Sensitivity Analysis Methodology for a Complex System Computational Model

James J. Filliben
National Institute of Standards and Technology
Gaithersburg, MD 20899

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Computing Science and Statistics
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Doubletree Hotel, Philadelphia, PA

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Complex systems are of many types—biological (the human brain), physical (the World Trade Center collapse), social (the U.S. domestic aircraft transportation network), and informational (the Internet). Many such complex systems are successfully advanced by the judicious construction of computational models to serve as predictive surrogates for the system. The use of such models increasingly serves as the backbone for characterizing, modeling, predicting and ultimately optimizing the systems themselves.

The results of such efforts gain credence only after a proper V&V (verification and validation) of such computational models. This task itself is extremely difficult and can frequently be achieved only in a matter of degrees. In practice, an essential component in this V&V is an appropriate sensitivity analysis of the computational model. Gaining an appreciation of the dominant factors (and the ever-present interactions) of a computational model for a complex system is always an essential component in accepting/rejecting such a model, and (after acceptance) in gaining deeper insights and understanding as to what actually drives the complex system itself.

This talk describes the methodology (experiment design and statistical analysis) which was brought to bear to carry out a sensitivity analysis for computational models for a specific complex informational system (a network). Such methodology has application to assessing models of other complex system types.

NIST 5-Year Competence Project

Measurement Science for Complex Information Systems

K. Mills[892], C. Dabrowski[897], J. Filliben[898], D. Genin[+], J. Hagedorn[891], F. Hunt[891], M. Laverne[^], D. Leber[898], V. Marbukh[892], Edward Schwartz[#], Bert Rust[891], J. Terrill[891] and J. Yuan[*]

[+]NRC post-doc
[#]NSF SURF student
[^]Guest Researcher from ISIMA
[*]Professor at Tsinghua University

March 28, 2007
Innovations in Measurement Science

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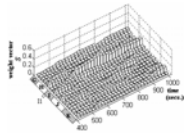
$$E_j = \frac{1}{N_j}\sum_k |d_X(j,k)|^2$$



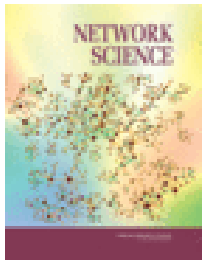
What is the problem?

No one understands how to measure, predict or control macroscopic behavior in complex information systems

- threatening our nation's security
- costing billions of dollars

"[Despite] society's profound dependence on networks, fundamental knowledge about them is primitive. [G]lobal communication … networks have quite advanced technological implementations but their behavior under stress still cannot be predicted reliably…. There is no science today that offers the fundamental knowledge necessary to design large complex networks [so] that their behaviors can be predicted prior to building them."

— Network Science 2006, recently released NRC report



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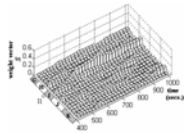

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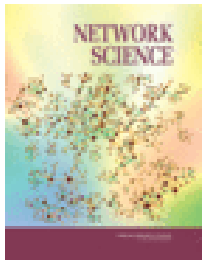

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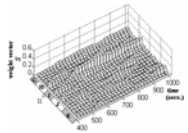

How is it solved today?

Network Technology	*Network Test Facilities*	*Network Science*	*Network Measurement*
Very active	Very active	Little work	Some work
IPv6 Transition	Emulab	Analyzing Spatiotemporal Properties	Archiving Traffic Samples
Autonomic Computing	DETER	Visualizing Macroscopic Evolution	Visualizing Topologies
Service-Oriented Architectures	National Lamda Rail	Predicting Phase Transitions	Analyzing Self-Similarity
Mobile and Wireless Devices	TeraGrid	Controlling Global Behavior	Estimating Network Conditions
Peer-to-Peer Services	GENI		

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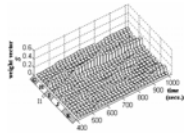
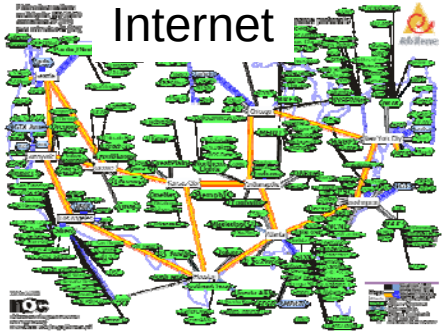
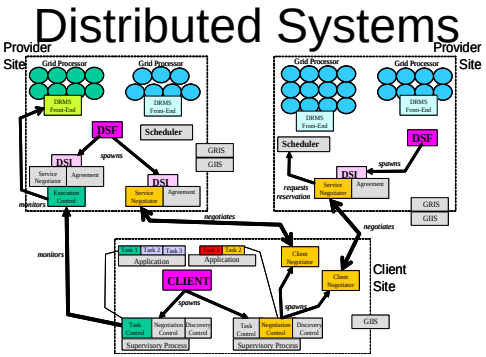


Leverage models and mathematics from the physical sciences to define a systematic method to measure, understand, predict and control macroscopic behavior in the Internet and distributed software systems built on the Internet



Technical Approach

- Establish models and analysis methods
  - Computationally tractable
  - Reveal macroscopic behavior
  - Establish predictability and causality
- Characterize distributed control techniques
  - Economic mechanisms to elicit desired behaviors
  - Biological mechanisms to organize components



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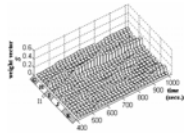

Current Activities (FY07)

Model Development

- Micro-scale model of compute grid *(Dabrowski and Mills)*
- Meso-scale model of compute grid *(Laverne)*
- Agent automata model of Internet *(Mills, Schwartz and Yuan)*

Data Repository Development

- Configuration & event repository for grid models *(Laverne and Hagedorn)*

Experiment Designs

- Grid model sensitivity & key factors *(Filliben, Leber and Laverne)*

Visualization Methods

- Grid model visualization *(Filliben, Hagedorn, Laverne and Terrill)*

Abstract Models and Analysis Methods

- Phase-transition models for queuing networks *(Hunt and Marbukh)*
- Fluid-flow models of the Internet *(Genin and Mills)*
- Time series analysis for Internet models *(Rust and Mills)*

Theory

- Internet behavioral predictions *(Marbukh)*
- Grid resource allocation models *(Marbukh and Mills)*

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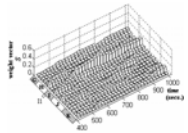

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Insight

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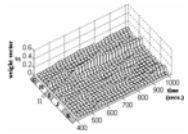

What is the global behavior of the Internet?

- Modeling Approach – Agent Automaton
- Simulated topology
- Agent rules
  - backbone routers, backbone links, enterprise routers, receivers, sources, department routers
- Model dimensions
- Sample model measurements
- Next steps – and some comparison with measurements
- Issues to consider
  - How to improve the model?
  - What analysis methods to use on the measurements?

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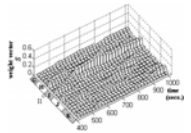


Agent Automata Model of Internet-like Network

- A network topology of routers, links and flows (source-receiver pairs)
  - Links have distances (and corresponding propagation delays)
  - Routers have (finite) queues (and thus varying queuing delays)
  - Routers have forwarding capacities (that vary with router type)
  - Assume fixed-length shortest path among routers (others assumptions possible)
  - Flows have random ON and OFF durations (various distributions possible)
  - Flows implement TCP congestion-control algorithm (others possible)

- Packets (data and acknowledgments) associated with flows progress between sources and receivers following routes through routers and links in the topology

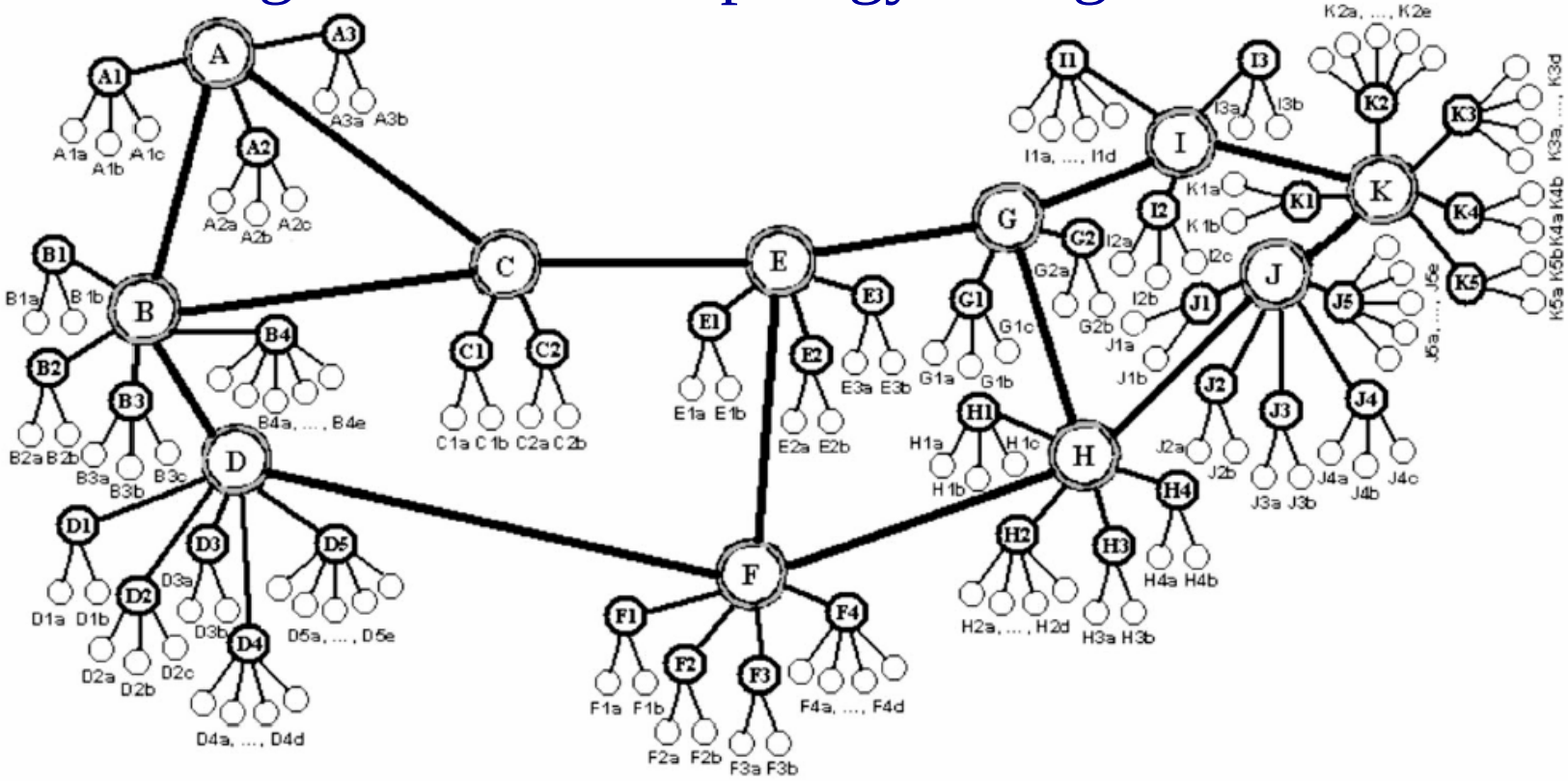
- Every model element updated at each time step

- Measurements taken every "measurement" interval (e.g., 200 time steps)

Abilene Network

$$E_j = \frac{1}{N_j}\sum_k \left| d_X(j,k) \right|^2$$

Starting with Fixed Topology – original Abilene net



Router-level network with three tiers: backbone (160 ppts), enterprise (20 ppts), department (5 ppts)

\+ 200 flow sources/department (1 ppts)

≤ 800 flow receivers/department (1 ppts)

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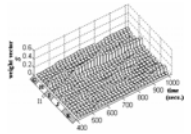

Rules for Backbone Router

Rules for Backbone Link

Rules for Enterprise Router

Rules for Receiver

Rules for Source

Rules for Department Router (outbound packet)

Rules for Department Router (inbound data packet)

Rules for Department Router (inbound ACK/NAK)

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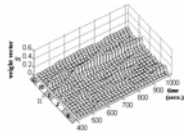

Rules for Backbone Router

If there are packets in the queue then lookup the next hop router
If the next hop router is in the same domain
    lookup the enterprise router of the next hop
    if the queue in the enterprise router is not full
        then forward the packet
        else drop the packet
    endif
else
    lookup the backbone link on which to send the packet
    forward the packet on the backbone link and set the time it will be propagated
endif

Rules for Backbone Link

If the first packet on the link has been propagated
    if the sink backbone router for the link has room in its queue
        then forward the packet from the link to the sink router
        else drop the packet
    endif
endif

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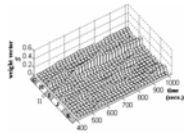
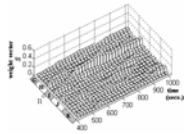


Model Dimensions

- Elements updated per time step: all backbone routers, backbone links, enterprise routers, department routers, source and active receivers
  - 11 + 28 + 40 +110 +22,000 + 22,000 = 45,000
- Measurement interval = 200 time steps and run for 4000 measurement intervals = 800,000 time steps (other configurations possible)
- Model size is about 1100 lines of source code
  - MATLAB version (pre-project prototype) required 280 CPU hours to compute
  - SLX version (developed during project) requires < 3 CPU hours to compute
  - Recently required ~16 CPU hours to simulate 7.2 million time steps with a measurement granularity of 100 times per interval (to throw away first 3.6 million time steps)
- Can model size be expanded and still execute reasonably?
  - Concatenate 10 networks (i.e., about 500,000 elements)?

$$E_j = \frac{1}{N_j}\sum_k \left| d_X(j,k) \right|^2$$



Sample measurements (per interval)

- Packets flowing into and out of the network
- Count of packets bound (*sort of*) from domain x to leaf y
- Active flows
- Router queue size
- Network-wide loss rate
- Domain with maximum flowing heading into it and the number of flows
- Packets transiting selected monitored links
- Loss Rate = (In-Out)/In

. . .

Measurements drive memory usage ~ 100 to 200 Mbytes (depending on measurements)

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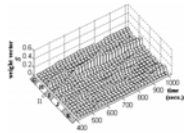
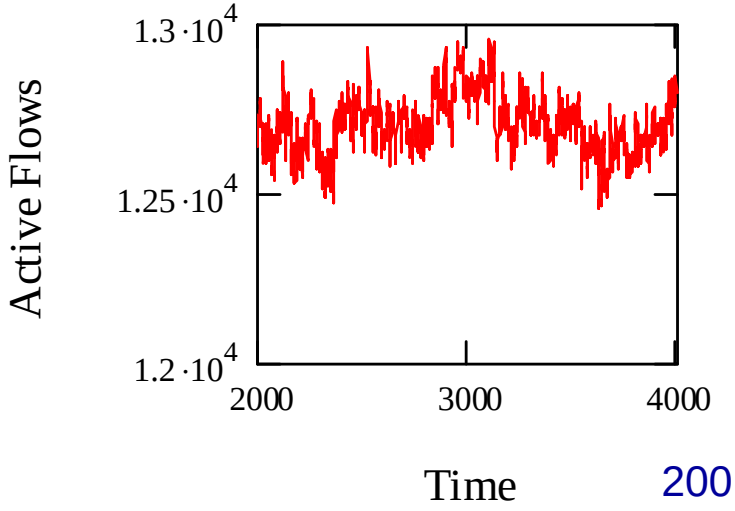
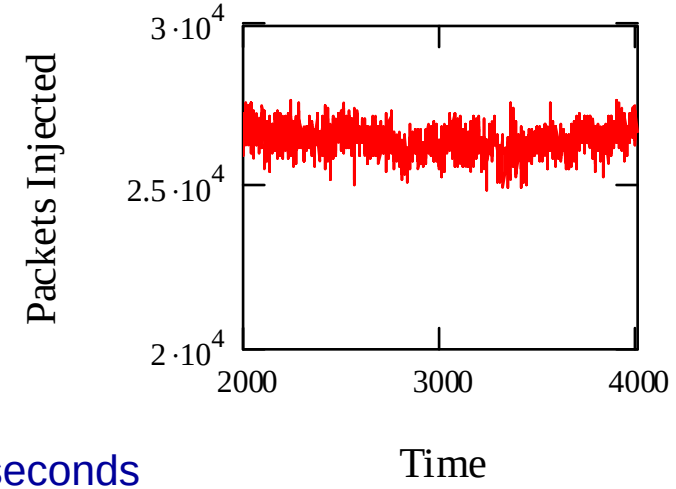
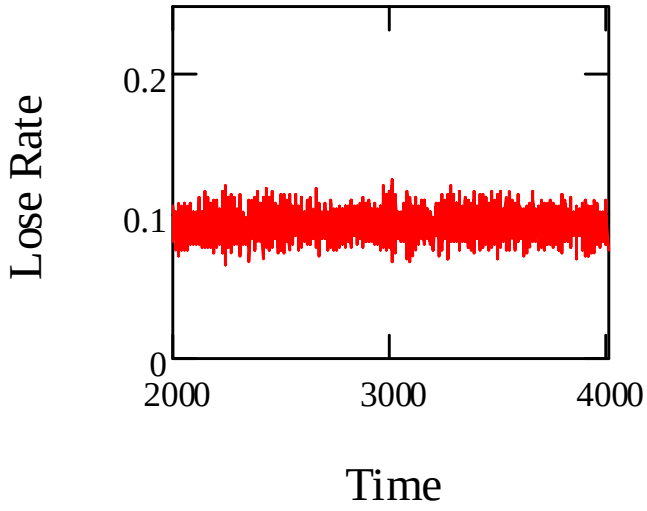


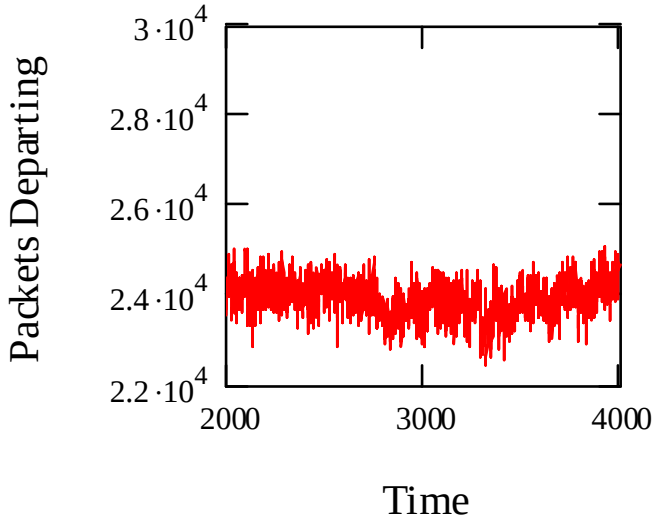
Some sample time series for aggregate measures





200 simulated seconds





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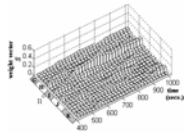
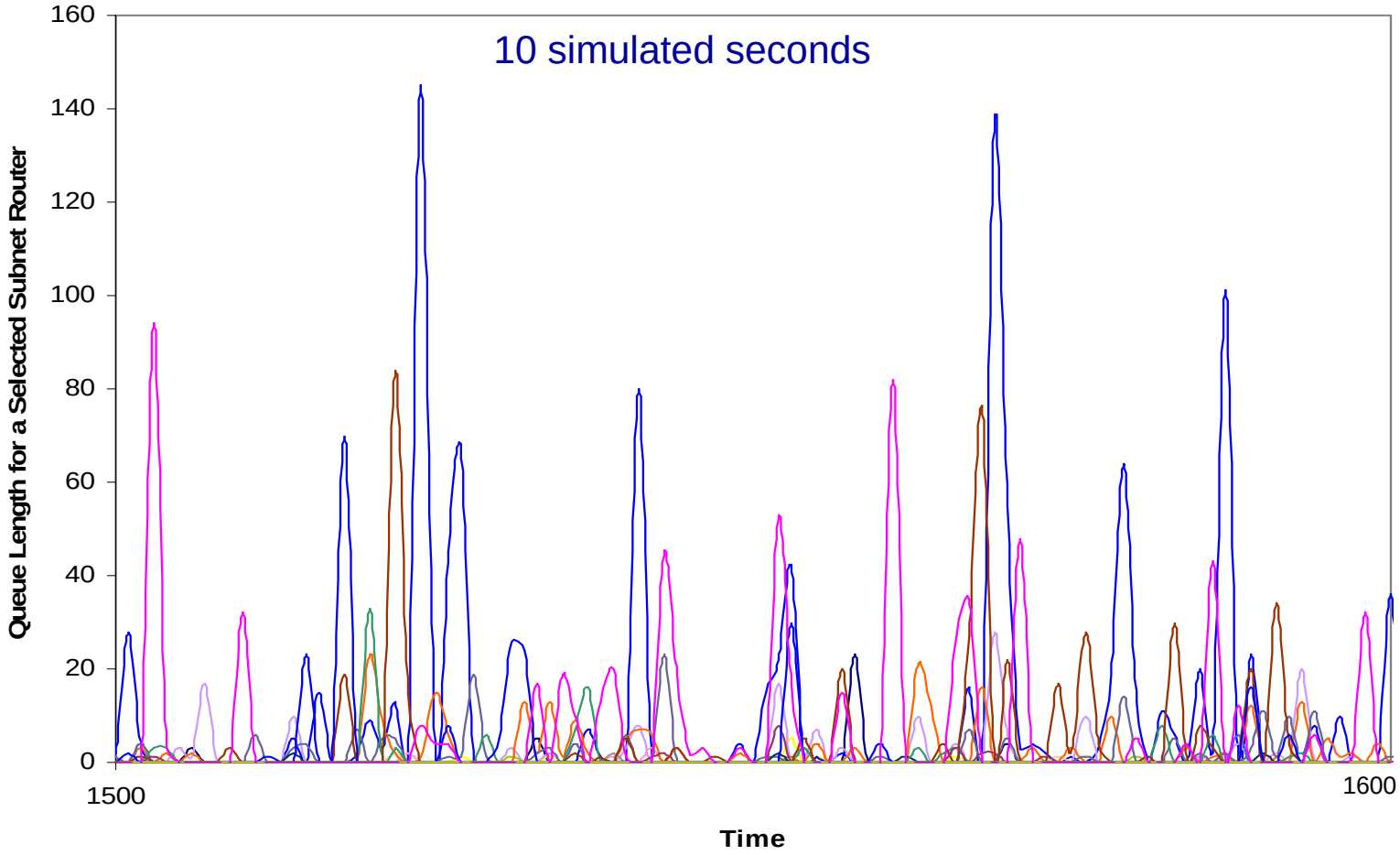


Sample time series of Enterprise Router Q Lengths



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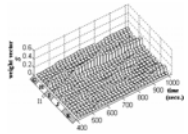
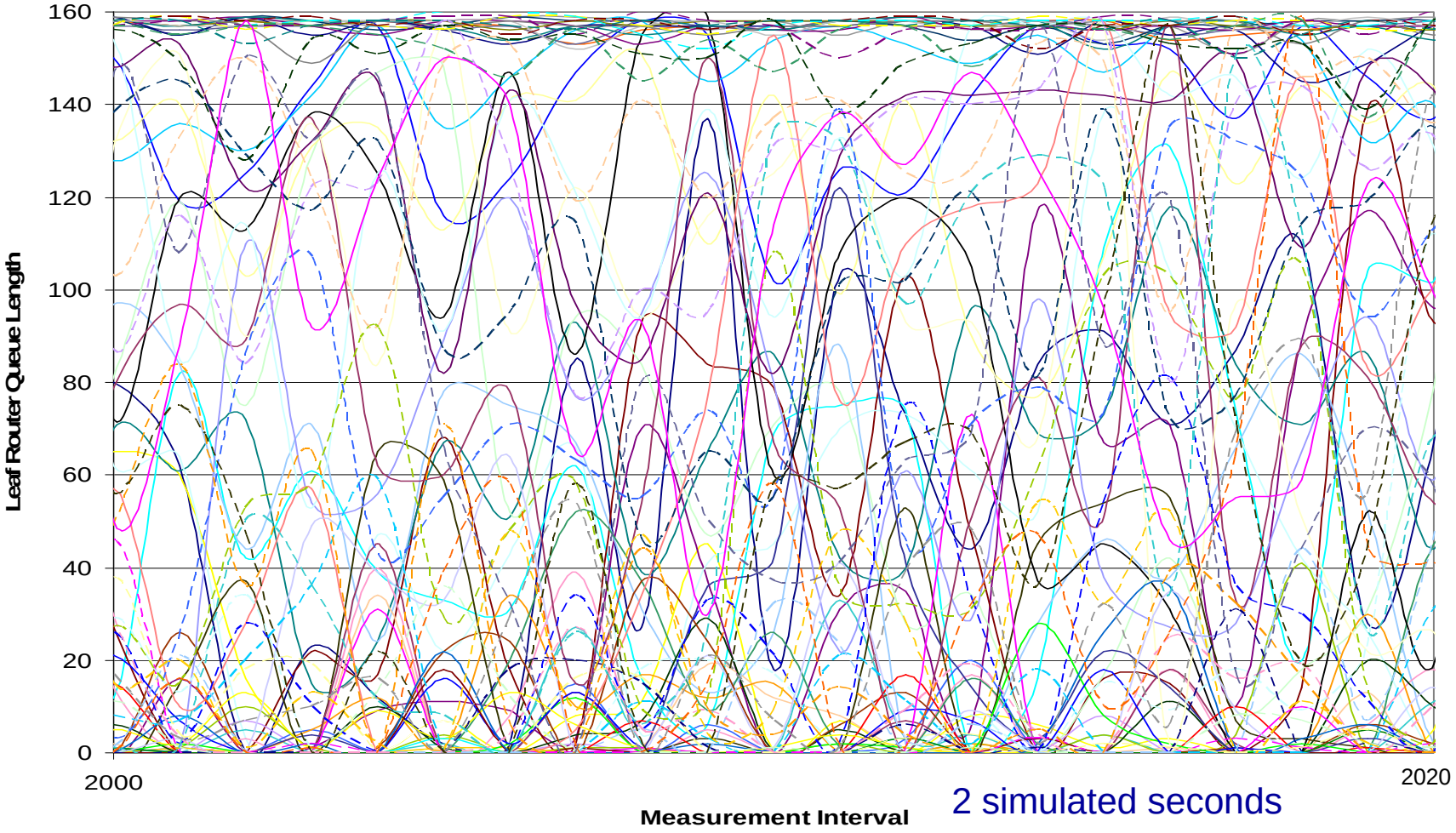


Sample time series of Department Router Q Lengths



2 simulated seconds

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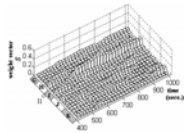

Questions ...

