.5} \mid X > x_{0.5} \} \times 0.5}{0.5} = \Pr\{ Y > y_{0.5} \mid X > x_{0.5} \} = \mathrm{Med}(Y|X)$$

Conditional Median Matrix

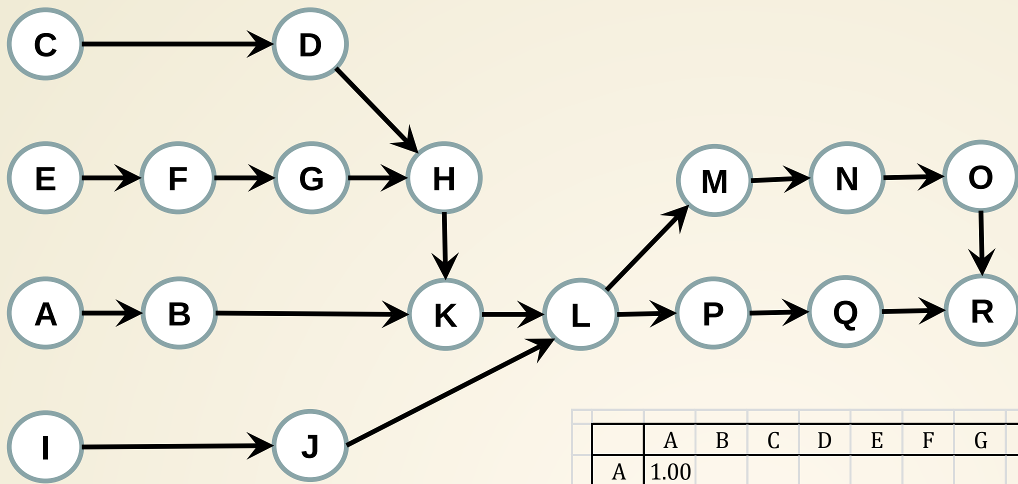
Notation: Pr { Y > Med (Y) | X > Med (X) } = Med(Y|X)

	A	B	C	D	E
A	1	Med(B|A)	Med(C|A)	Med(D|A)	Med(E|A)
B		1	Med(C|B)	Med(D|B)	Med(E|B)
C			1	Med(D|C)	Med(E|C)
D				1	Med(E|D)
E					1

Average Conditional Median

$$\overline{Med(\cdot|\cdot)} = \frac{\sum_{\substack{Y \in \{A,B,C,D,E\} \\ Y \neq X}} \sum_{X \in \{A,B,C,D,E\}} Med(Y|X)}{5 \times (5-1)}$$

Back to Case Study



Eliciting only activity-to-activity conditional medians that are directly connected in Project Network reduces elicitation burden here from:

$$\binom{18}{2} \; \mathit{to}\; 18 \quad \text{conditional medians}$$

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
A	1.00																	
B	0.65	1.00																
C			1.00															
D			0.65	1.00														
E					1.00													
F					0.70	1.00												
G						0.65	1.00											
H				0.70			0.60	1.00										
I									1.00									
J									0.70	1.00								
K		0.75						0.65			1.00							
L										0.65	0.60	1.00						
M												0.70	1.00					
N													0.55	1.00				
O														0.70	1.00			
P												0.65				1.00		
Q																0.65	1.00	
R															0.70		0.60	1.00

Average Conditional Median ≈ 0.658

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Algorithmic Selection Procedure Parameters β and n:

1. For different values of β and n do:

- Sample 1000 joint activity samples from joint prior (defined by BN)
- Evaluate Average Prior Marginal Activity Variance
- Evaluate Average Prior Activity Statistical Dependence

2. Select values of β and n such that:

- Average Prior Marginal Activity Variance close to Average Modified PERT Variance across Project Network
- Average Prior Activity to Activity Statistical Dependence close to Elicited Average Activity to Activity Statistical Dependence

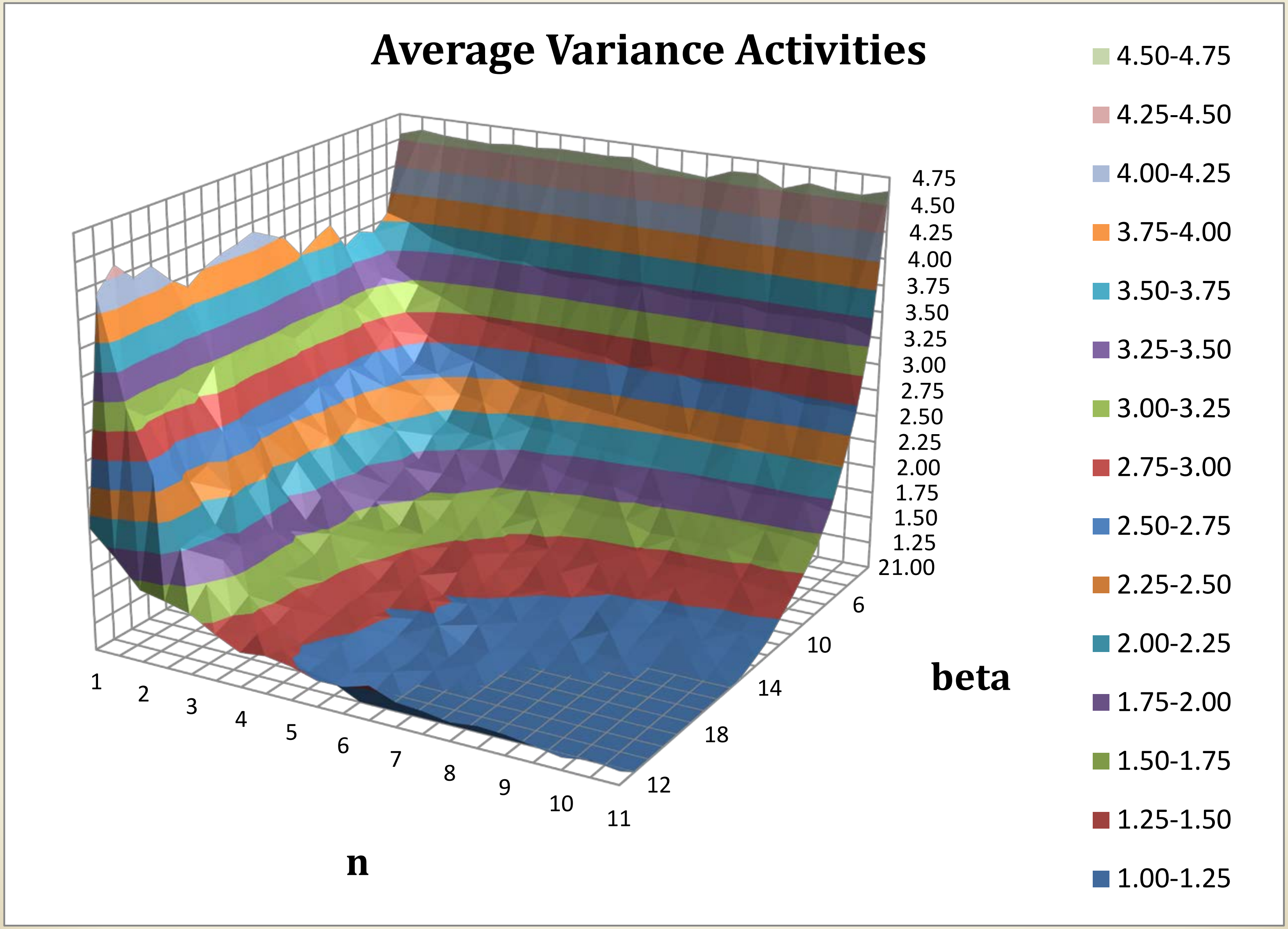
3. For selected values of β and n do:

a. Sample 1000 Joint activities from Bayesian Network Prior
b. Evaluate Average Prior Marginal Activity Variance
c. Evaluate Average Prior Activity Statistical Dependence
d. Repeat Steps a, b and c one 1000 times and plot:

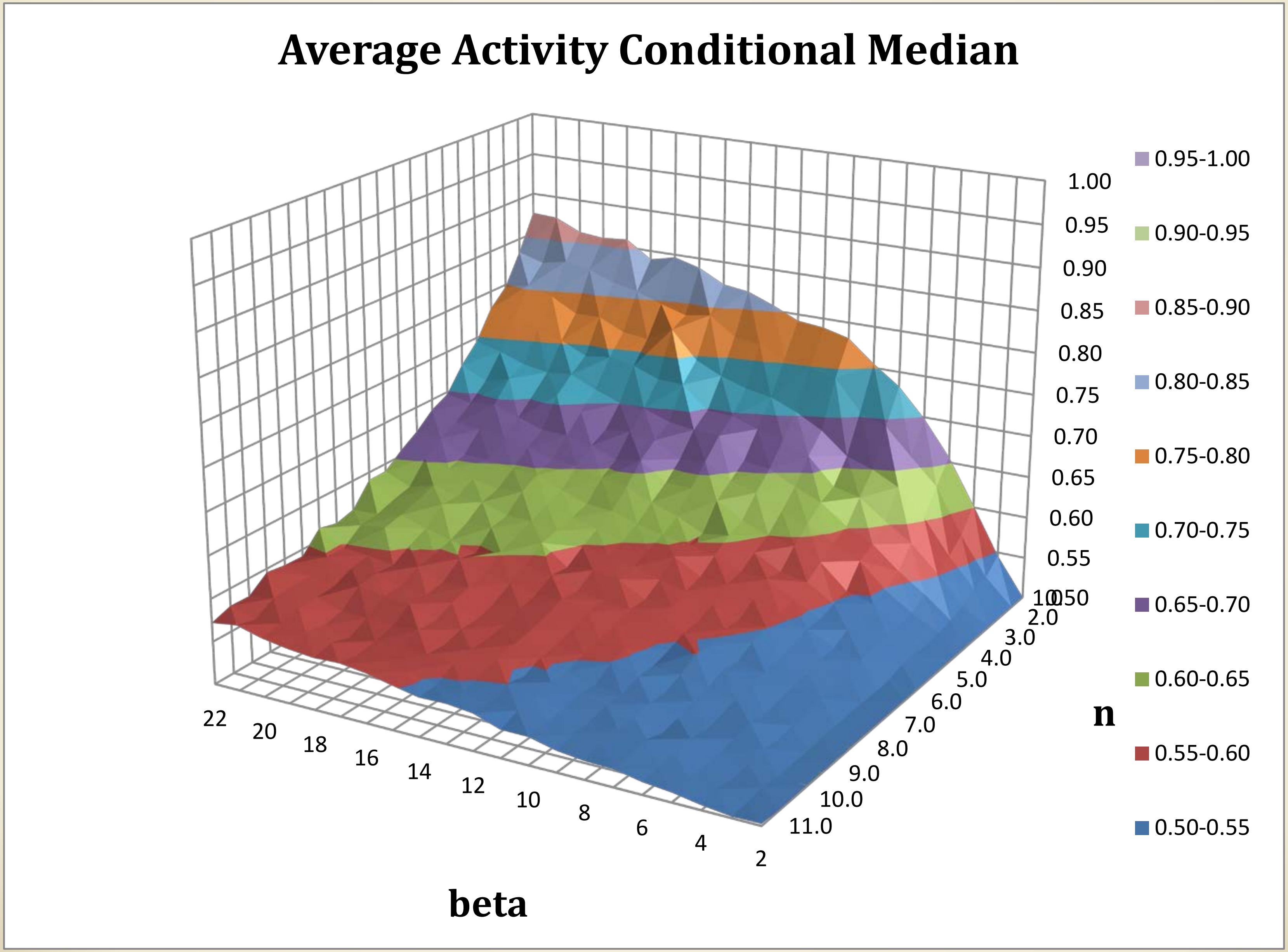
   - Average Prior Marginal Activity Variance Uncertainty
   - Average Prior Activity to Activity Statistical Dependence Uncertainty

e. Test if Average Modified PERT Variance and Elicited Average Statistical dependence fall within 90% credibility limits of uncertainty distributions

STEP 1: Prior Average Variance (β, n)



STEP 1: Prior Average Activity Cond. Med(β, n)



STEP 2: Select values of β and n that are close

β

n

Prior Average Activity Variance between 1.50 and 2.00

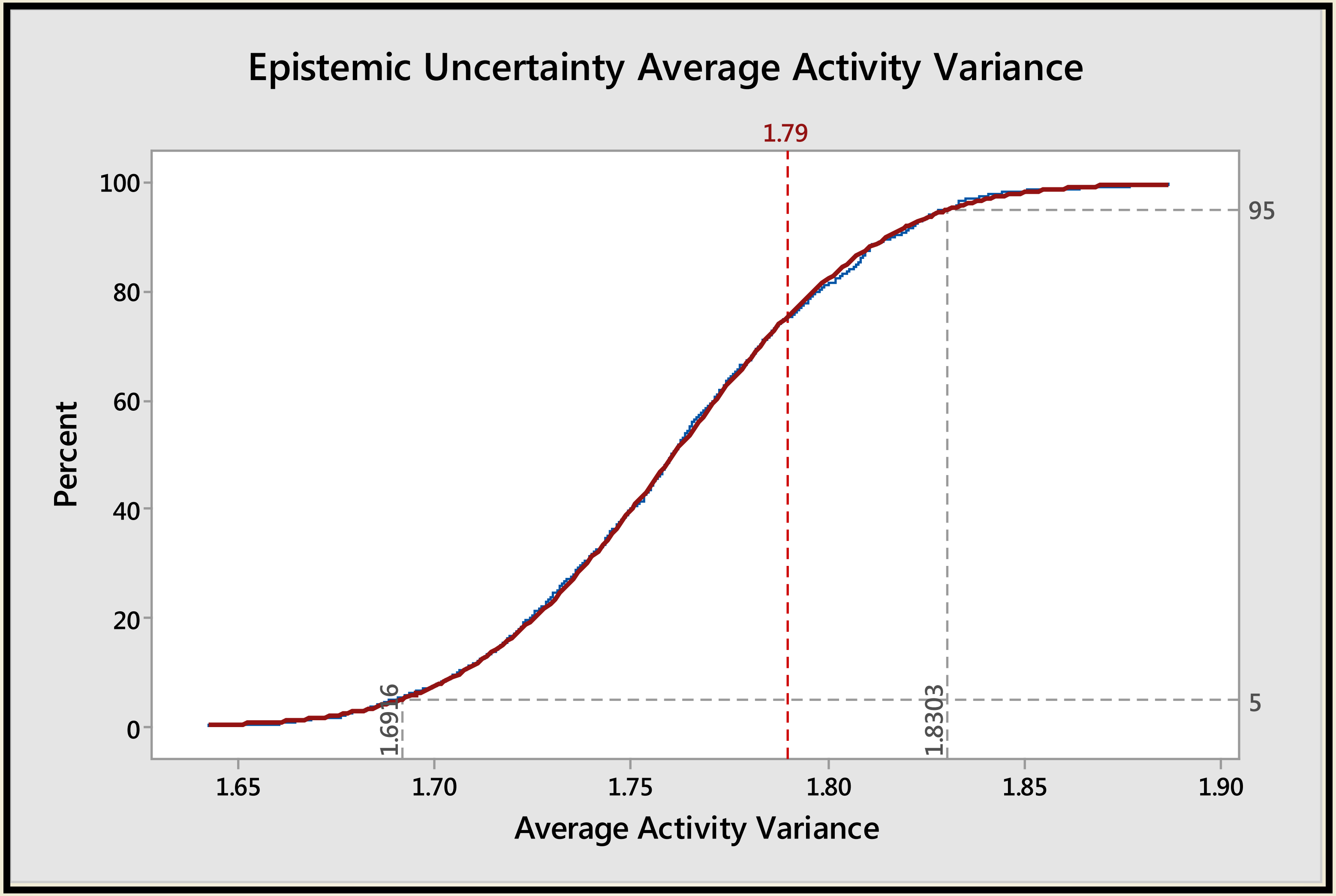
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1.0	4.53	3.80	3.65	3.59	3.66	3.69	3.77	3.96	3.83	3.78	4.00	3.98	3.97	4.13	4.19	3.93	4.30	4.26	4.16	4.28	4.31
1.5	4.54	3.69	3.40	3.34	3.23	3.23	3.10	3.17	3.19	3.12	3.10	3.04	3.22	3.09	3.14	3.12	3.18	3.17	3.20	3.17	3.11
2.0	4.56	3.61	3.19	3.01	2.90	2.83	2.59	2.61	2.75	2.67	2.56	2.57	2.52	2.72	2.53	2.53	2.49	2.50	2.61	2.61	2.62
2.5	4.61	3.62	3.15	2.87	2.68	2.52	2.40	2.42	2.35	2.33	2.30	2.17	2.16	2.13	2.22	2.13	2.13	2.03	2.11	2.15	2.12
3.0	4.65	3.57	2.99	2.64	2.49	2.37	2.25	2.15	2.09	2.04	2.06	2.00	1.87	1.89	1.83	1.75	1.78	1.74	1.84	1.79	1.78
3.5	4.58	3.56	2.94	2.64	2.42	2.25	2.12	1.96	1.95	1.85	1.93	1.69	1.74	1.73	1.65	1.60	1.69	1.58	1.59	1.52	1.56
4.0	4.62	3.51	2.91	2.54	2.28	2.13	2.01	1.84	1.73	1.75	1.71	1.55	1.61	1.57	1.51	1.46	1.38	1.40	1.40	1.35	1.35
4.5	4.57	3.48	2.88	2.46	2.19	2.07	1.89	1.75	1.73	1.53	1.56	1.49	1.48	1.45	1.39	1.35	1.35	1.31	1.27	1.23	1.25
5.0	4.54	3.46	2.86	2.49	2.15	2.00	1.84	1.68	1.64	1.56	1.44	1.36	1.35	1.30	1.27	1.28	1.22	1.21	1.10	1.14	1.14
5.5	4.62	3.44	2.82	2.43	2.13	1.91	1.78	1.69	1.53	1.47	1.37	1.33	1.31	1.24	1.21	1.18	1.11	1.12	1.11	1.07	1.06
6.0	4.60	3.46	2.83	2.39	2.08	1.90	1.67	1.61	1.48	1.41	1.34	1.27	1.23	1.21	1.14	1.10	1.09	1.05	1.02	0.99	1.00
6.5	4.55	3.37	2.80	2.27	2.07	1.88	1.70	1.56	1.46	1.35	1.31	1.23	1.16	1.18	1.11	1.08	1.04	1.07	0.96	0.91	0.98
7.0	4.61	3.41	2.75	2.35	2.05	1.87	1.67	1.52	1.40	1.35	1.23	1.20	1.17	1.09	1.09	1.01	0.99	0.99	0.97	0.89	0.88
7.5	4.54	3.41	2.78	2.31	2.01	1.77	1.67	1.48	1.40	1.30	1.22	1.19	1.12	1.04	1.03	1.00	0.96	0.91	0.92	0.89	0.85
8.0	4.55	3.46	2.74	2.30	2.01	1.77	1.62	1.45	1.39	1.26	1.20	1.12	1.08	1.01	1.00	0.93	0.94	0.87	0.85	0.84	0.83
8.5	4.58	3.41	2.69	2.30	1.95	1.73	1.59	1.45	1.35	1.24	1.14	1.13	1.05	1.01	0.94	0.91	0.89	0.86	0.82	0.80	0.77
9.0	4.57	3.38	2.79	2.30	1.95	1.74	1.57	1.42	1.28	1.21	1.16	1.10	1.00	0.97	0.94	0.93	0.87	0.85	0.80	0.77	0.76
9.5	4.63	3.39	2.73	2.29	1.91	1.70	1.55	1.40	1.31	1.24	1.14	1.06	1.02	0.96	0.93	0.85	0.83	0.78	0.78	0.80	0.78
10.0	4.55	3.43	2.71	2.27	1.95	1.71	1.53	1.42	1.29	1.19	1.13	1.03	1.01	0.95	0.89	0.85	0.82	0.77	0.77	0.76	0.73
10.5	4.59	3.37	2.73	2.24	1.95	1.70	1.51	1.36	1.26	1.17	1.09	1.01	0.94	0.91	0.89	0.85	0.81	0.79	0.76	0.72	0.69
11.0	4.63	3.45	2.67	2.24	1.96	1.68	1.53	1.36	1.28	1.16	1.10	1.02	0.96	0.93	0.88	0.85	0.79	0.75	0.76	0.73	0.69

Prior Average Conditional Median between 0.625 and 0.675

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1.0	0.50	0.55	0.60	0.66	0.70	0.73	0.75	0.78	0.79	0.79	0.81	0.82	0.82	0.84	0.85	0.84	0.86	0.86	0.86	0.87	0.88
1.5	0.50	0.53	0.58	0.63	0.66	0.69	0.71	0.74	0.75	0.75	0.77	0.77	0.79	0.79	0.80	0.81	0.81	0.83	0.83	0.82	0.83
2.0	0.50	0.53	0.56	0.60	0.63	0.65	0.66	0.69	0.70	0.72	0.72	0.73	0.75	0.78	0.76	0.77	0.78	0.78	0.80	0.80	0.80
2.5	0.50	0.52	0.55	0.58	0.60	0.63	0.63	0.66	0.68	0.69	0.70	0.70	0.72	0.73	0.74	0.74	0.74	0.75	0.76	0.77	0.78
3.0	0.50	0.51	0.54	0.56	0.59	0.60	0.62	0.64	0.65	0.66	0.68	0.68	0.69	0.70	0.70	0.71	0.73	0.72	0.73	0.74	0.75
3.5	0.50	0.51	0.53	0.55	0.58	0.59	0.61	0.62	0.63	0.64	0.66	0.66	0.68	0.68	0.68	0.69	0.71	0.70	0.72	0.71	0.73
4.0	0.50	0.51	0.52	0.54	0.55	0.58	0.59	0.60	0.61	0.63	0.64	0.64	0.66	0.66	0.67	0.67	0.68	0.69	0.70	0.69	0.70
4.5	0.50	0.51	0.52	0.54	0.55	0.57	0.57	0.59	0.61	0.60	0.62	0.63	0.64	0.64	0.65	0.66	0.66	0.67	0.67	0.68	0.69
5.0	0.50	0.51	0.52	0.54	0.54	0.56	0.58	0.58	0.59	0.60	0.60	0.61	0.62	0.62	0.63	0.65	0.65	0.65	0.65	0.67	0.67
5.5	0.50	0.50	0.52	0.53	0.54	0.55	0.56	0.58	0.58	0.60	0.60	0.60	0.61	0.62	0.63	0.64	0.63	0.64	0.65	0.65	0.66
6.0	0.50	0.50	0.52	0.53	0.54	0.55	0.55	0.56	0.57	0.58	0.59	0.59	0.60	0.61	0.62	0.62	0.63	0.63	0.64	0.63	0.64
6.5	0.50	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.57	0.58	0.59	0.59	0.61	0.61	0.61	0.61	0.63	0.63	0.62	0.64
7.0	0.50	0.50	0.52	0.52	0.53	0.53	0.55	0.55	0.56	0.57	0.57	0.58	0.59	0.59	0.60	0.59	0.60	0.61	0.62	0.62	0.61
7.5	0.50	0.50	0.51	0.52	0.53	0.54	0.55	0.55	0.55	0.56	0.57	0.58	0.58	0.58	0.59	0.60	0.60	0.60	0.62	0.61	0.61
8.0	0.50	0.50	0.51	0.52	0.52	0.53	0.54	0.54	0.55	0.56	0.56	0.57	0.57	0.57	0.58	0.58	0.59	0.59	0.59	0.60	0.61
8.5	0.50	0.50	0.51	0.52	0.52	0.53	0.53	0.54	0.55	0.55	0.56	0.57	0.56	0.57	0.58	0.58	0.58	0.59	0.59	0.60	0.59
9.0	0.50	0.50	0.51	0.51	0.52	0.52	0.53	0.53	0.54	0.54	0.55	0.56	0.56	0.57	0.57	0.58	0.58	0.59	0.58	0.59	0.59
9.5	0.50	0.50	0.51	0.51	0.52	0.52	0.53	0.54	0.54	0.55	0.55	0.56	0.56	0.56	0.57	0.57	0.57	0.57	0.58	0.58	0.60
10.0	0.50	0.50	0.51	0.51	0.52	0.53	0.53	0.53	0.53	0.54	0.55	0.55	0.56	0.56	0.56	0.56	0.56	0.57	0.58	0.58	0.58
10.5	0.50	0.50	0.51	0.51	0.52	0.52	0.53	0.53	0.53	0.54	0.54	0.54	0.55	0.55	0.56	0.56	0.57	0.57	0.57	0.57	0.58
11.0	0.50	0.50	0.51	0.51	0.51	0.52	0.52	0.52	0.53	0.53	0.54	0.55	0.55	0.55	0.56	0.56	0.56	0.56	0.57	0.58	0.57