- What is a reasonable topology?
  - Selected tier 3 sites (e.g., Google, Yahoo) will provide higher capacities for expected increased load
  - Internet is a network of networks (ASes)
- Where should sources be placed relative to receivers?
  - Web surfing puts sources and receivers at different places
  - Peer-to-peer interaction provides more even distribution of sources and receivers
  - Content-distribution networks might also provide more even distribution
- What are reasonable distributions for the pattern of flows?
  - Web surfing suggests concentration of flow to selected receivers
  - Special events suggest hot spots
  - Collaborative interactions suggest peer-to-peer
- What ON/OFF regimes should flows observe and in what mix?
  - File transfers might differ from Web accesses and from interactive games and streaming voice and video
- What special techniques should simulated routers employ?
  - Random-early drop might mitigate congestion
  - Flow reservations and prioritized queues might provide varying quality of service

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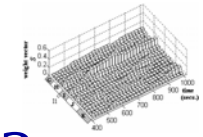
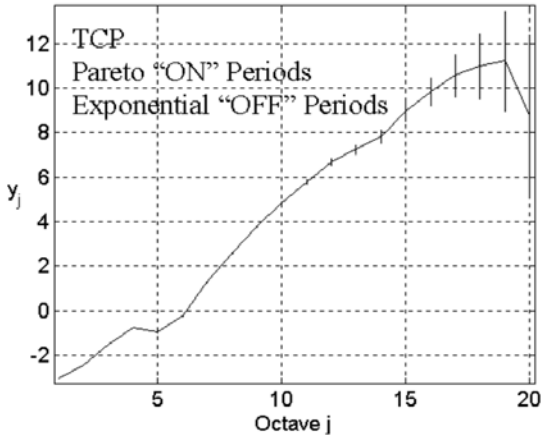
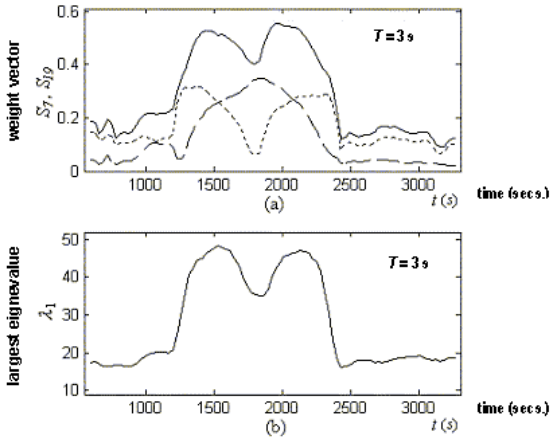


What analysis techniques will provide insight?

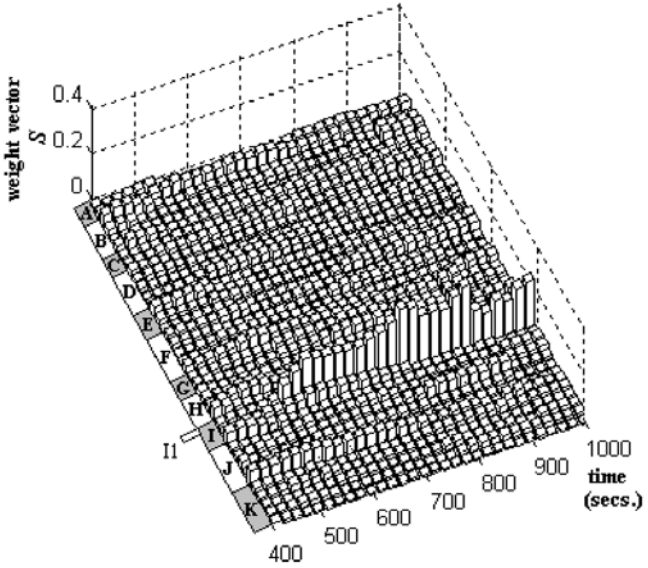
Wavelets



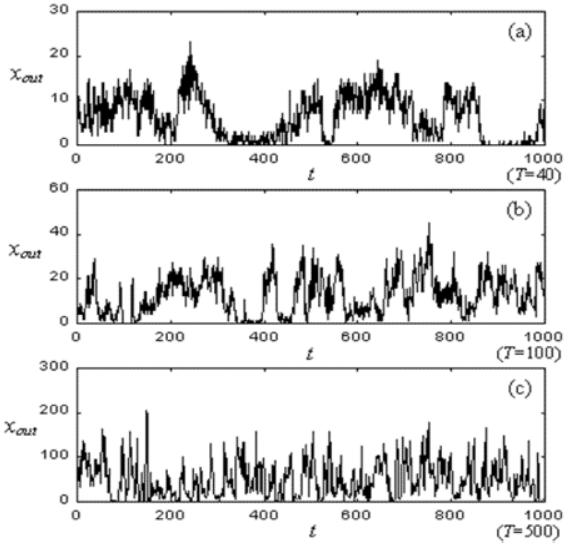
Eigen analysis



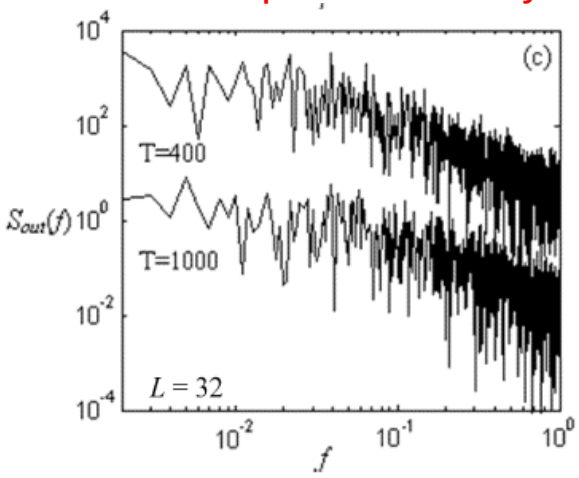
Relative Flow Strengths



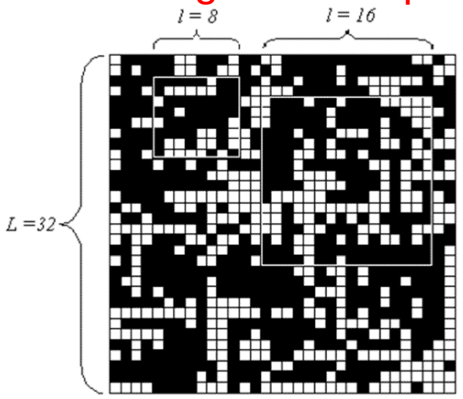
Multi-scale Time Series



Power Spectral Density



Congestion Maps



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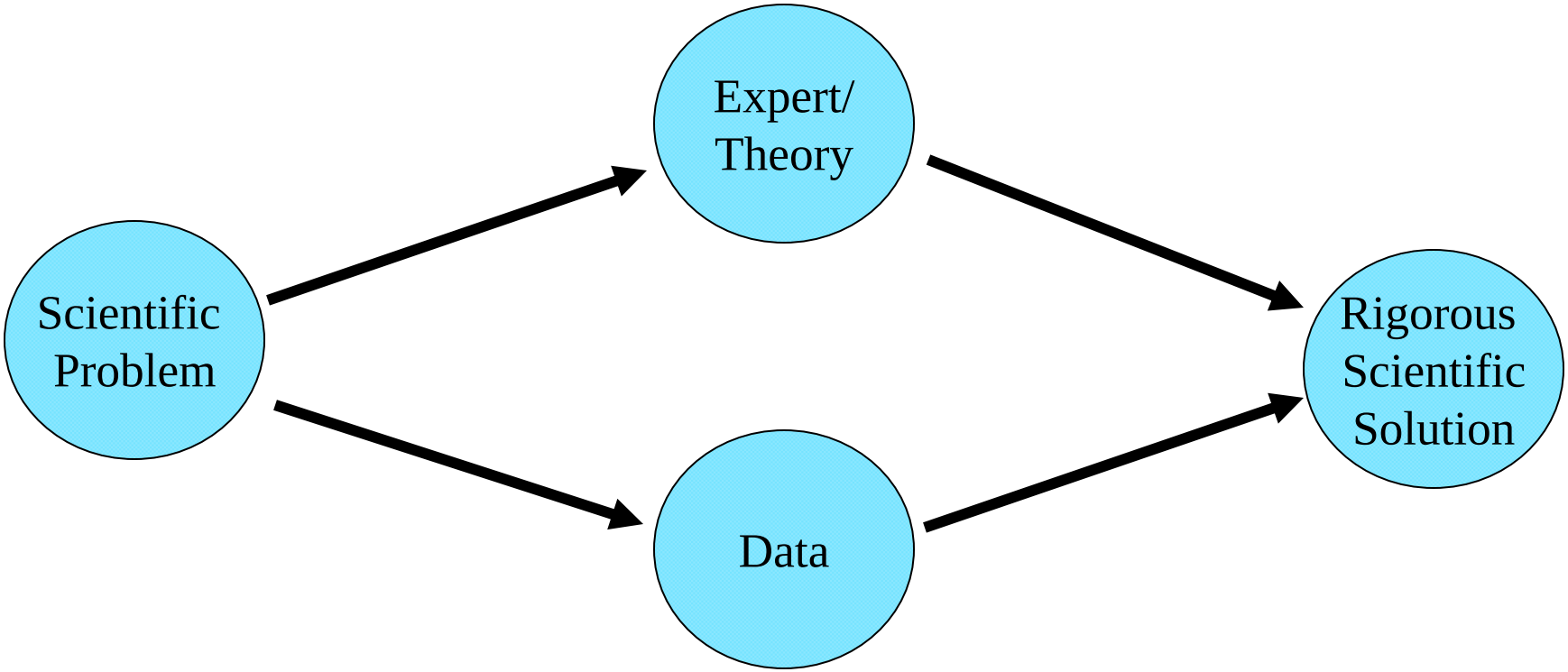
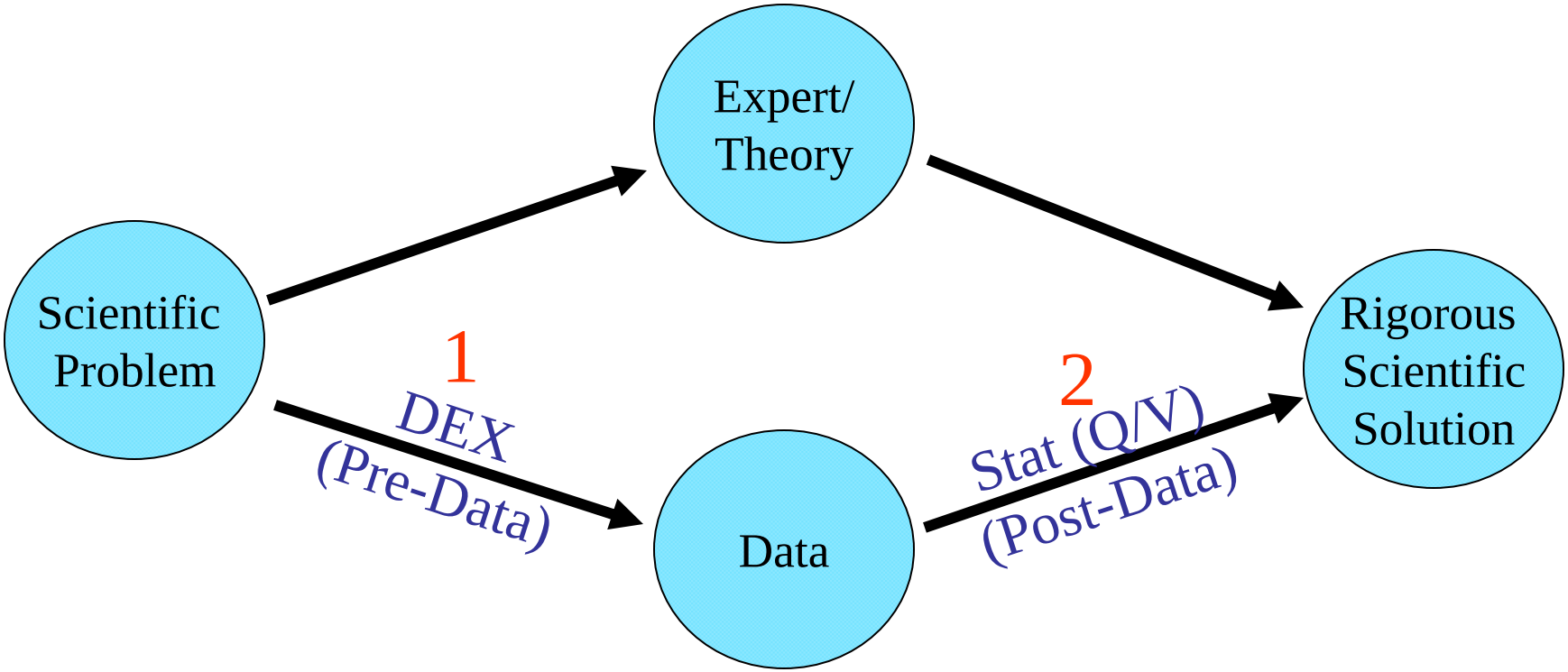
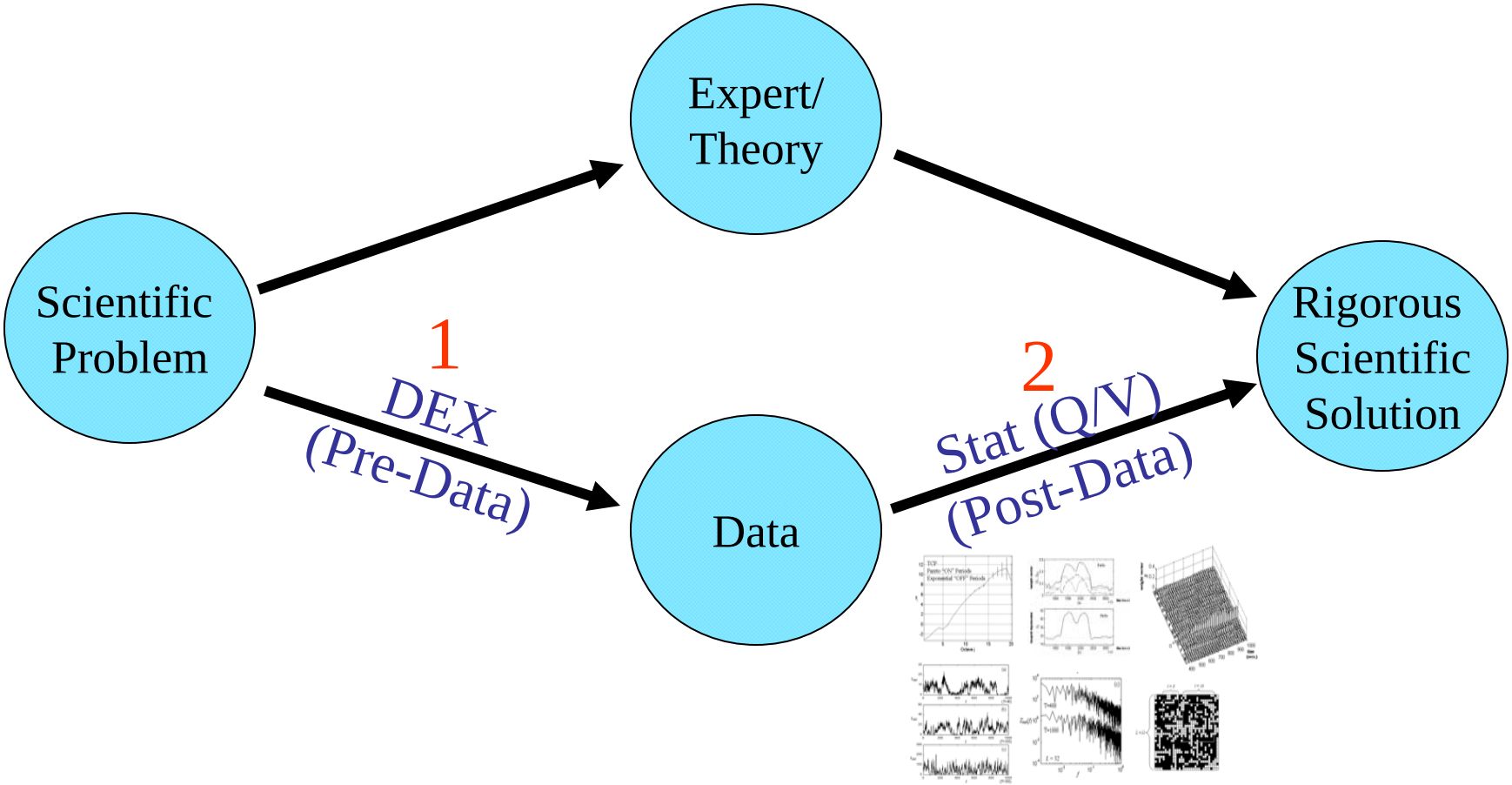
Stat Problem-Solving Approach/Framework



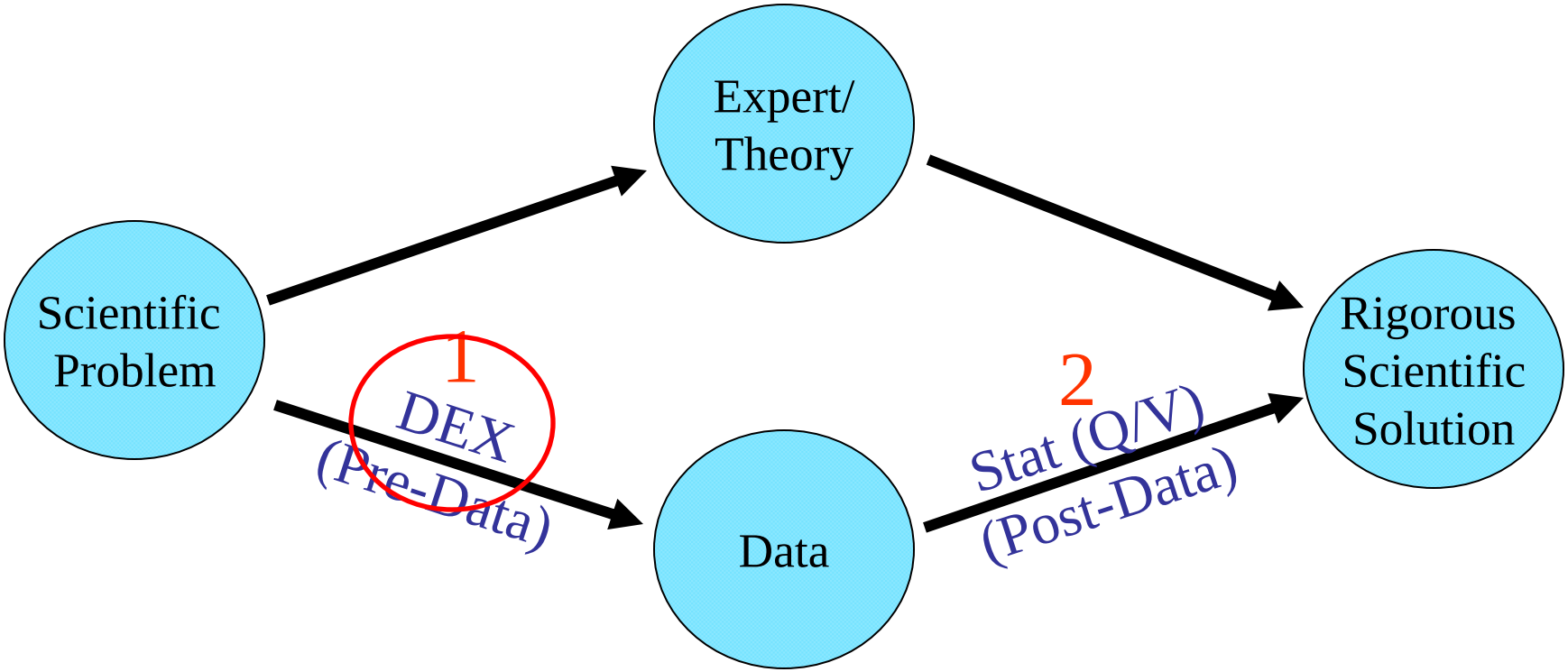
Stat Problem-Solving Approach/Framework



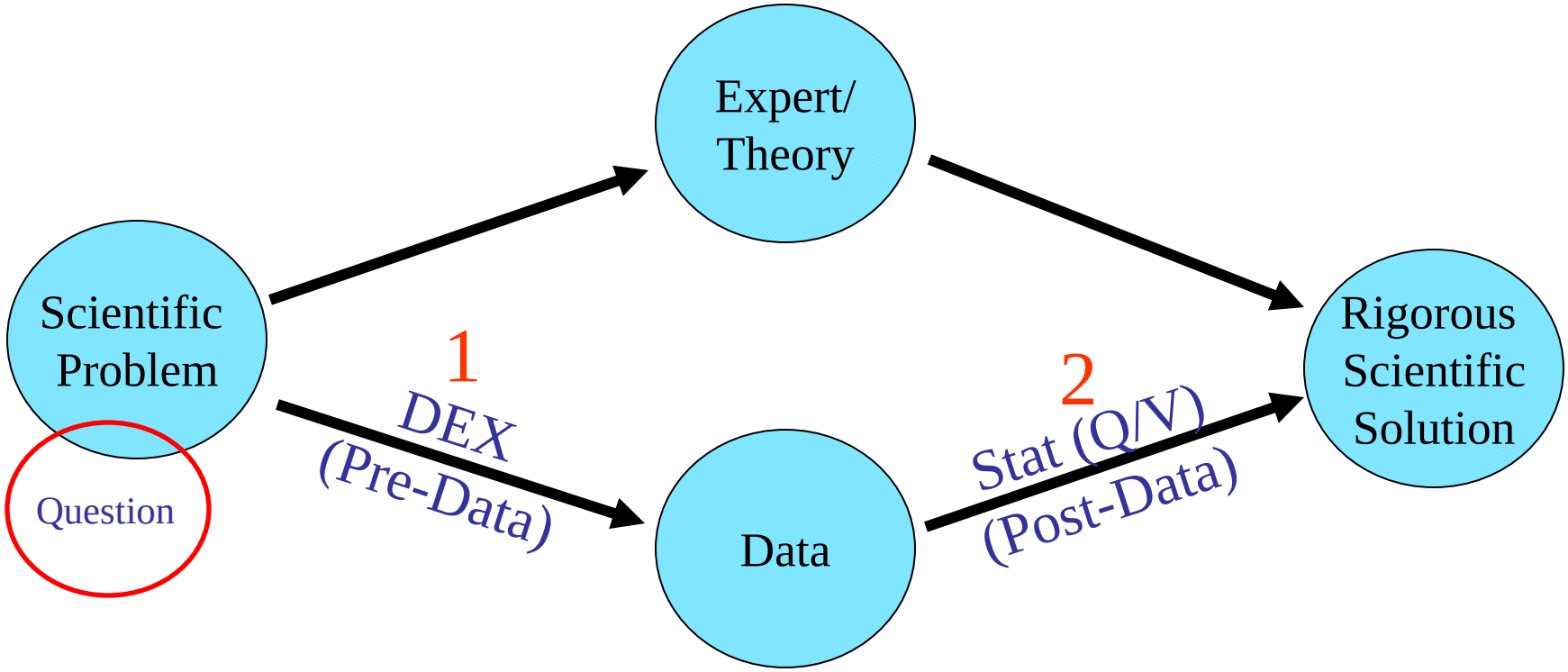
Stat Problem-Solving Approach/Framework



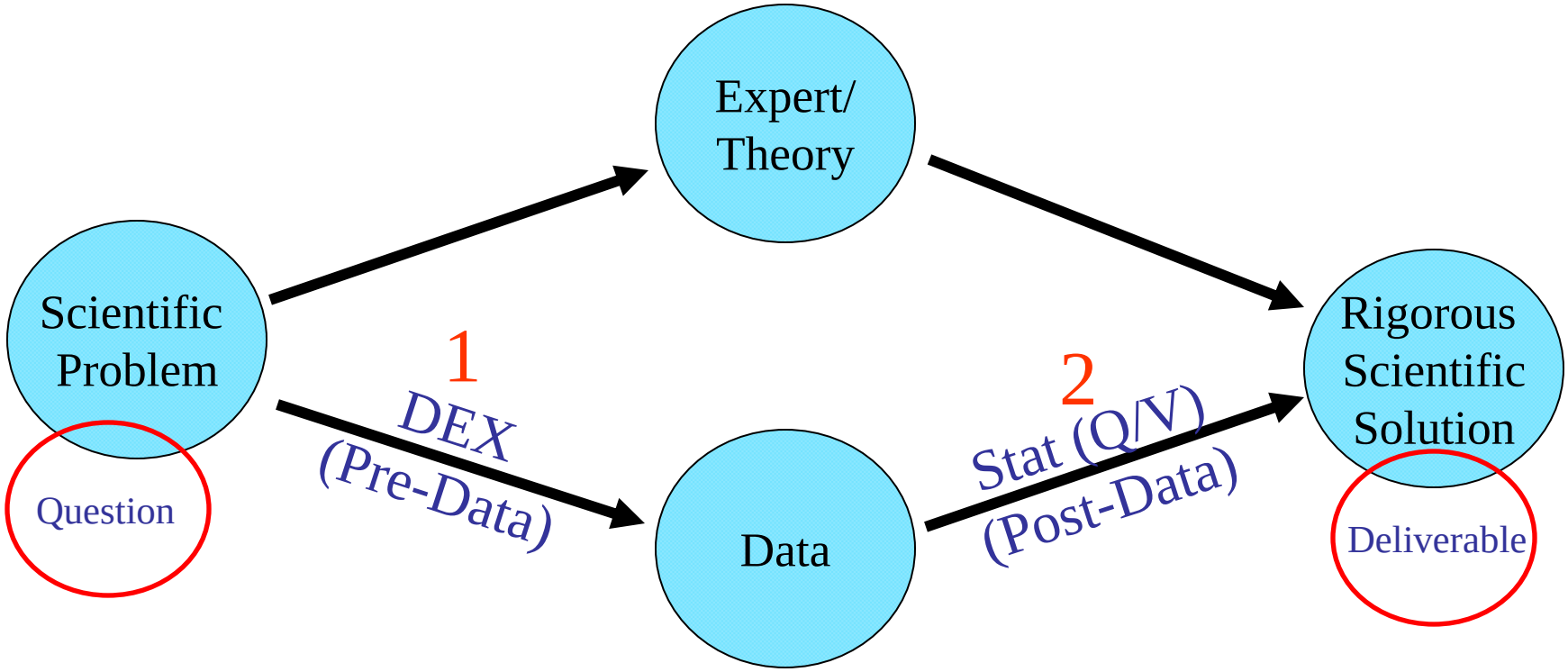
Stat Problem-Solving Approach/Framework



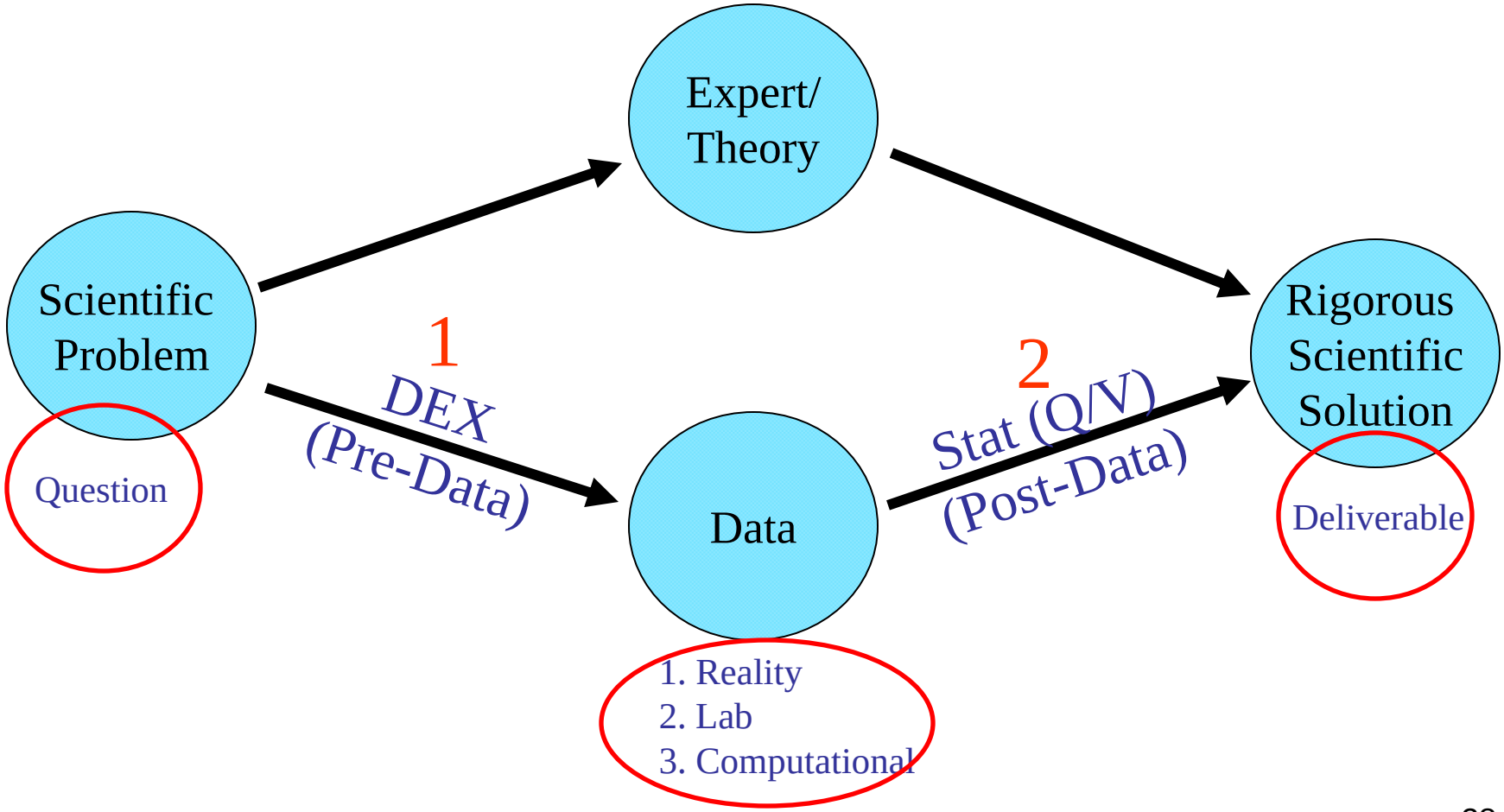
Stat Problem-Solving Approach/Framework



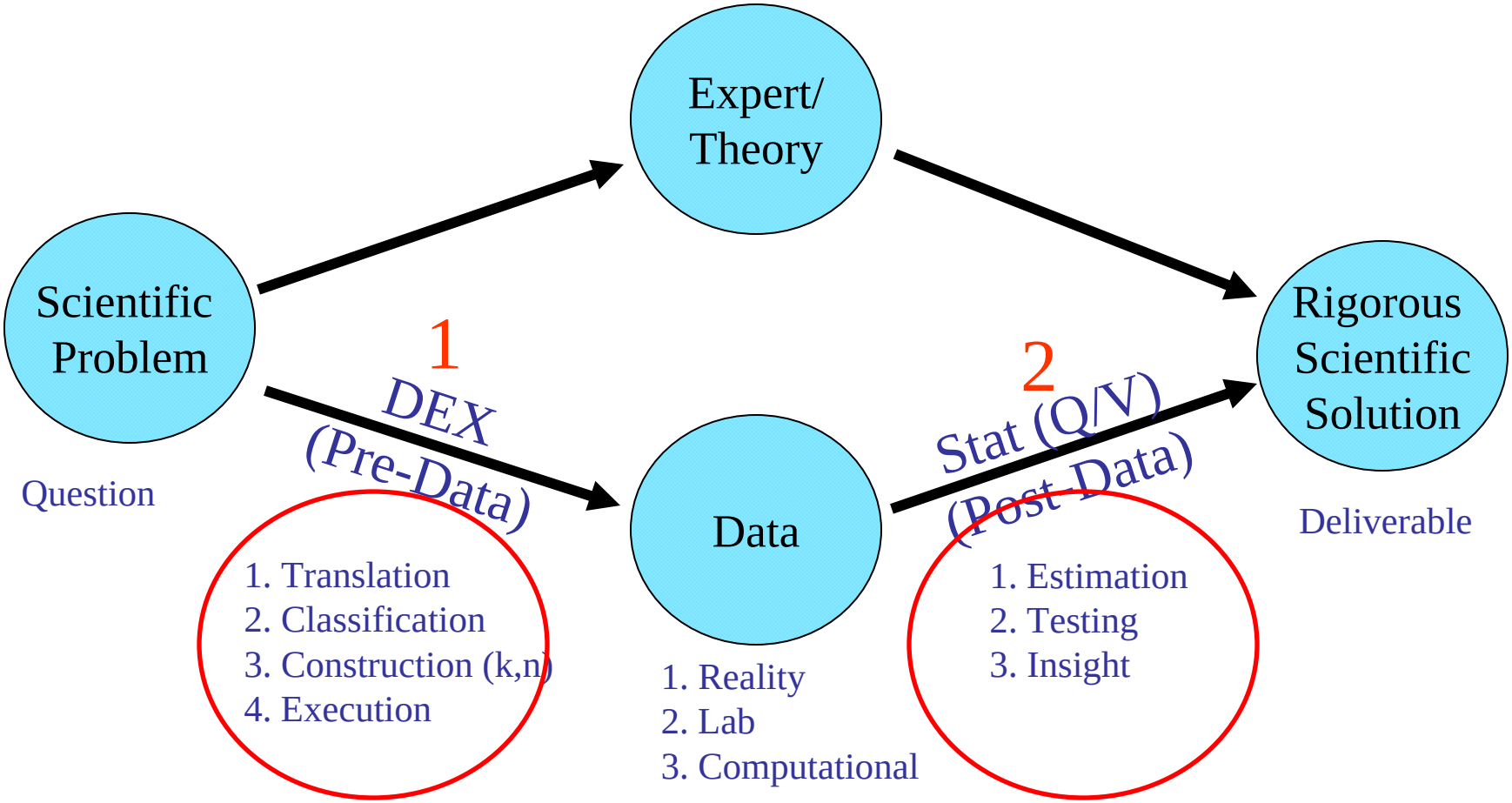
Stat Problem-Solving Approach/Framework



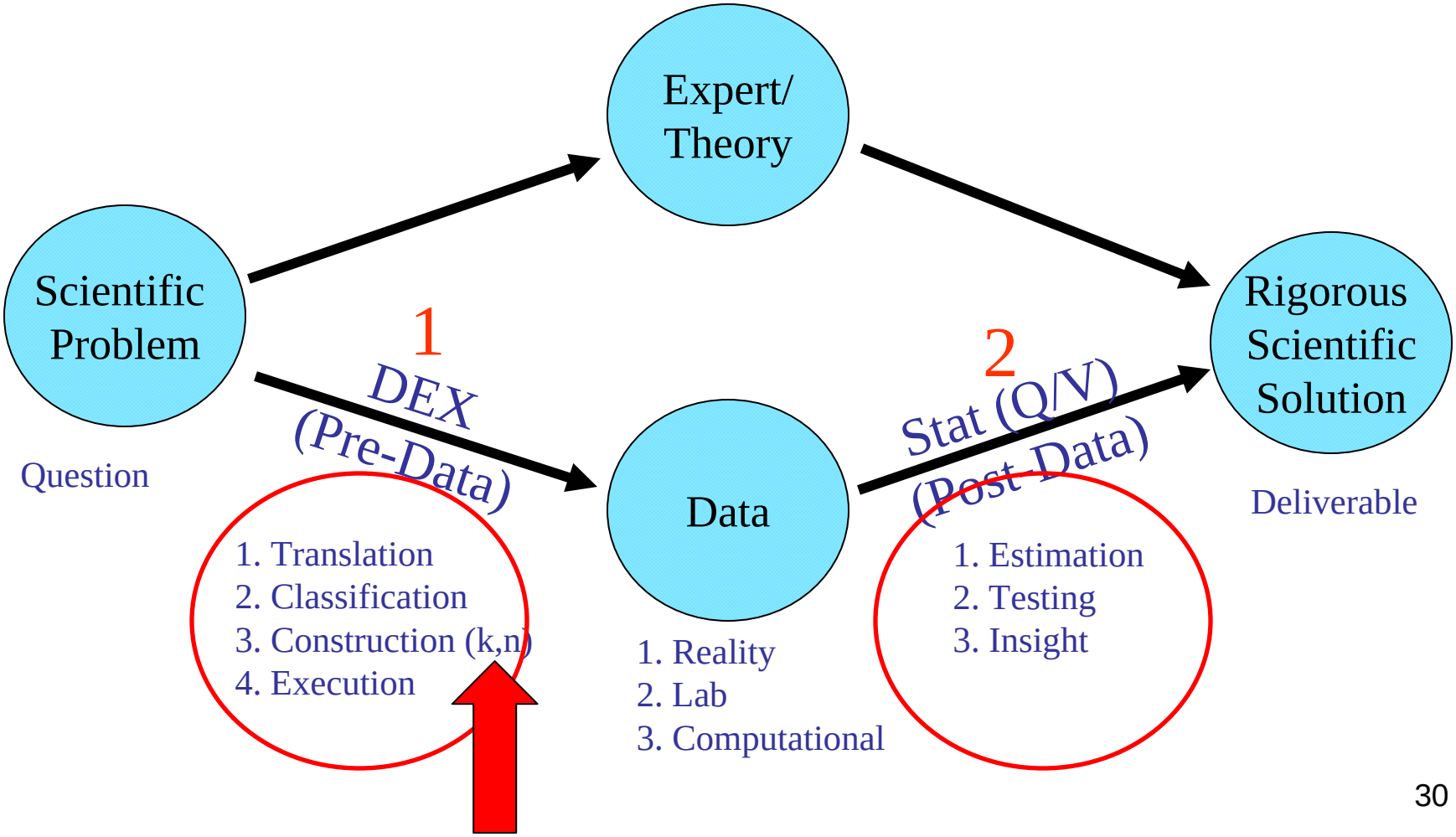
Stat Problem-Solving Approach/Framework



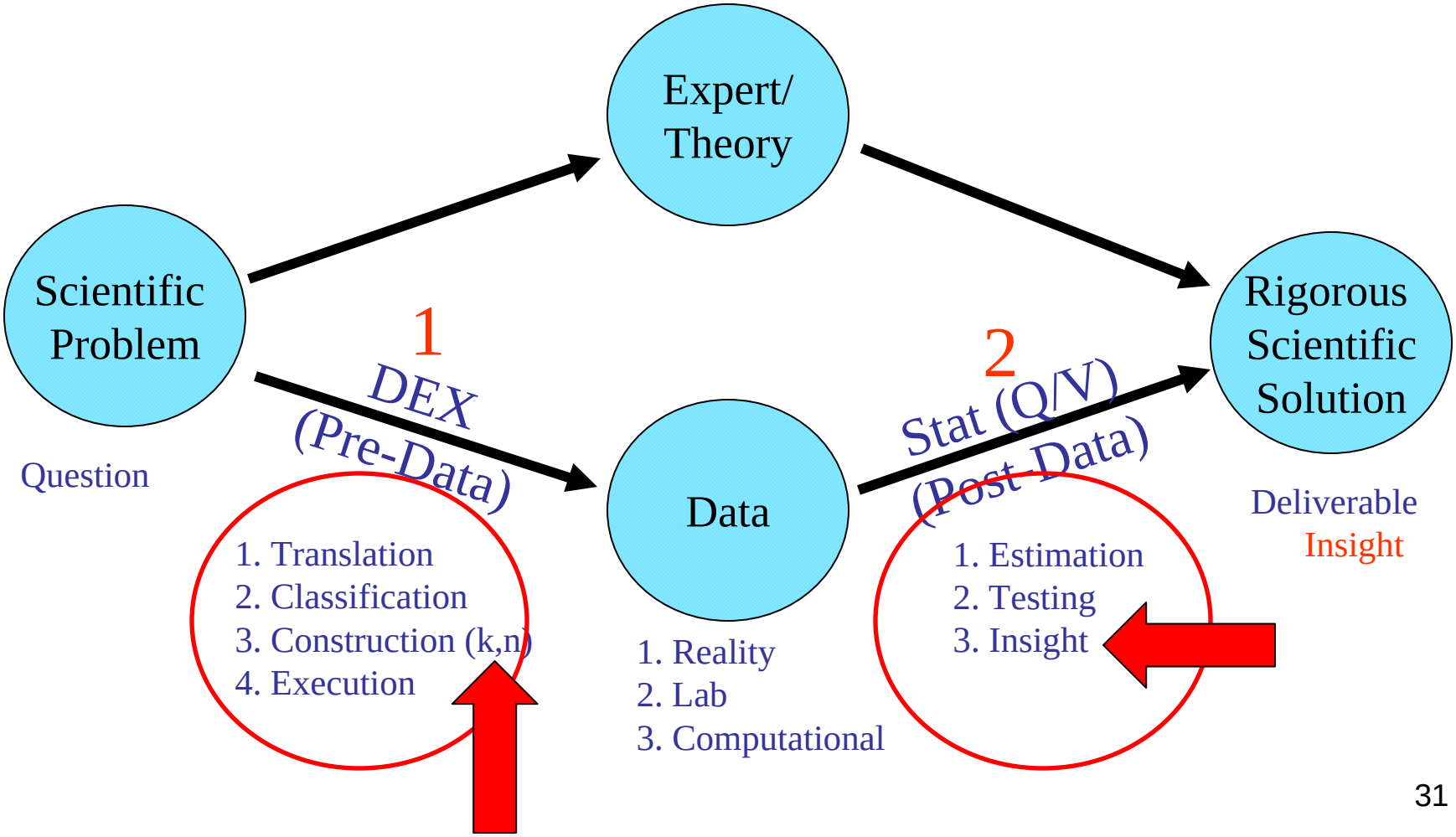
Stat Problem-Solving Approach/Framework



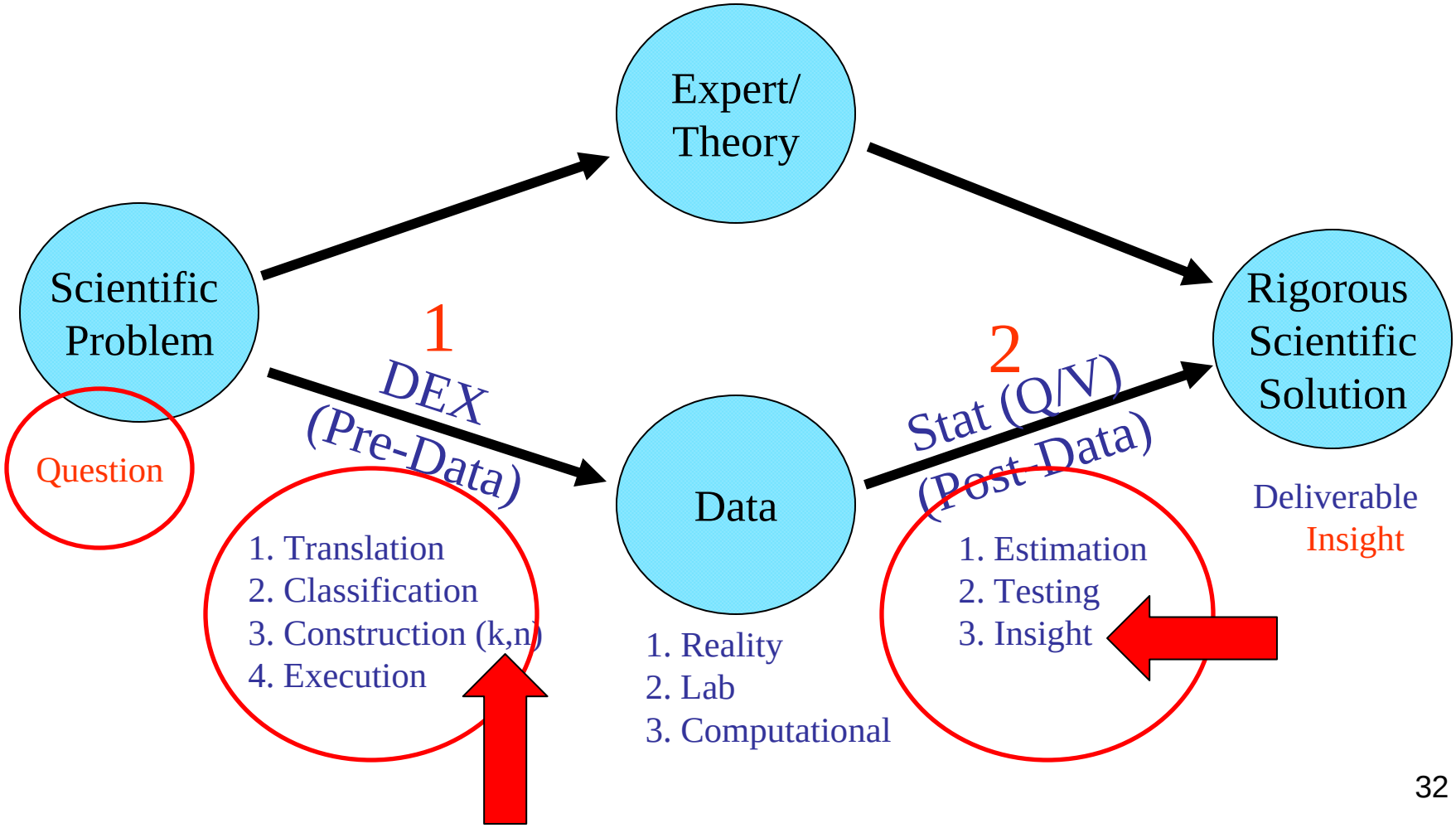
Stat Problem-Solving Approach/Framework



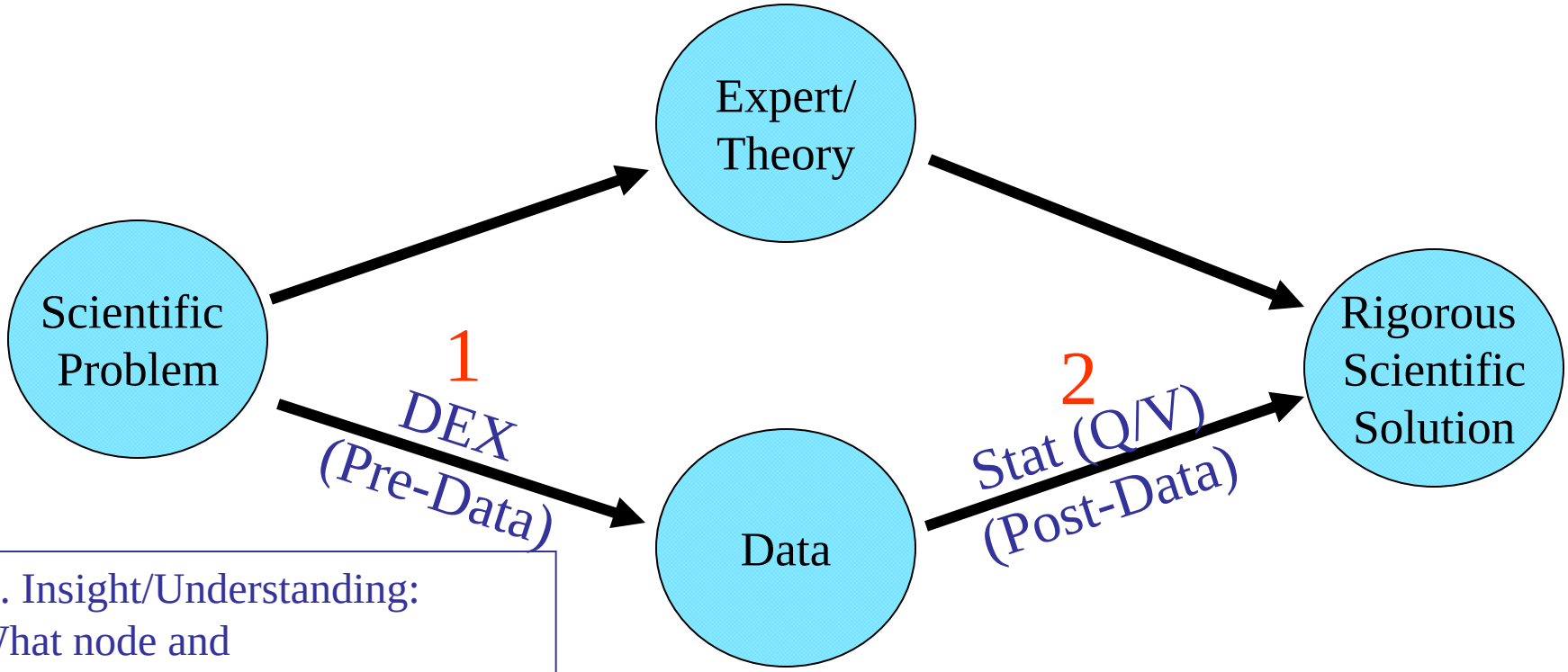
Stat Problem-Solving Approach/Framework



Stat Problem-Solving Approach/Framework

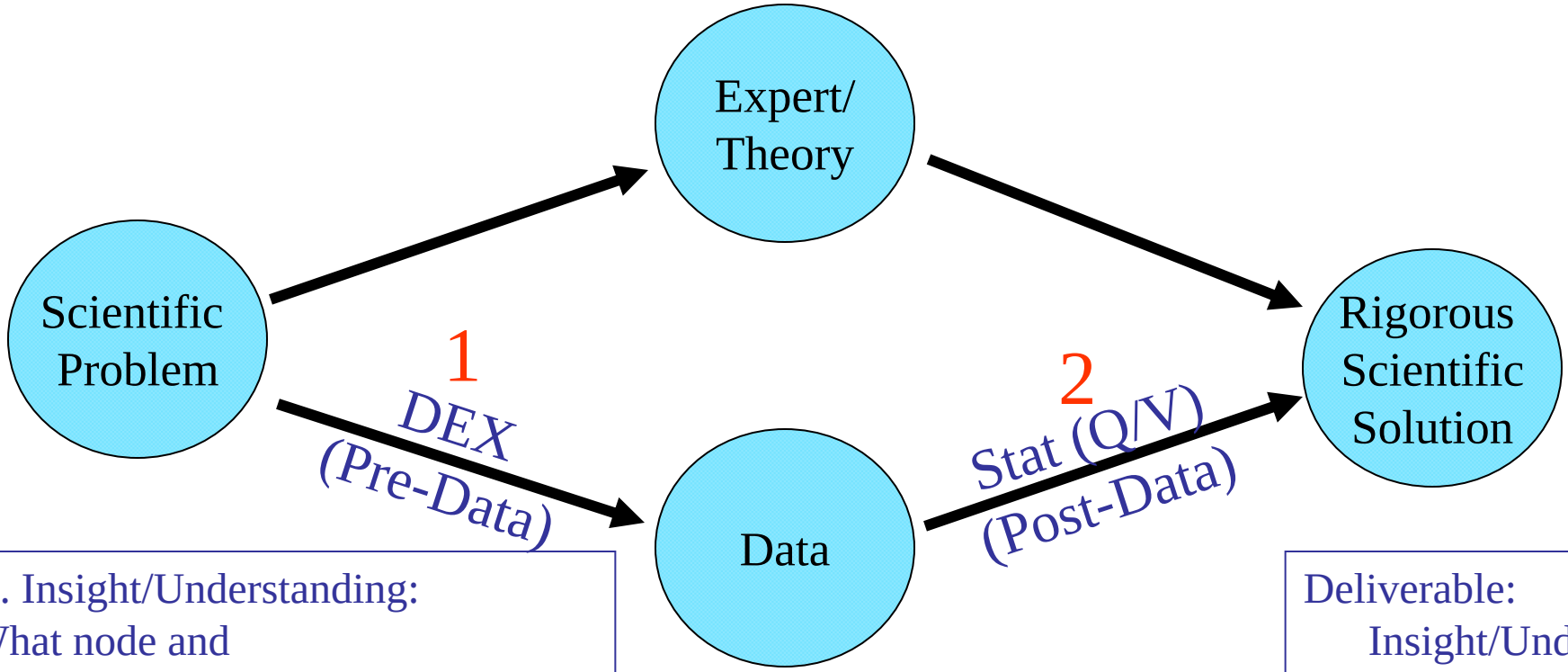


Stat Problem-Solving Approach/Framework



Q. Insight/Understanding:
What node and
system "parameters"
(= factors) are most important
wrt affecting the performance
of the Abilene network
simulator? (Sensitivity Analysis)

Stat Problem-Solving Approach/Framework



Q. Insight/Understanding:
What node and
system "parameters"
(= factors) are most important
wrt affecting the performance
(mean active flows per
interval) of the Abilene
network simulator? (Sens. Analysis)

Deliverable:
Insight/Und.:
Ranked List

$$(k = ?, n = ?)$$

(k = 10, n = ?)