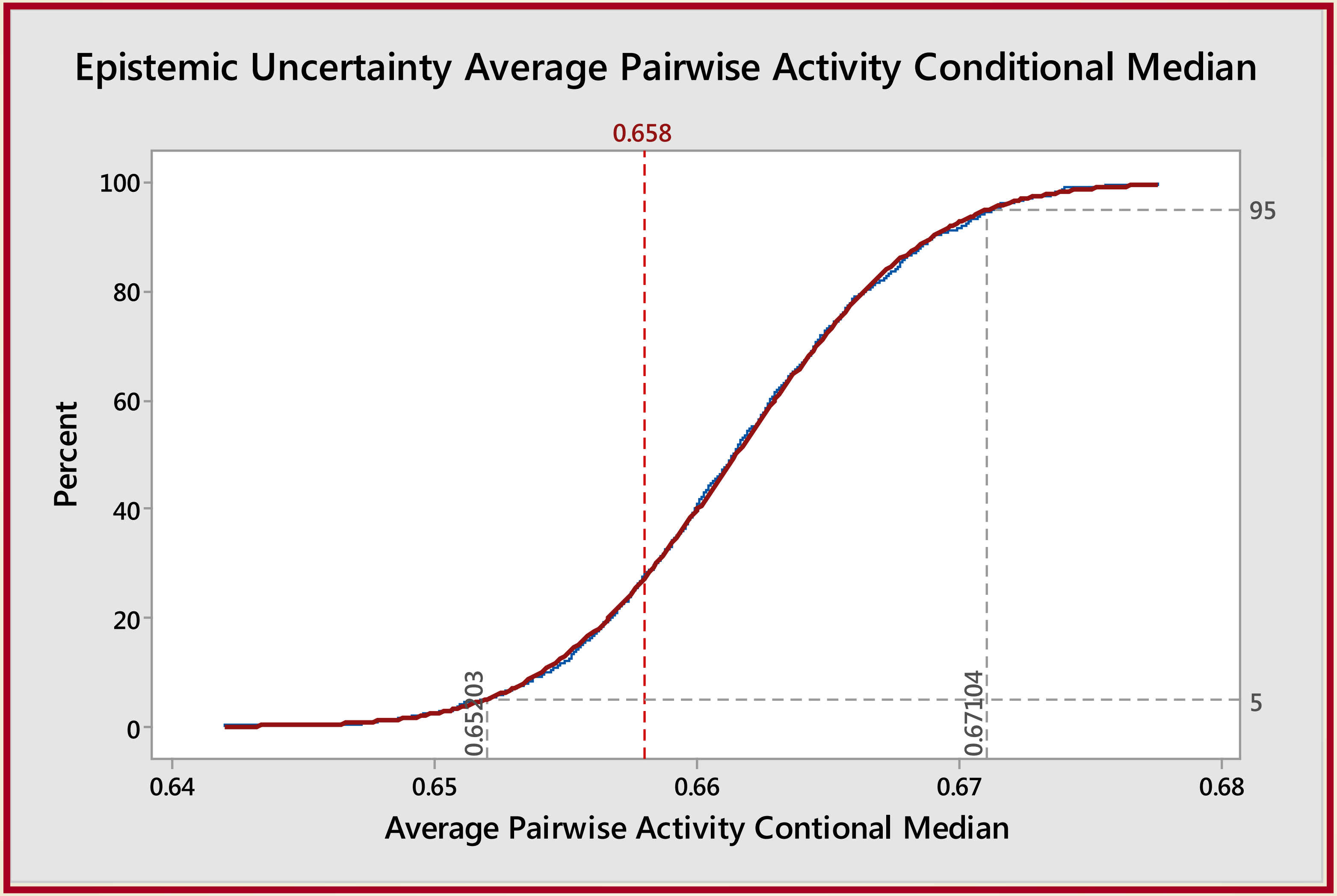
Set n =3.5 and β = 13

STEP 3: Evaluate Uncertainty given selected β and n



Setting n =3.5 and β = 13

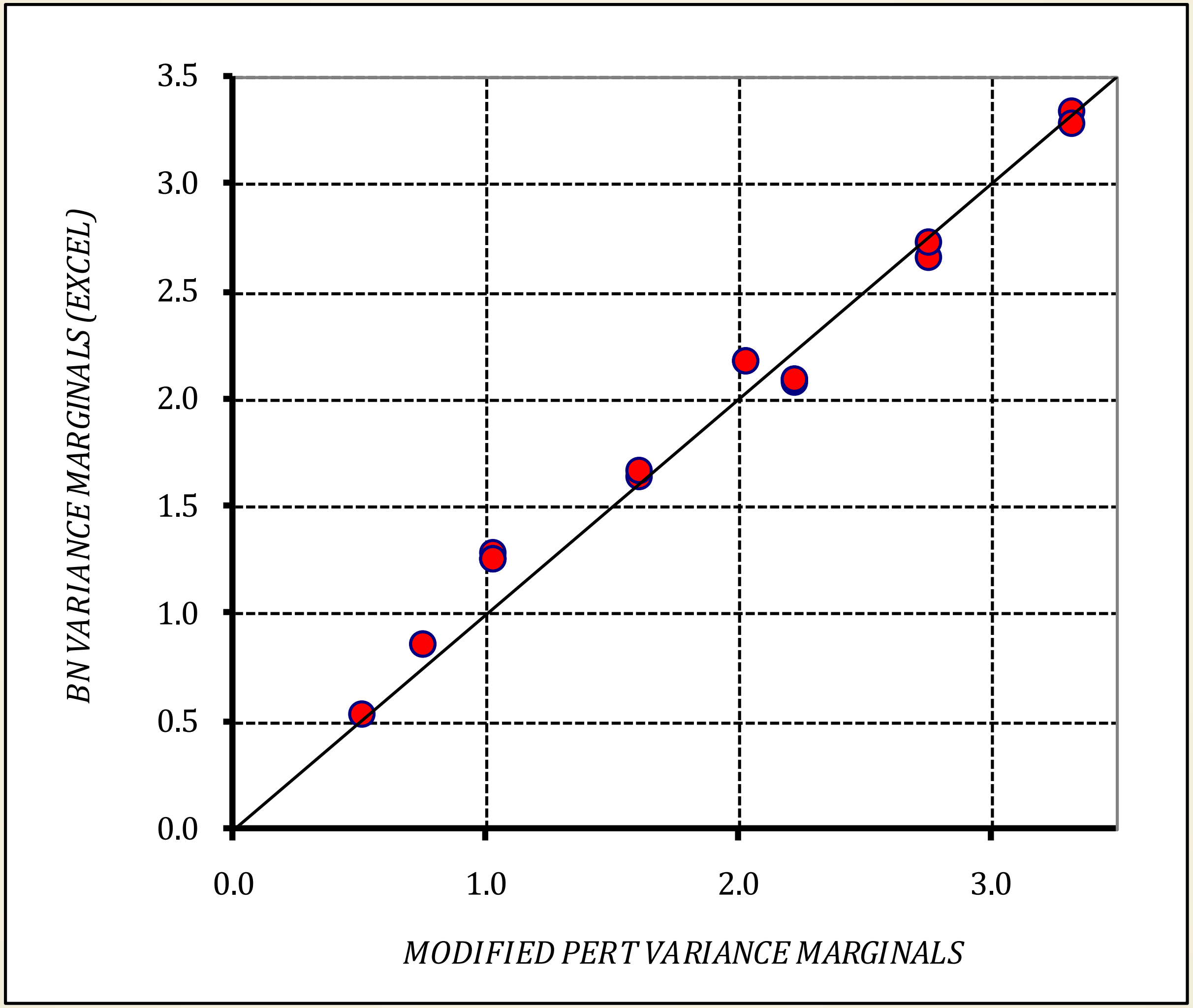
STEP 3: Evaluate Uncertainty given selected β and n



Setting n =3.5 and β = 13

Additional Feedback for selected values of β and n

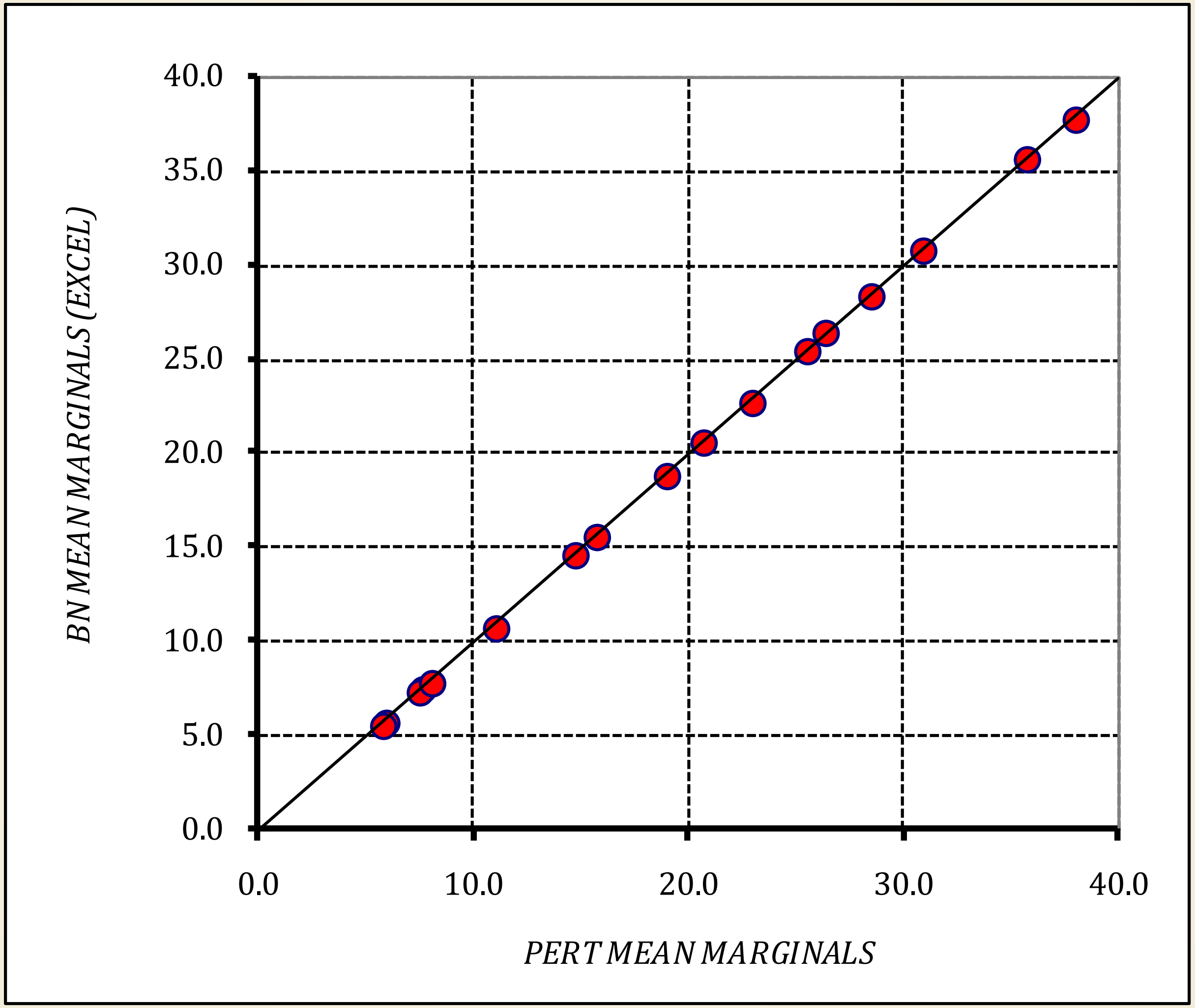
Setting n =3.5 and β = 13



Activity Variances are close to Modified PERT Variances

Additional Feedback for selected values of β and n

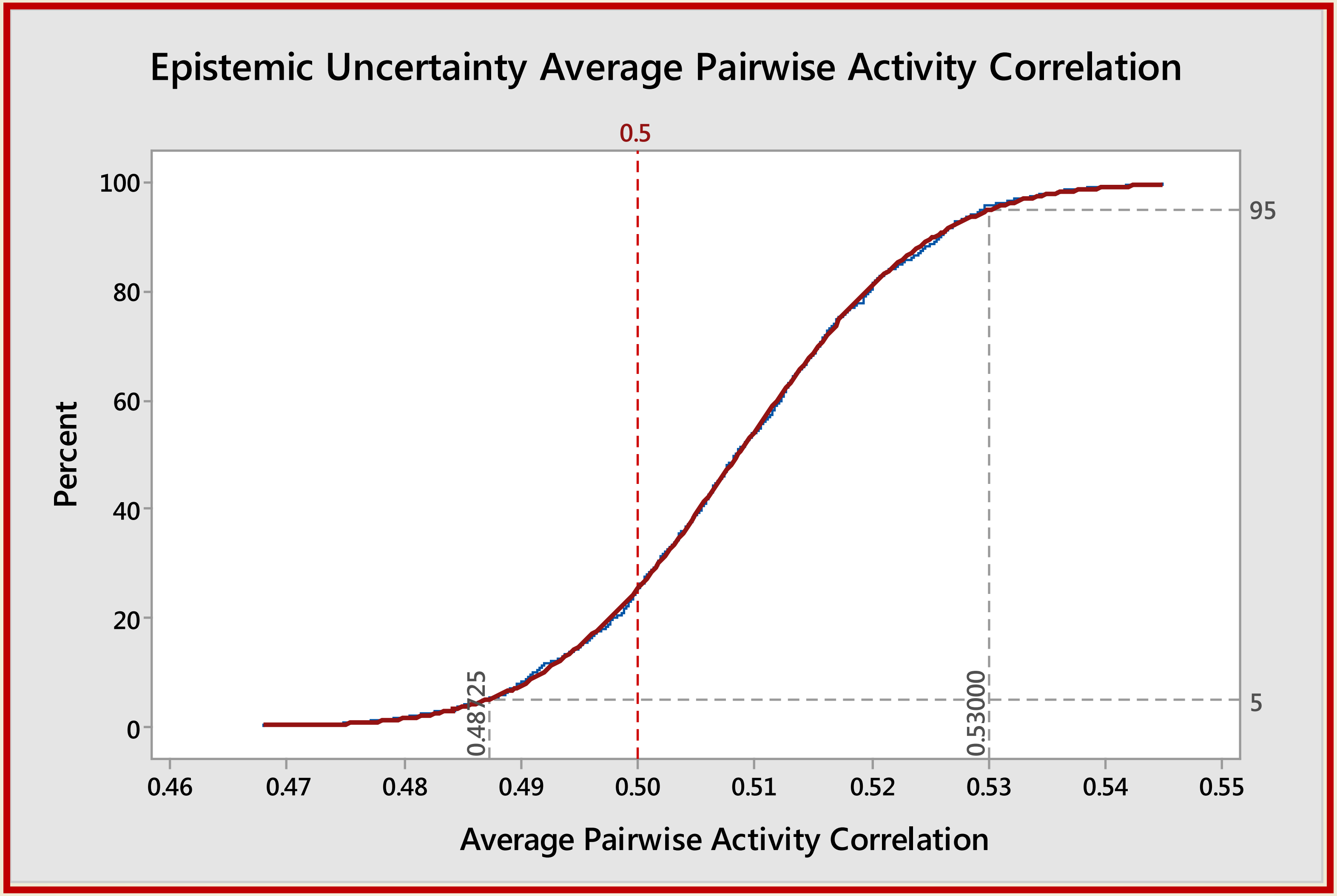
Setting n =3.5 and β = 13



Activity Means are close to PERT Means

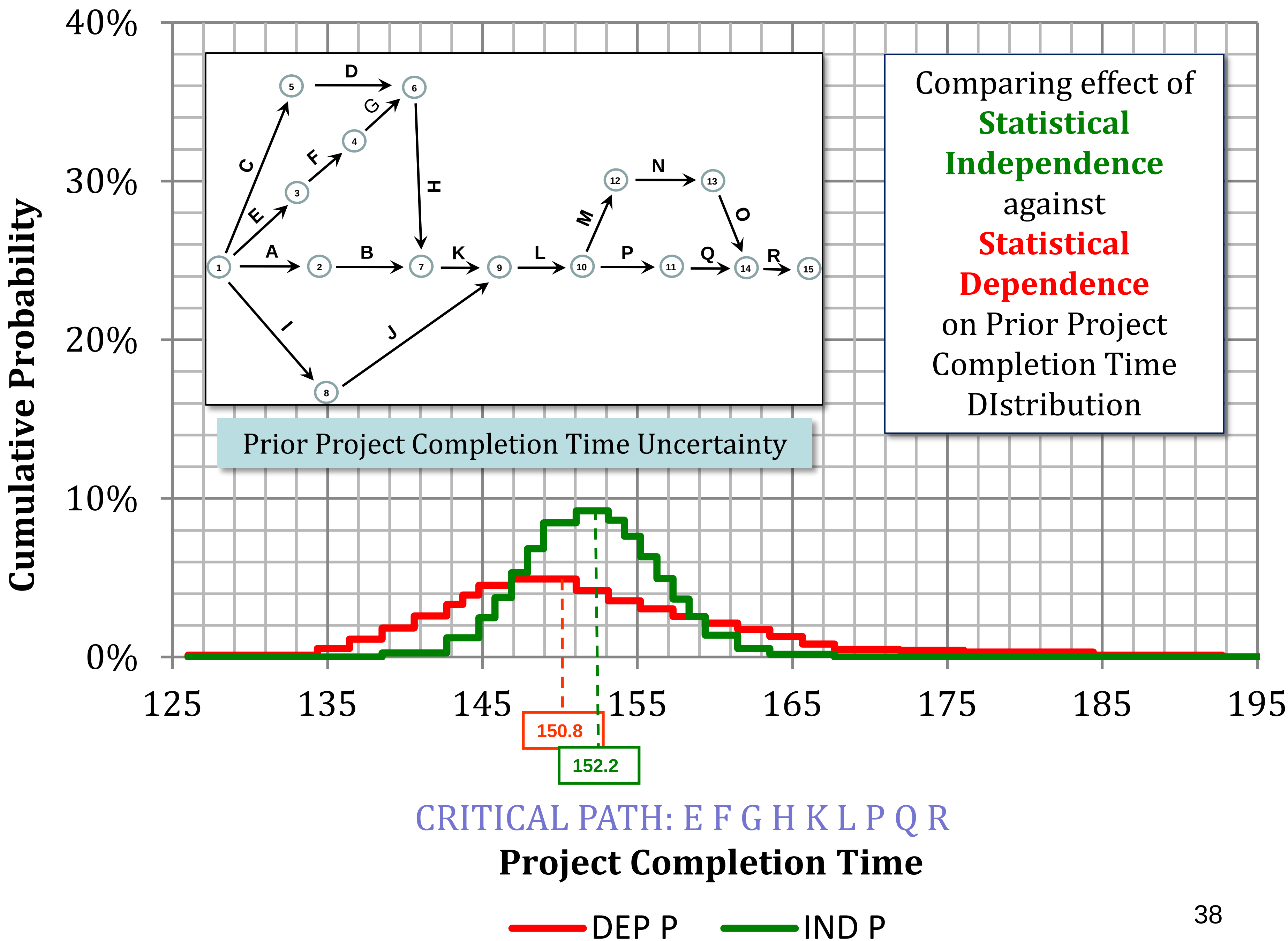
Additional Feedback for selected values of β and n

Setting n =3.5 and β = 13



Average Pairwise Activity Correlation is close to 0.5

- Case Study Description
- Bayesian Network Model
- Statistical Dependence Elicitation
- Uncertainty (n) and Dependence (β) Parameter Selection
- Prior Completion Time Uncertainty
- Posterior Analysis: Monitoring Uncertainty
- Conclusion


Cumulative Probability
40%
30%
20%
10%
0%
125
135
145
155
165
175
185
195
D
C
G
F
E
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K
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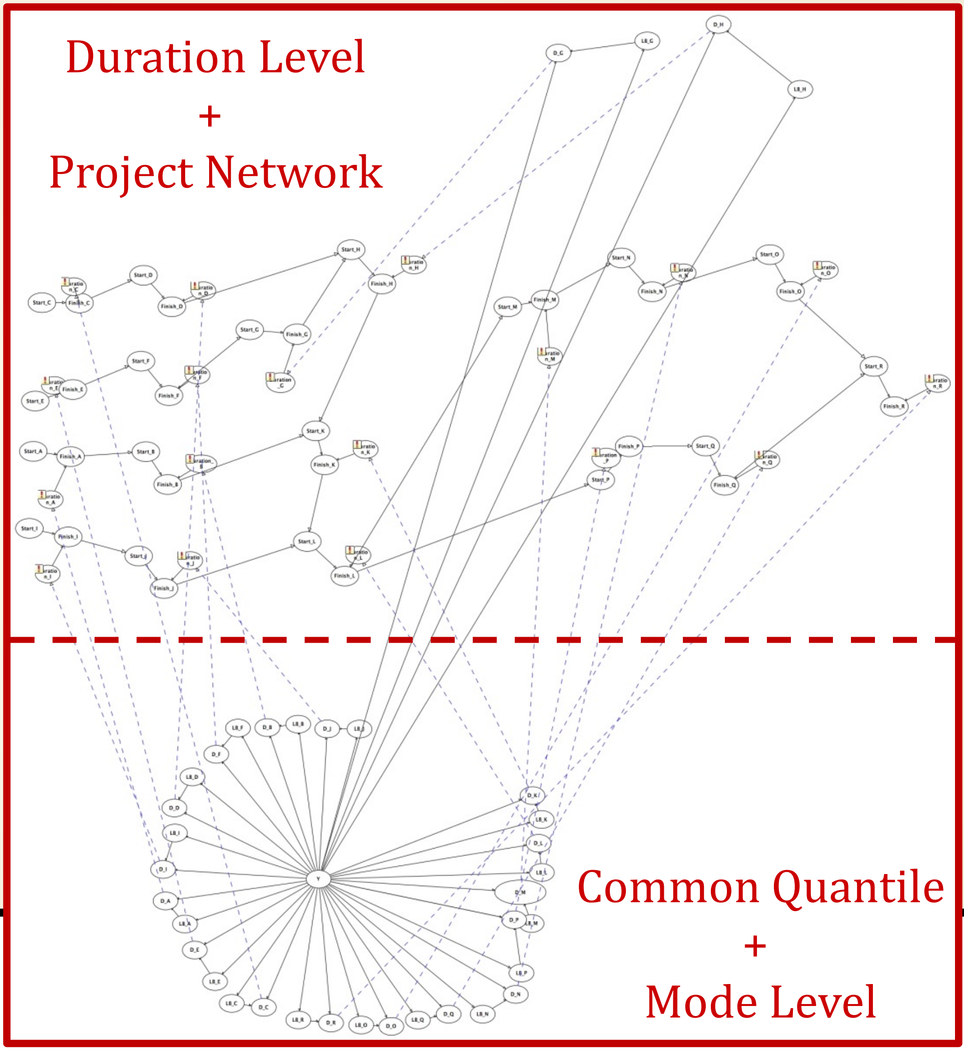
15
Prior Project Completion Time Uncertainty
Comparing effect of
Statistical Independence
against
Statistical Dependence
on Prior Project Completion Time DIstribution
150.8
152.2
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P
IND P

Bayesian Network Dependence Model for Project Risk Analysis (BNDM_PRA)

Project and
Bayes Network
Representation

in Software
Agena Risk



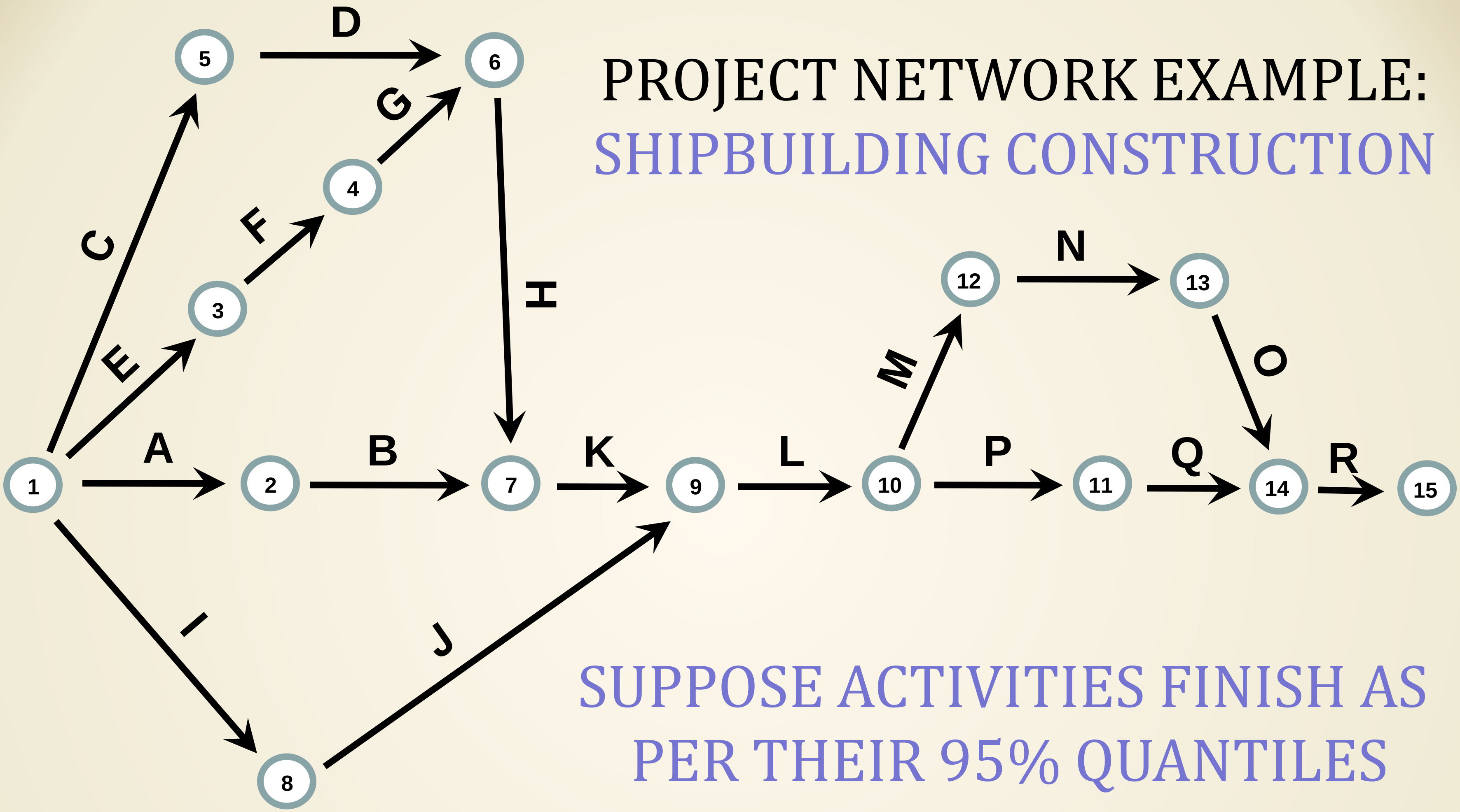
Posterior Analysis
performed in Software:

agena

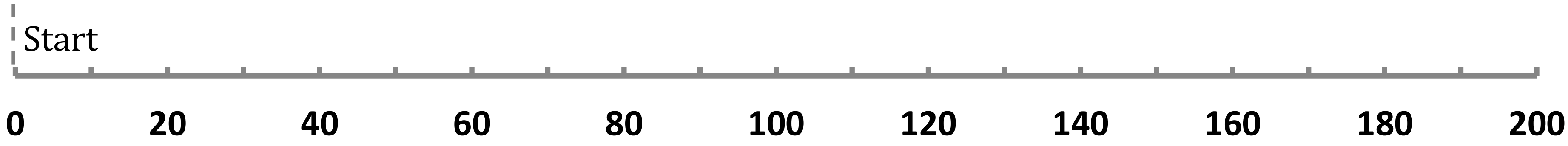
Bayesian Network and Simulation Software for Risk Analysis and Decision Support

- Case Study Description
- Bayesian Network Model
- Statistical Dependence Elicitation
- Uncertainty (n) and Dependence (β) Parameter Selection
- Prior Completion Time Uncertainty
- Posterior Analysis: Monitoring Uncertainty
- Conclusion