(10 hours of CPU time)

➔ n <= 50

(k = 10, n <= 50)

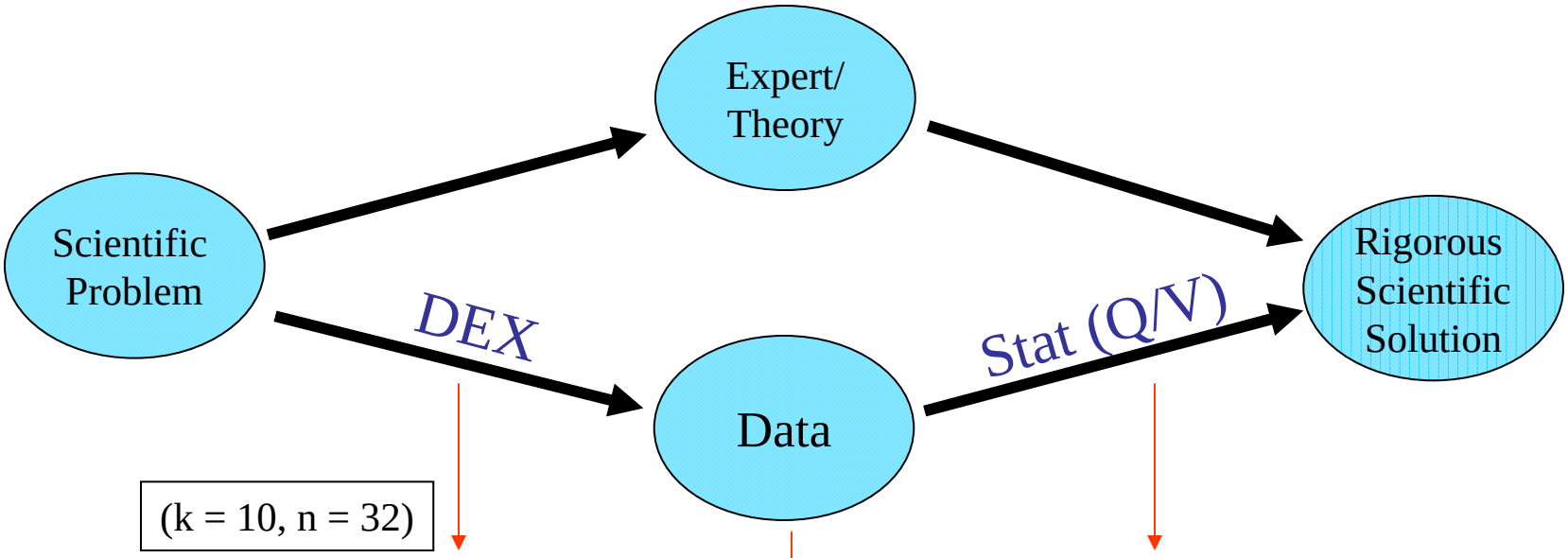
(k = 10, n <= 50)

➔ ***2^{10-5} Fractional Factorial Design***

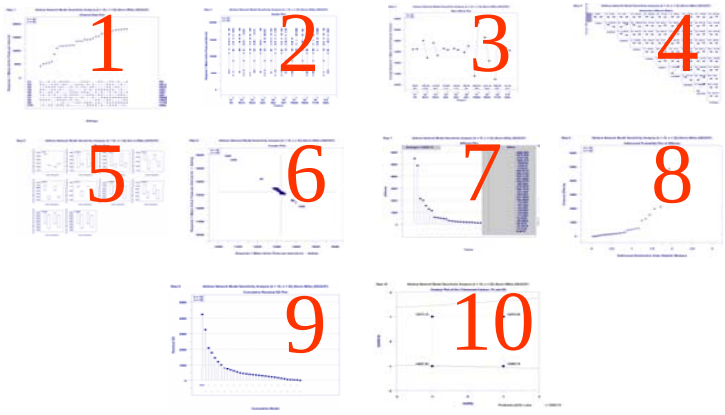
(k = 10, n = 32)

1 + 10 + 45

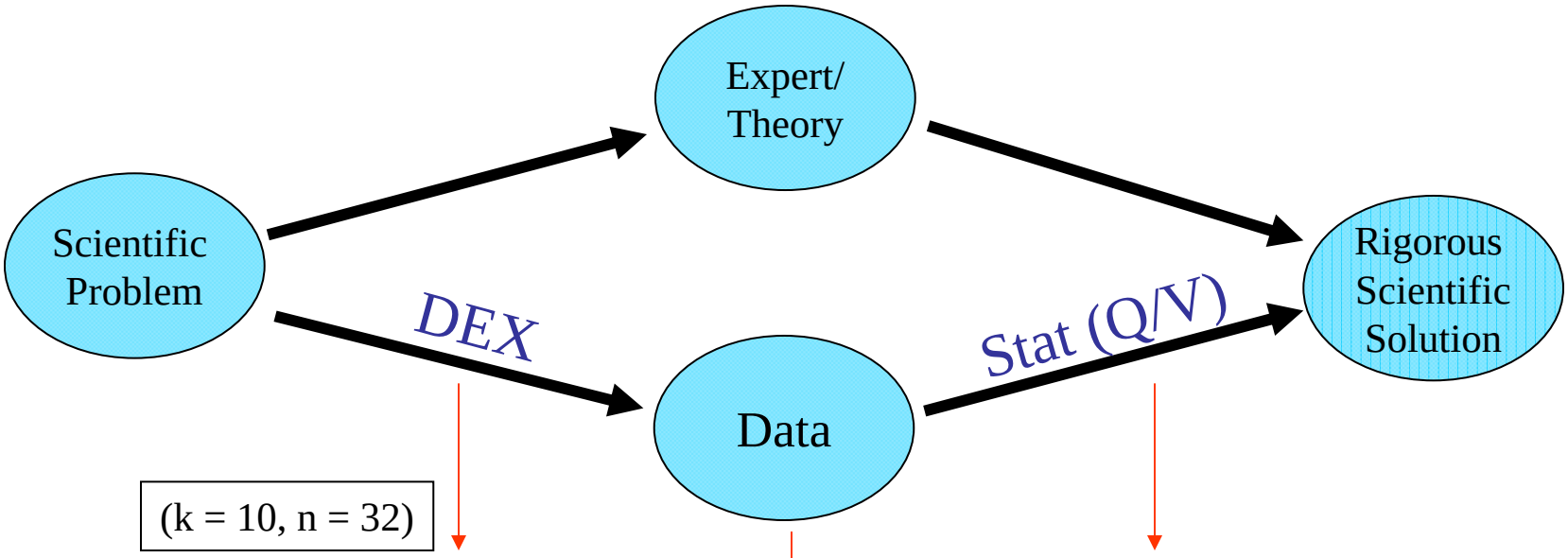
Abilene Network Model Sensitivity Analysis



Run #	X1 Prop Delay	X2 Rel Router Speed (1,2)	X3 Rel Router Speed (2,3)	X4 Queue Size (1)	X5 Queue Size (2)	X6 Queue Size (3)	X7 Pareto Mean	X8 Pareto Shape	X9 Exp Mean	X10 Start Up Mix	Y Average Flows per Interval
1	1	8	4	160	160	80	100	1.2	2500	2	18174
2	2	8	4	160	160	160	50	1.5	5000	2	11981
3	1	4	4	160	160	160	50	1.5	2500	1	13708
4	2	4	4	160	160	80	100	1.2	5000	1	11963
5	1	8	2	160	160	160	50	1.2	5000	1	5375
6	2	8	2	160	160	80	100	1.5	2500	1	17942
7	1	4	2	160	160	80	100	1.5	5000	2	14775
8	2	4	2	160	160	160	50	1.2	2500	2	11882
9	1	8	4	80	160	160	100	1.5	5000	1	16547
10	2	8	4	80	160	80	50	1.2	2500	1	15499
11	1	4	4	80	160	80	50	1.2	5000	2	5120
12	2	4	4	80	160	160	100	1.5	2500	2	17621
13	1	8	2	80	160	80	50	1.5	2500	2	14336
14	2	8	2	80	160	160	100	1.2	5000	2	11817
15	1	4	2	80	160	160	100	1.2	2500	1	16761
16	2	4	2	80	160	80	50	1.5	5000	1	8774
17	1	8	4	160	80	80	50	1.5	5000	1	12153
18	2	8	4	160	80	160	100	1.2	2500	1	18235
19	1	4	4	160	80	160	100	1.2	5000	2	10994
20	2	4	4	160	80	80	50	1.5	2500	2	14280
21	1	8	2	160	80	160	100	1.5	2500	2	17910
22	2	8	2	160	80	80	50	1.2	5000	2	5507
23	1	4	2	160	80	80	50	1.2	2500	1	13637
24	2	4	2	160	80	160	100	1.5	5000	1	13709
25	1	8	4	80	80	160	50	1.2	2500	2	15424
26	2	8	4	80	80	80	100	1.5	5000	2	16391
27	1	4	4	80	80	80	100	1.5	2500	1	18012
28	2	4	4	80	80	160	50	1.2	5000	1	4300
29	1	8	2	80	80	80	100	1.2	5000	1	12142
30	2	8	2	80	80	160	50	1.5	2500	1	14274
31	1	4	2	80	80	160	50	1.5	5000	2	5978
32	2	4	2	80	80	80	100	1.2	2500	2	17298



Abilene Network Model Sensitivity Analysis



(k = 10, n = 32)

Run #	X1 Prop Delay	X2 Rel Router Speed (1,2)	X3 Rel Router Speed (2,3)	X4 Queue Size (1)	X5 Queue Size (2)	X6 Queue Size (3)	X7 Pareto Mean	X8 Pareto Shape	X9 Exp Mean	X10 Start Up Mix	Y Average Flows per Interval
1	1	8	4	160	160	80	100	1.2	2500	2	18174
2	2	8	4	160	160	160	50	1.5	5000	2	11981
3	1	4	4	160	160	160	50	1.5	2500	1	13708
4	2	4	4	160	160	80	100	1.2	5000	1	11963
5	1	8	2	160	160	160	50	1.2	5000	1	5375
6	2	8	2	160	160	80	100	1.5	2500	1	17942
7	1	4	2	160	160	80	100	1.5	5000	2	14775
8	2	4	2	160	160	160	50	1.2	2500	2	11882
9	1	8	4	80	160	160	100	1.5	5000	1	16547
10	2	8	4	80	160	80	50	1.2	2500	1	15499
11	1	4	4	80	160	80	50	1.2	5000	2	5120
12	2	4	4	80	160	160	100	1.5	2500	2	17621
13	1	8	2	80	160	80	50	1.5	2500	2	14336
14	2	8	2	80	160	160	100	1.2	5000	2	11817
15	1	4	2	80	160	160	100	1.2	2500	1	16761
16	2	4	2	80	160	80	50	1.5	5000	1	8774
17	1	8	4	160	80	80	50	1.5	5000	1	12153
18	2	8	4	160	80	160	100	1.2	2500	1	18235
19	1	4	4	160	80	160	100	1.2	5000	2	10994
20	2	4	4	160	80	80	50	1.5	2500	2	14280
21	1	8	2	160	80	160	100	1.5	2500	2	17910
22	2	8	2	160	80	80	50	1.2	5000	2	5507
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25	1	8	4	80	80	160	50	1.2	2500	2	15424
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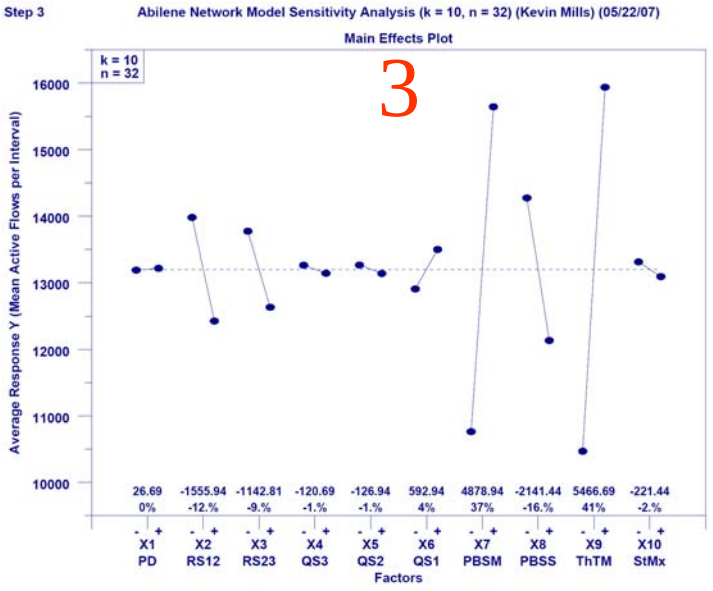
30	2	8	2	80	80	160	50	1.5	2500	1	14274
31	1	4	2	80	80	160	50	1.5	5000	2	5978
32	2	4	2	80	80	80	100	1.2	2500	2	17298



The Input Data File

This is data file mills21.dat DEX #1: 2**(10-5) Kevin Mills, 05/22/07
Contents: Results of Abilene Network Designed Experiment #1
Number of observations = 32 (= 2**(10-5))
Number of variables per line image = 16 (= 6 responses + 10 factors)

Order of variables on a line image:

1. Response variable 1 = Computer (= Processor) ID
2. Response variable 2 = CPU Time (hours)
3. Response variable 3 = Average active flows per interval
4. Response variable 4 = Average packets in per interval
5. Response variable 5 = Average packets out per interval
6. Response variable 6 = Average loss rate per interval

7. Factor 1 = Propagation Delay (2 levels: (-,+) = (current,2 x current))
8. Factor 2 = (L1/L2) Rel. Router Speed (2 levels: (-,+) = (8 ,4))
9. Factor 3 = (L2/L3) Rel. Router Speed (2 levels: (-,+) = (8 ,4))
10. Factor 4 = Level 3 Queue Size (2 levels: (-,+) = (160 ,80))
11. Factor 5 = Level 2 Queue Size (2 levels: (-,+) = (160 ,80))
12. Factor 6 = Level 1 Queue Size (2 levels: (-,+) = (160 ,80))
13. Factor 7 = Packet Block Size Pareto Mean (2 levels: (-,+) = (50 ,100))
14. Factor 8 = Packet Block Size Pareto Shape(2 levels: (-,+) = (1.5 ,1.2)
15. Factor 9 = "Think Time" Exponential Mean (2 levels: (-,+) = (5000,2500)
16. Factor 10 = Start-up Mix (2 levels: (-,+) = (100/0/0/0, 0/0/0/100))

To read this data file into dataplot:
skip 25; read mills21.dat y1 to y6 x1 to x10

Response 1: Average Active Flows per Interval
Response 2: Average Packets In per Interval
Response 3: Average Packets Out per Interval
Response 4: Average Loss per Interval

Experiment Design(2^{10-5}) & Data

Y1	Y2	Y3	Y4	Y5	Y6	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
9.	2.7	18174.	30708.	27201.	0.114	-1	-1	-1	-1	-1	1	1	1	1	1
9.	2.1	11981.	25754.	23760.	0.077	1	-1	-1	-1	-1	-1	-1	-1	-1	1
9.	2.7	13708.	45354.	41588.	0.083	-1	1	-1	-1	-1	-1	-1	-1	1	-1
9.	2.6	11963.	40133.	37346.	0.069	1	1	-1	-1	-1	1	1	1	-1	-1
9.	1.8	5375.	35369.	34098.	0.036	-1	-1	1	-1	-1	-1	-1	1	-1	-1
9.	3.3	17942.	41631.	37839.	0.091	1	-1	1	-1	-1	1	1	-1	1	-1
9.	2.6	14775.	38251.	35576.	0.070	-1	1	1	-1	-1	1	1	-1	-1	1
9.	2.8	11882.	43527.	41083.	0.056	1	1	1	-1	-1	-1	-1	1	1	1
10.	2.5	16547.	29859.	26022.	0.128	-1	-1	-1	1	-1	-1	1	-1	-1	-1
10.	2.6	15499.	28445.	25530.	0.102	1	-1	-1	1	-1	1	-1	1	1	-1
10.	2.1	5120.	35889.	34010.	0.052	-1	1	-1	1	-1	1	-1	1	-1	1
10.	3.4	17621.	44769.	41228.	0.079	1	1	-1	1	-1	-1	1	-1	1	1
10.	2.7	14336.	42241.	38093.	0.098	-1	-1	1	1	-1	1	-1	-1	1	1
10.	2.9	11817.	39438.	36931.	0.063	1	-1	1	1	-1	-1	1	1	-1	1
10.	3.5	16761.	45876.	41996.	0.084	-1	1	1	1	-1	-1	1	1	1	-1
10.	2.2	8774.	33817.	32476.	0.039	1	1	1	1	-1	1	-1	-1	-1	-1
7.	8.6	12153.	26565.	24133.	0.091	-1	-1	-1	-1	1	1	-1	-1	-1	-1
7.	10.0	18235.	29763.	26782.	0.100	1	-1	-1	-1	1	-1	1	1	1	-1
7.	9.7	10994.	44638.	41353.	0.074	-1	1	-1	-1	1	-1	1	1	-1	1
7.	9.1	14280.	40275.	37192.	0.076	1	1	-1	-1	1	1	-1	-1	1	1
7.	10.3	17910.	44611.	39225.	0.121	-1	-1	1	-1	1	-1	1	-1	1	1
7.	7.8	5507.	33339.	32084.	0.038	1	-1	1	-1	1	1	-1	1	-1	1
7.	10.0	13637.	38776.	36270.	0.064	-1	1	1	-1	1	1	-1	1	1	-1
7.	10.2	13709.	41547.	38815.	0.066	1	1	1	-1	1	-1	1	-1	-1	-1
8.	9.4	15424.	29771.	26212.	0.119	-1	-1	-1	1	1	-1	-1	1	1	1
8.	9.6	16391.	28419.	25299.	0.110	1	-1	-1	1	1	1	1	-1	-1	1
8.	10.4	18012.	44761.	39966.	0.107	-1	1	-1	1	1	1	1	-1	1	-1
8.	7.6	4300.	36237.	35304.	0.026	1	1	-1	1	1	-1	-1	1	-1	-1
8.	9.7	12142.	41541.	37585.	0.095	-1	-1	1	1	1	1	1	1	-1	-1
8.	10.0	14274.	40689.	37398.	0.081	1	-1	1	1	1	-1	-1	-1	1	-1
8.	9.7	5978.	40673.	38877.	0.044	-1	1	1	1	1	-1	-1	-1	-1	1
8.	10.2	17298.	38919.	36318.	0.067	1	1	1	1	1	1	1	1	1	1

Response 1:
Average Active Flow per Interval

Experiment Design(2^{10-5}) & Data

Run #	X1 Prop Delay	X2 Rel Router Speed (1,2)	X3 Rel Router Speed (2,3)	X4 Queue Size (1)	X5 Queue Size (2)	X6 Queue Size (3)	X7 Pareto Mean	X8 Pareto Shape	X9 Exp Mean	X10 Start Up Mix	Y Average Flows per Interval
1	1	8	4	160	160	80	100	1.2	2500	2	18174
2	2	8	4	160	160	160	50	1.5	5000	2	11981
3	1	4	4	160	160	160	50	1.5	2500	1	13708
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8	2	4	2	160	160	160	50	1.2	2500	2	11882
9	1	8	4	80	160	160	100	1.5	5000	1	16547
10	2	8	4	80	160	80	50	1.2	2500	1	15499
11	1	4	4	80	160	80	50	1.2	5000	2	5120
12	2	4	4	80	160	160	100	1.5	2500	2	17621
13	1	8	2	80	160	80	50	1.5	2500	2	14336
14	2	8	2	80	160	160	100	1.2	5000	2	11817
15	1	4	2	80	160	160	100	1.2	2500	1	16761
16	2	4	2	80	160	80	50	1.5	5000	1	8774
17	1	8	4	160	80	80	50	1.5	5000	1	12153
18	2	8	4	160	80	160	100	1.2	2500	1	18235
19	1	4	4	160	80	160	100	1.2	5000	2	10994
20	2	4	4	160	80	80	50	1.5	2500	2	14280
21	1	8	2	160	80	160	100	1.5	2500	2	17910
22	2	8	2	160	80	80	50	1.2	5000	2	5507
23	1	4	2	160	80	80	50	1.2	2500	1	13637
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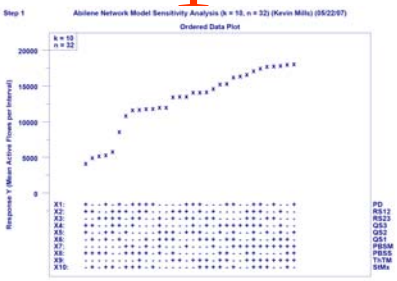
27	1	4	4	80	80	80	100	1.5	2500	1	18012
28	2	4	4	80	80	160	50	1.2	5000	1	4300
29	1	8	2	80	80	80	100	1.2	5000	1	12142
30	2	8	2	80	80	160	50	1.5	2500	1	14274
31	1	4	2	80	80	160	50	1.5	5000	2	5978
32	2	4	2	80	80	80	100	1.2	2500	2	17298

10-Step Data Analysis (Dataplot Macro dexplot.dp)

1



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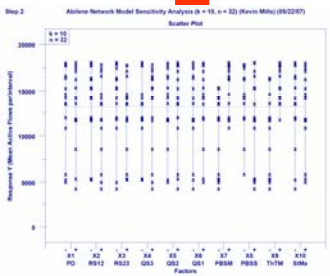
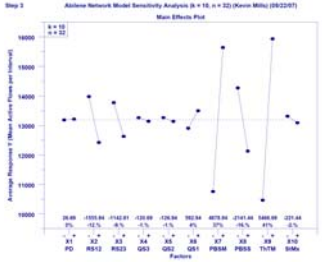


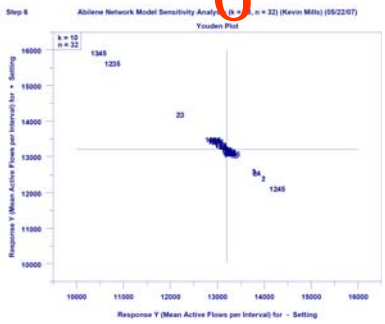
3



4

5

6



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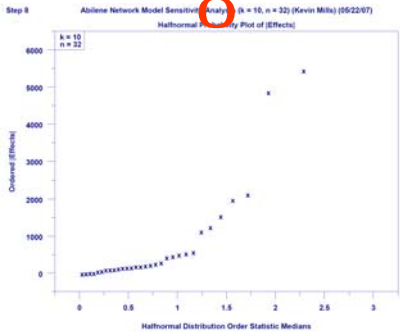