PROJECT NETWORK EXAMPLE: SHIPBUILDING CONSTRUCTION

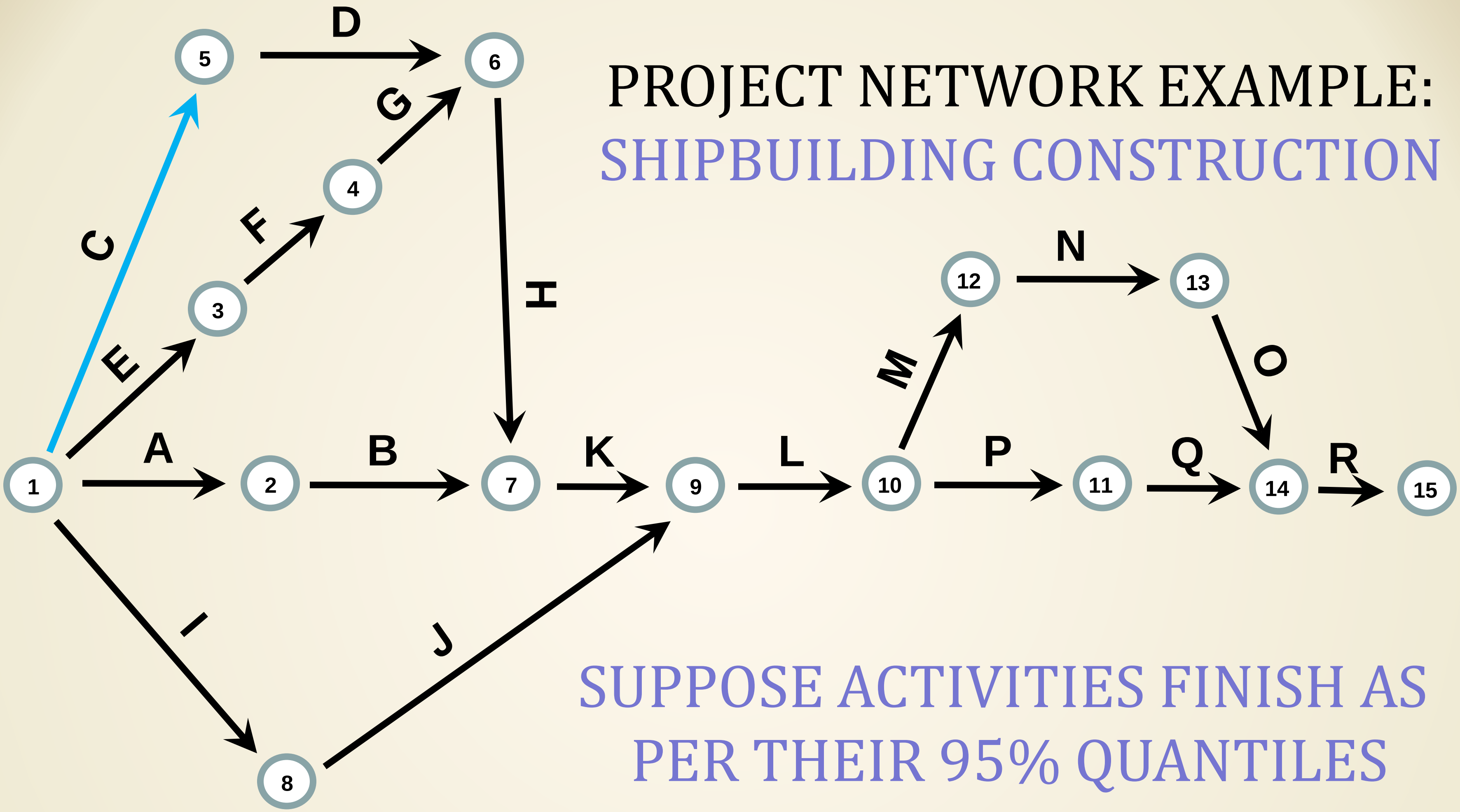


SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES

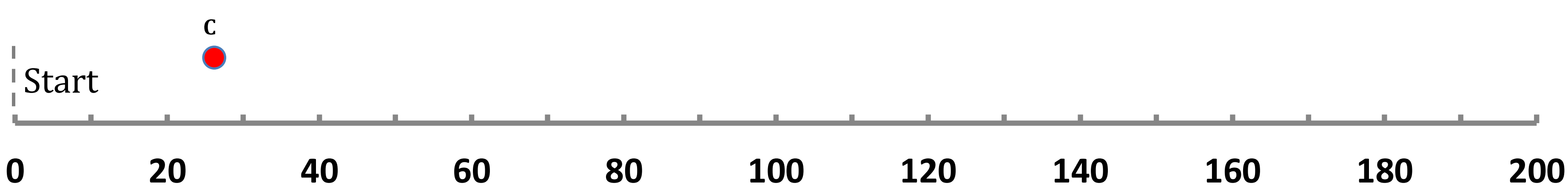


PROJECT NETWORK EXAMPLE:

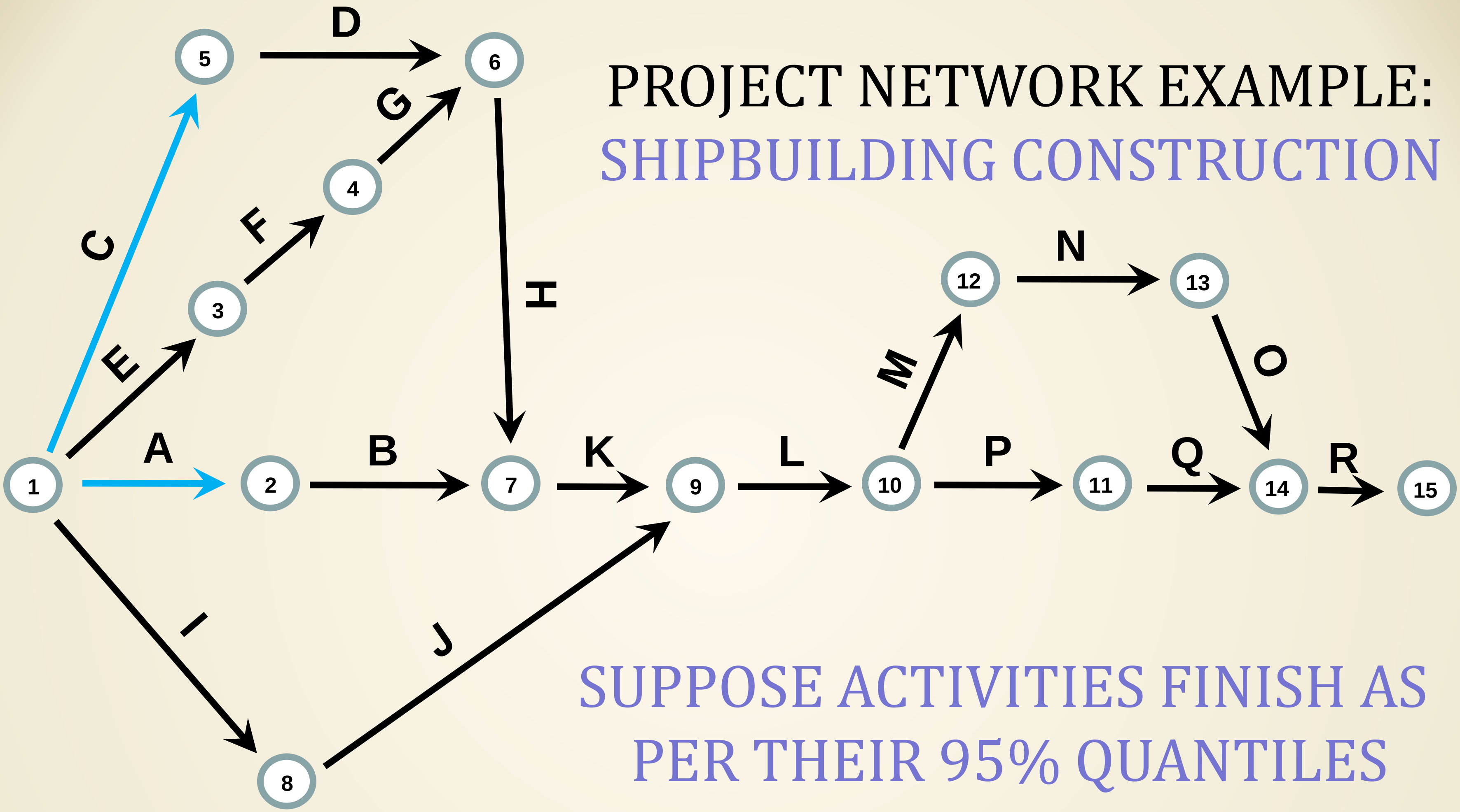
SHIPBUILDING CONSTRUCTION



SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES



PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION



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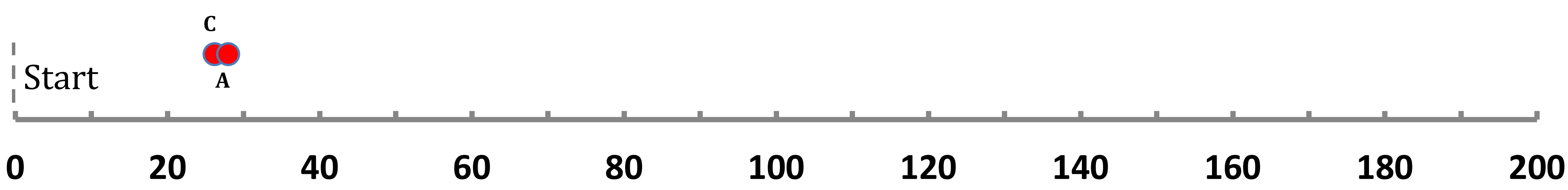
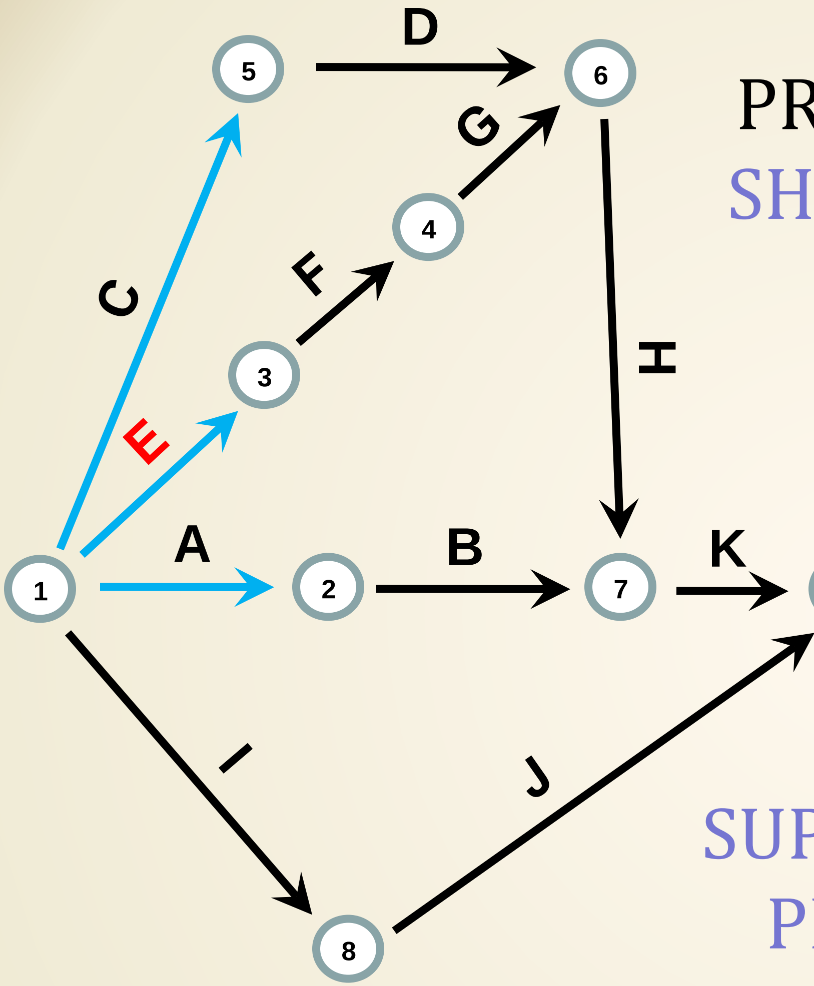


PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION



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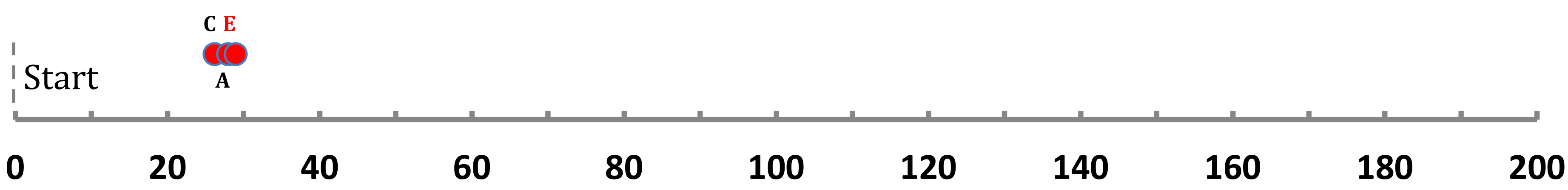
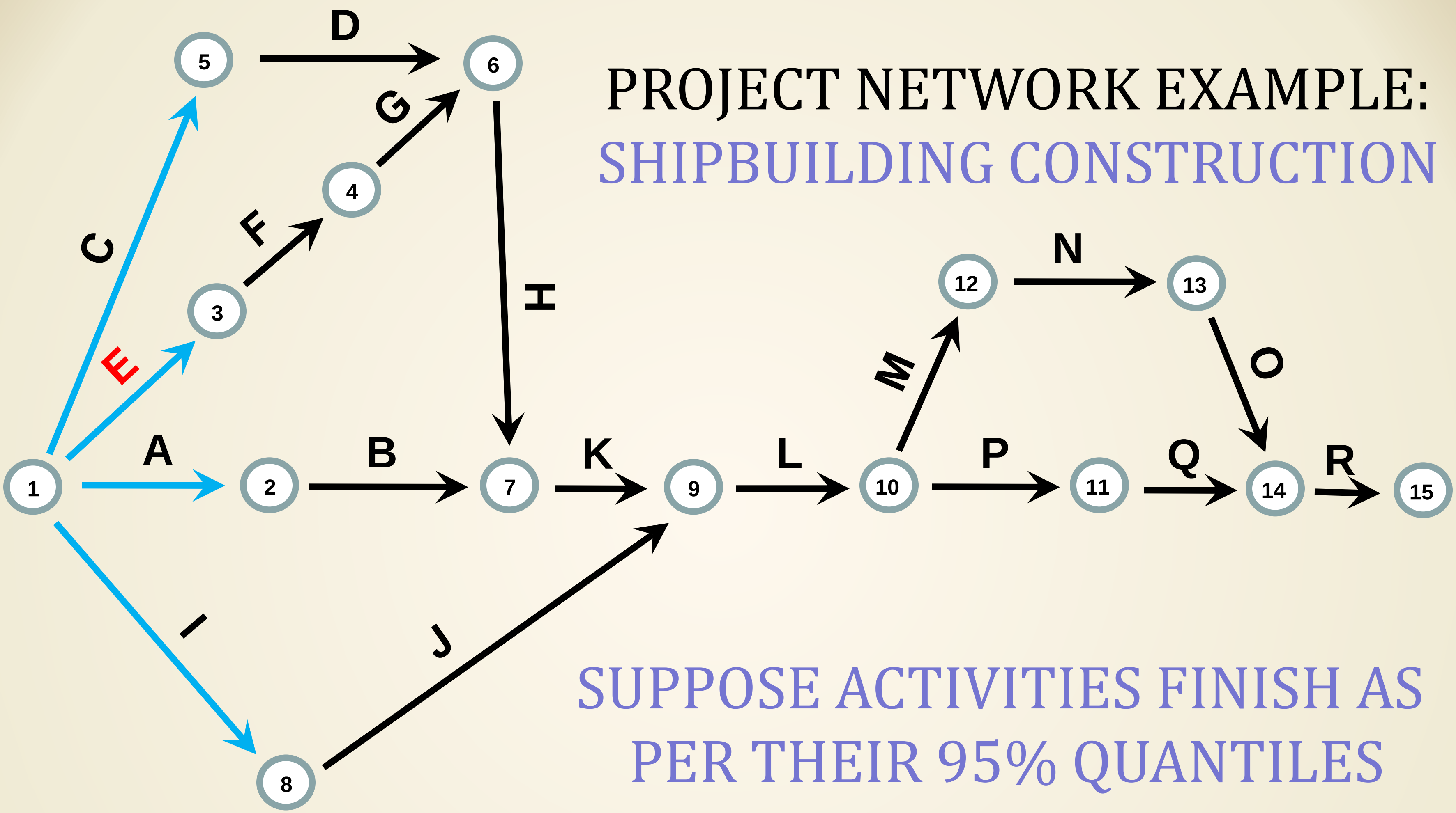
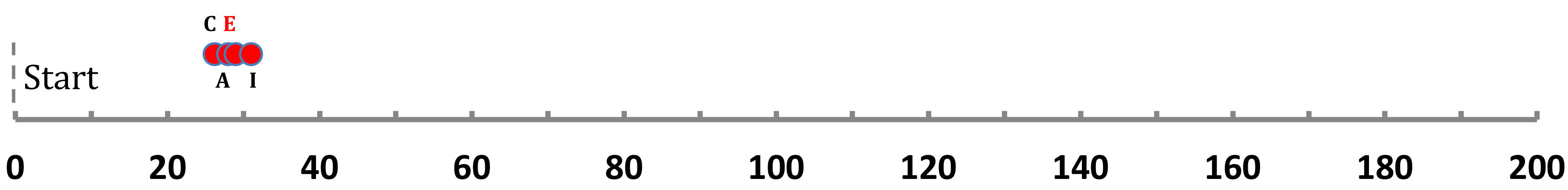


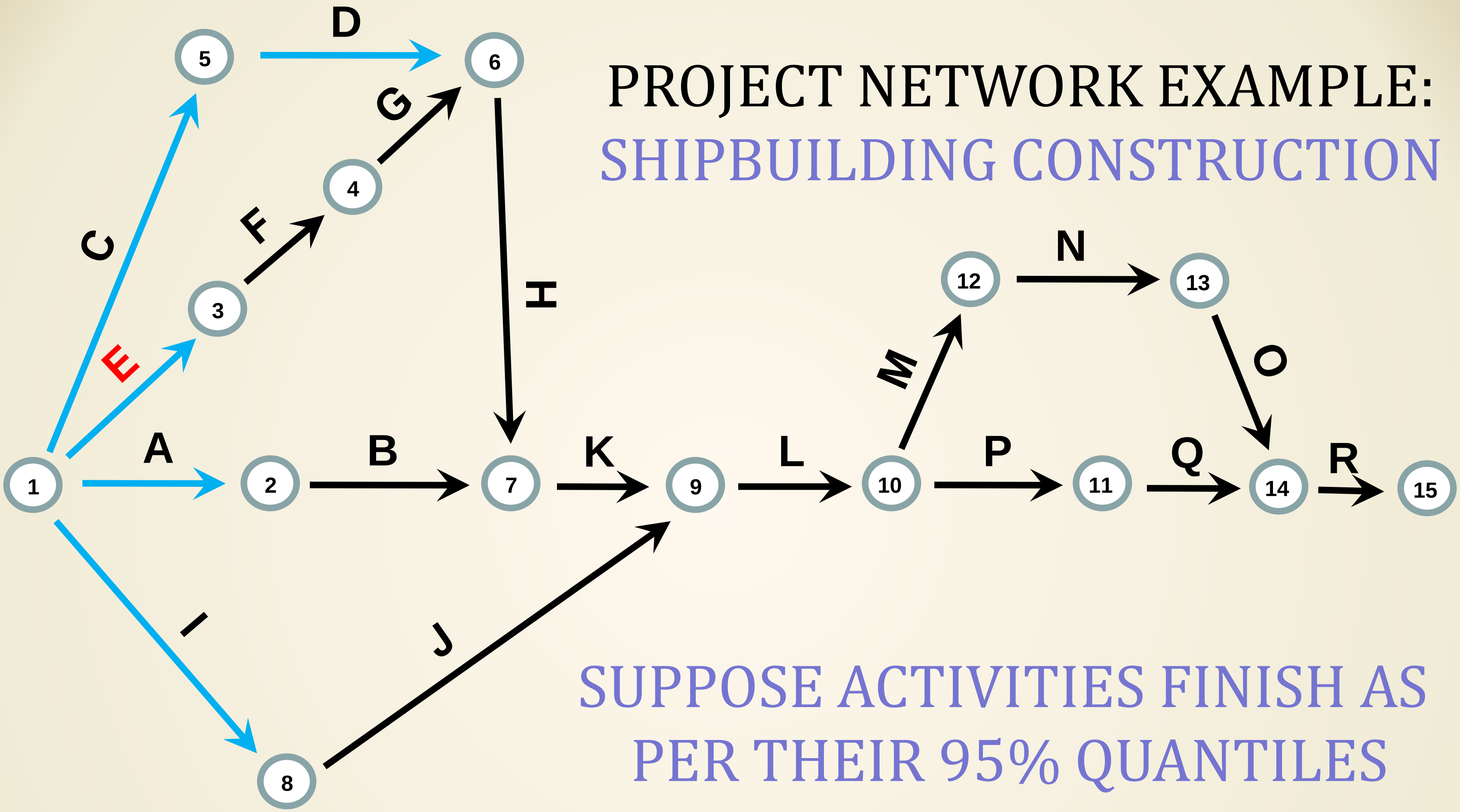
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION



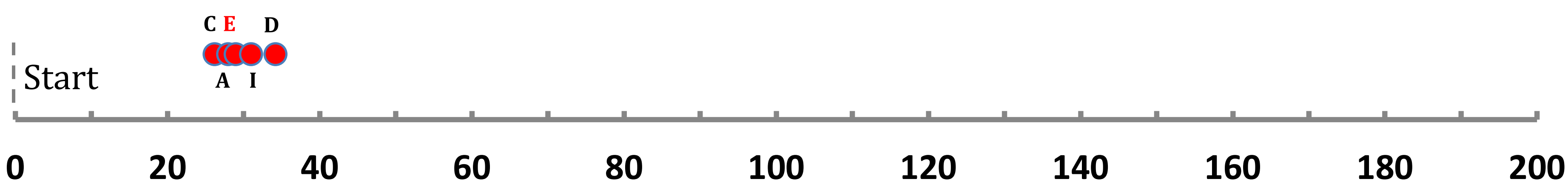
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES



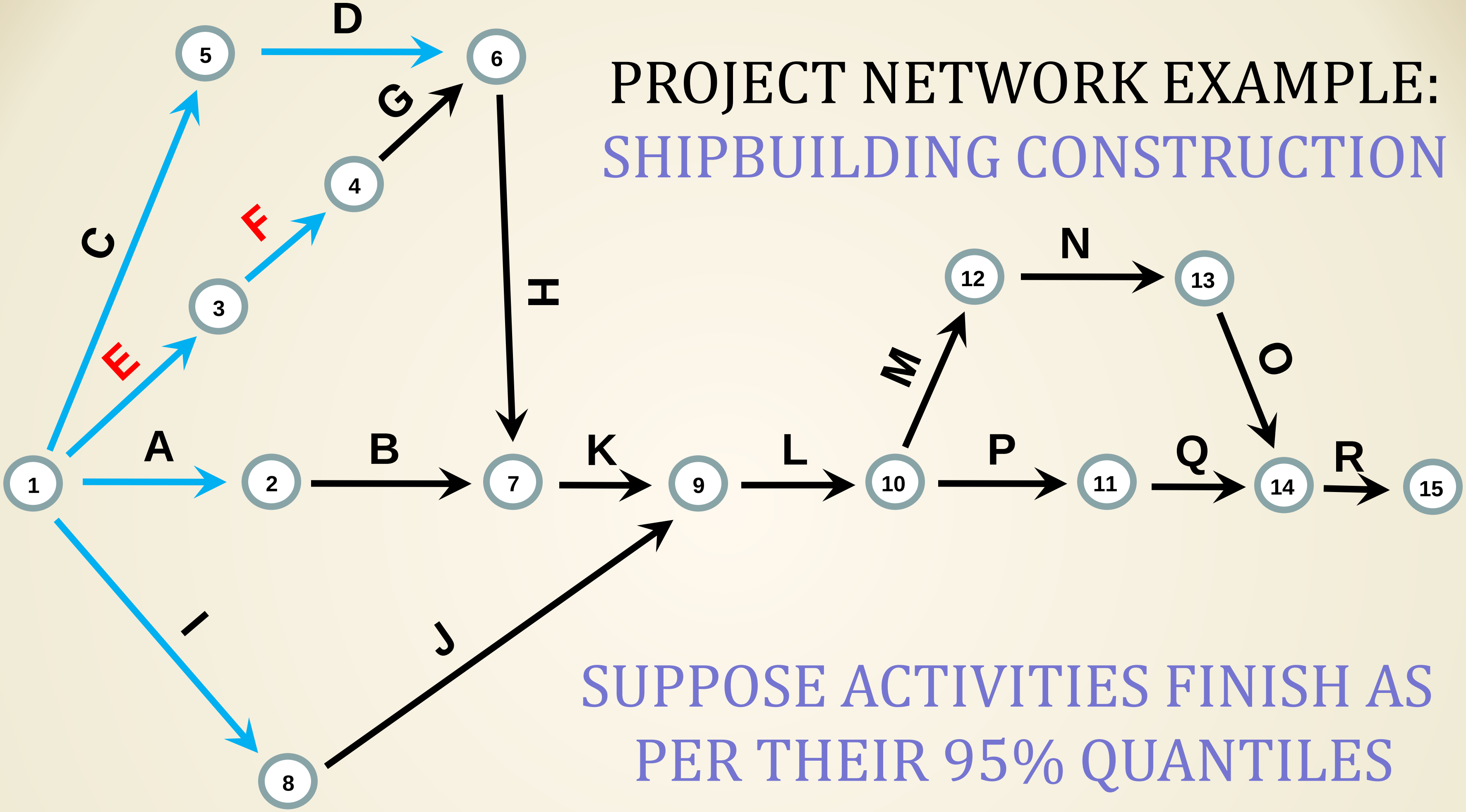
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION



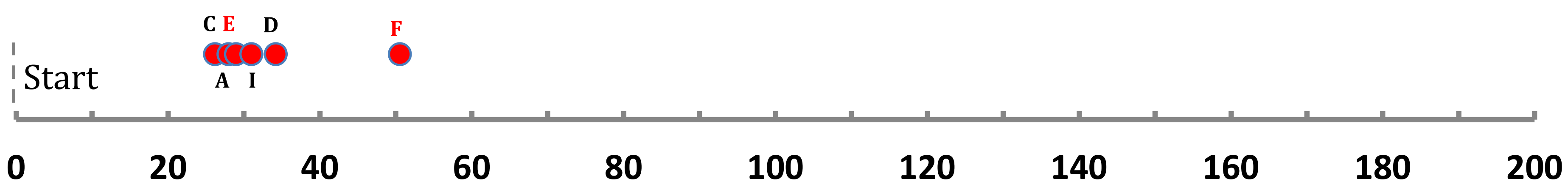
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES



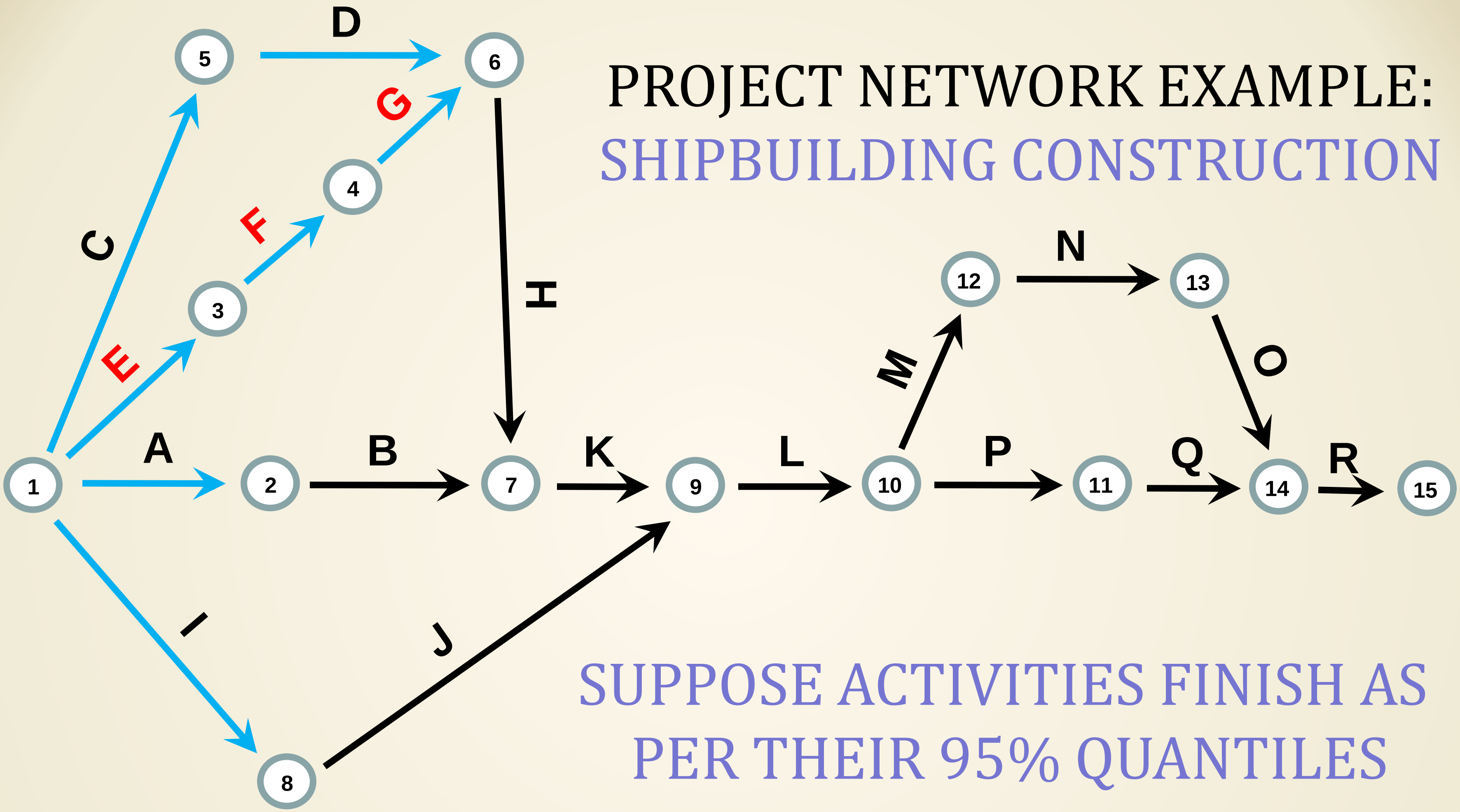
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION



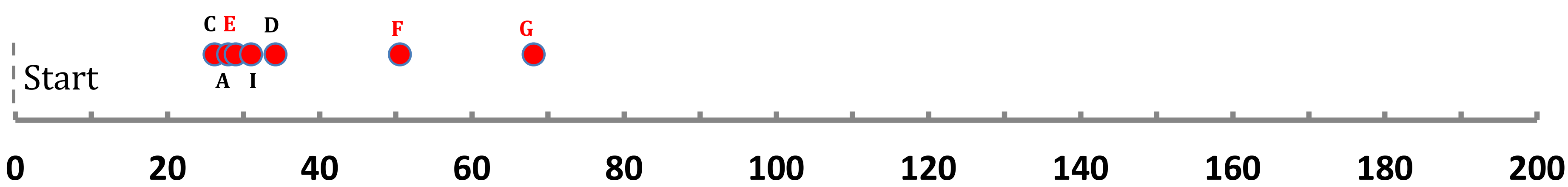
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES



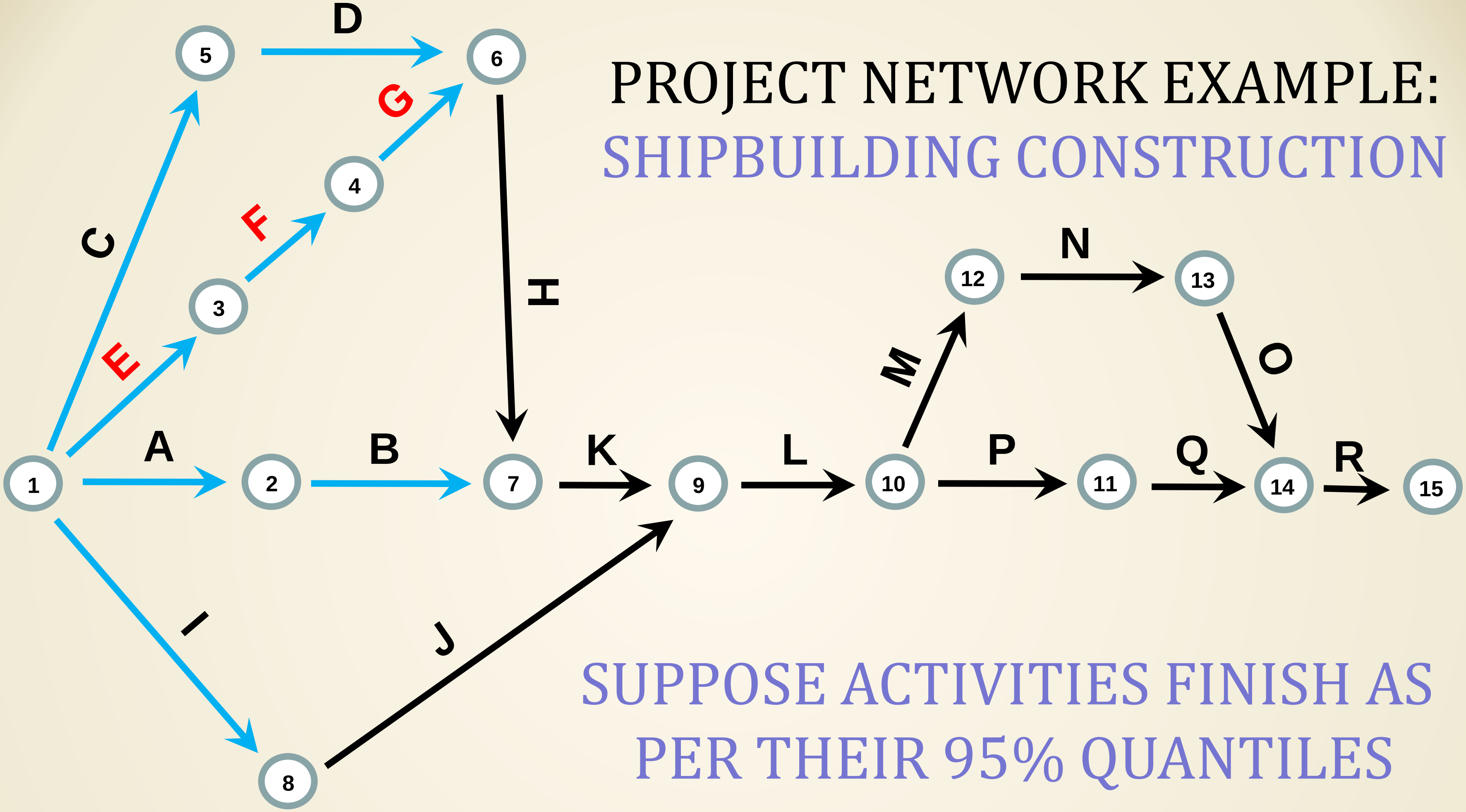
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION



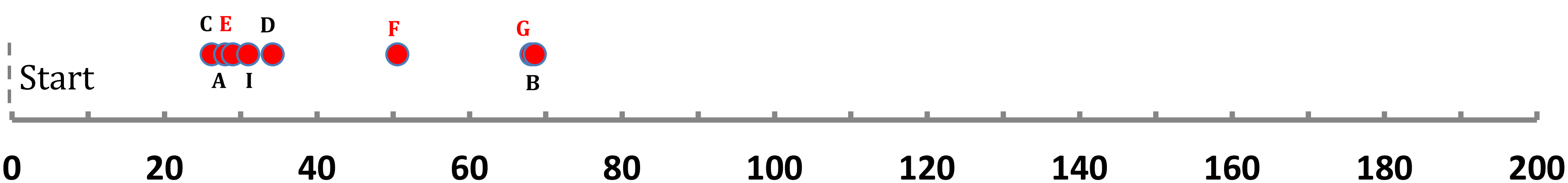
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES



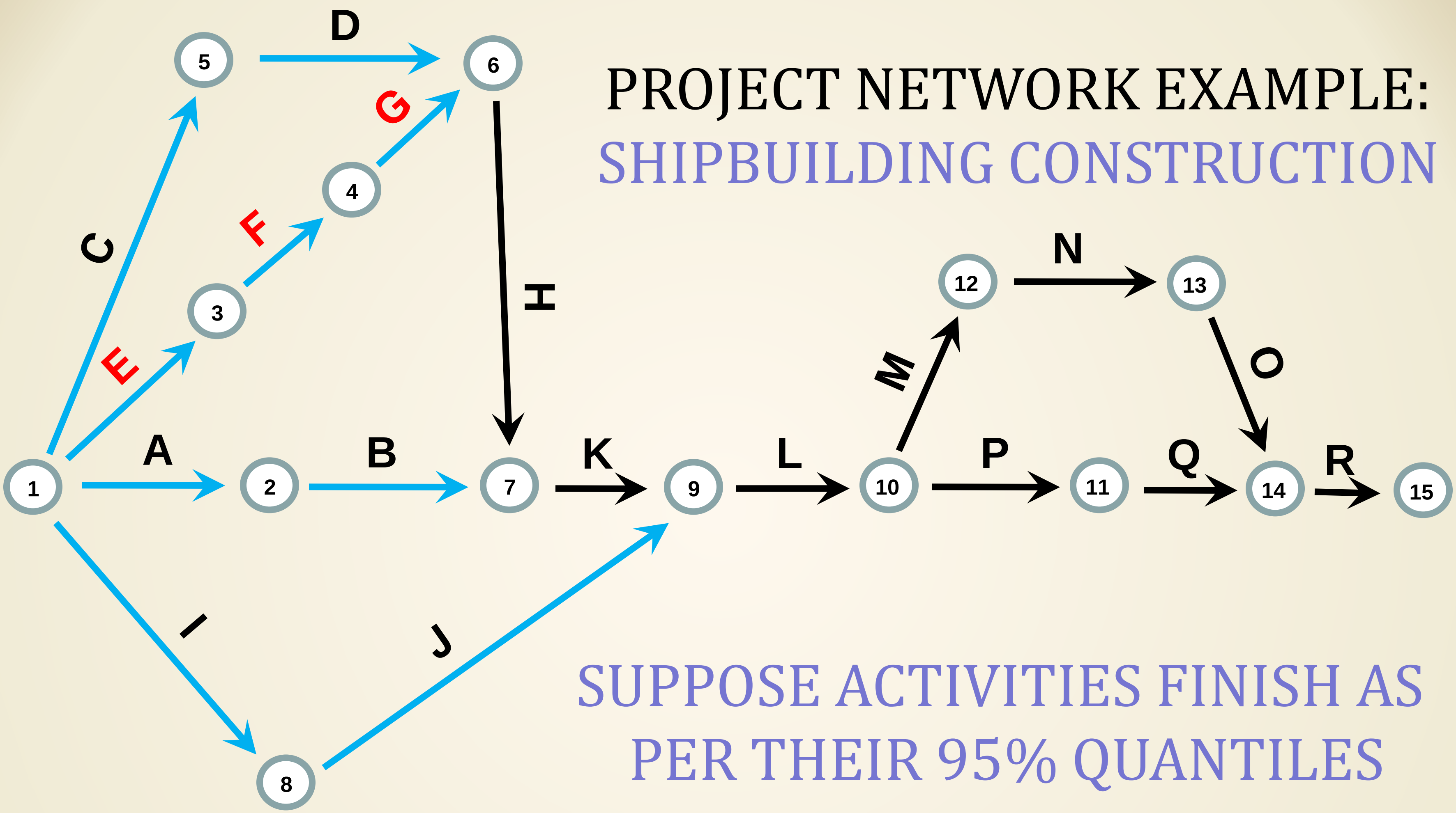
PROJECT NETWORK EXAMPLE: SHIPBUILDING CONSTRUCTION



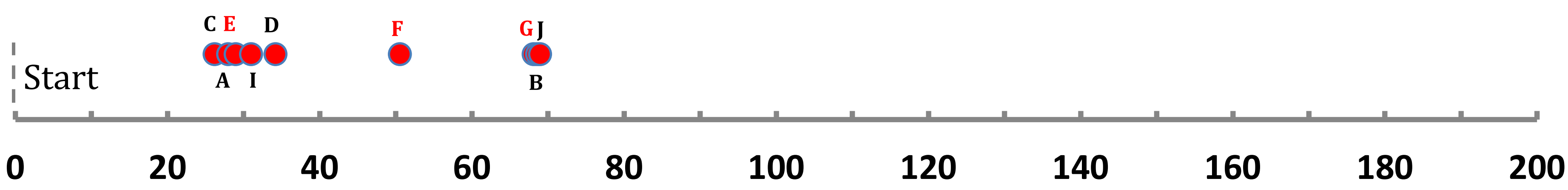
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES



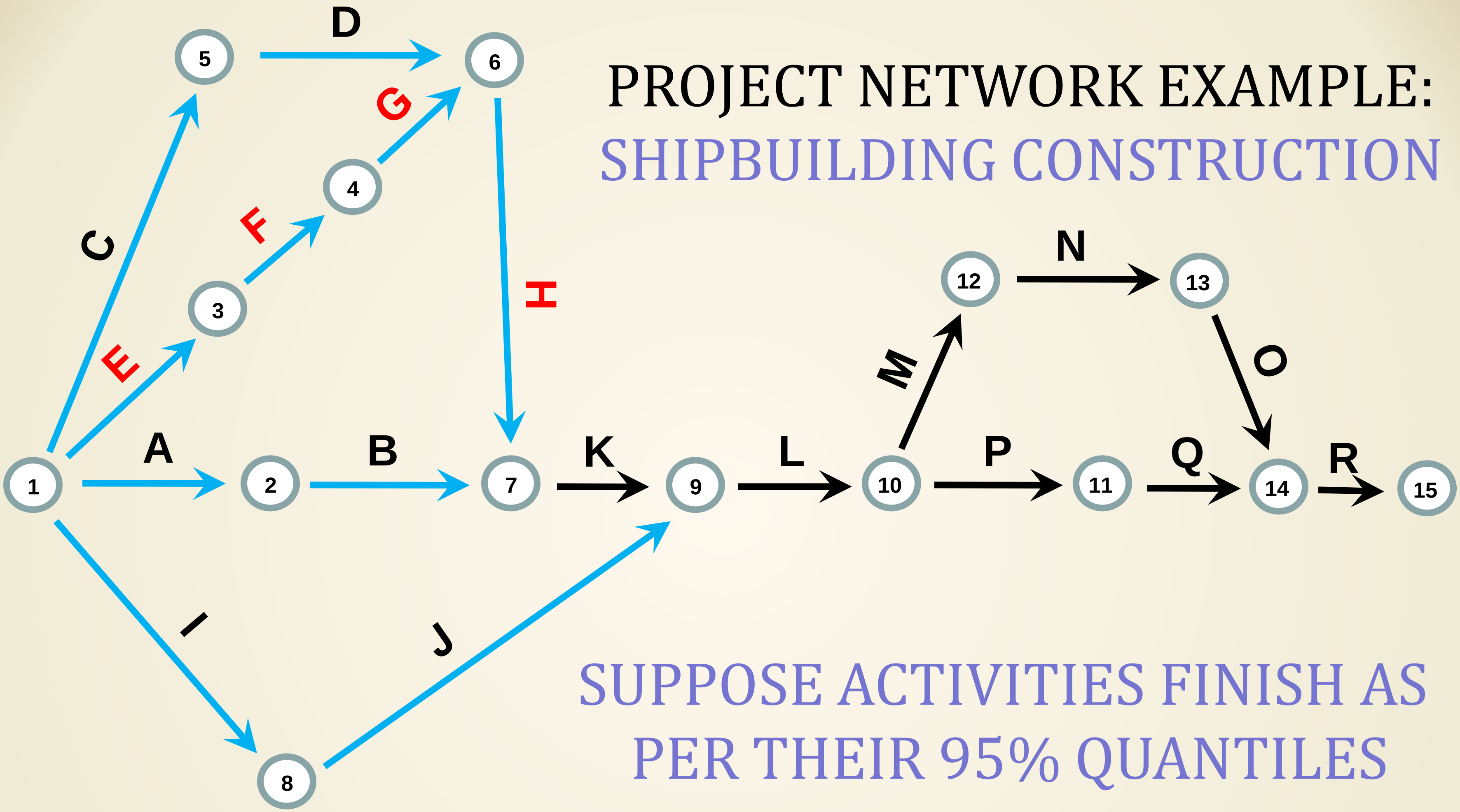
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION



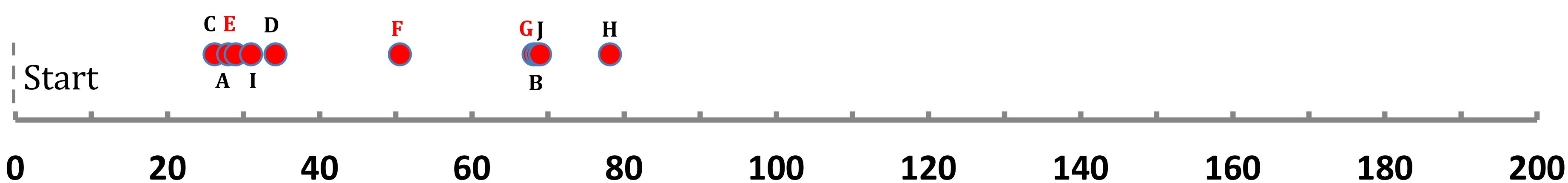
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES



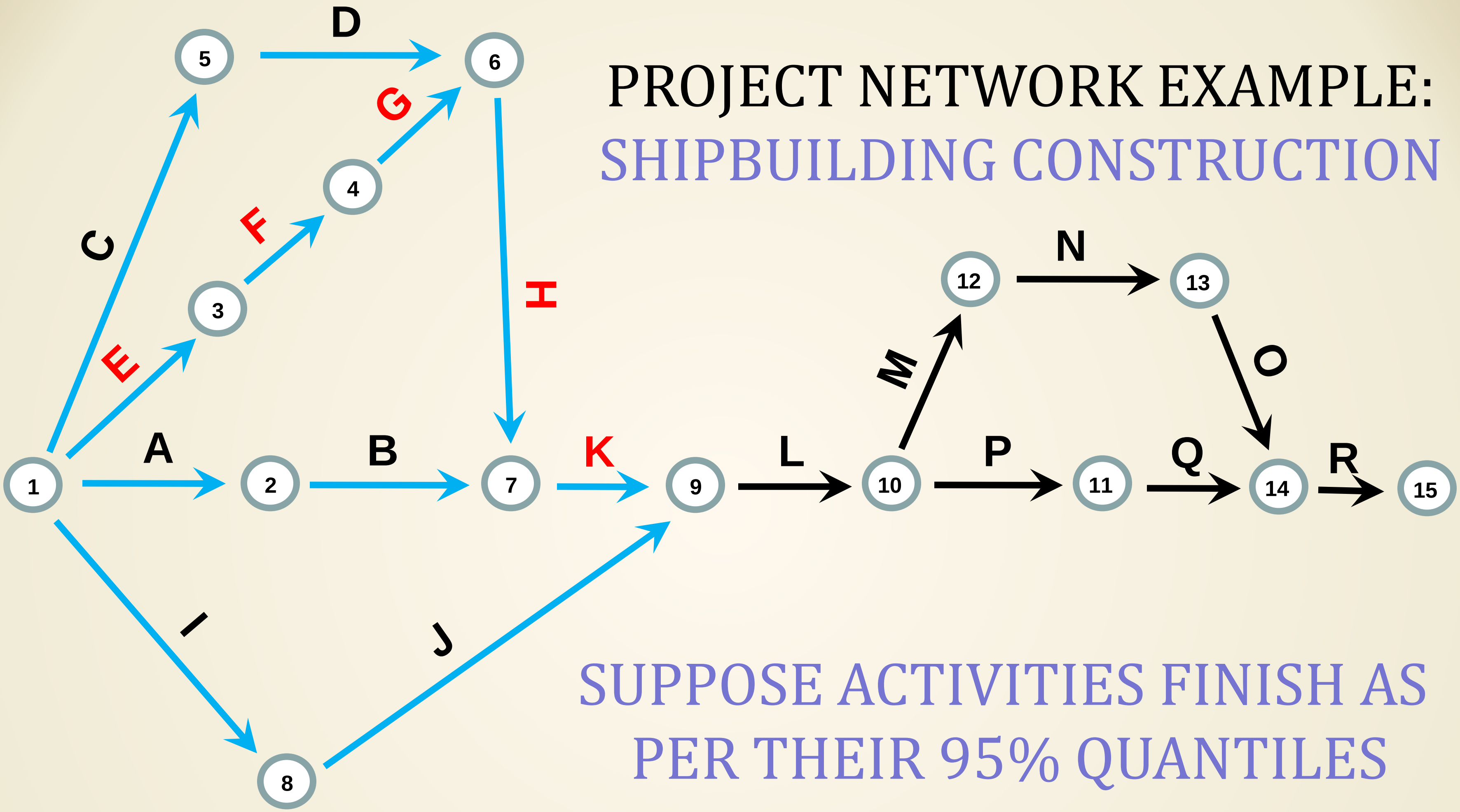
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION



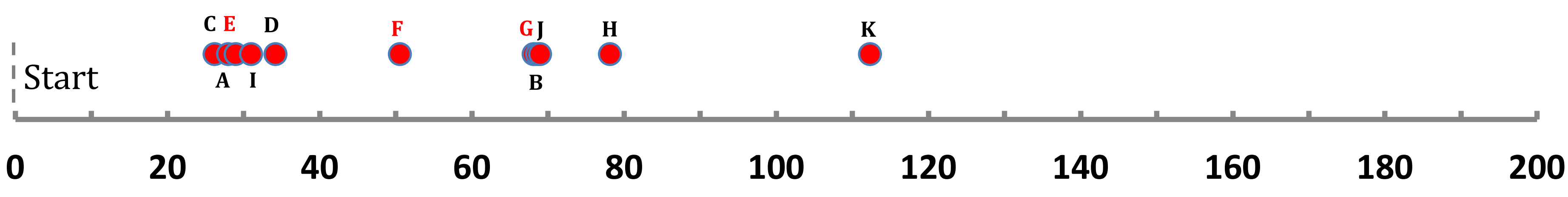
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES



PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION



SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES



PROJECT NETWORK EXAMPLE:

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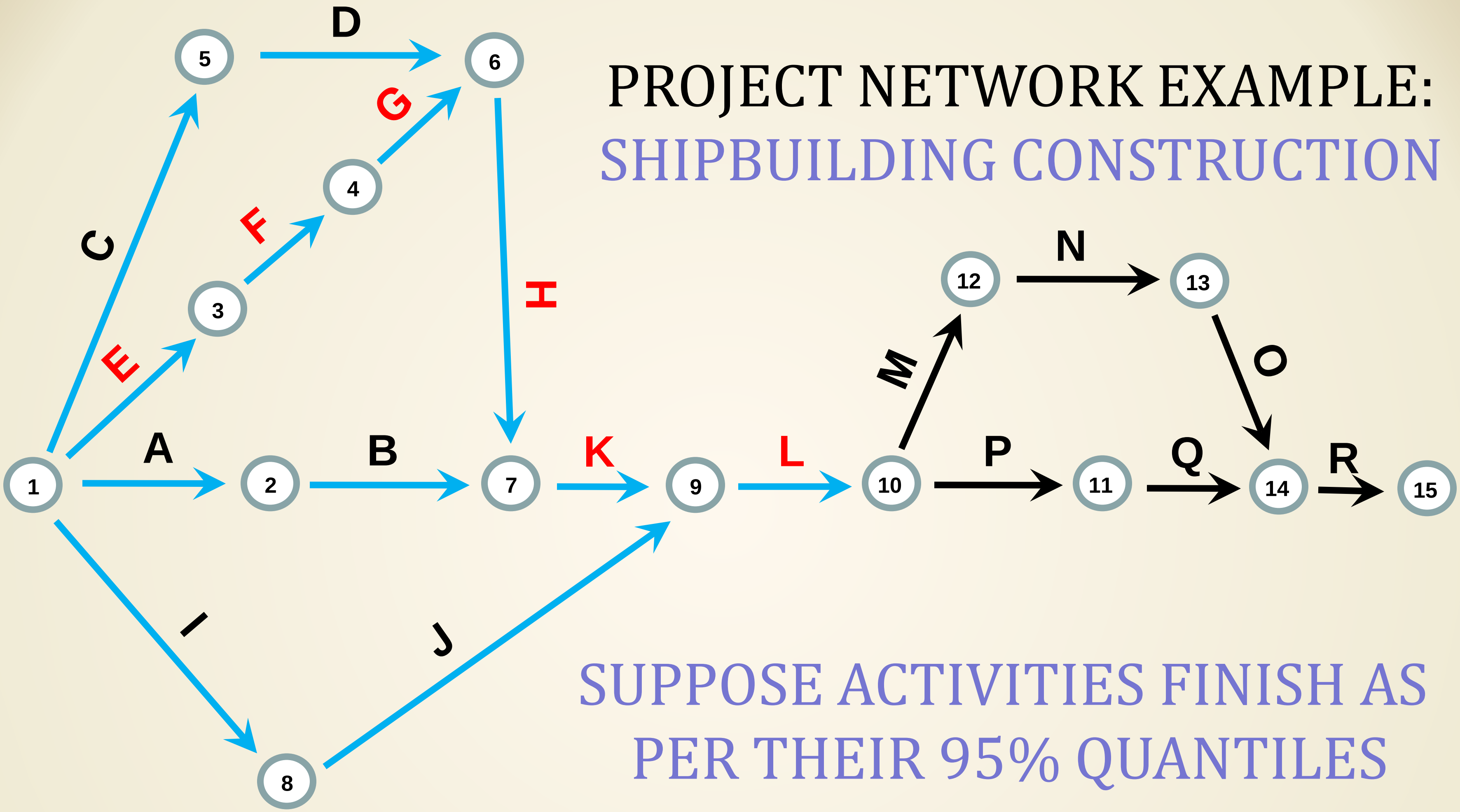