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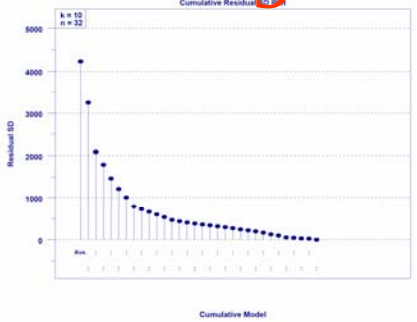

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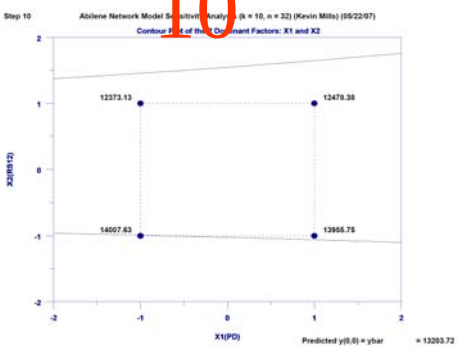
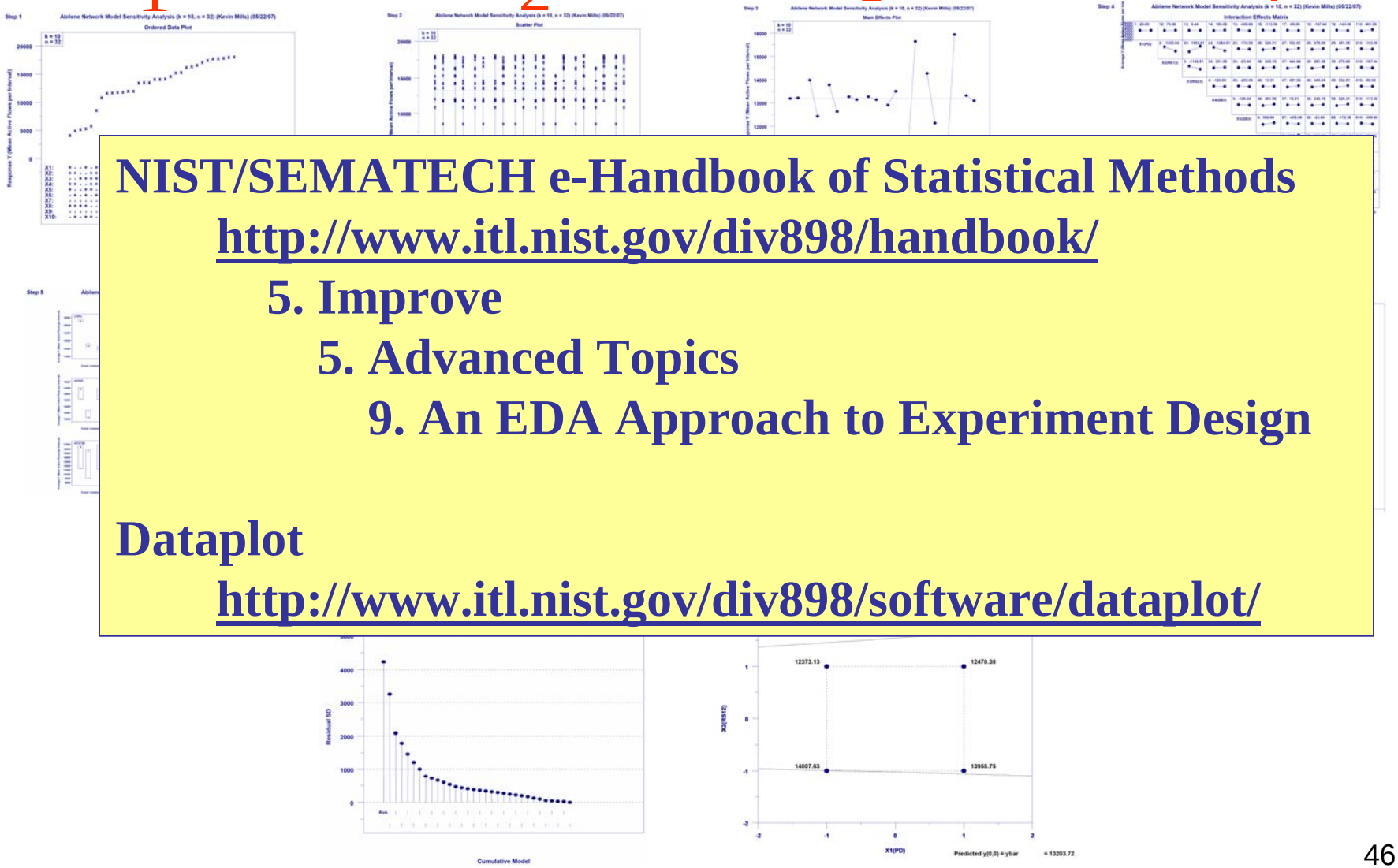


10-Step Data Analysis (Dataplot Macro dexplot.dp)

1 2 3 4



NIST/SEMATECH e-Handbook of Statistical Methods

http://www.itl.nist.gov/div898/handbook/

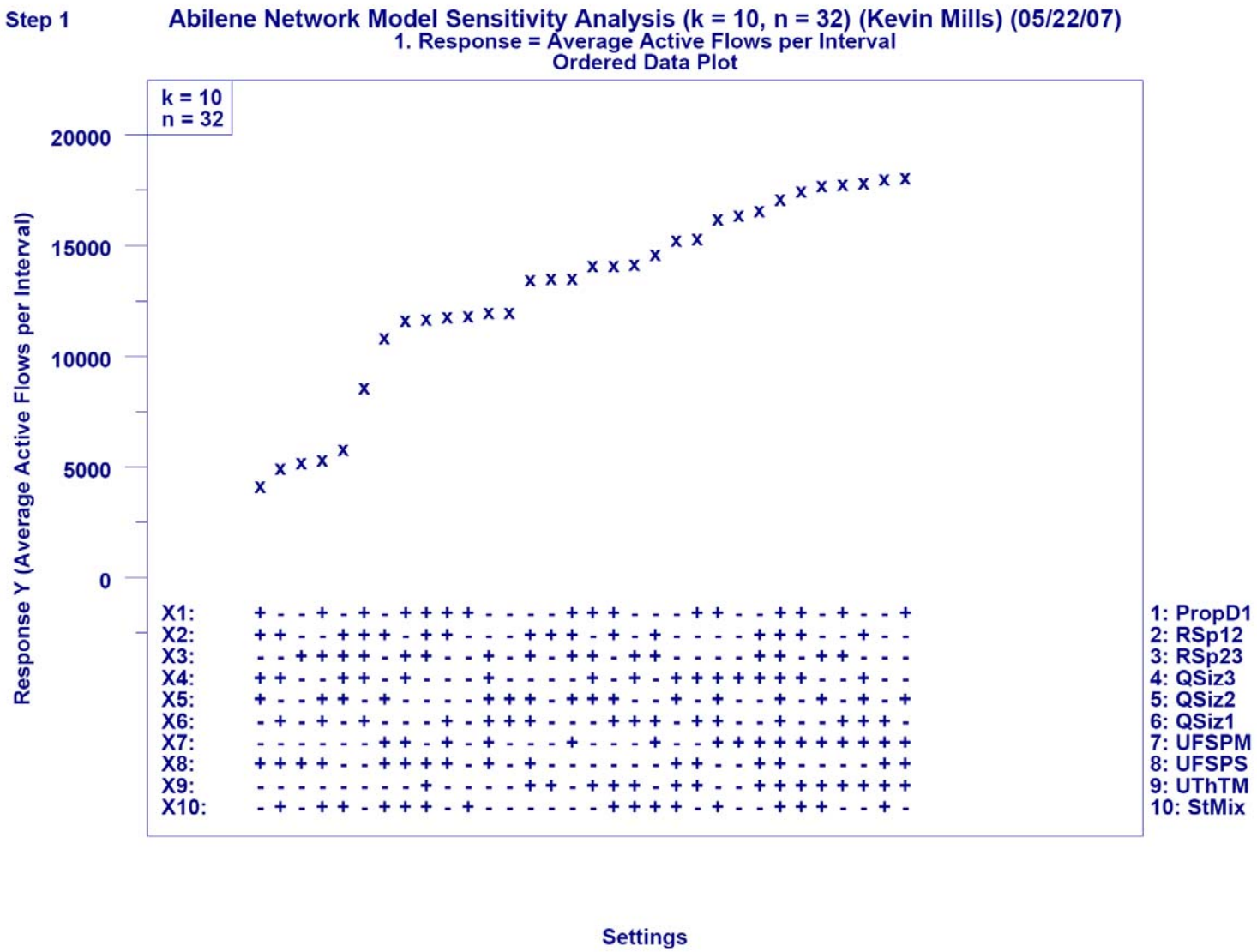
5. Improve

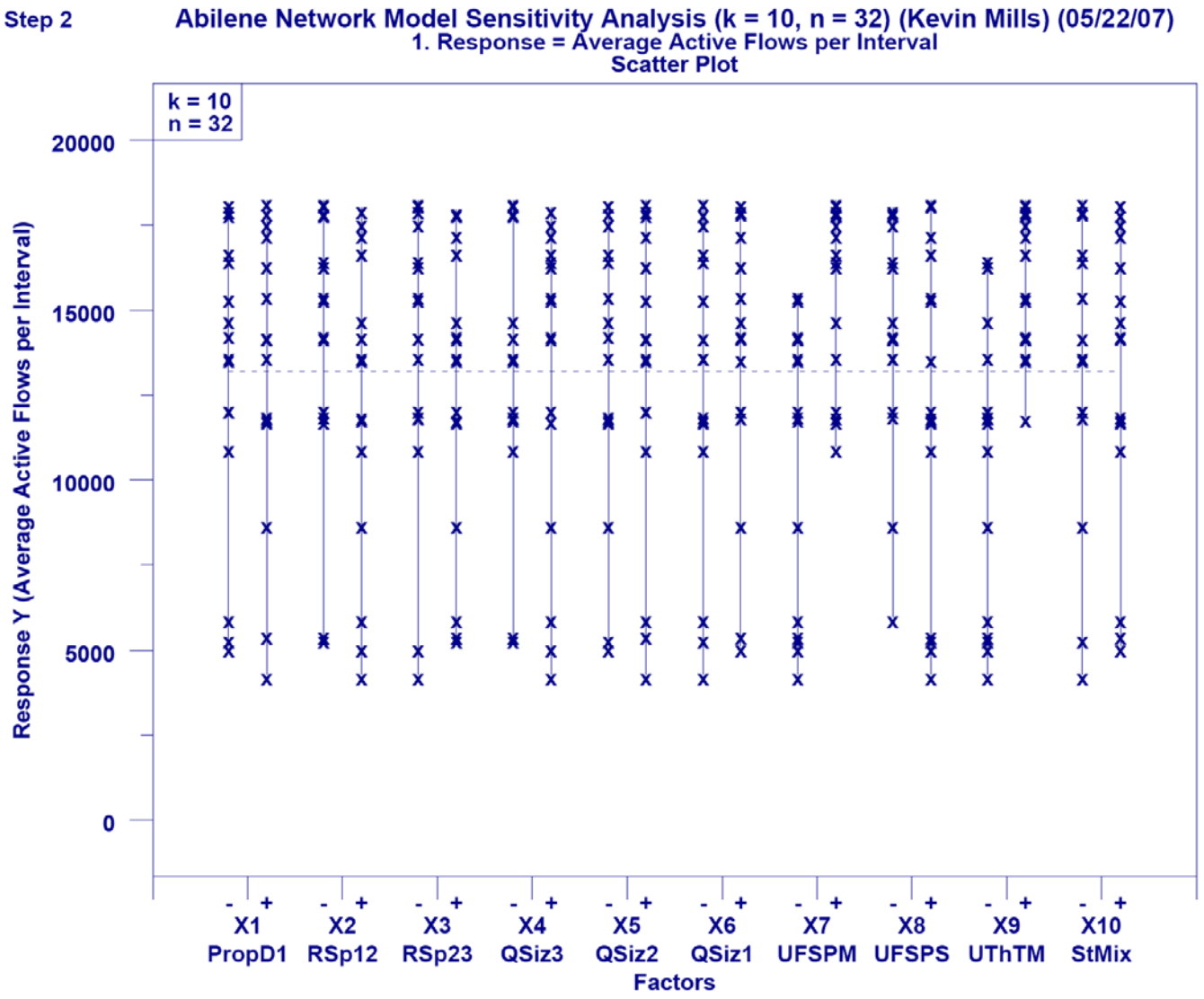
5. Advanced Topics

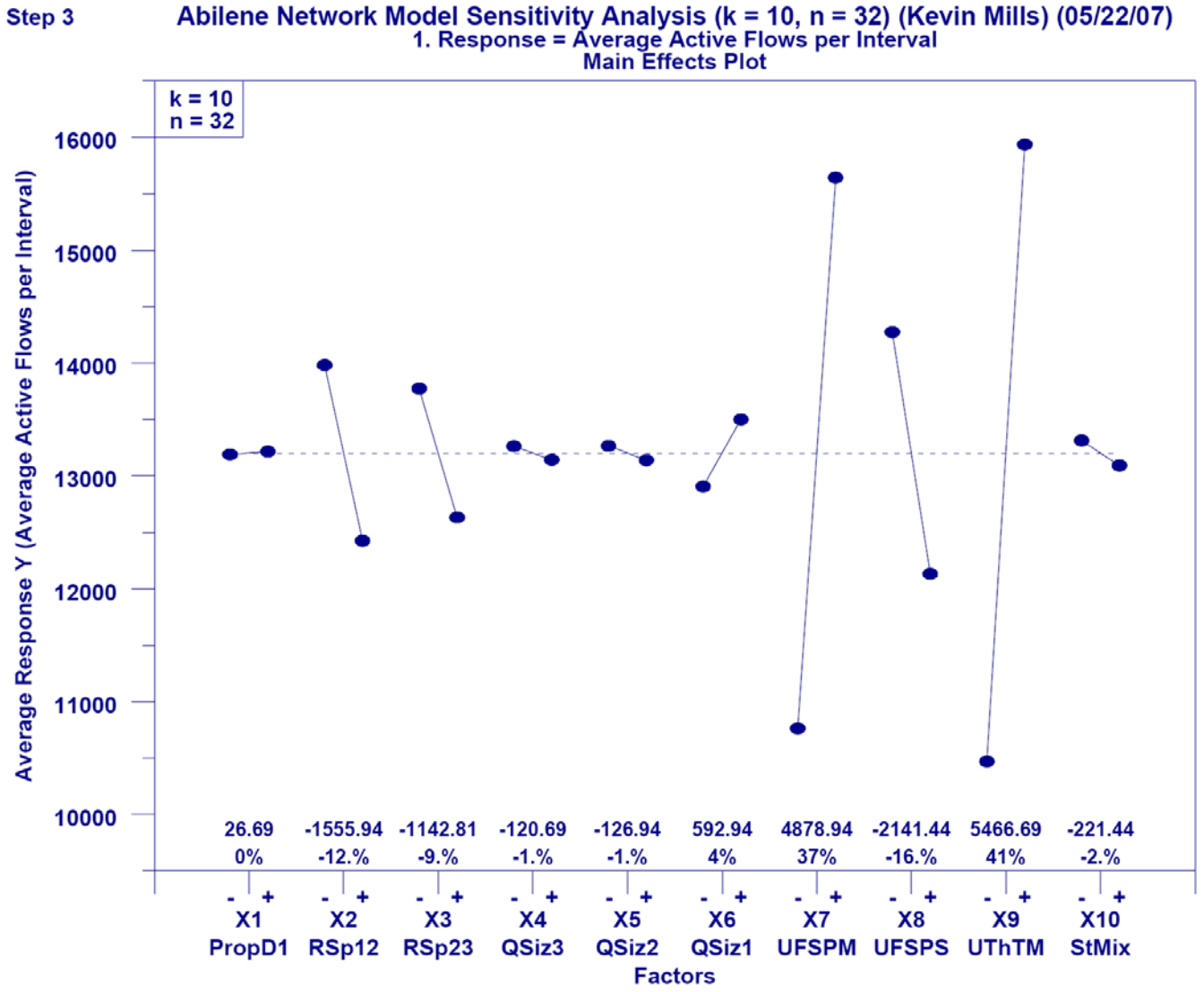
9. An EDA Approach to Experiment Design

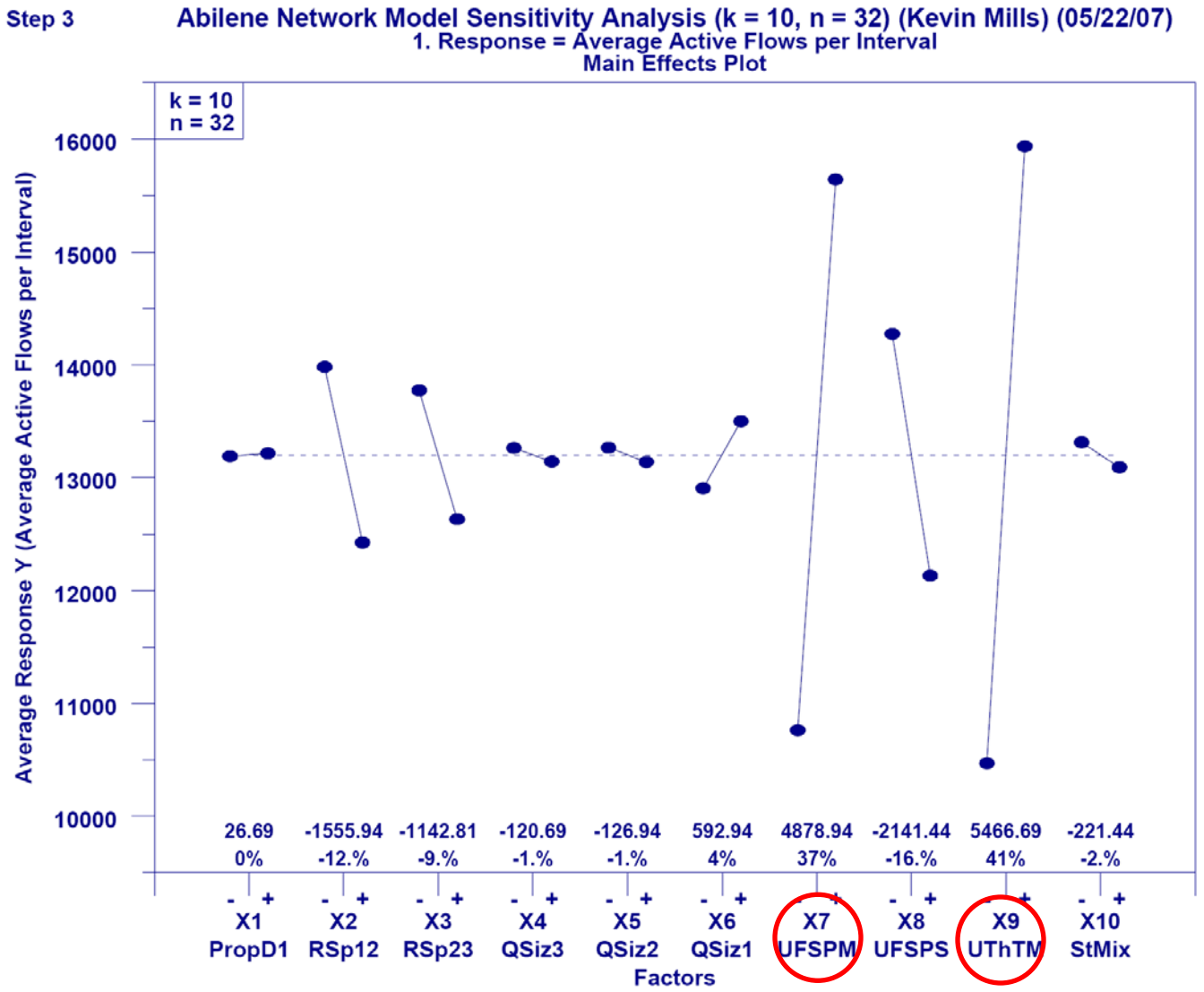
Dataplot

http://www.itl.nist.gov/div898/software/dataplot/

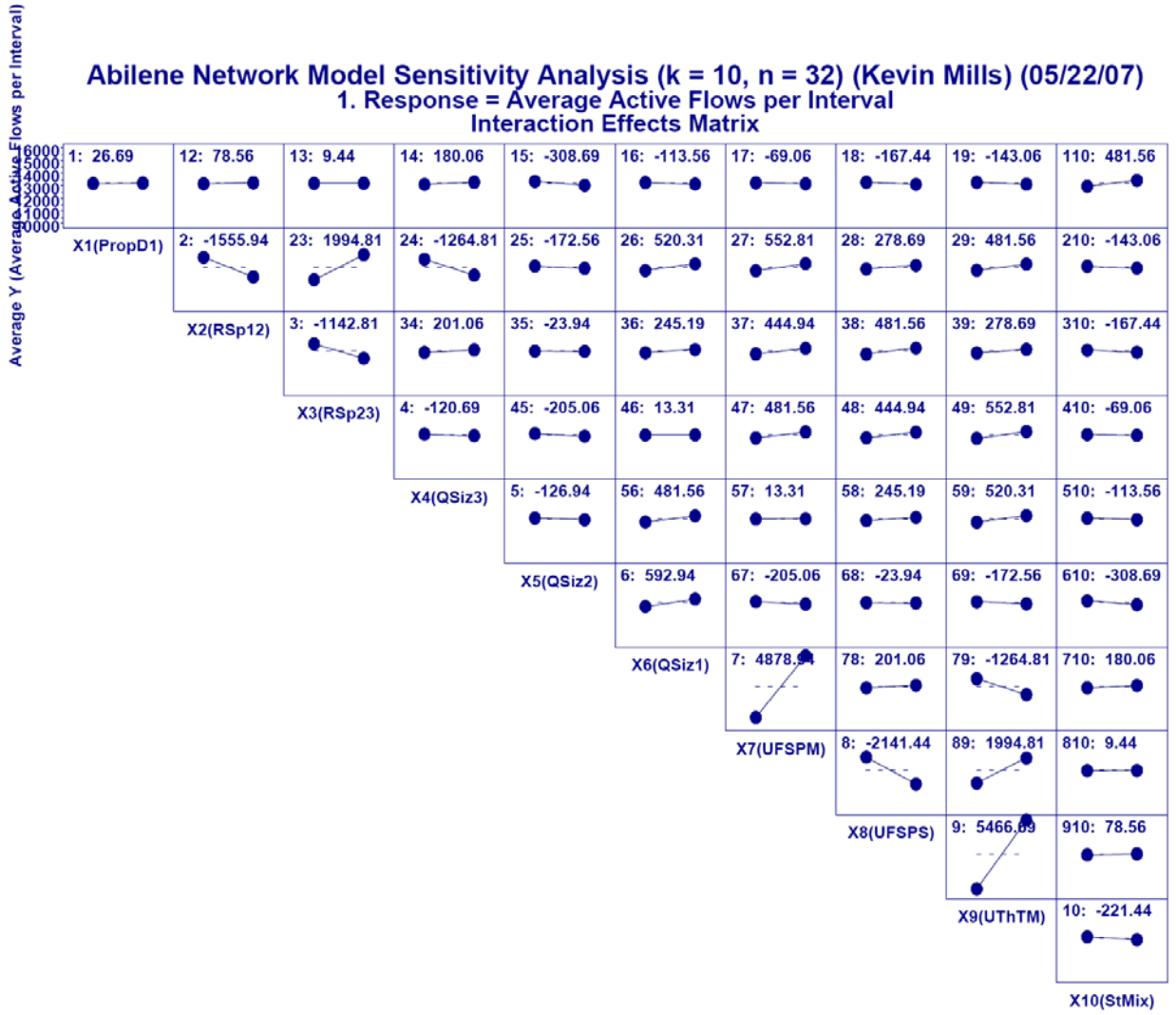

Step 1
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Ordered Data Plot
k = 10
n = 32
Response Y (Average Active Flows per Interval)
20000
15000
10000
5000
0
X1: + - - + - + - + + + + - - - - + + + - - - + + - - + + - + - - +
X2: + + - - + + + - + + - - - + + + - + - + - - - - + + + - - + - -
X3: - - + + + + - + + - - + - + - + + - + + - - - - + + - + + - - -
X4: + + - - + + - + - - - + - - - - + - + - + + + + + + + - - + - -
X5: + - - + + - + - - - - + + + - + + + - - + - + - - + - + - + - +
X6: - + - + - + - - - + - + + + - - - + + + - + + - - + - - + + + -
X7: - - - - - - - + + - + - + - - - + - - - + - - + + + + + + + + +
X8: + + + + - - + + + + - + - + - - - - - - - + + - - + + - - - - + +
X9: - - - - - - - - - + - - - - + + - + + + - + + - - + + + + + + + +
X10: - + - + + - + + + - + - - - - - - + + + + - + - - + + + - - + -
1: PropD1
2: RSp12
3: RSp23
4: QSiz3
5: QSiz2
6: QSiz1
7: UFSPM
8: UFSPS
9: UThTM
10: StMix
Settings


Step 2
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Scatter Plot
k = 10
n = 32
Response Y (Average Active Flows per Interval)
20000
15000
10000
5000
0
- + - + - + - + - + - + - + - + - + - +
X1 PropD1
X2 RSp12
X3 RSp23
X4 QSiz3
X5 QSiz2
X6 QSiz1
X7 UFSPM
X8 UFSPS
X9 UThTM
X10 StMix
Factors

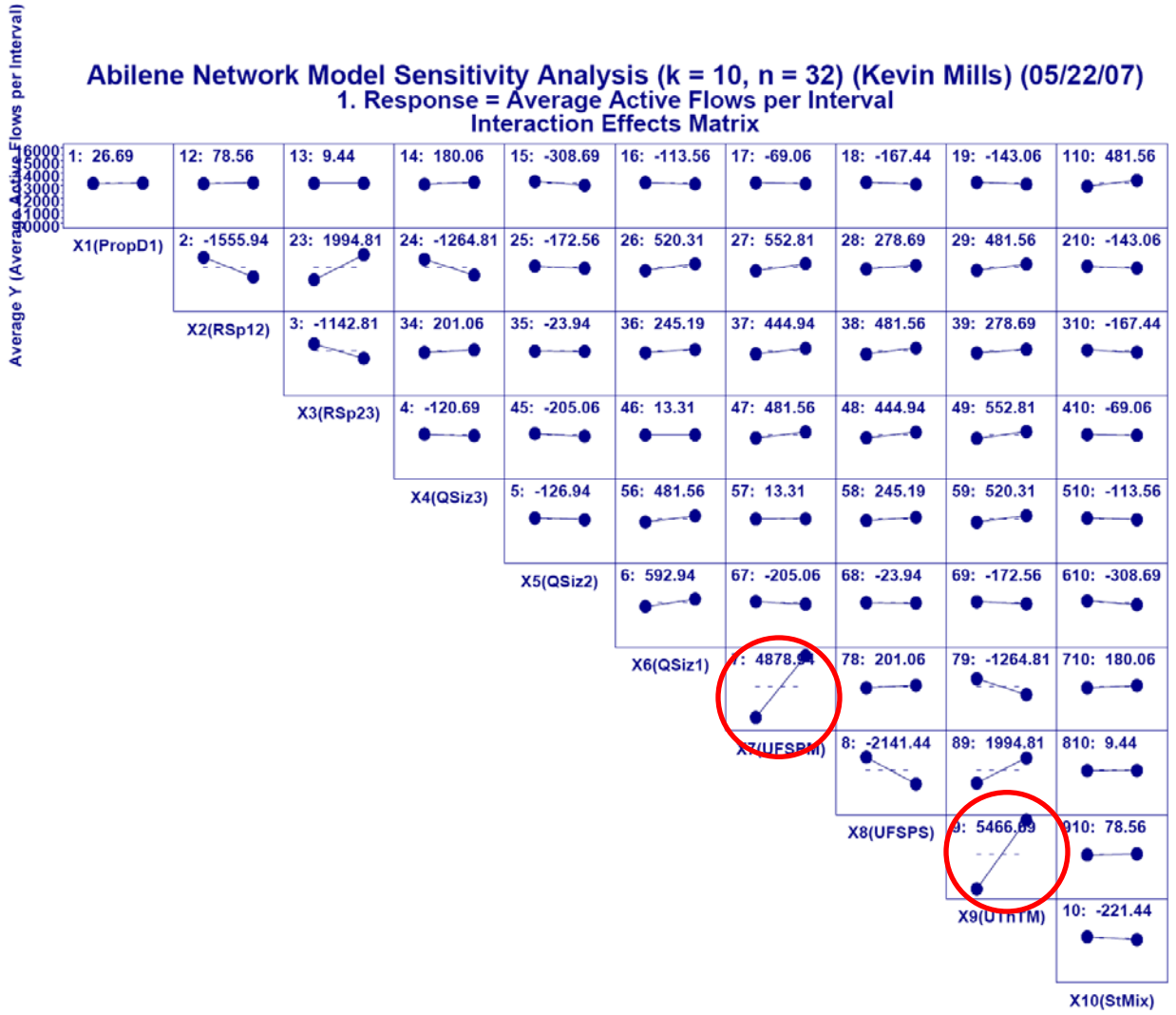

Step 3
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Active Flows per Interval)
16000
15000
14000
13000
12000
11000
10000
26.69
0%
-1555.94
-12.%
-1142.81
-9.%
-120.69
-1.%
-126.94
-1.%
592.94
4%
4878.94
37%
-2141.44
-16.%
5466.69
41%
-221.44
-2.%
- +
X1
PropD1
X2
RSp12
X3
RSp23
X4
QSiz3
X5
QSiz2
X6
QSiz1
X7
UFSPM
X8
UFSPS
X9
UThTM
X10
StMix
Factors


Step 3
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Active Flows per Interval)
16000
15000
14000
13000
12000
11000
10000
26.69
0%
-1555.94
-12.%
-1142.81
-9.%
-120.69
-1.%
-126.94
-1.%
592.94
4%
4878.94
37%
-2141.44
-16.%
5466.69
41%
-221.44
-2.%
X1
PropD1
X2
RSp12
X3
RSp23
X4
QSiz3
X5
QSiz2
X6
QSiz1
X7
UFSPM
X8
UFSPS
X9
UThTM
X10
StMix
Factors

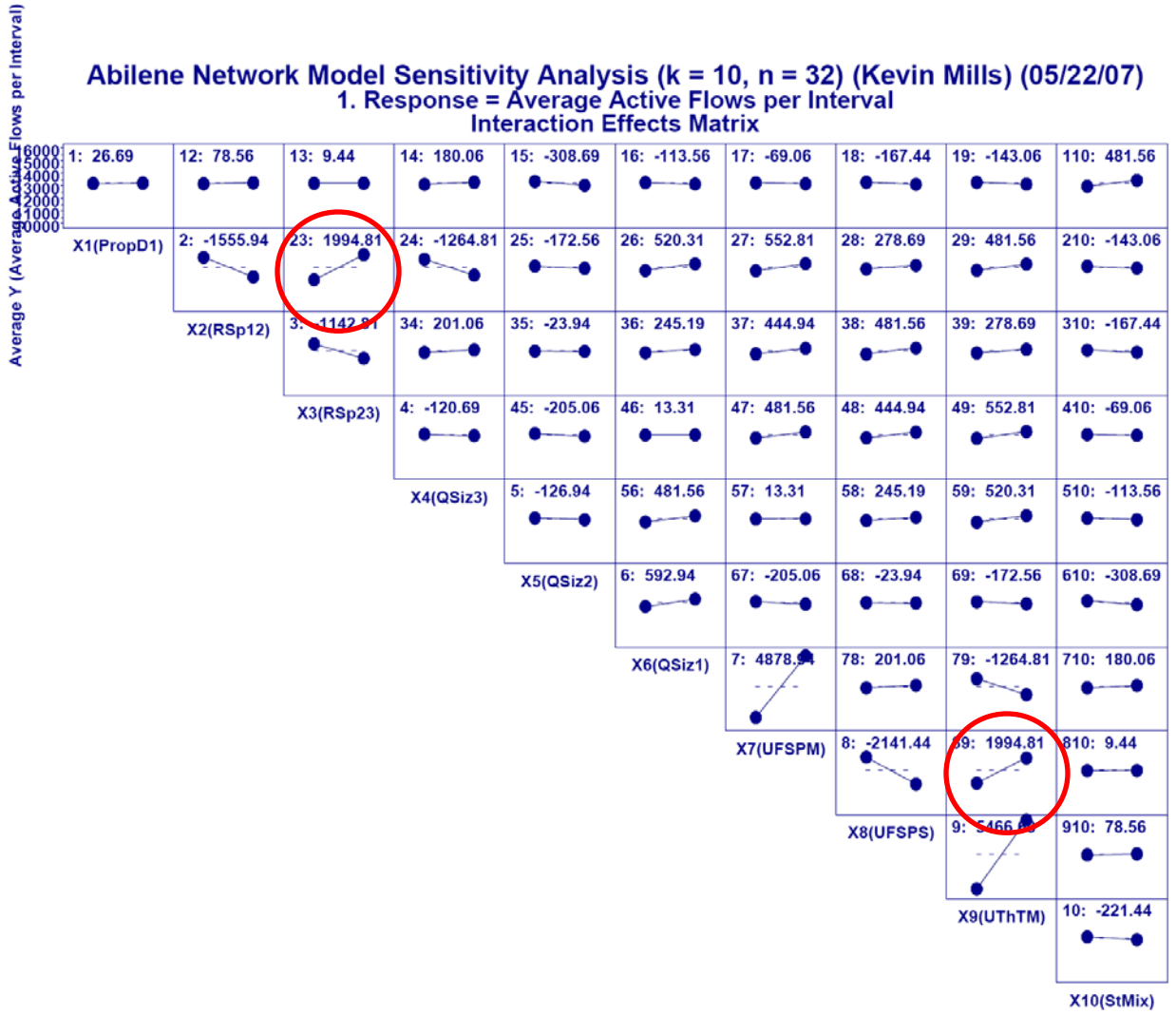
Step 4


Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Interaction Effects Matrix
Average Y (Average Active Flows per Interval)
6000
5000
4000
3000
2000
1000
0
1: 26.69
12: 78.56
13: 9.44
14: 180.06
15: -308.69
16: -113.56
17: -69.06
18: -167.44
19: -143.06
110: 481.56
X1(PropD1)
2: -1555.94
23: 1994.81
24: -1264.81
25: -172.56
26: 520.31
27: 552.81
28: 278.69
29: 481.56
210: -143.06
X2(RSp12)
3: -1142.81
34: 201.06
35: -23.94
36: 245.19
37: 444.94
38: 481.56
39: 278.69
310: -167.44
X3(RSp23)
4: -120.69
45: -205.06
46: 13.31
47: 481.56
48: 444.94
49: 552.81
410: -69.06
X4(QSiz3)
5: -126.94
56: 481.56
57: 13.31
58: 245.19
59: 520.31
510: -113.56
X5(QSiz2)
6: 592.94
67: -205.06
68: -23.94
69: -172.56
610: -308.69
X6(QSiz1)
7: 4878.94
78: 201.06
79: -1264.81
710: 180.06
X7(UFSPM)
8: -2141.44
89: 1994.81
810: 9.44
X8(UFSPS)
9: 5466.69
910: 78.56
X9(UThTM)
10: -221.44
X10(StMix)

Step 4


Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Interaction Effects Matrix
Average Y (Average Active Flows per Interval)
6000
5000
4000
3000
2000
1000
0
1: 26.69
12: 78.56
13: 9.44
14: 180.06
15: -308.69
16: -113.56
17: -69.06
18: -167.44
19: -143.06
110: 481.56
X1(PropD1)
2: -1555.94
23: 1994.81
24: -1264.81
25: -172.56
26: 520.31
27: 552.81
28: 278.69
29: 481.56
210: -143.06
X2(RSp12)
3: -1142.81
34: 201.06
35: -23.94
36: 245.19
37: 444.94
38: 481.56
39: 278.69
310: -167.44
X3(RSp23)
4: -120.69
45: -205.06
46: 13.31
47: 481.56
48: 444.94
49: 552.81
410: -69.06
X4(QSiz3)
5: -126.94
56: 481.56
57: 13.31
58: 245.19
59: 520.31
510: -113.56
X5(QSiz2)
6: 592.94
67: -205.06
68: -23.94
69: -172.56
610: -308.69
X6(QSiz1)
78: 201.06
79: -1264.81
710: 180.06
X7(UFSPM)
8: -2141.44
89: 1994.81
810: 9.44
X8(UFSPS)
910: 78.56
X9(UThTM)
10: -221.44
X10(StMix)

Step 4

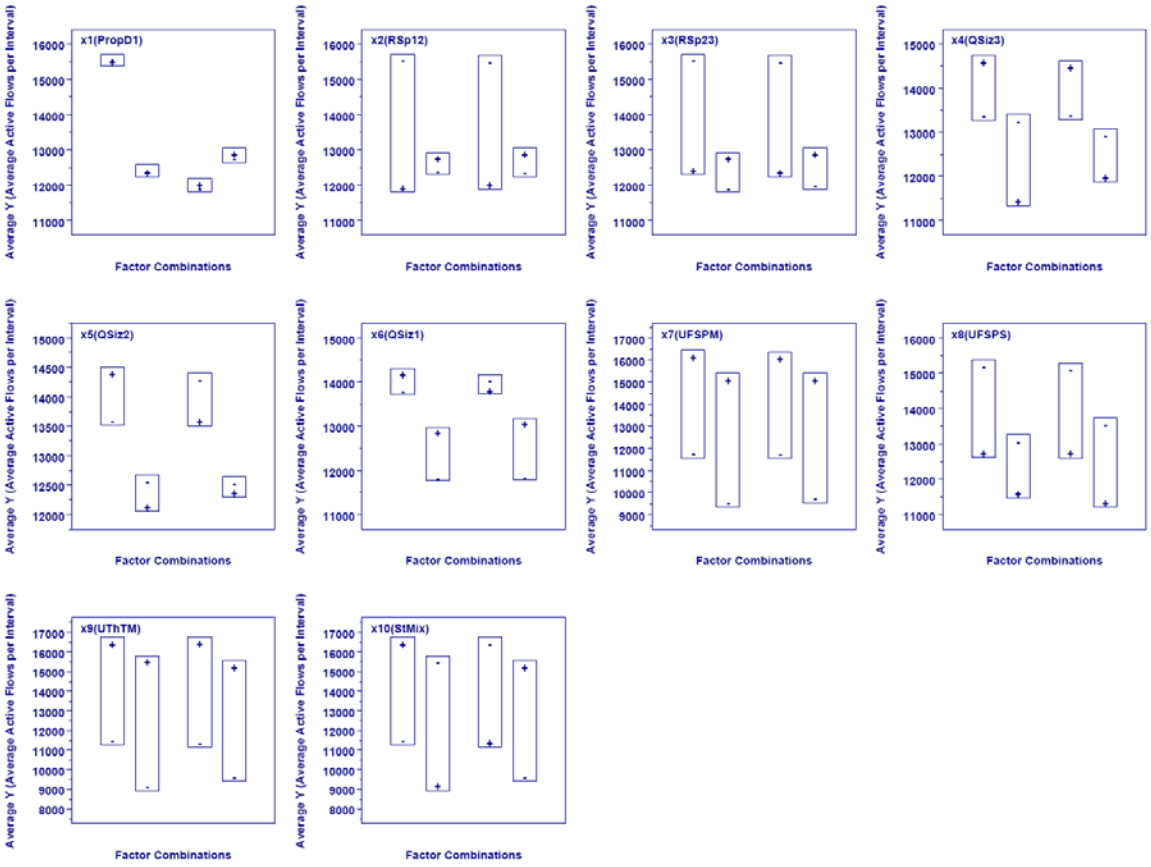

Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Interaction Effects Matrix
Average Y (Average Active Flows per Interval)
6000
5000
4000
3000
2000
1000
0
1: 26.69
12: 78.56
13: 9.44
14: 180.06
15: -308.69
16: -113.56
17: -69.06
18: -167.44
19: -143.06
110: 481.56
X1(PropD1)
2: -1555.94
23: 1994.81
24: -1264.81
25: -172.56
26: 520.31
27: 552.81
28: 278.69
29: 481.56
210: -143.06
X2(RSp12)
34: 201.06
35: -23.94
36: 245.19
37: 444.94
38: 481.56
39: 278.69
310: -167.44
X3(RSp23)
4: -120.69
45: -205.06
46: 13.31
47: 481.56
48: 444.94
49: 552.81
410: -69.06
X4(QSiz3)
5: -126.94
56: 481.56
57: 13.31
58: 245.19
59: 520.31
510: -113.56
X5(QSiz2)
6: 592.94
67: -205.06
68: -23.94
69: -172.56
610: -308.69
X6(QSiz1)
78: 201.06
79: -1264.81
710: 180.06
X7(UFSPM)
8: -2141.44
810: 9.44
X8(UFSPS)
910: 78.56
X9(UThTM)
10: -221.44
X10(StMix)

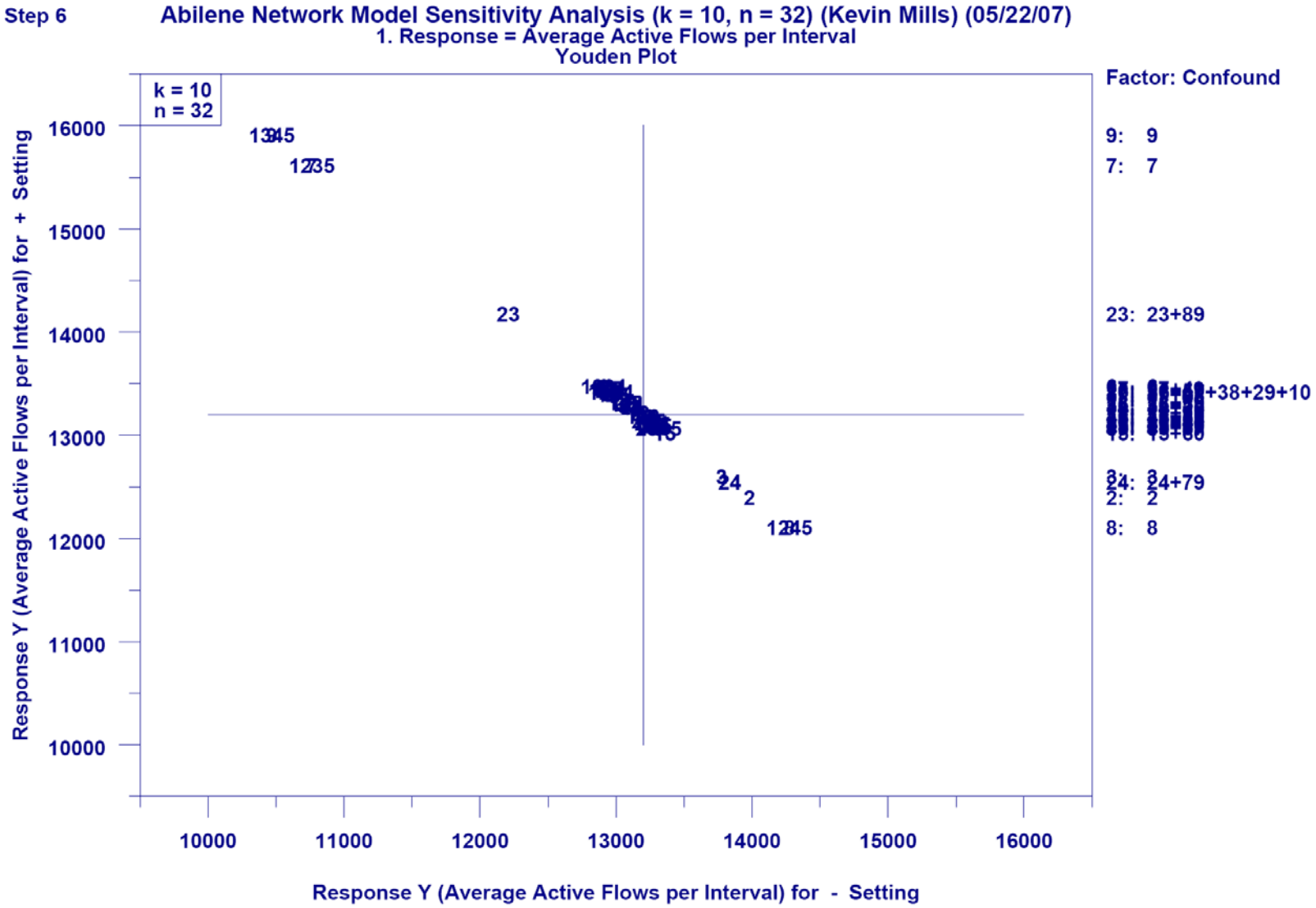
Step 5

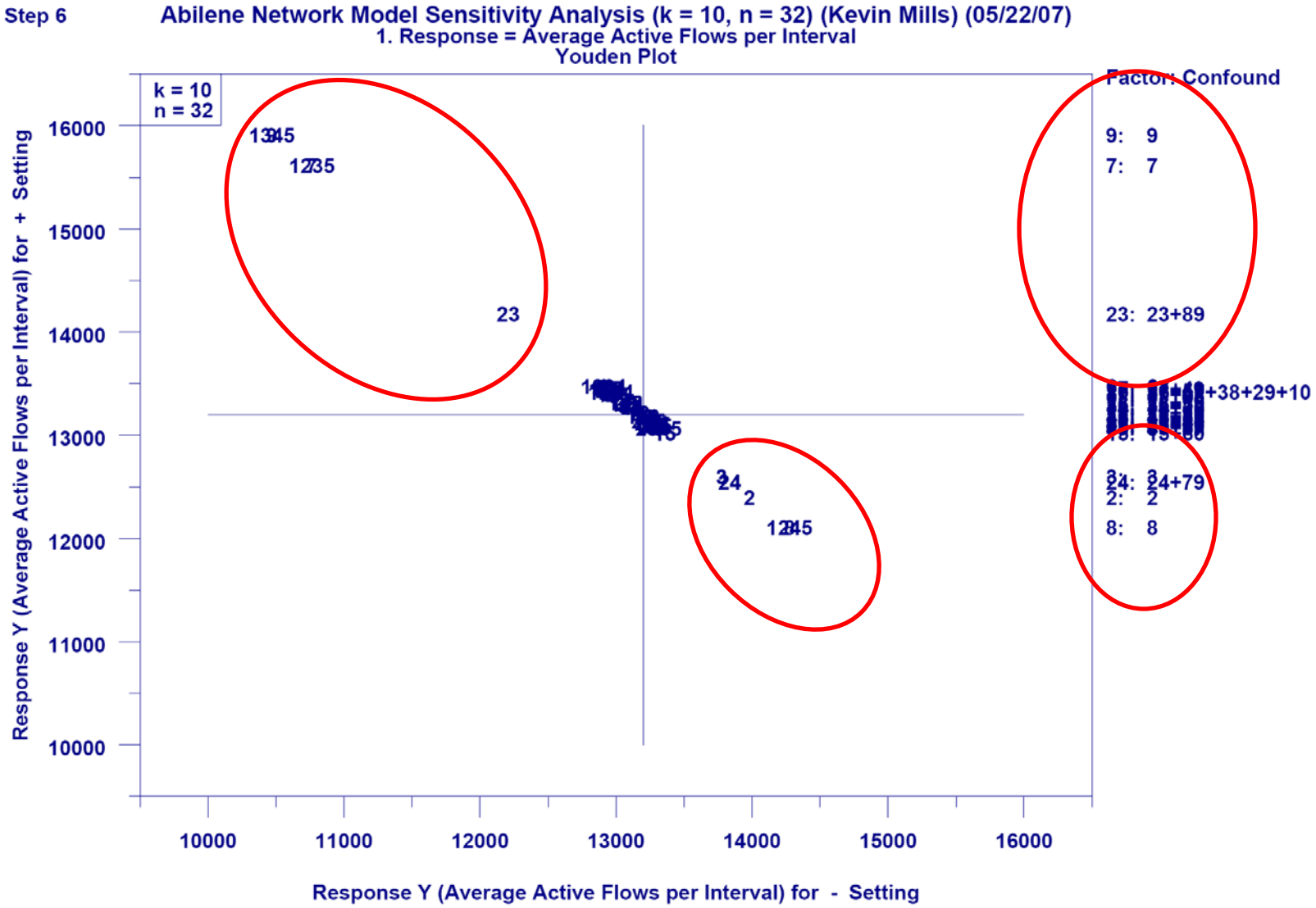
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)