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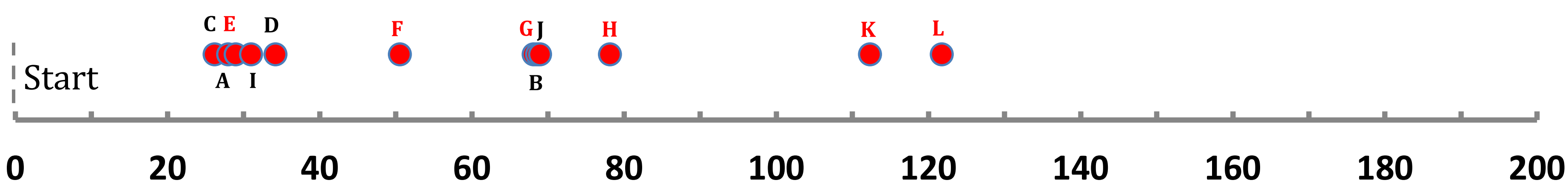
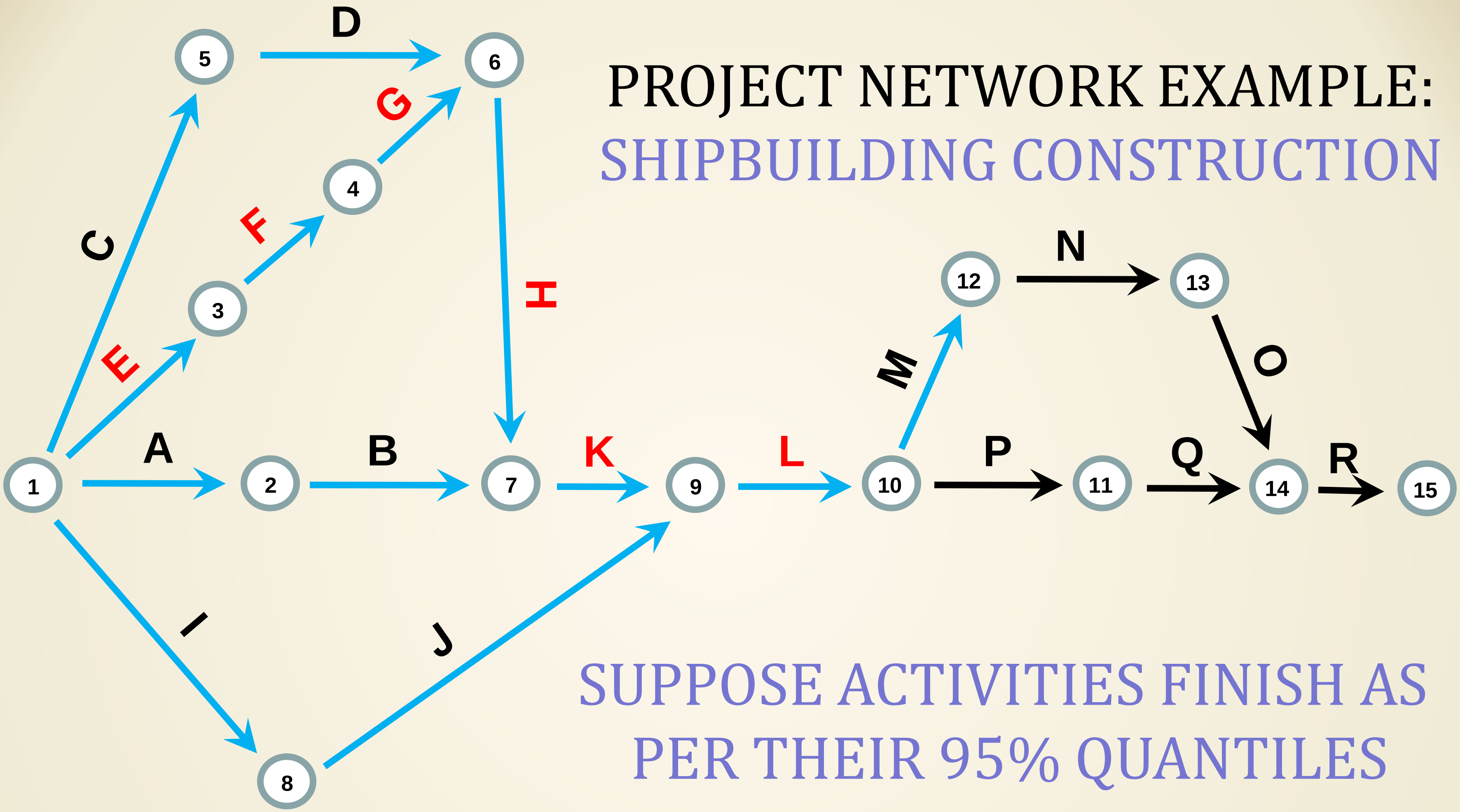
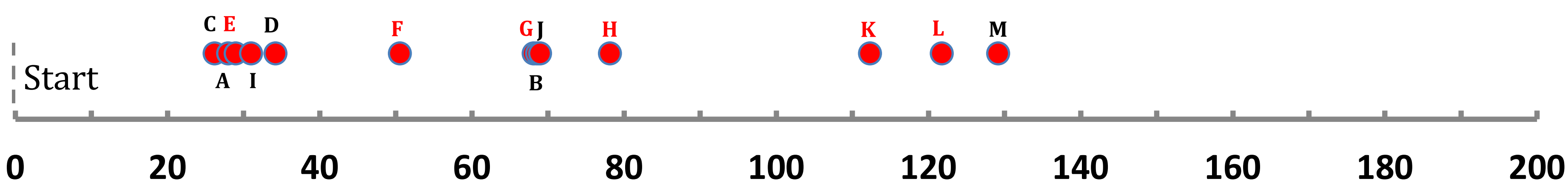


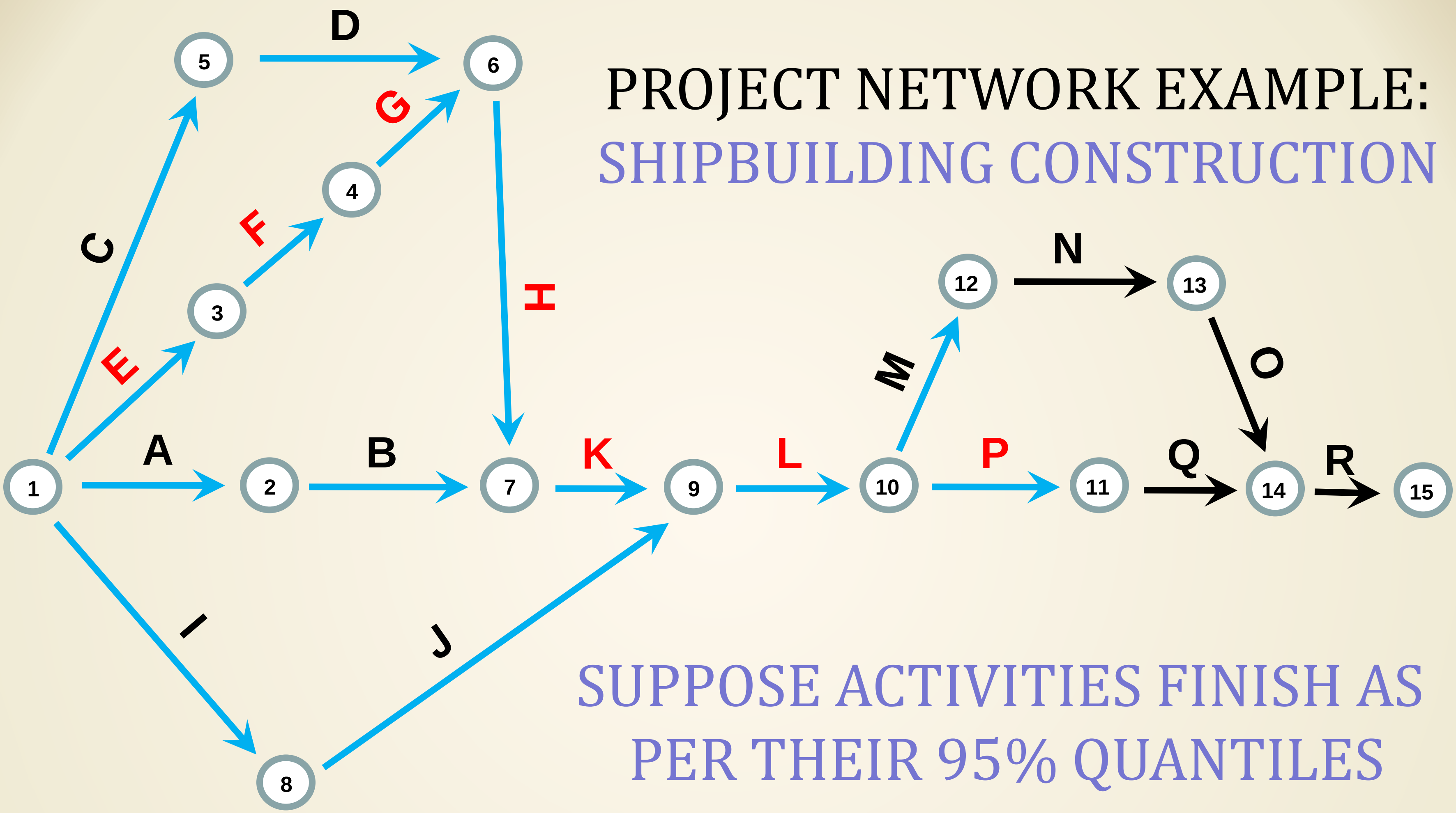
PROJECT NETWORK EXAMPLE: SHIPBUILDING CONSTRUCTION



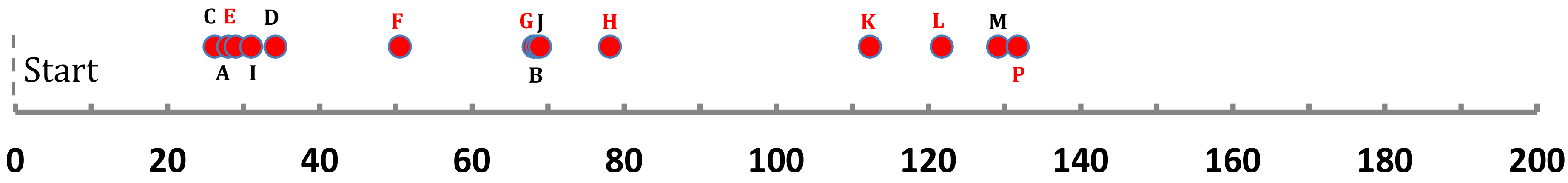
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES

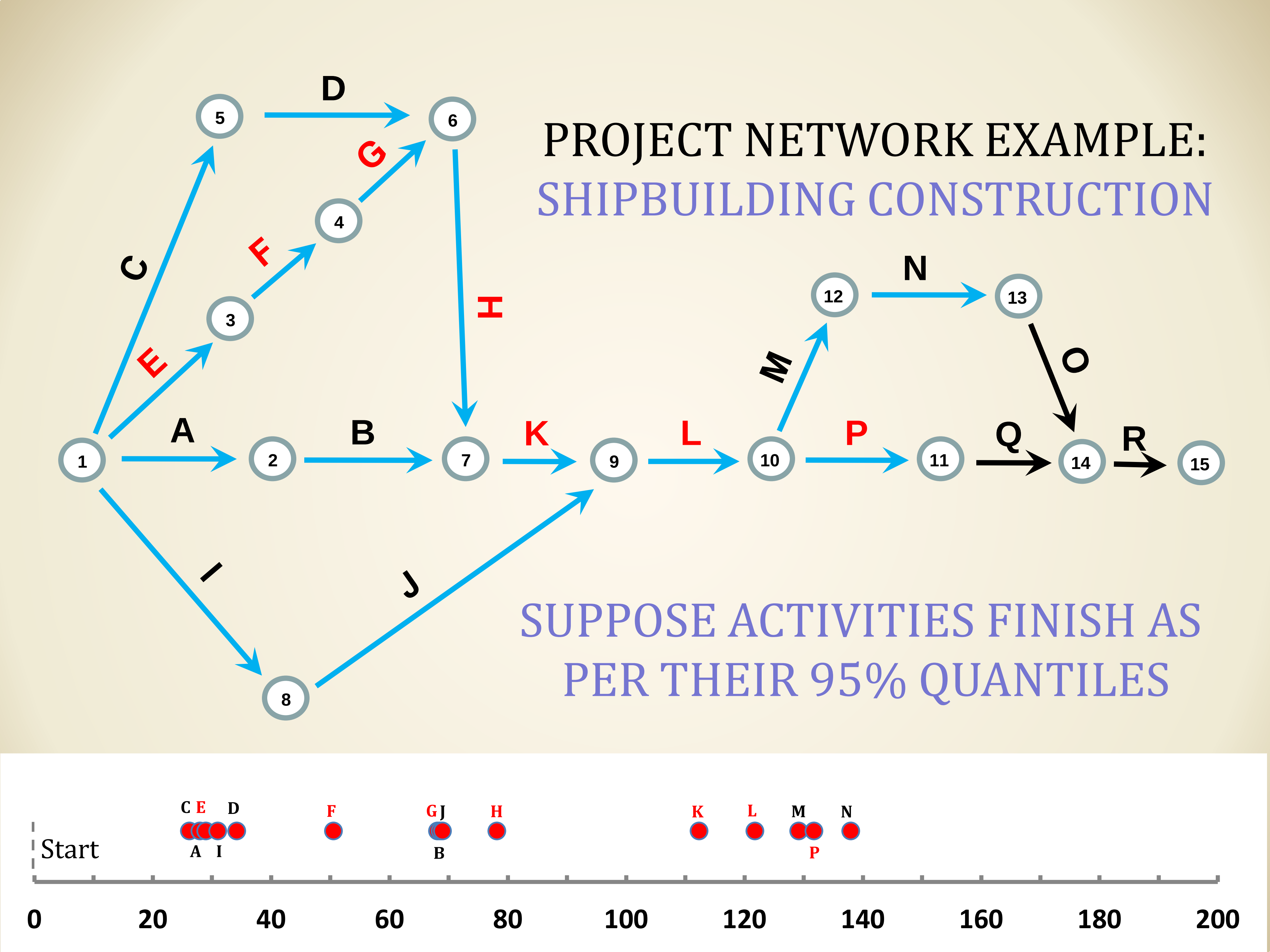


PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION



SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES




PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES
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M
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Q
R
Start
C E D F G J H K L M N
A I B P
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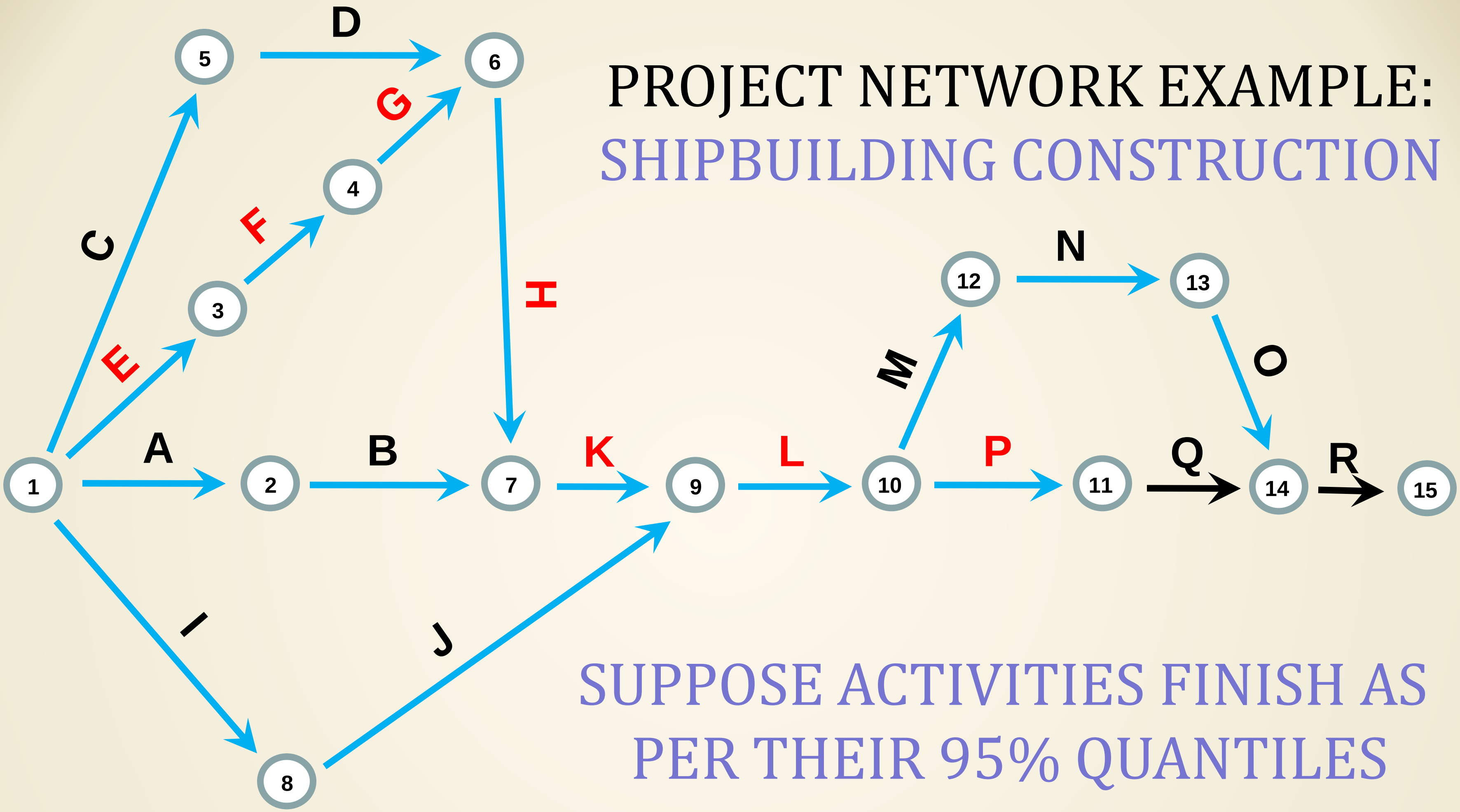
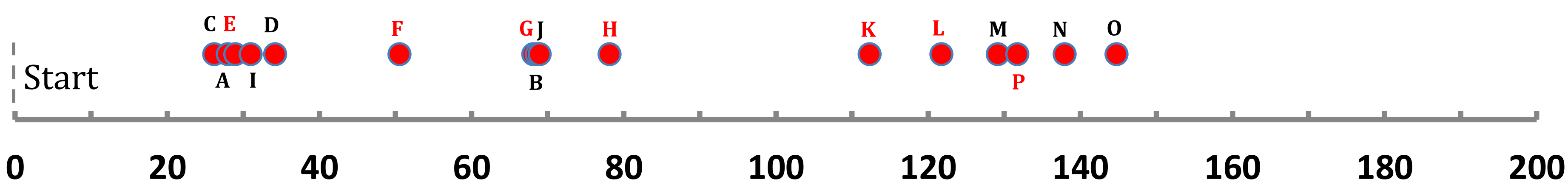
80
100
120
140
160
180
200

PROJECT NETWORK EXAMPLE: SHIPBUILDING CONSTRUCTION

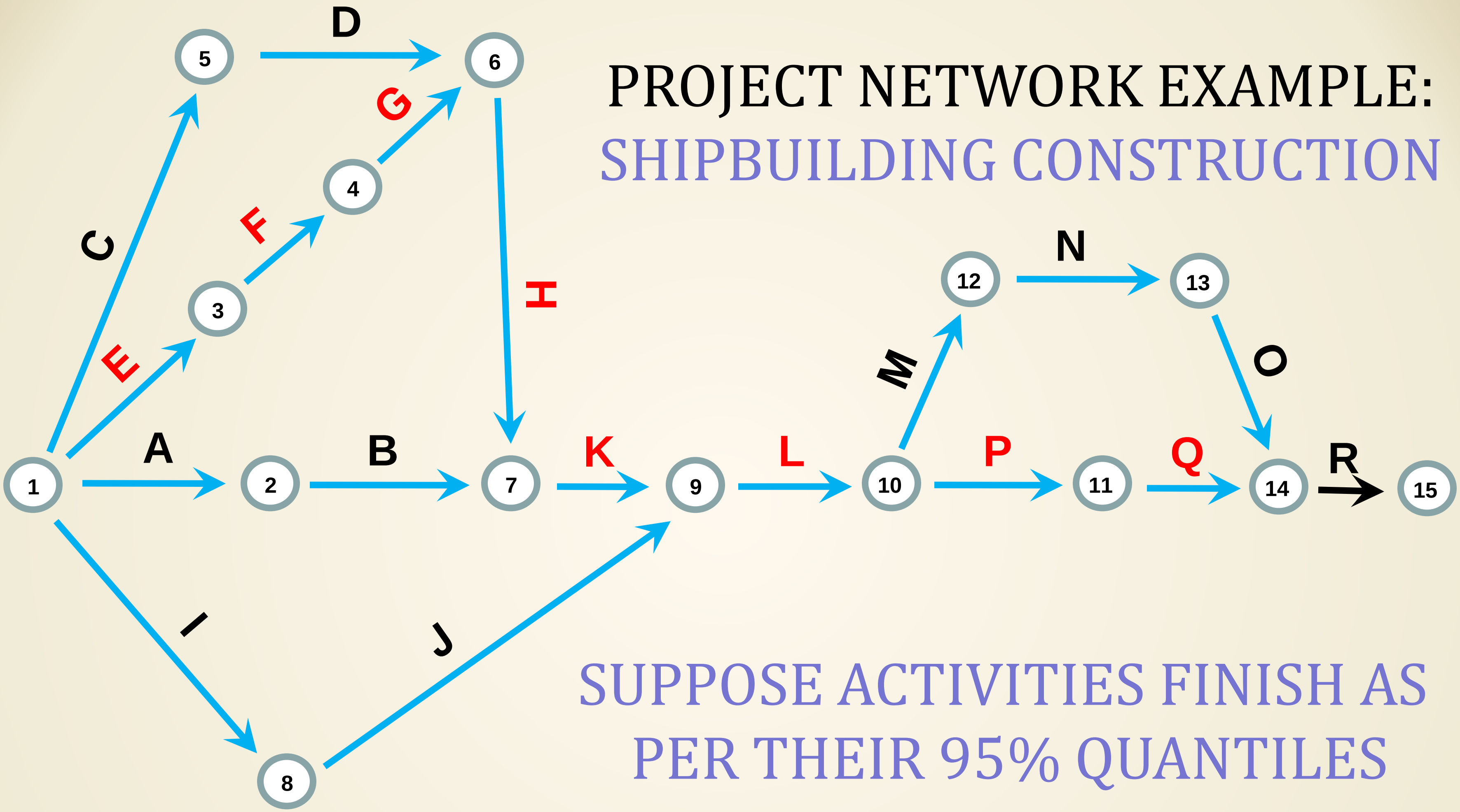


SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES

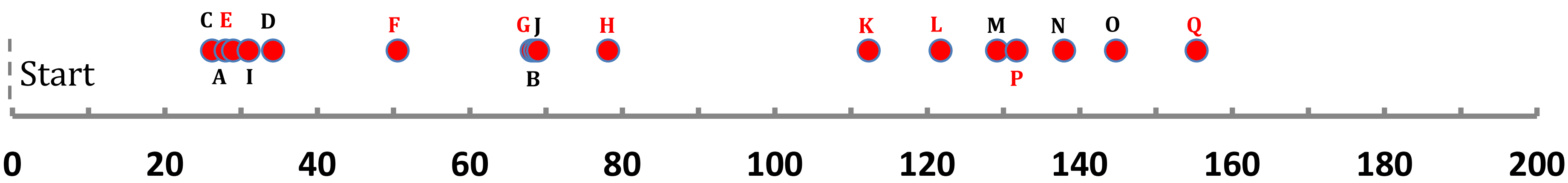


PROJECT NETWORK EXAMPLE:

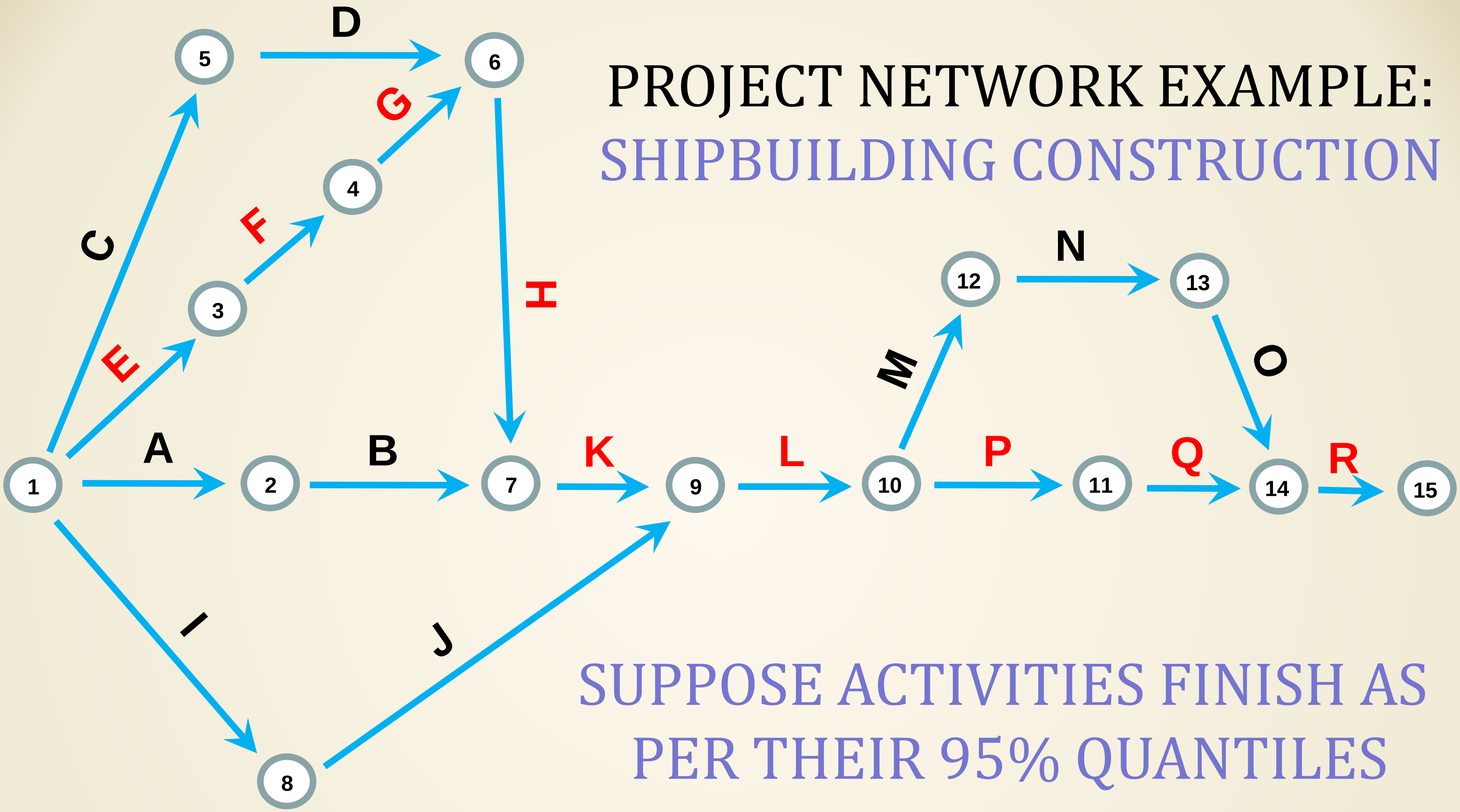
SHIPBUILDING CONSTRUCTION



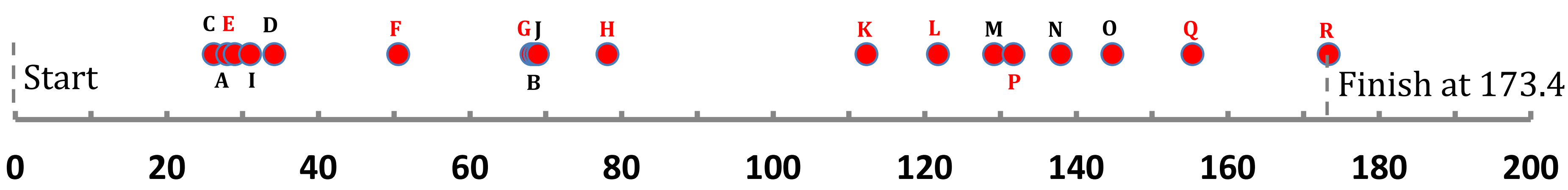
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES



PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION



SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES

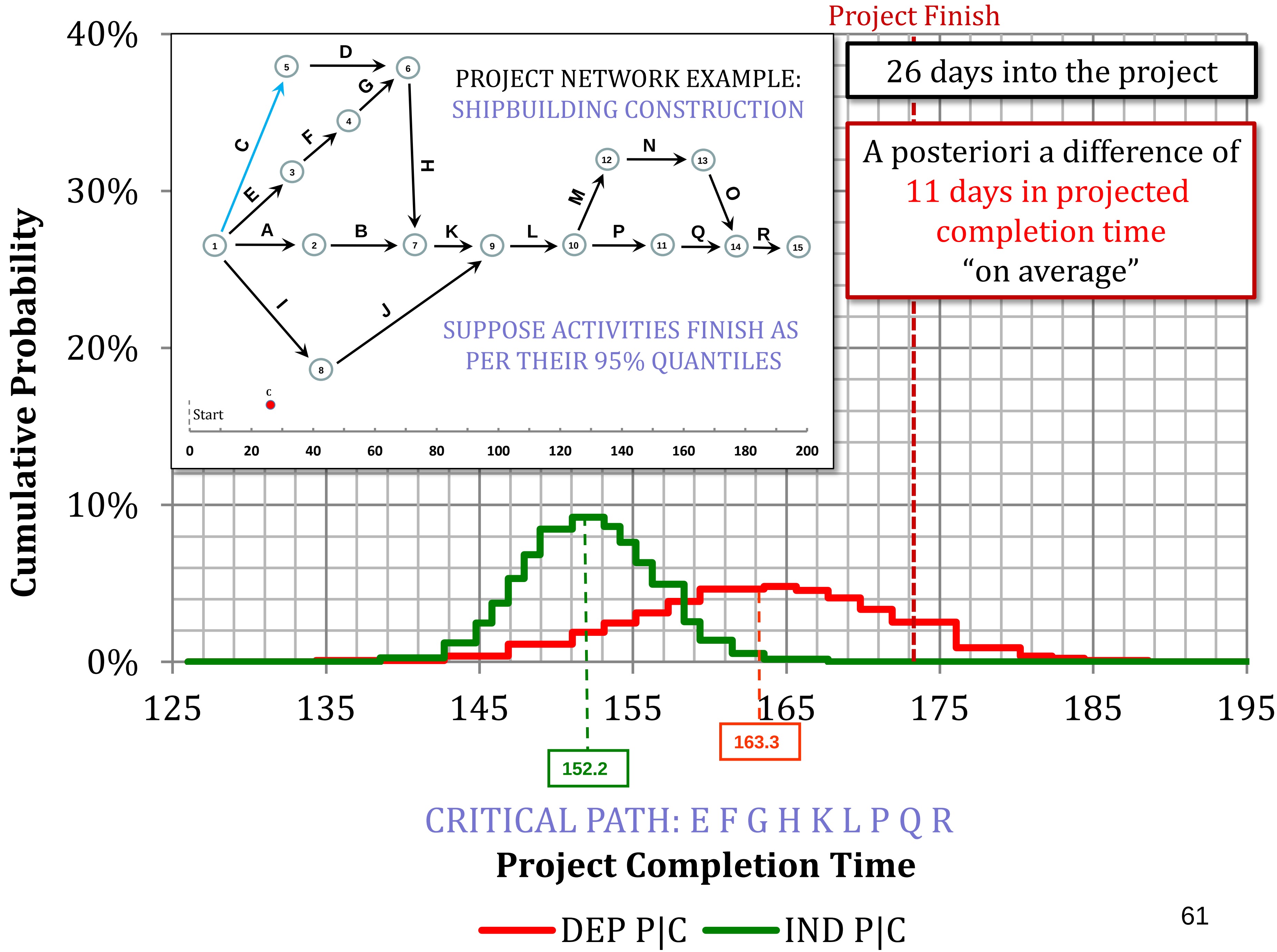


Our objective is to re-evaluate/monitor remaining **Project Completion Time Uncertainty** as activities finish one by one

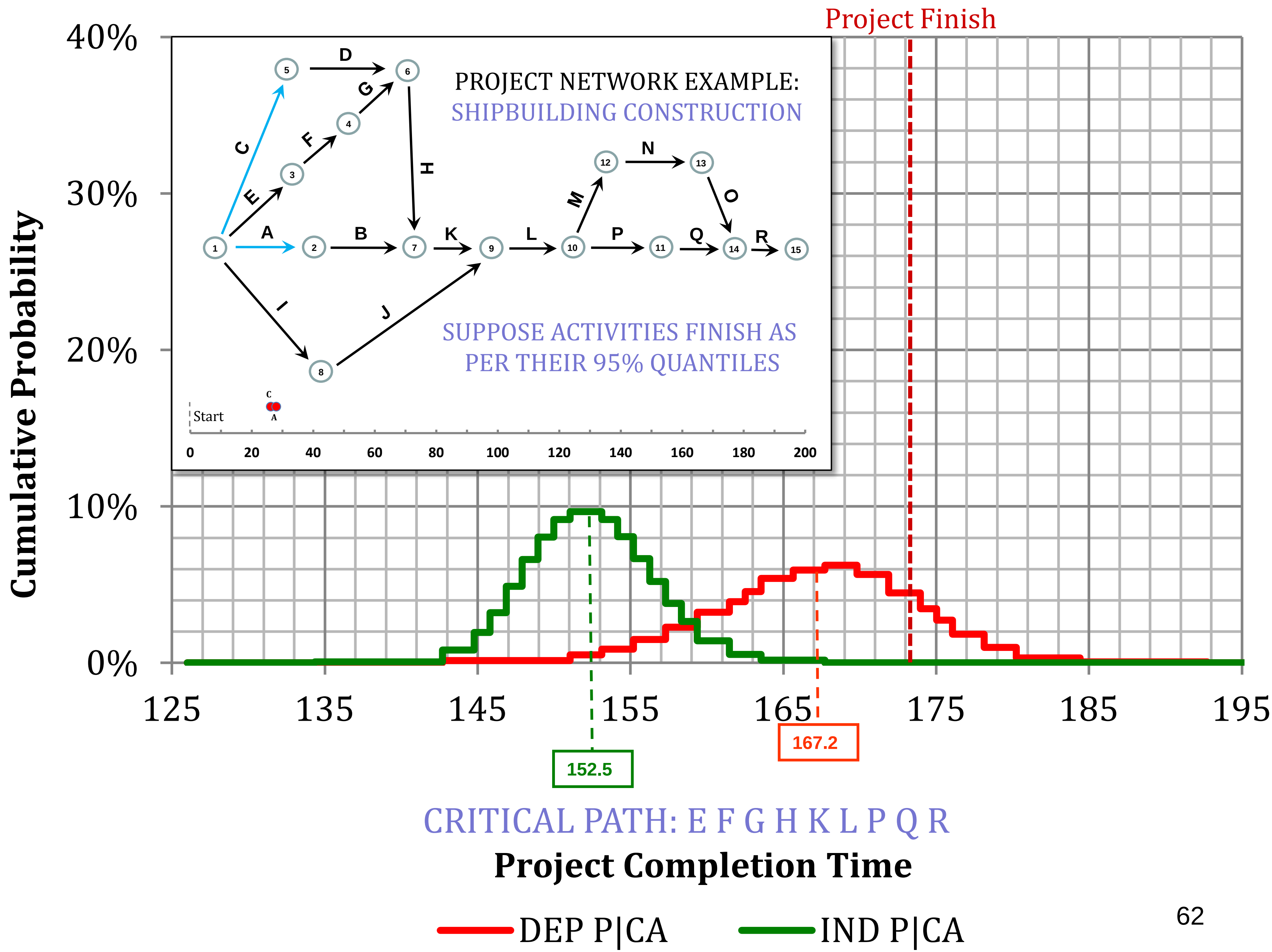
and

To compare the potential implication of neglecting **Activity Statistical Dependence** amongst remaining activities to be completed.

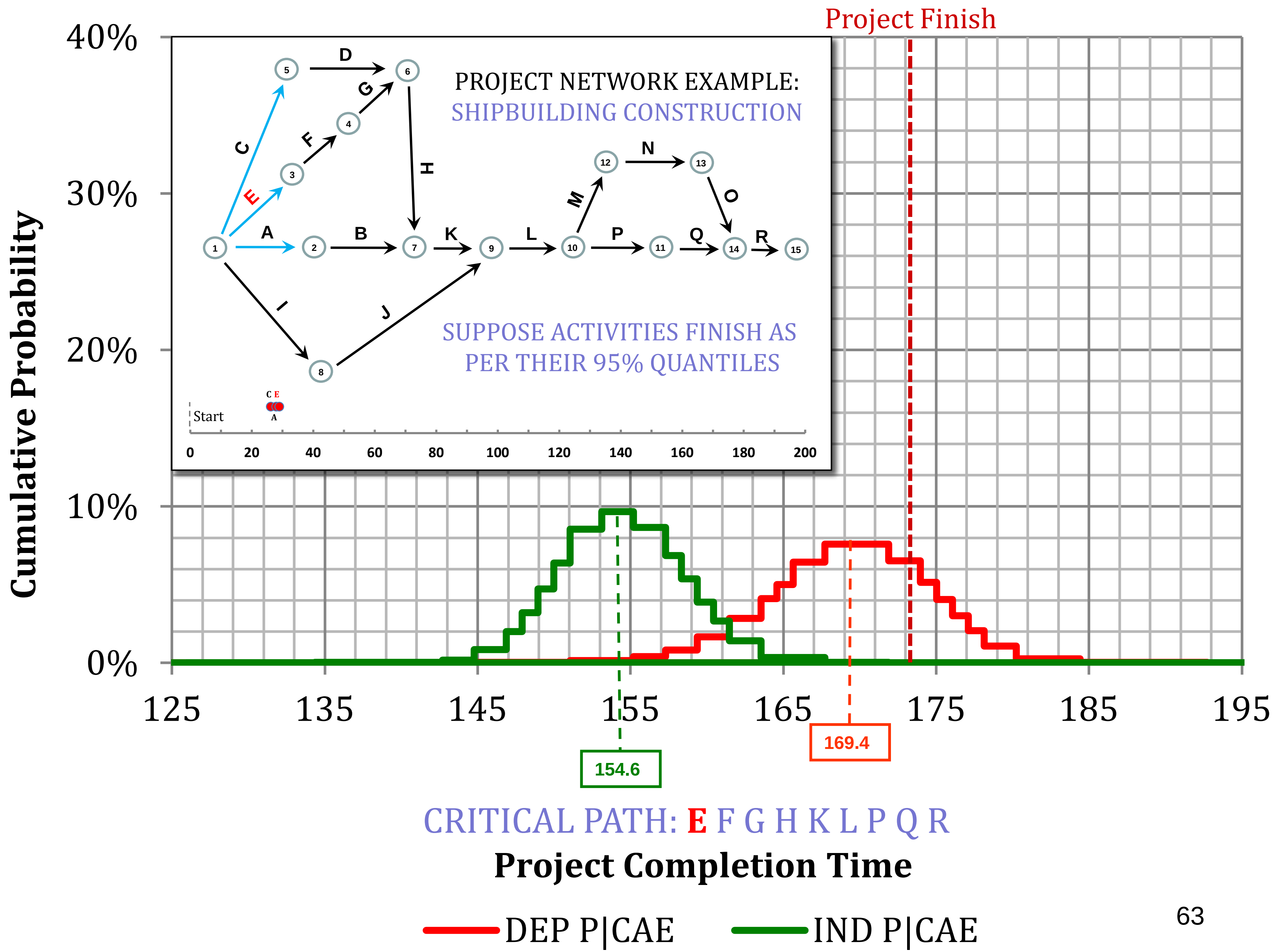
In this case study average **activity correlation is approximately 0.5**. Effects to be observed would be amplified at higher correlation levels.



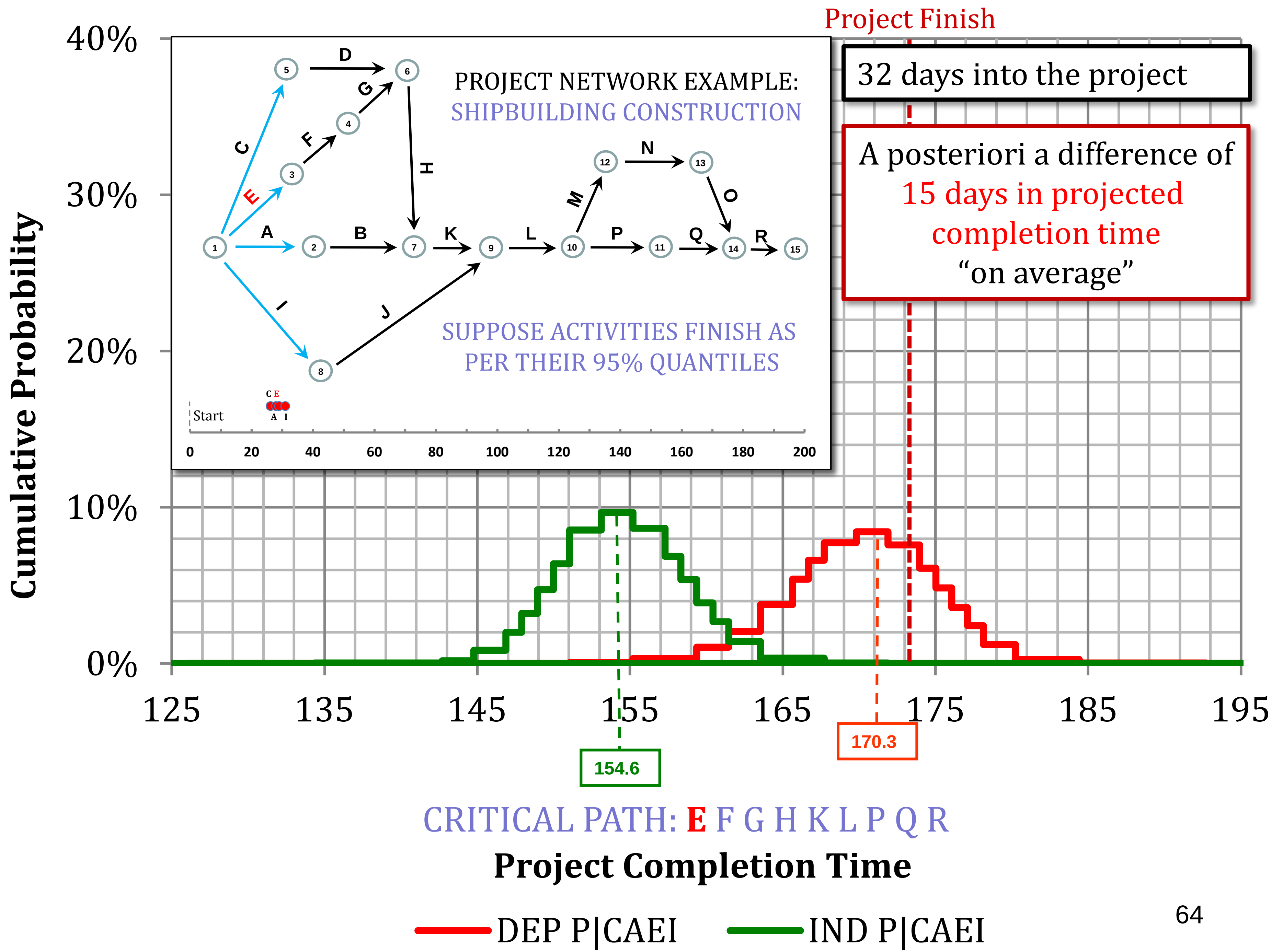
Project Finish
26 days into the project
A posteriori a difference of
11 days in projected
completion time
"on average"
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS
PER THEIR 95% QUANTILES
Start
Cumulative Probability
Project Completion Time
CRITICAL PATH: E F G H K L P Q R
152.2
163.3
DEP P|C
IND P|C

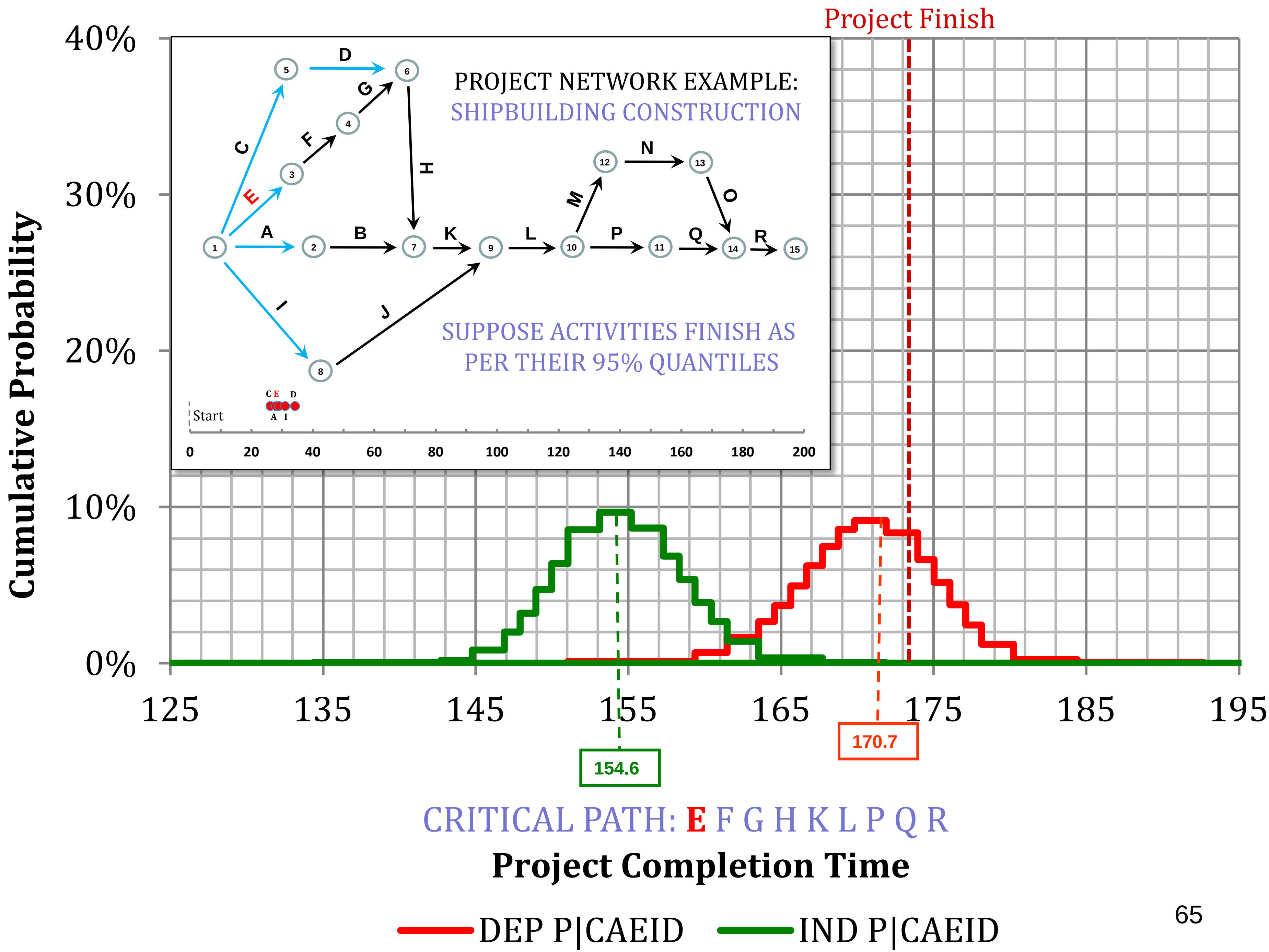


Project Finish
40%
30%
20%
10%
0%
Cumulative Probability
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES
Start
0 20 40 60 80 100 120 140 160 180 200
125 135 145 155 165 175 185 195
152.5
167.2
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CA
IND P|CA

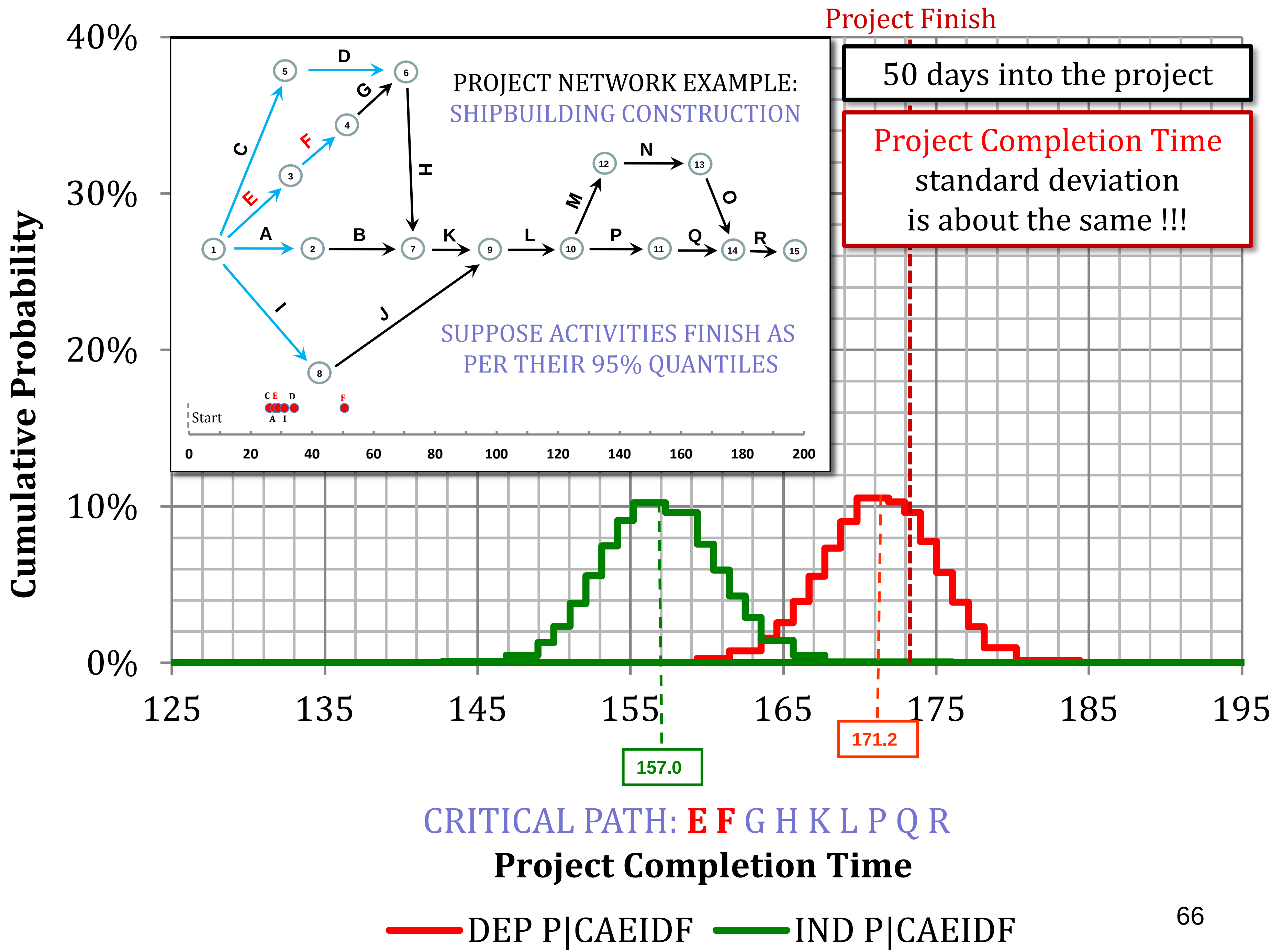


Project Finish
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS
PER THEIR 95% QUANTILES
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Start
0
20
40
60
80
100
120
140
160
180
200
Cumulative Probability
40%
30%
20%
10%
0%
125
135
145
155
165
175
185
195
154.6
169.4
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAE
IND P|CAE