1. Response = Average Active Flows per Interval

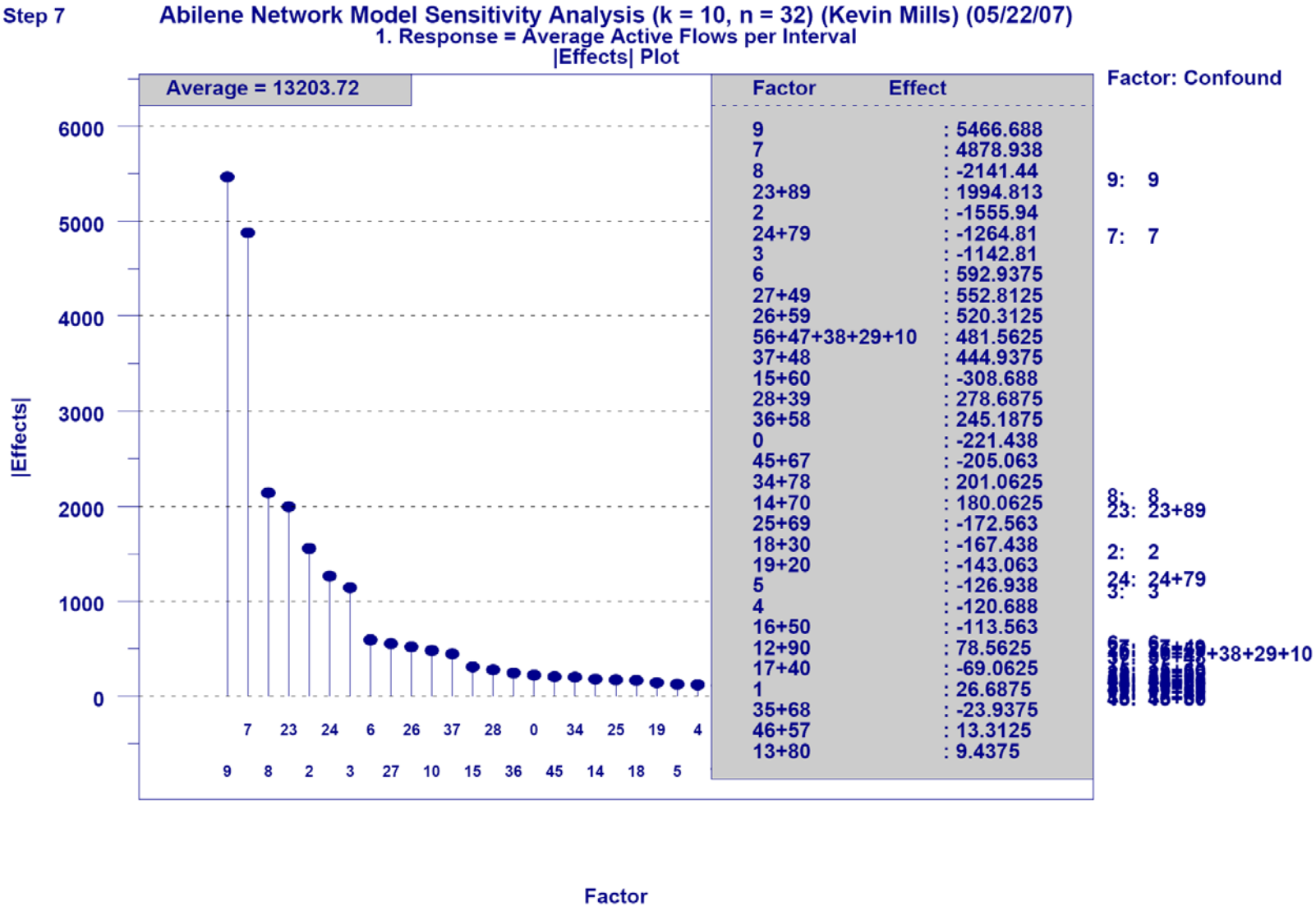
Block Plots

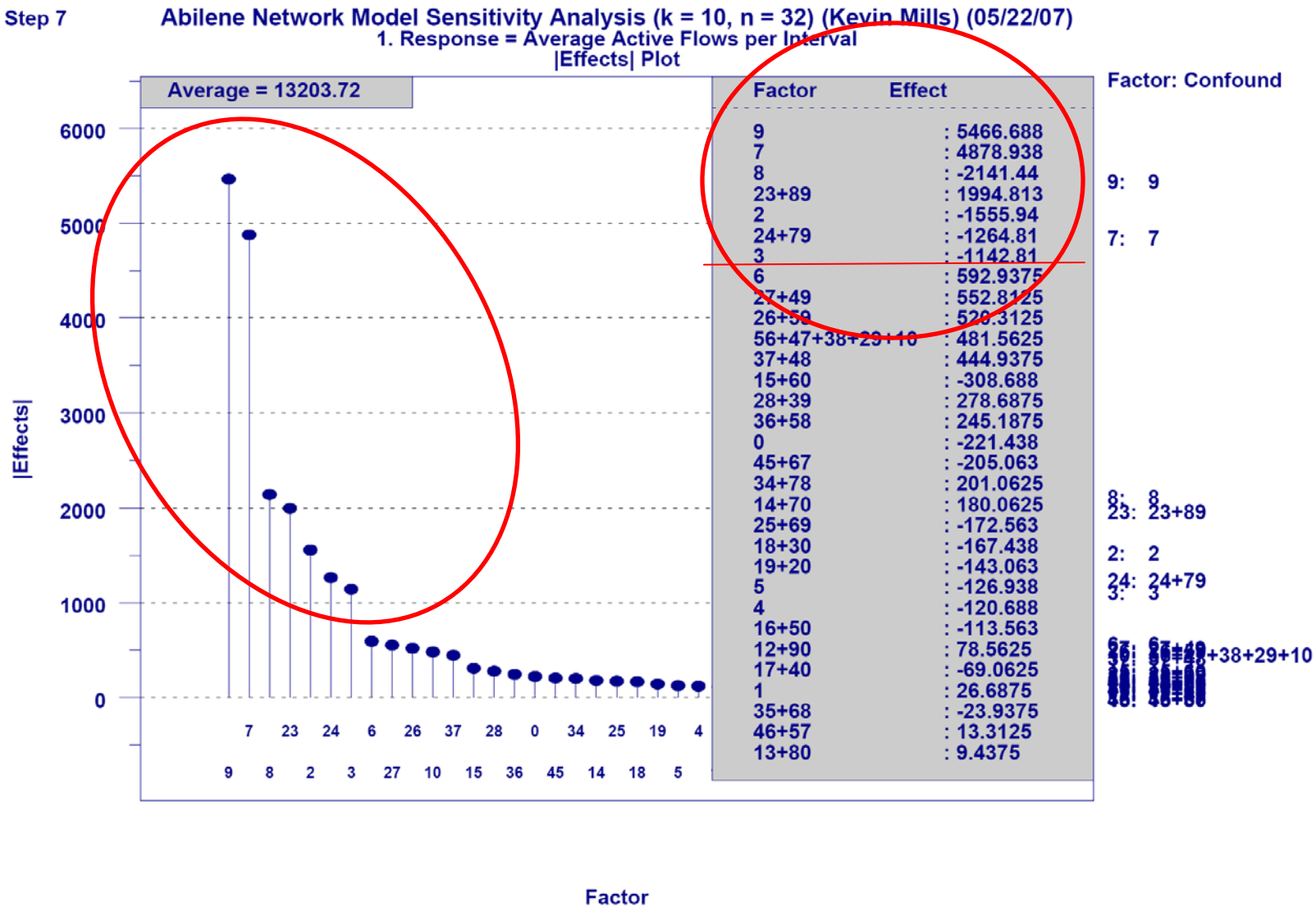


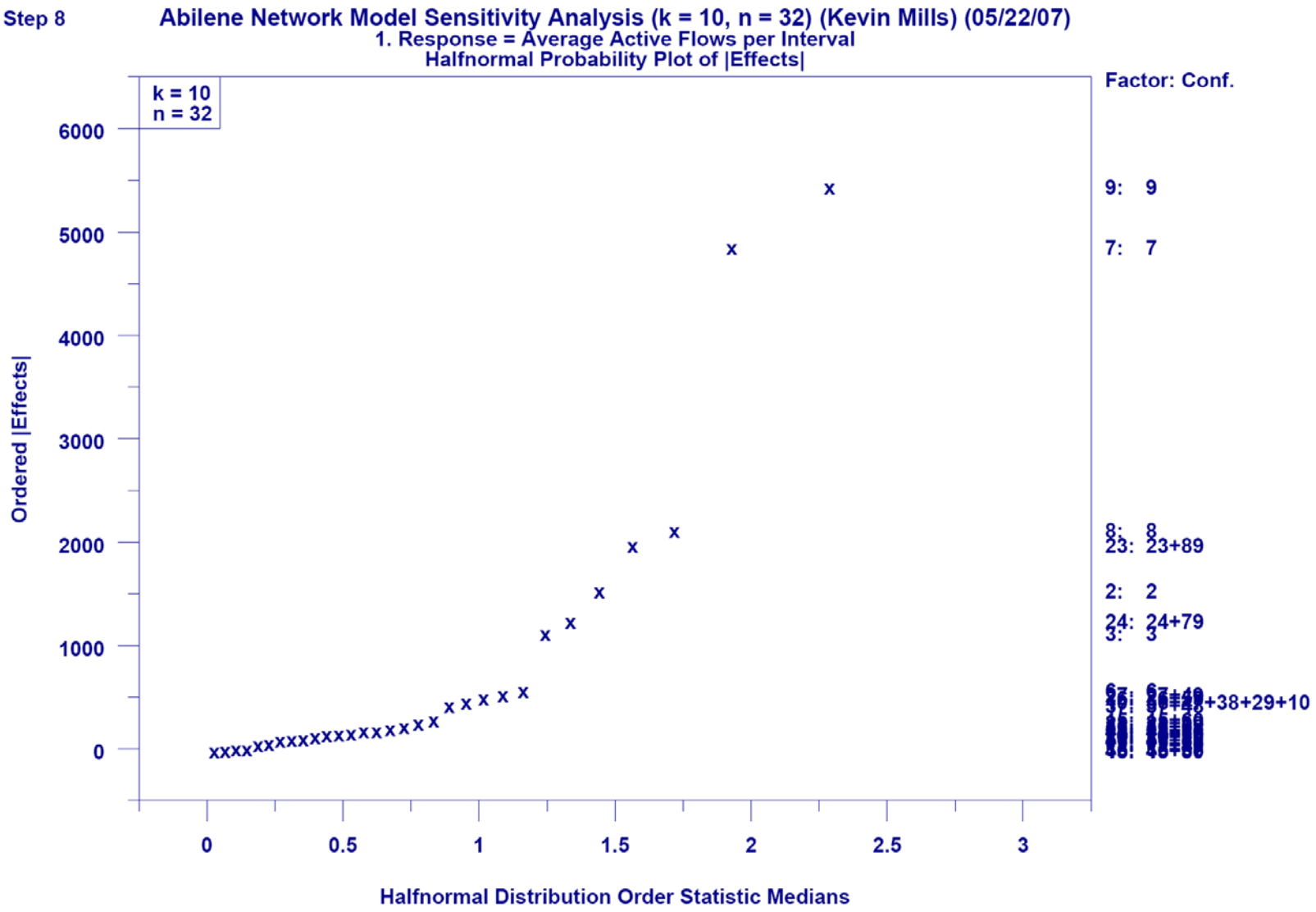

Step 6
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Youden Plot
k = 10
n = 32
Factor: Confound
9: 9
7: 7
23: 23+89
24: 24+79
2: 2
8: 8
+38+29+10
16000
15000
14000
13000
12000
11000
10000
Response Y (Average Active Flows per Interval) for + Setting
Response Y (Average Active Flows per Interval) for - Setting

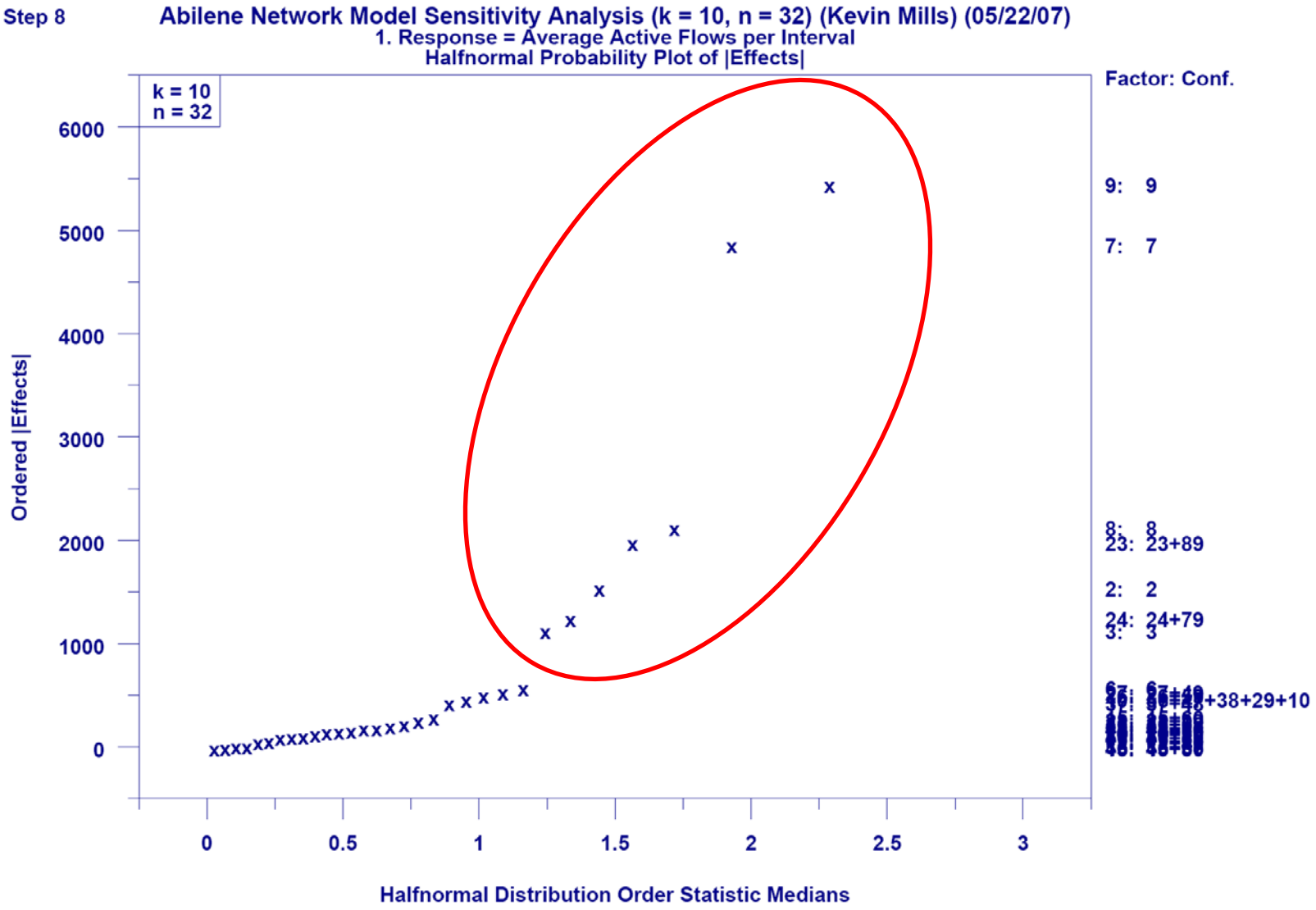

Step 6
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Youden Plot
k = 10
n = 32
Factor: Confound
9: 9
7: 7
23: 23+89
+38+29+10
24: 24+79
2: 2
8: 8
Response Y (Average Active Flows per Interval) for + Setting
Response Y (Average Active Flows per Interval) for - Setting
10000
11000
12000
13000
14000
15000
16000

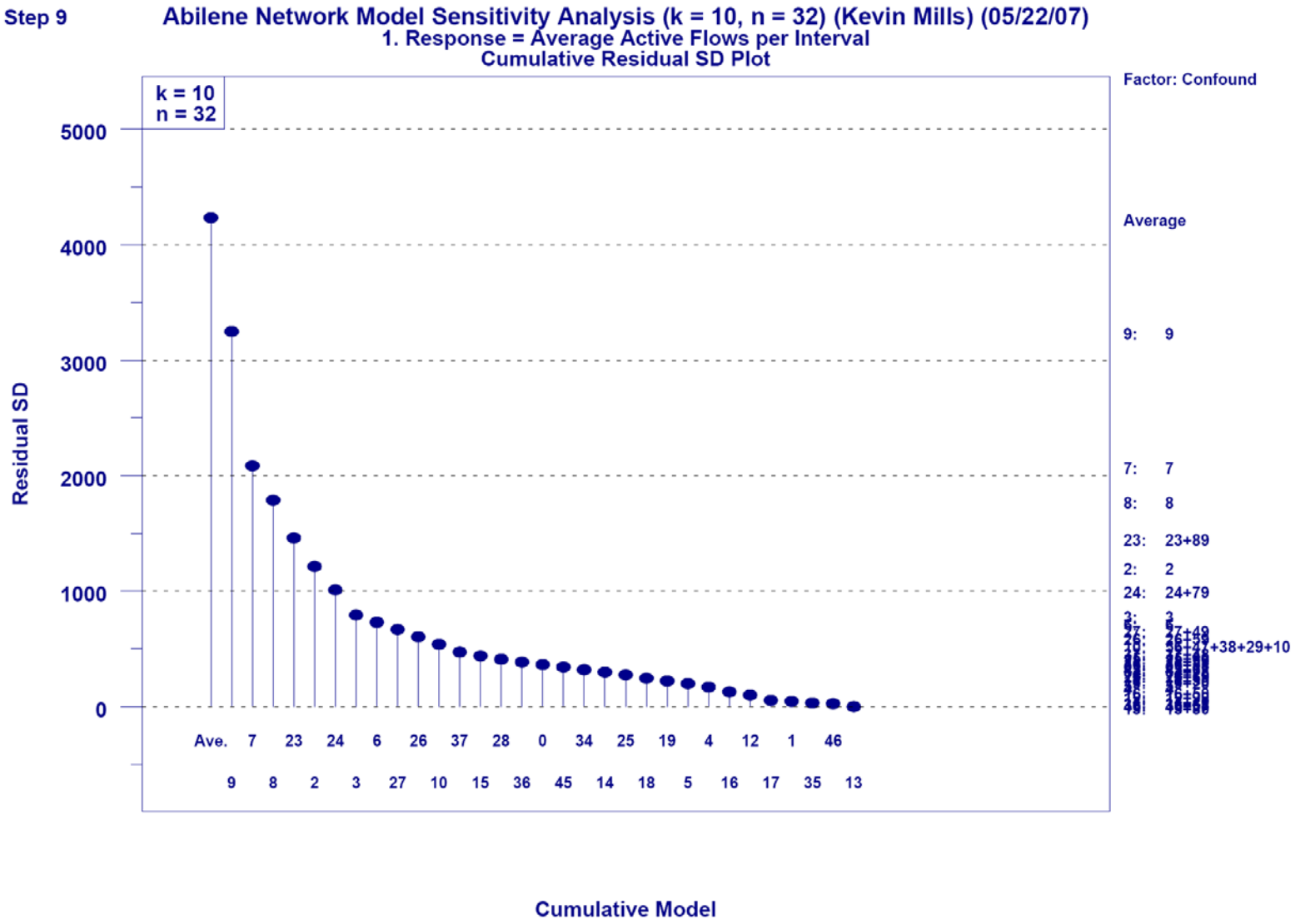
Step 7

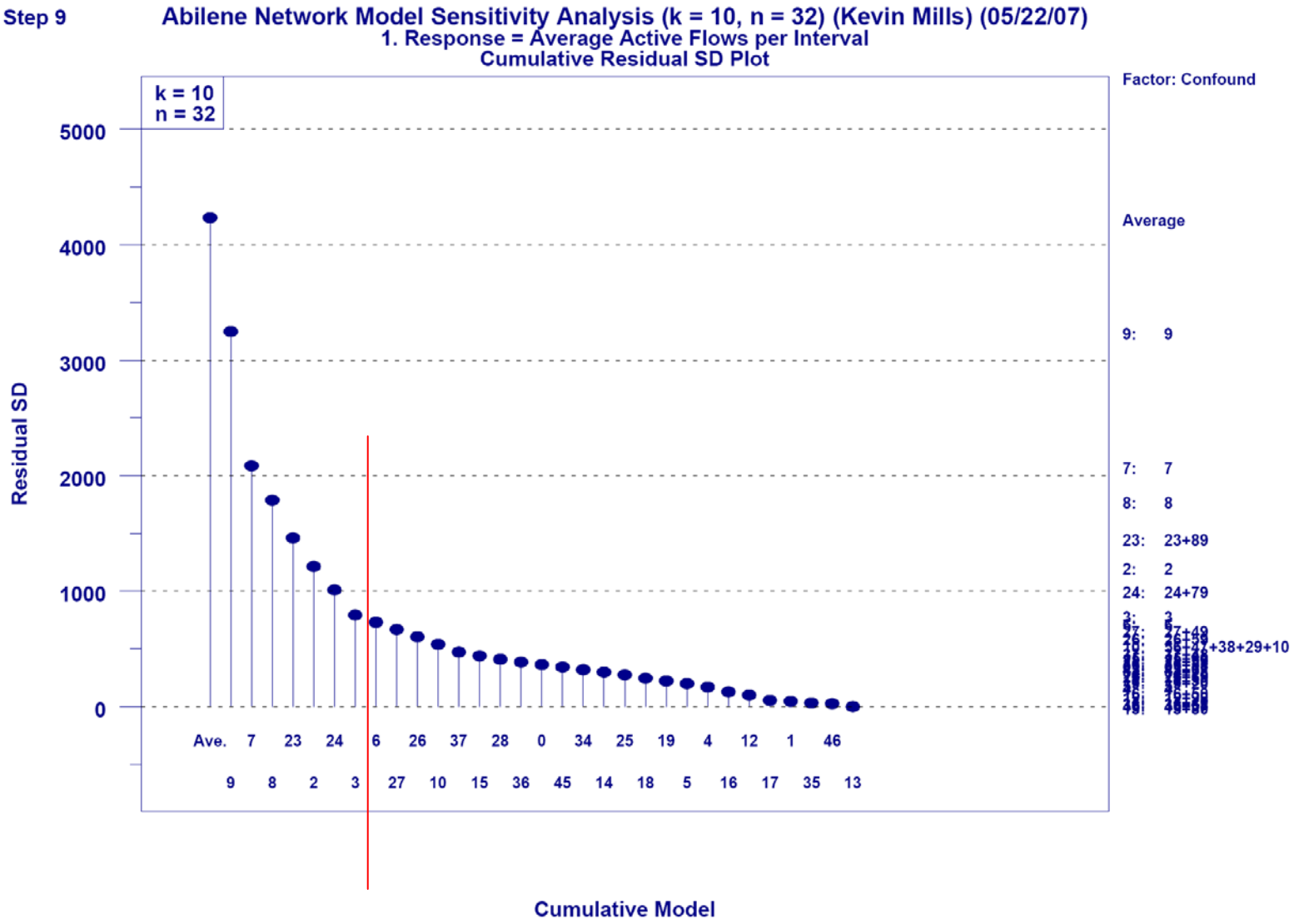

Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
|Effects| Plot
Average = 13203.72
|Effects|
6000
5000
4000
3000
2000
1000
0
7 23 24 6 26 37 28 0 34 25 19 4
9 8 2 3 27 10 15 36 45 14 18 5
Factor
Effect
9 : 5466.688
7 : 4878.938
8 : -2141.44
23+89 : 1994.813
2 : -1555.94
24+79 : -1264.81
3 : -1142.81
6 : 592.9375
27+49 : 552.8125
26+59 : 520.3125
56+47+38+29+10 : 481.5625
37+48 : 444.9375
15+60 : -308.688
28+39 : 278.6875
36+58 : 245.1875
0 : -221.438
45+67 : -205.063
34+78 : 201.0625
14+70 : 180.0625
25+69 : -172.563
18+30 : -167.438
19+20 : -143.063
5 : -126.938
4 : -120.688
16+50 : -113.563
12+90 : 78.5625
17+40 : -69.0625
1 : 26.6875
35+68 : -23.9375
46+57 : 13.3125
13+80 : 9.4375
Factor: Confound
9: 9
7: 7
8: 8
23: 23+89
2: 2
24: 24+79
3: 3
56: 56+47+38+29+10

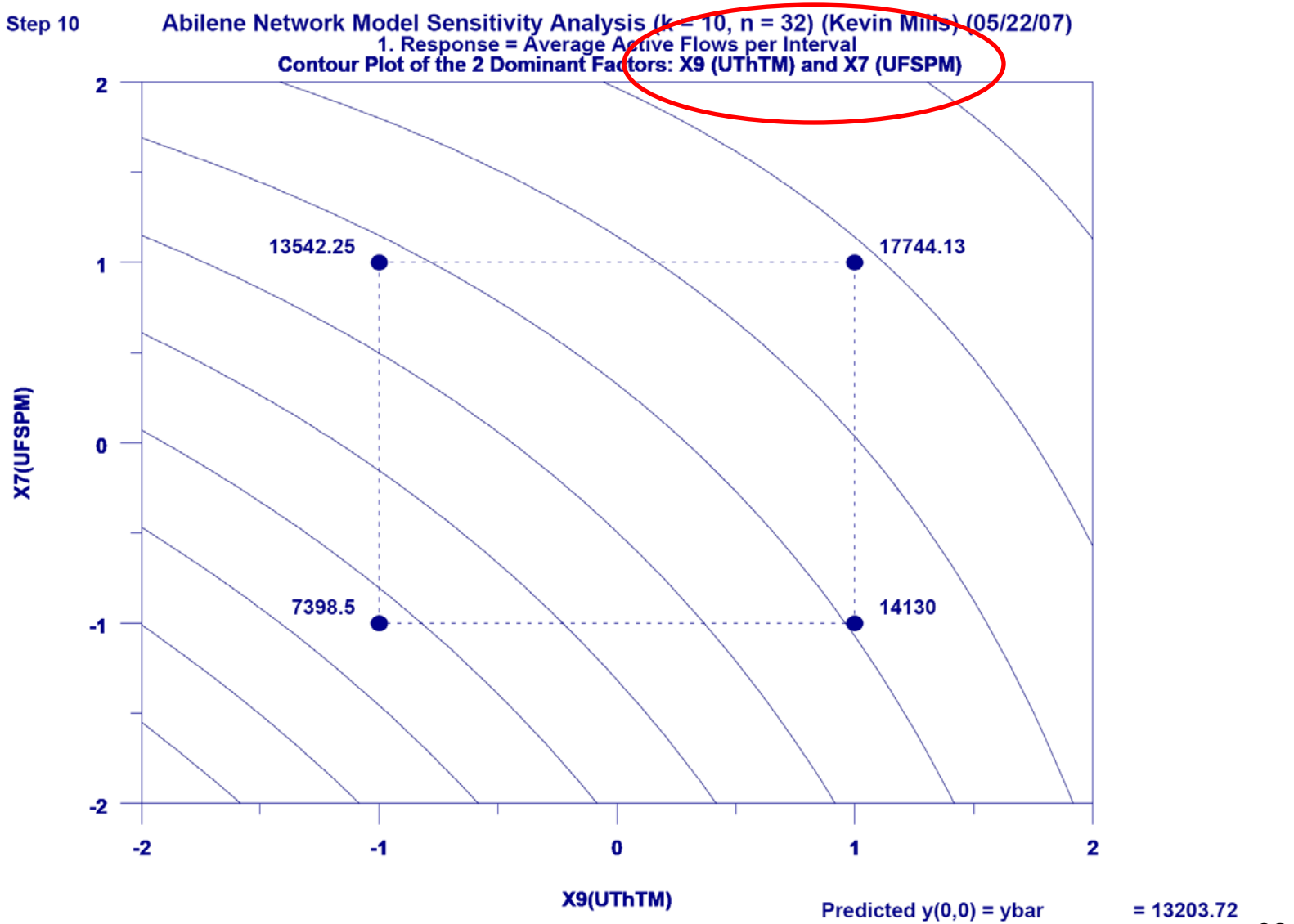

Step 7
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
|Effects| Plot
Average = 13203.72
|Effects|
6000
5000
4000
3000
2000
1000
0
7 23 24 6 26 37 28 0 34 25 19 4
9 8 2 3 27 10 15 36 45 14 18 5
Factor
Effect
9 : 5466.688
7 : 4878.938
8 : -2141.44
23+89 : 1994.813
2 : -1555.94
24+79 : -1264.81
3 : -1142.81
6 : 592.9375
27+49 : 552.8125
26+59 : 529.3125
56+47+38+29+10 : 481.5625
37+48 : 444.9375
15+60 : -308.688
28+39 : 278.6875
36+58 : 245.1875
0 : -221.438
45+67 : -205.063
34+78 : 201.0625
14+70 : 180.0625
25+69 : -172.563
18+30 : -167.438
19+20 : -143.063
5 : -126.938
4 : -120.688
16+50 : -113.563
12+90 : 78.5625
17+40 : -69.0625
1 : 26.6875
35+68 : -23.9375
46+57 : 13.3125
13+80 : 9.4375
Factor: Confound
9: 9
7: 7
8: 8
23: 23+89
2: 2
24: 24+79
3: 3
56: 56+47+38+29+10