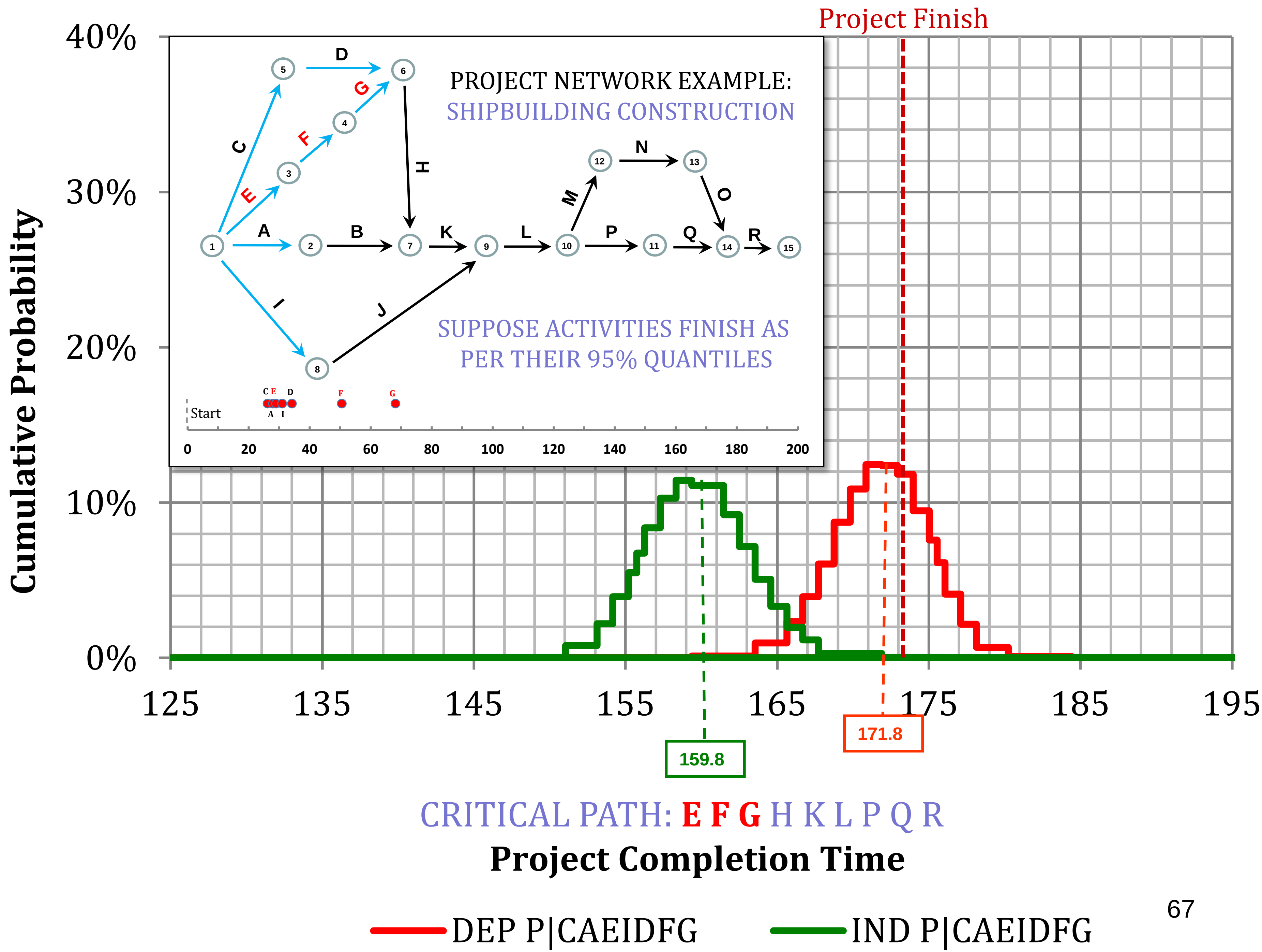

Project Finish
32 days into the project
A posteriori a difference of
15 days in projected
completion time
"on average"
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS
PER THEIR 95% QUANTILES
Start
CRITICAL PATH: E F G H K L P Q R
Cumulative Probability
Project Completion Time
154.6
170.3
DEP P|CAEI
IND P|CAEI

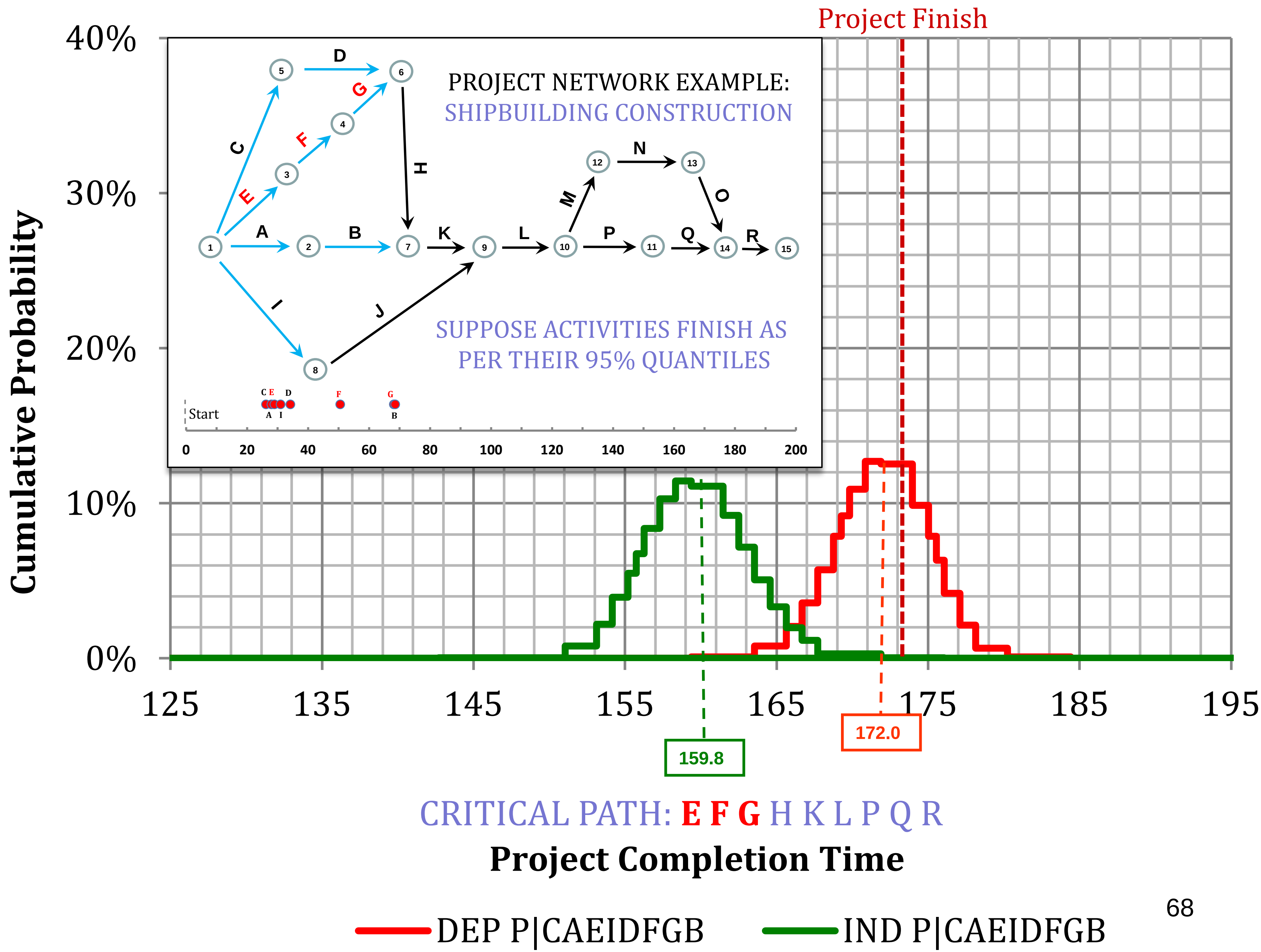


Project Finish
40%
30%
20%
10%
0%
Cumulative Probability
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS
PER THEIR 95% QUANTILES
A B C D E F G H I J K L M N O P Q R
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Start
0 20 40 60 80 100 120 140 160 180 200
125 135 145 155 165 175 185 195
154.6
170.7
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAEID
IND P|CAEID

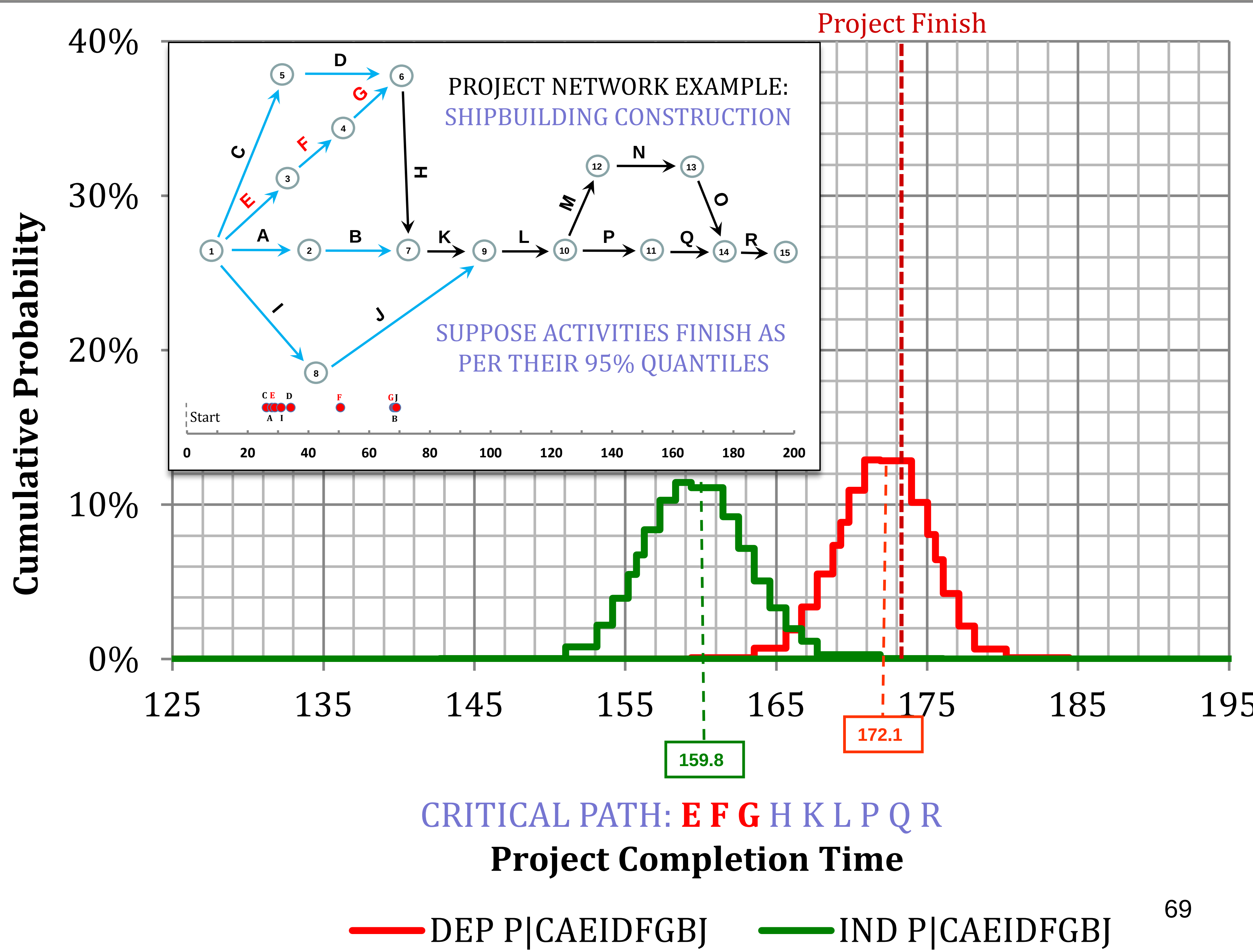


Project Finish
50 days into the project
Project Completion Time
standard deviation
is about the same !!!
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS
PER THEIR 95% QUANTILES
Start
0 20 40 60 80 100 120 140 160 180 200
Cumulative Probability
40% 30% 20% 10% 0%
125 135 145 155 165 175 185 195
157.0
171.2
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAEIDF
IND P|CAEIDF

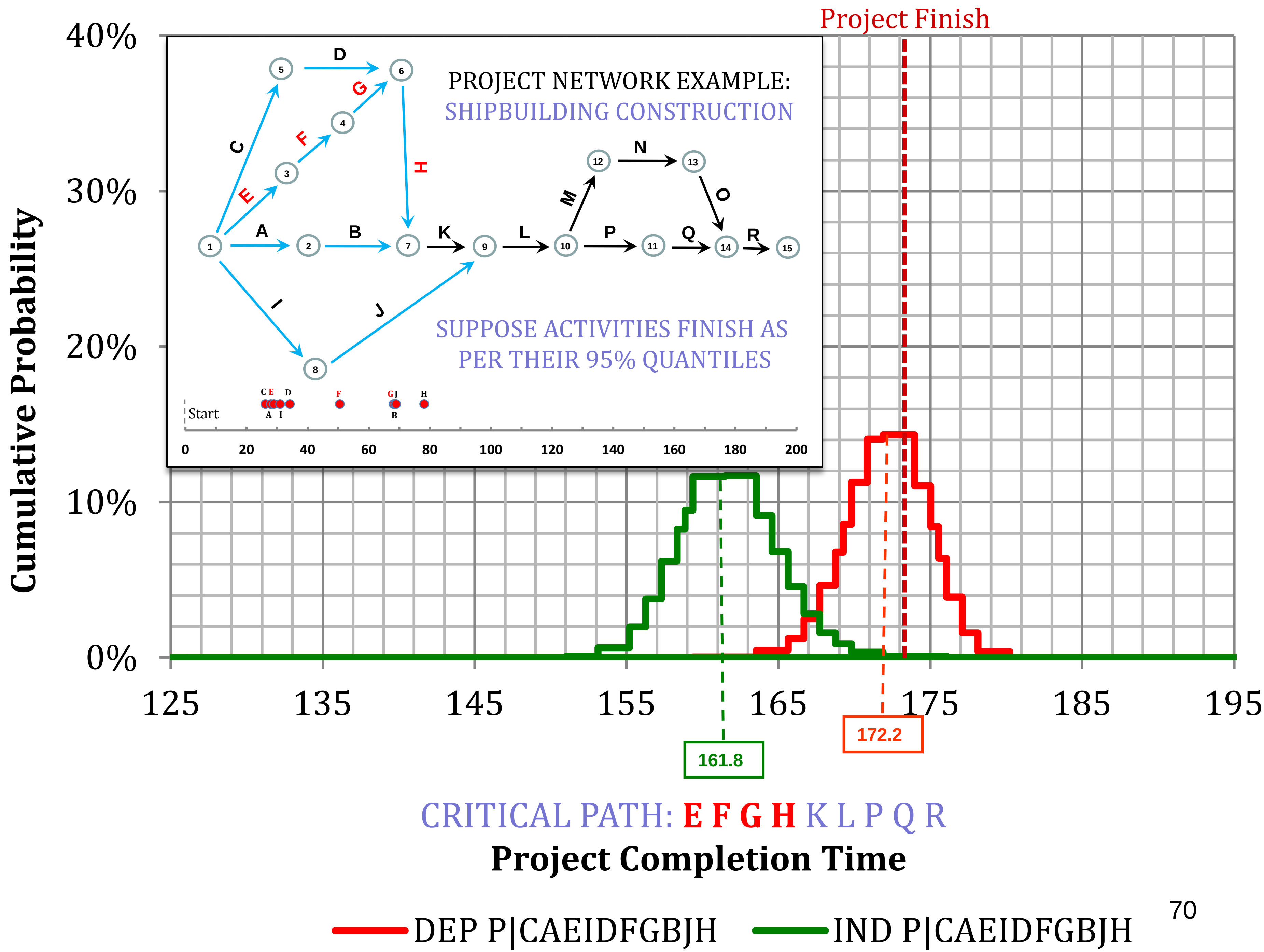

Project Finish
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS
PER THEIR 95% QUANTILES
A B C D E F G H I J K L M N O P Q R
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Start
0 20 40 60 80 100 120 140 160 180 200
Cumulative Probability
40% 30% 20% 10% 0%
125 135 145 155 165 175 185 195
159.8
171.8
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAEIDFG
IND P|CAEIDFG

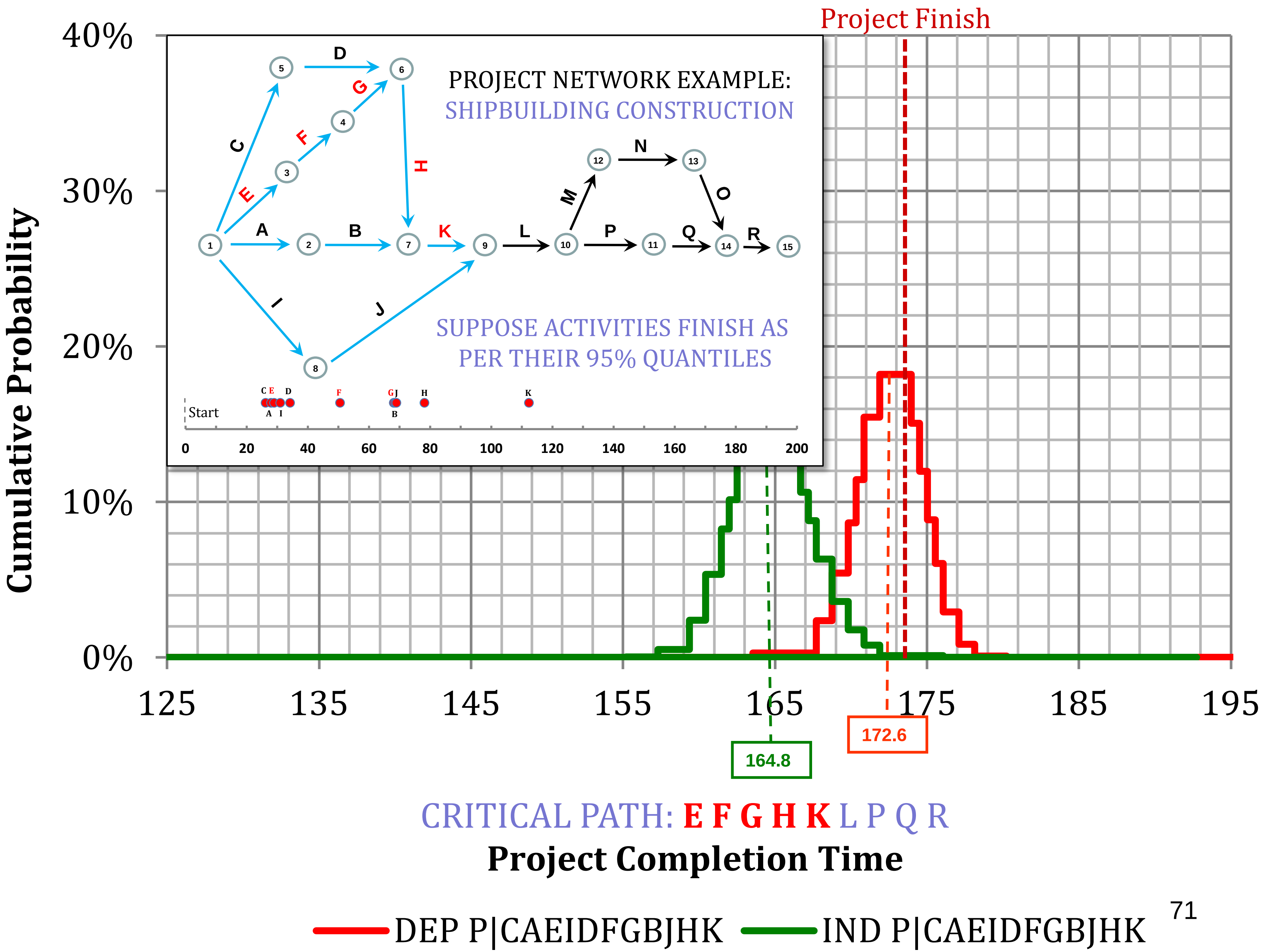


Project Finish
40%
30%
20%
10%
0%
Cumulative Probability
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES
A B C D E F G H I J K L M N O P Q R
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Start
0 20 40 60 80 100 120 140 160 180 200
125 135 145 155 165 175 185 195
159.8
172.0
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAEIDFGB
IND P|CAEIDFGB

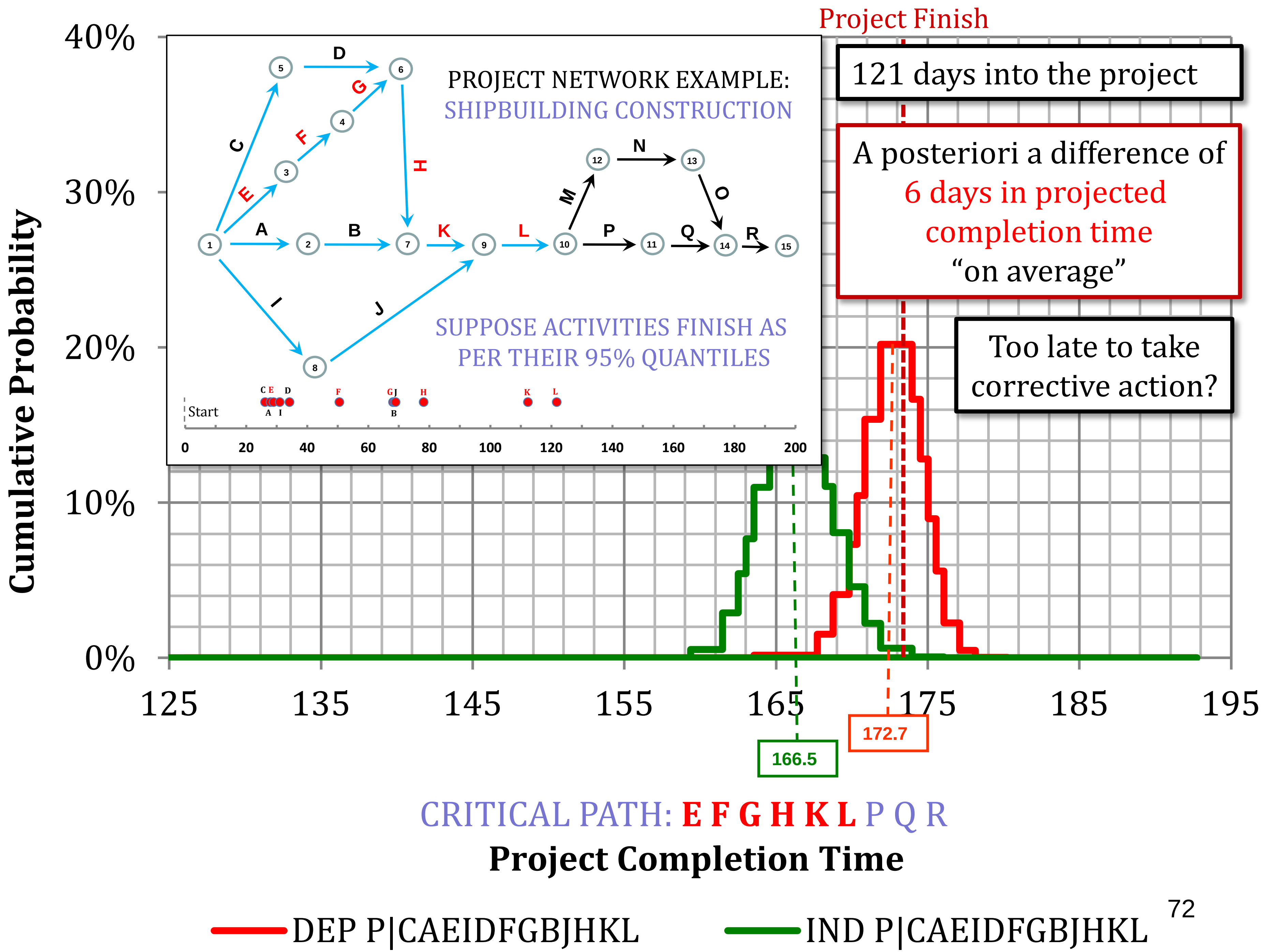


Project Finish
40%
30%
20%
10%
0%
Cumulative Probability
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS
PER THEIR 95% QUANTILES
Start
0 20 40 60 80 100 120 140 160 180 200
125 135 145 155 165 175 185 195
159.8
172.1
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAEIDFGBJ
IND P|CAEIDFGBJ

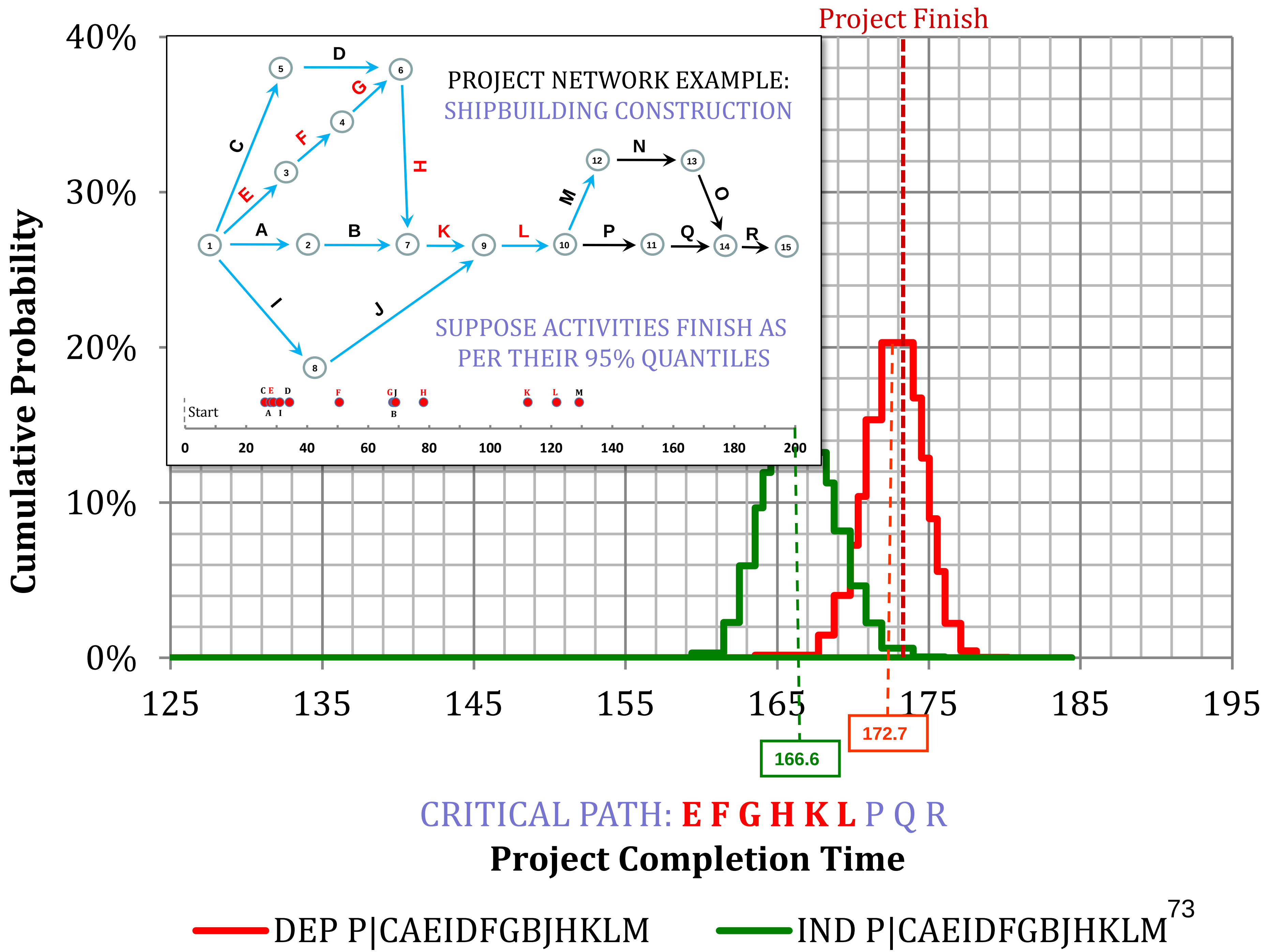

Project Finish
Cumulative Probability
40%
30%
20%
10%
0%
125
135
145
155
165
175
185
195
161.8
172.2
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES
A B C D E F G H I J K L M N O P Q R
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Start
0 20 40 60 80 100 120 140 160 180 200
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAEIDFGBJH
IND P|CAEIDFGBJH



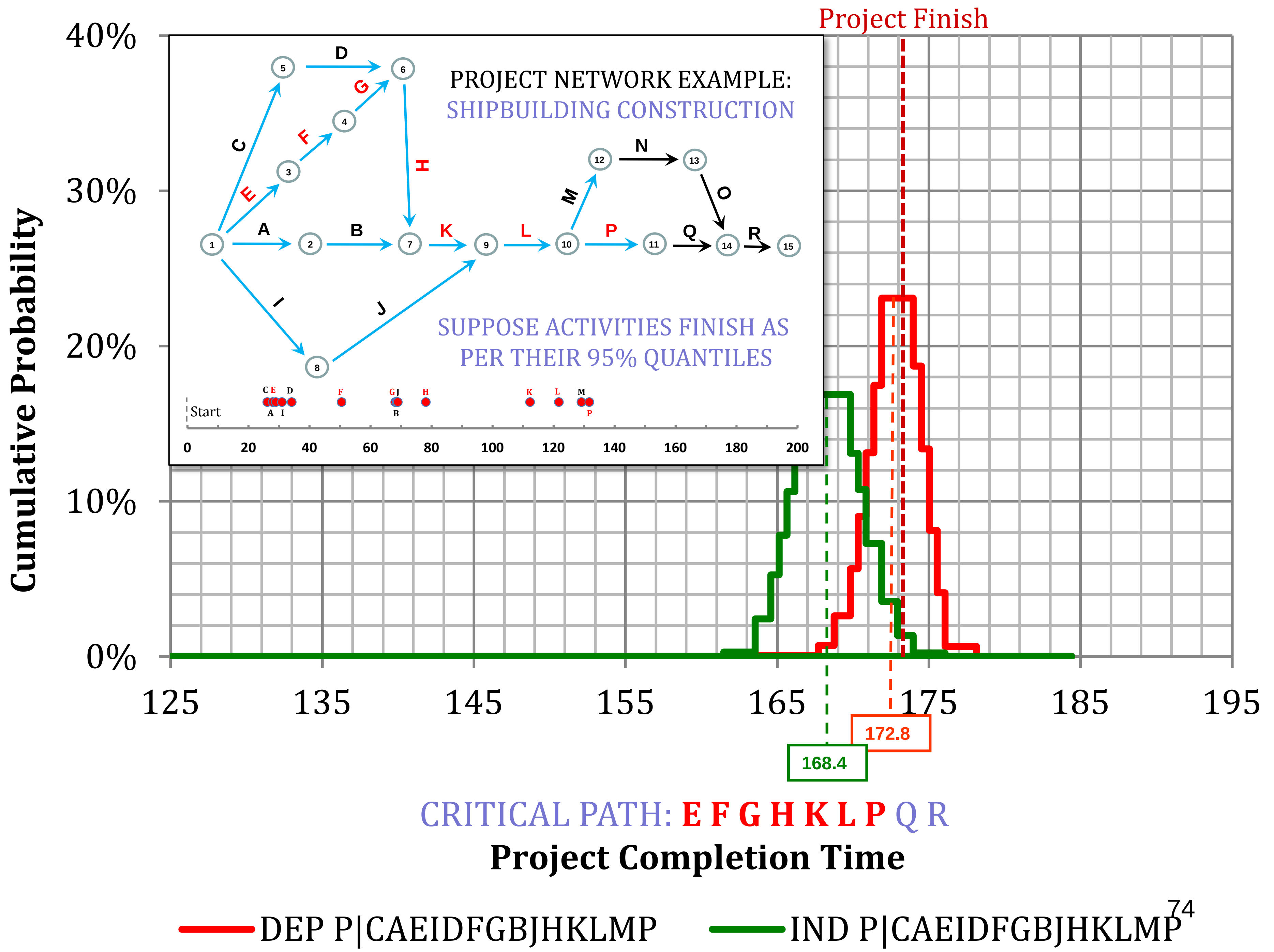
Project Finish
40%
30%
20%
10%
0%
Cumulative Probability
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES
A B C D E F G H I J K L M N O P Q R
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Start
0 20 40 60 80 100 120 140 160 180 200
125 135 145 155 165 175 185 195
164.8
172.6
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAEIDFGBJHK
IND P|CAEIDFGBJHK

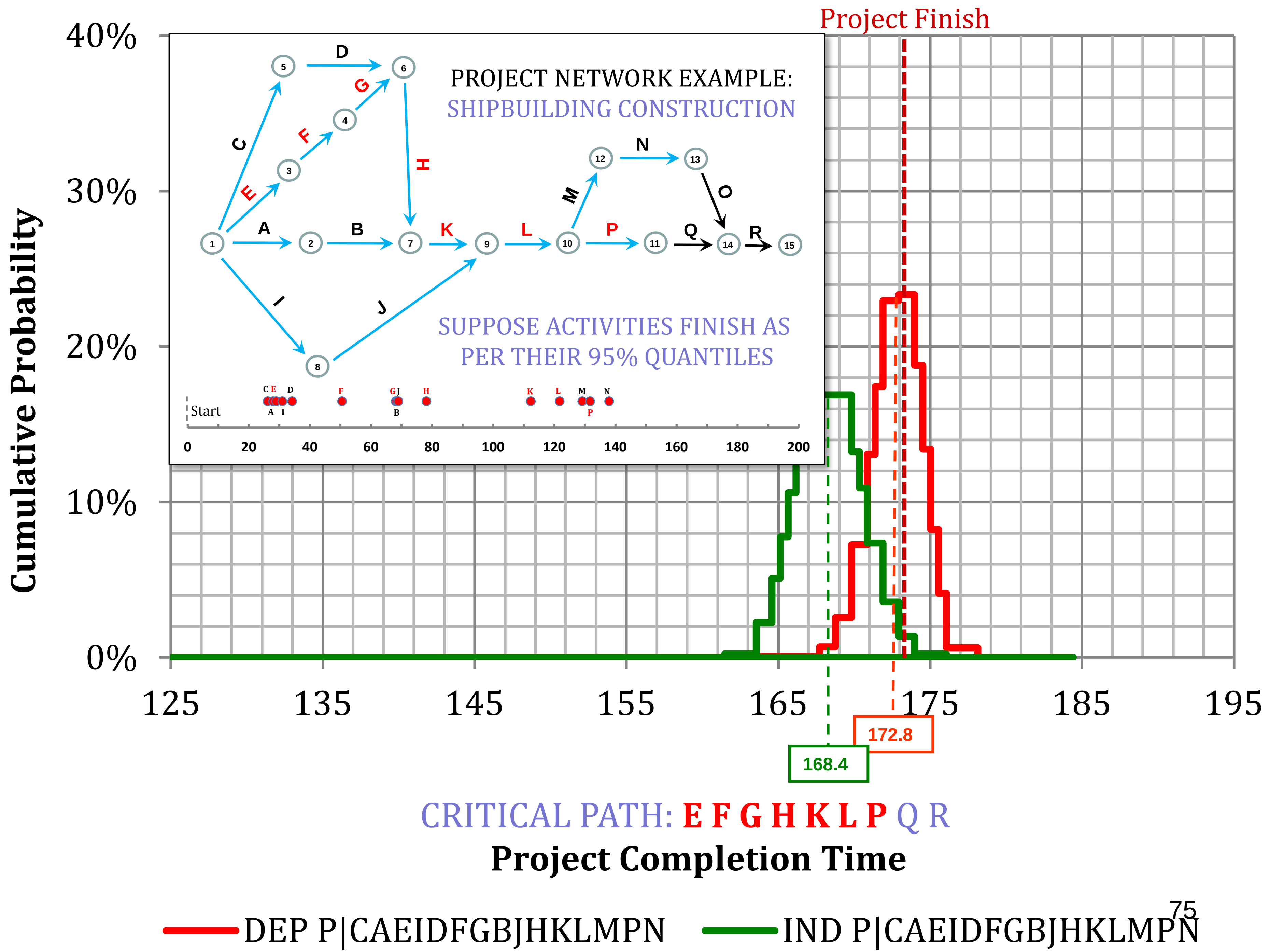


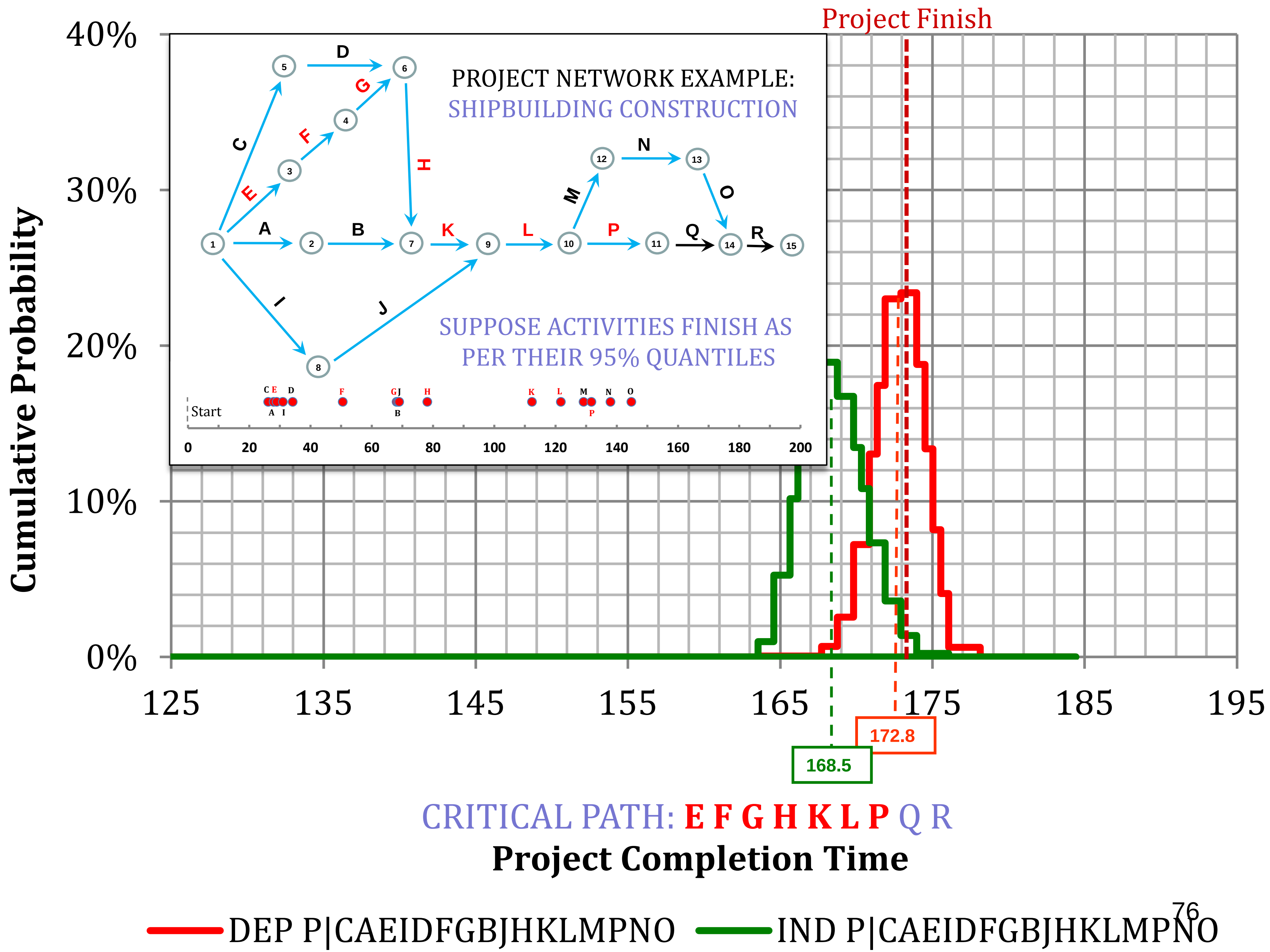
Project Finish
121 days into the project
A posteriori a difference of
6 days in projected
completion time
“on average”
Too late to take
corrective action?
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS
PER THEIR 95% QUANTILES
Start
0 20 40 60 80 100 120 140 160 180 200
A B C D E F G H I J K L M N O P Q R
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Cumulative Probability
0% 10% 20% 30% 40%
125 135 145 155 165 175 185 195
166.5
172.7
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAEIDFGBJHKL
IND P|CAEIDFGBJHKL

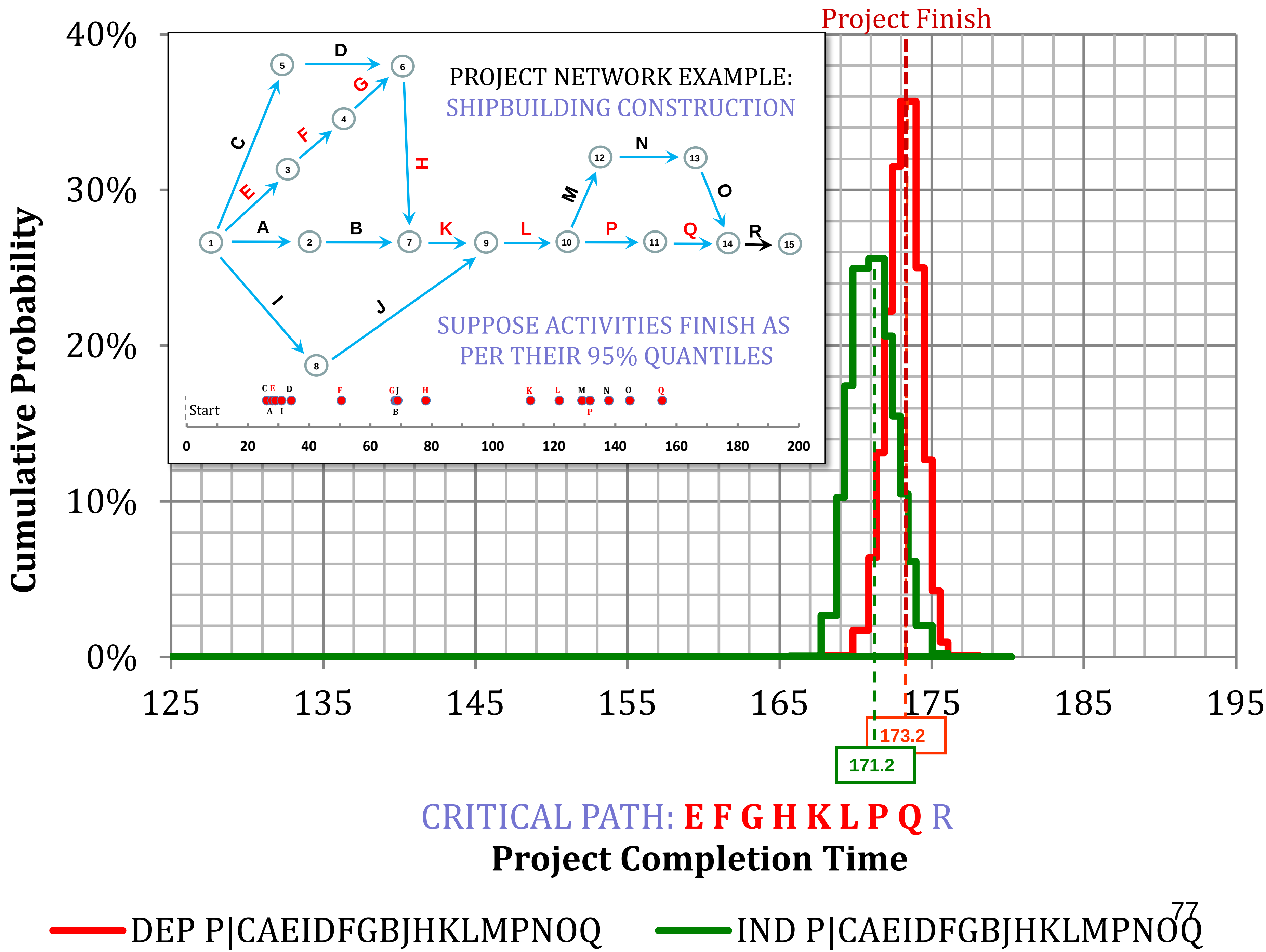


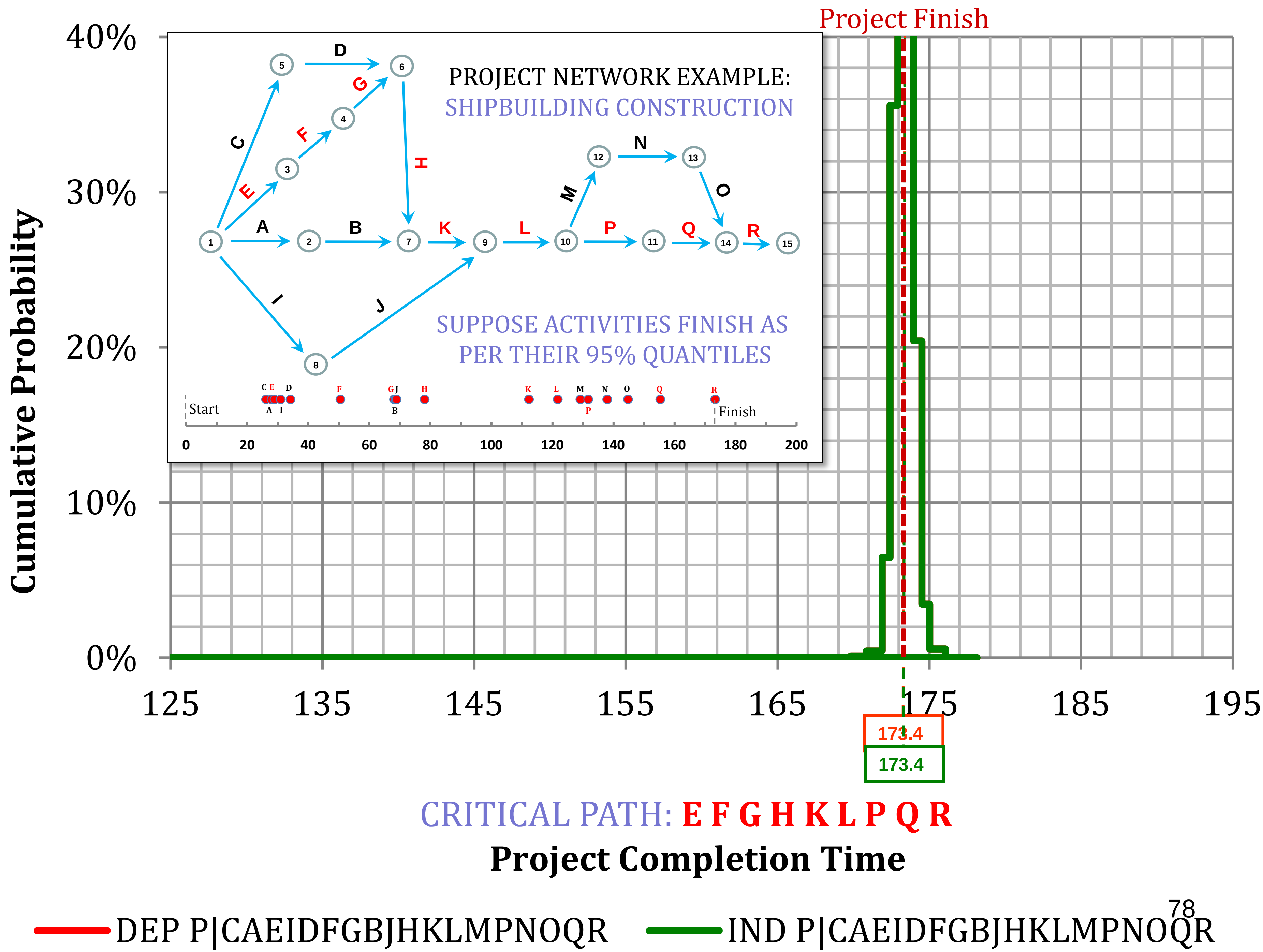
Project Finish
40%
30%
20%
10%
0%
Cumulative Probability
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS
PER THEIR 95% QUANTILES
Start
0 20 40 60 80 100 120 140 160 180 200
125 135 145 155 165 175 185 195
166.6
172.7
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAEIDFGBJHKLM
IND P|CAEIDFGBJHKLM


Project Finish
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS PER THEIR 95% QUANTILES
Start
Cumulative Probability
40%
30%
20%
10%
0%
125
135
145
155
165
175
185
195
172.8
168.4
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAEIDFGBJHKLMP
IND P|CAEIDFGBJHKLMP


Project Finish
40%
30%
20%
10%
0%
Cumulative Probability
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS
PER THEIR 95% QUANTILES
A B C D E F G H I J K L M N O P Q R
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Start
0 20 40 60 80 100 120 140 160 180 200
125 135 145 155 165 175 185 195
172.8
168.4
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAEIDFGBJHKLMPN
IND P|CAEIDFGBJHKLMPN


Project Finish
40%
30%
20%
10%
0%
Cumulative Probability
125
135
145
155
165
175
185
195
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS
PER THEIR 95% QUANTILES
A B C D E F G H I J K L M N O P Q R
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Start
0 20 40 60 80 100 120 140 160 180 200
172.8
168.5
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAEIDFGBJHKLMPNO
IND P|CAEIDFGBJHKLMPNO


Project Finish
40%
30%
20%
10%
0%
Cumulative Probability
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
SUPPOSE ACTIVITIES FINISH AS
PER THEIR 95% QUANTILES
Start
0
20
40
60
80
100
120
140
160
180
200
125
135
145
155
165
175
185
195
173.2
171.2
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAEIDFGBJHKLMPNOQ
IND P|CAEIDFGBJHKLMPNOQ



Project Finish
40%
30%
20%
10%
0%
Cumulative Probability
PROJECT NETWORK EXAMPLE:
SHIPBUILDING CONSTRUCTION
SUPPOSE ACTIVITIES FINISH AS
PER THEIR 95% QUANTILES
Start
Finish
0 20 40 60 80 100 120 140 160 180 200
125 135 145 155 165 175 185 195
173.4
173.4
CRITICAL PATH: E F G H K L P Q R
Project Completion Time
DEP P|CAEIDFGBJHKLMPNOQR
IND P|CAEIDFGBJHKLMPNOQR

- Case Study Description
- Bayesian Network Model
- Statistical Dependence Elicitation
- Uncertainty (n) and Dependence (β) Parameter Selection
- Prior Completion Time Uncertainty
- Posterior Analysis: Monitoring Uncertainty
- Conclusion

Conclusion

1. Accounting for statistical dependence amongst activities results **a priori** in larger uncertainty bands for the project completion time - **Nothing new here!**
2. As activities complete using the Bayes Network analysis the remaining activity completion uncertainty distributions are updated (as if they were known at the start of the project)
3. The speed of learning about the project completion time is enhanced by modeling the activity statistical dependence using a Bayes Network.
4. In case study one third into the project (i.e. **a posteriori**) uncertainty bands are less taking into account activity statistical dependence.
5. The propagation of the completed activities together with updating remaining activity uncertainty distributions through the project and Bayes network structure allows for **more timely corrective actions** from a project management perspective avoiding:

Potential Suprises!!!!

QUESTIONS?