Step 8
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Halfnormal Probability Plot of |Effects|
k = 10
n = 32
Factor: Conf.
9: 9
7: 7
8: 8
23: 23+89
2: 2
24: 24+79
3: 3
Ordered |Effects|
6000
5000
4000
3000
2000
1000
0
0
0.5
1
1.5
2
2.5
3
Halfnormal Distribution Order Statistic Medians

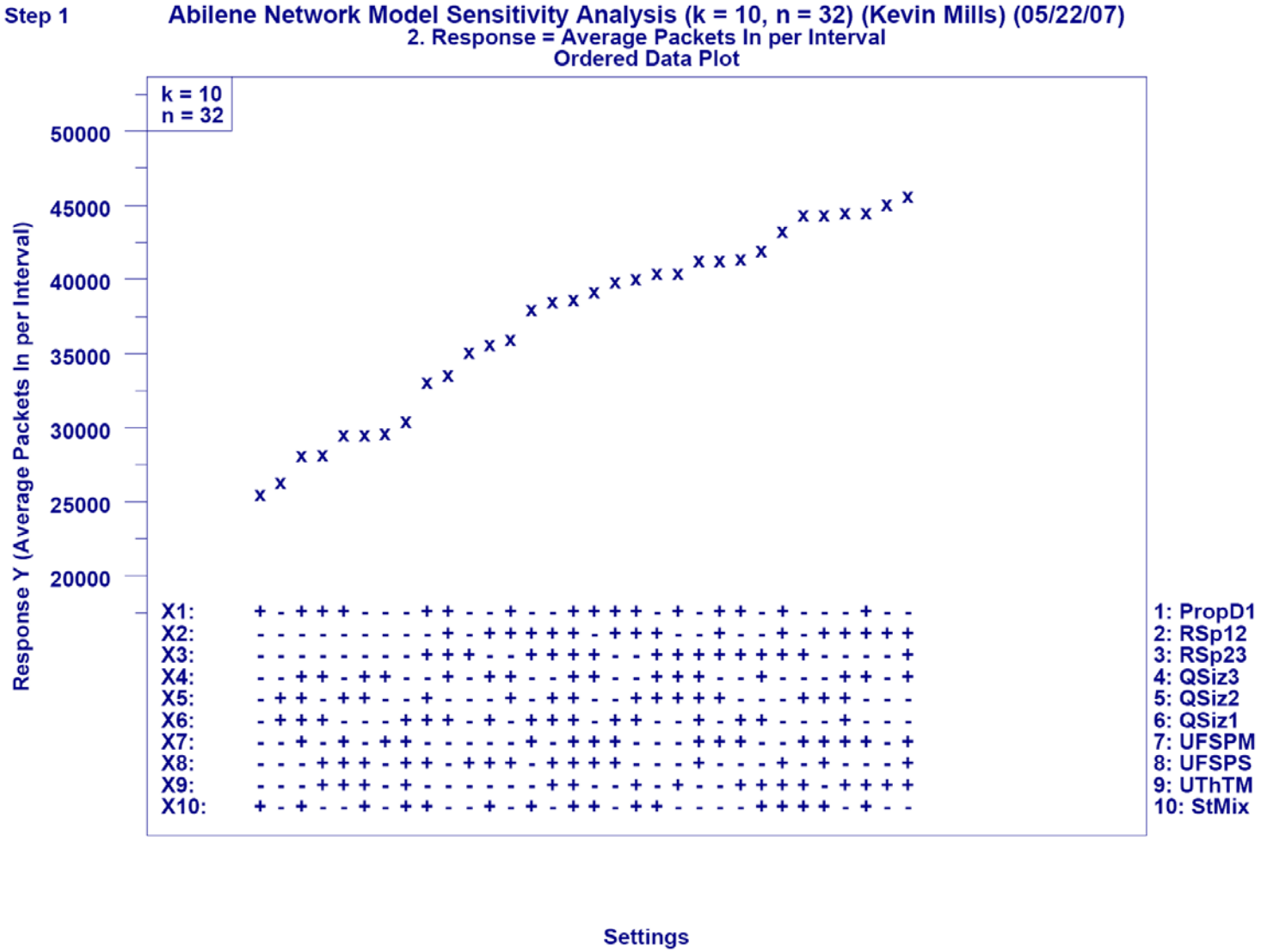

Step 8
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Halfnormal Probability Plot of |Effects|
k = 10
n = 32
Factor: Conf.
9: 9
7: 7
8: 8
23: 23+89
2: 2
24: 24+79
3: 3
+38+29+10
Ordered |Effects|
6000
5000
4000
3000
2000
1000
0
0
0.5
1
1.5
2
2.5
3
Halfnormal Distribution Order Statistic Medians

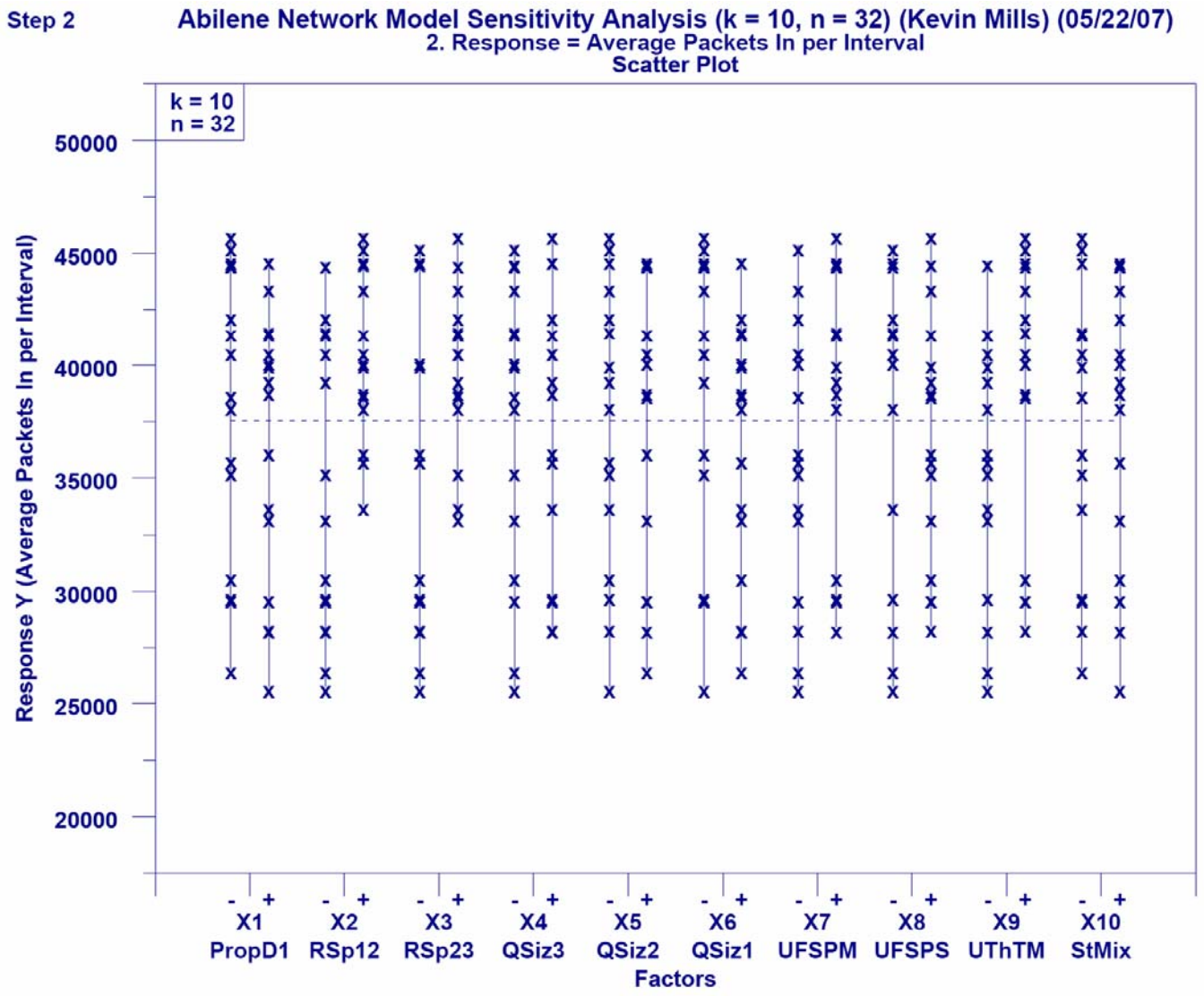

Step 9
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Cumulative Residual SD Plot
k = 10
n = 32
Factor: Confound
Average
9: 9
7: 7
8: 8
23: 23+89
2: 2
24: 24+79
+38+29+10
Residual SD
5000
4000
3000
2000
1000
0
Ave. 7 23 24 6 26 37 28 0 34 25 19 4 12 1 46
9 8 2 3 27 10 15 36 45 14 18 5 16 17 35 13
Cumulative Model


Step 9
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Cumulative Residual SD Plot
k = 10
n = 32
Factor: Confound
Average
9: 9
7: 7
8: 8
23: 23+89
2: 2
24: 24+79
Residual SD
5000
4000
3000
2000
1000
0
Ave. 7 23 24 6 26 37 28 0 34 25 19 4 12 1 46
9 8 2 3 27 10 15 36 45 14 18 5 16 17 35 13
Cumulative Model

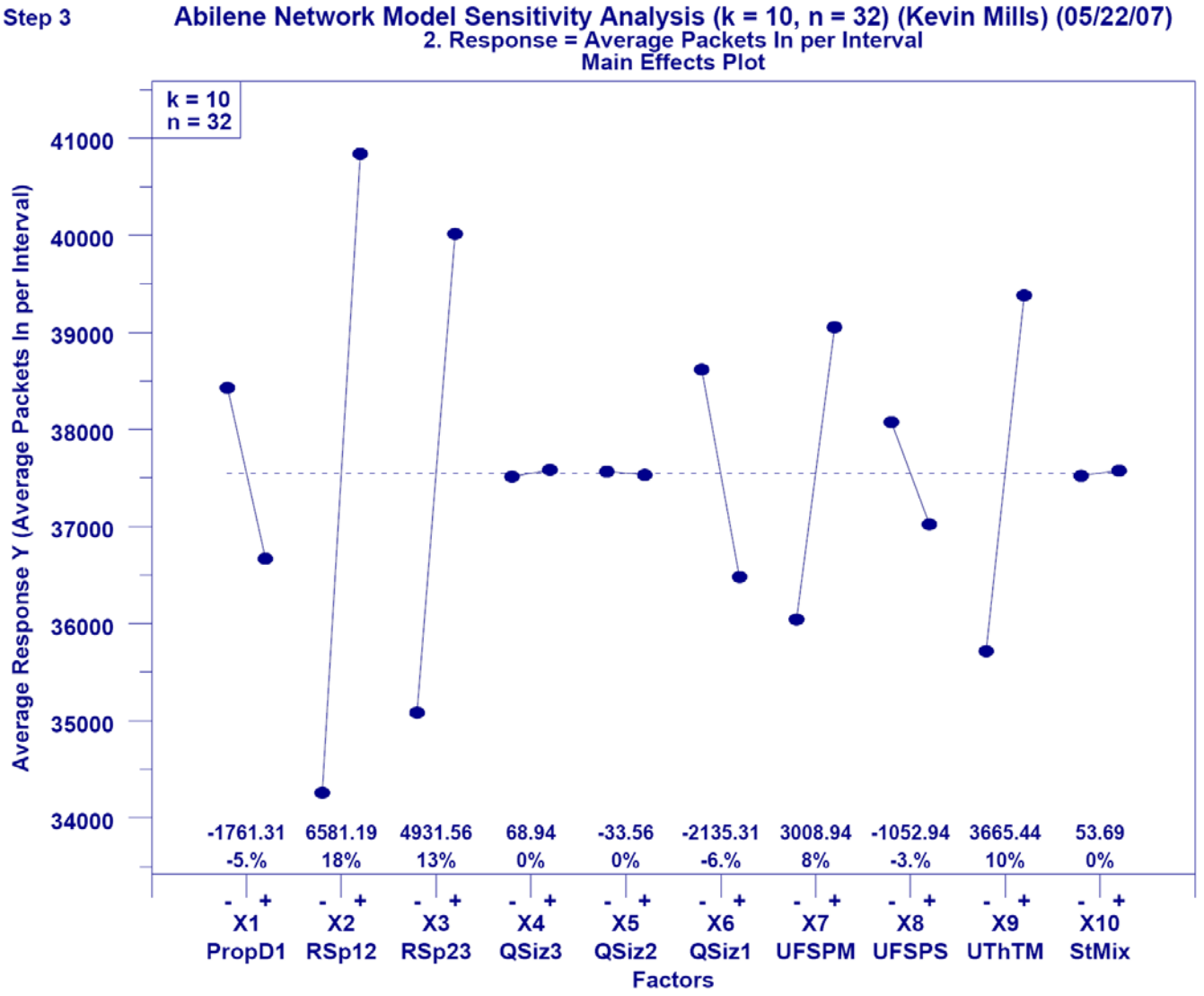

Step 10
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Contour Plot of the 2 Dominant Factors: X9 (UThTM) and X7 (UFSPM)
13542.25
17744.13
7398.5
14130
X7(UFSPM)
X9(UThTM)
2
1
0
-1
-2
-2
-1
0
1
2
Predicted y(0,0) = ybar = 13203.72

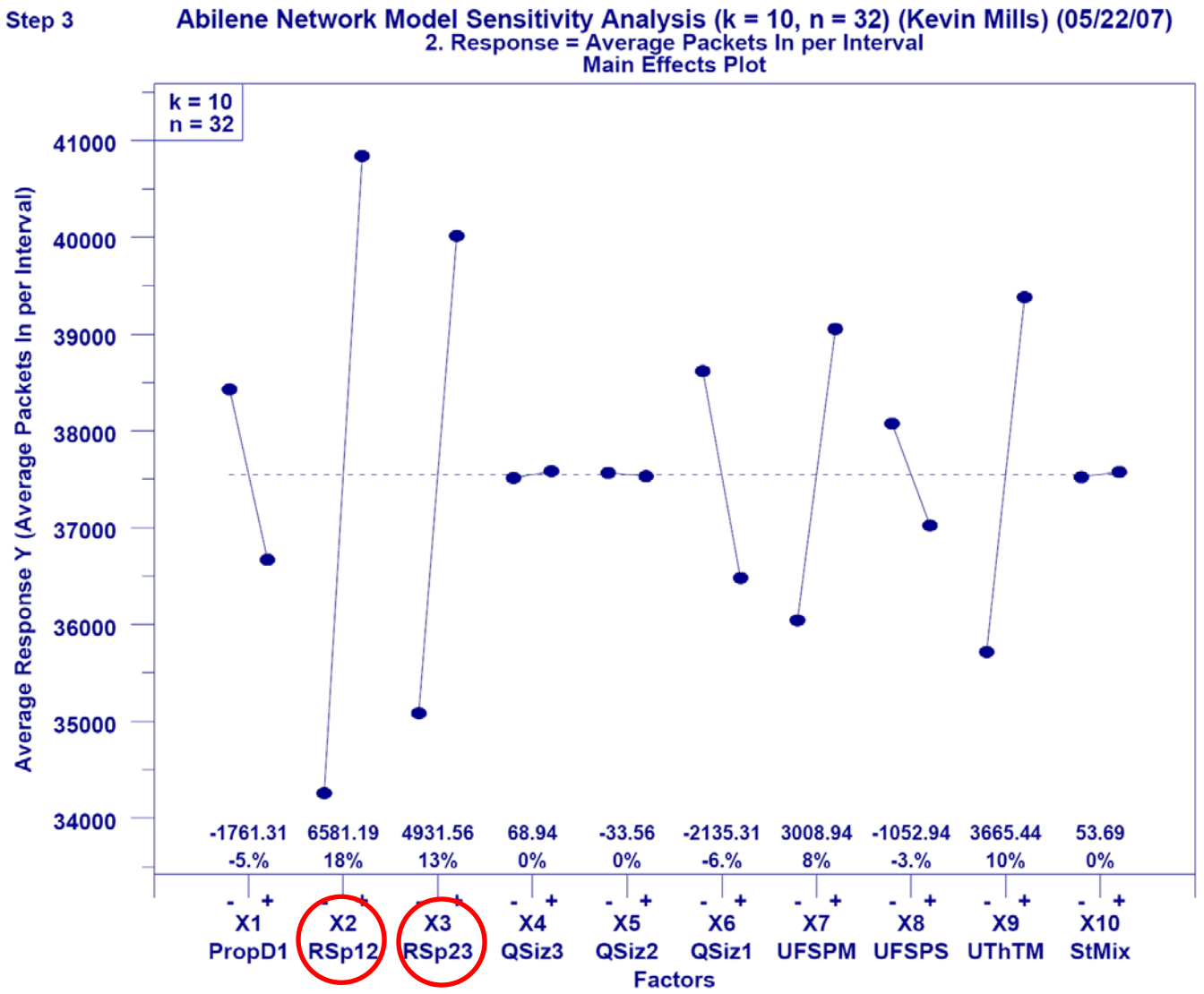
Response 2:
Average Packets In per Interval


Step 1
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
2. Response = Average Packets In per Interval
Ordered Data Plot
k = 10
n = 32
Response Y (Average Packets In per Interval)
50000
45000
40000
35000
30000
25000
20000
X1: + - + + + - - - + + - - + - - + + + + - + - + + - + - - - + - -
X2: - - - - - - - - - + - + + + + + - + + + - - + - - + - + + + + +
X3: - - - - - - - - + + + - - + + + + - - + + + + + + + + - - - - +
X4: - - + + - + + - - + - + + - - + + - - + + + - - - + + - + - +
X5: - + + - + + - - + - - - + - + + - - + + + + + - - - + + + - - -
X6: - + + + - - - + + + - + - + + + - + + - - + - + + - - - + - - -
X7: - - + - + - + + - - - - - + - + + + - - - + + + - - + + + + - +
X8: - - - + + + - + + - + + + - + + + + - - - + - - - + - + - - - +
X9: - - - + + + - + - - - - - - + + - - + - + - - + + + + - + + + +
X10: + - + - - + - + + - - + - + - + + - + + - - - - + + + + - + - -
1: PropD1
2: RSp12
3: RSp23
4: QSiz3
5: QSiz2
6: QSiz1
7: UFSPM
8: UFSPS
9: UThTM
10: StMix
Settings

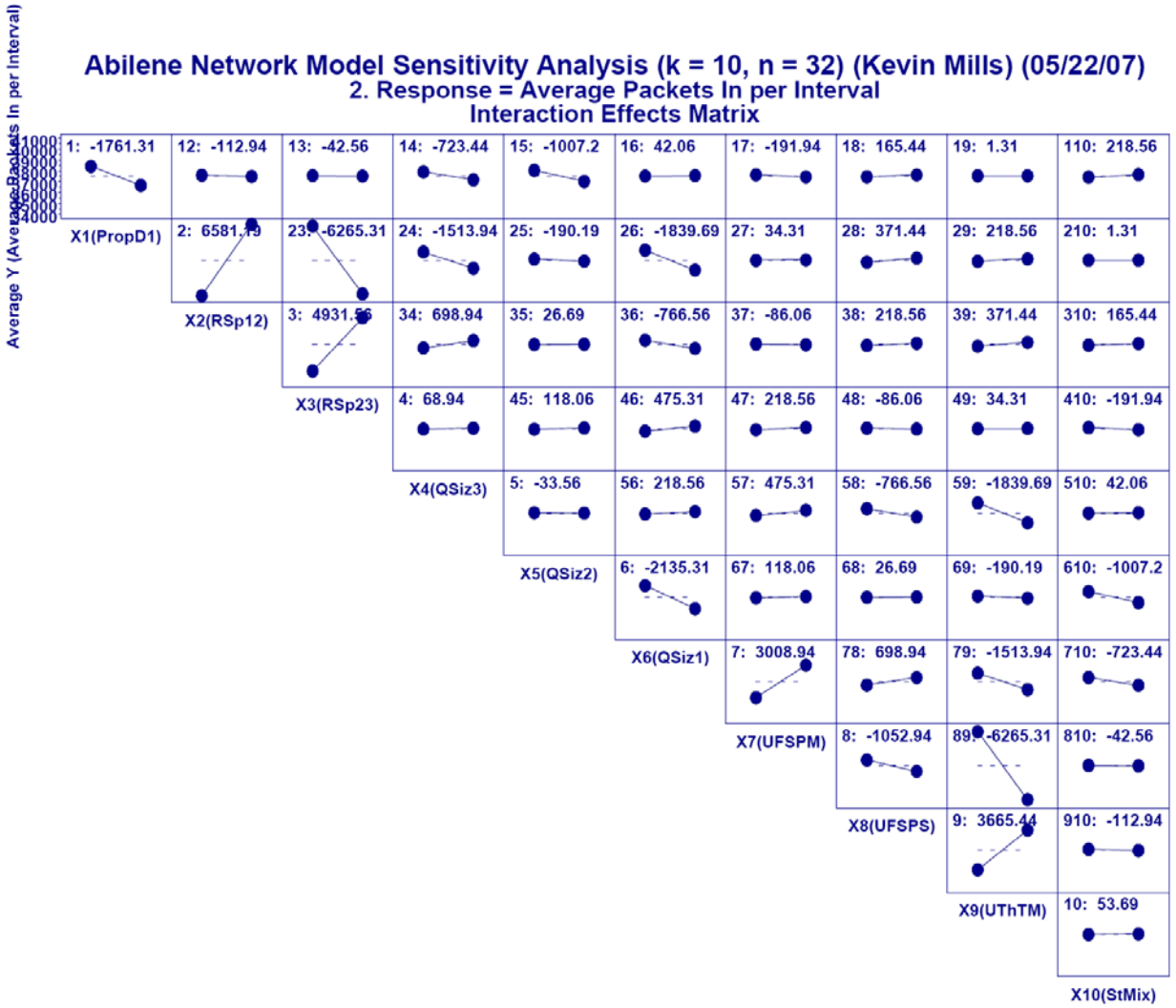

Step 2
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
2. Response = Average Packets In per Interval
Scatter Plot
k = 10
n = 32
Response Y (Average Packets In per Interval)
50000
45000
40000
35000
30000
25000
20000
- + - + - + - + - + - + - + - + - + - +
X1 PropD1
X2 RSp12
X3 RSp23
X4 QSiz3
X5 QSiz2
X6 QSiz1
X7 UFSPM
X8 UFSPS
X9 UThTM
X10 StMix
Factors

Step 3


Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
2. Response = Average Packets In per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Packets In per Interval)
41000
40000
39000
38000
37000
36000
35000
34000
-1761.31
-5.%
6581.19
18%
4931.56
13%
68.94
0%
-33.56
0%
-2135.31
-6.%
3008.94
8%
-1052.94
-3.%
3665.44
10%
53.69
0%
- +
X1
PropD1
X2
RSp12
X3
RSp23
X4
QSiz3
X5
QSiz2
X6
QSiz1
X7
UFSPM
X8
UFSPS
X9
UThTM
X10
StMix
Factors


Step 3
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
2. Response = Average Packets In per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Packets In per Interval)
41000
40000
39000
38000
37000
36000
35000
34000
-1761.31
-5.%
6581.19
18%
4931.56
13%
68.94
0%
-33.56
0%
-2135.31
-6.%
3008.94
8%
-1052.94
-3.%
3665.44
10%
53.69
0%
X1
PropD1
X2
RSp12
X3
RSp23
X4
QSiz3
X5
QSiz2
X6
QSiz1
X7
UFSPM
X8
UFSPS
X9
UThTM
X10
StMix
Factors

Step 4

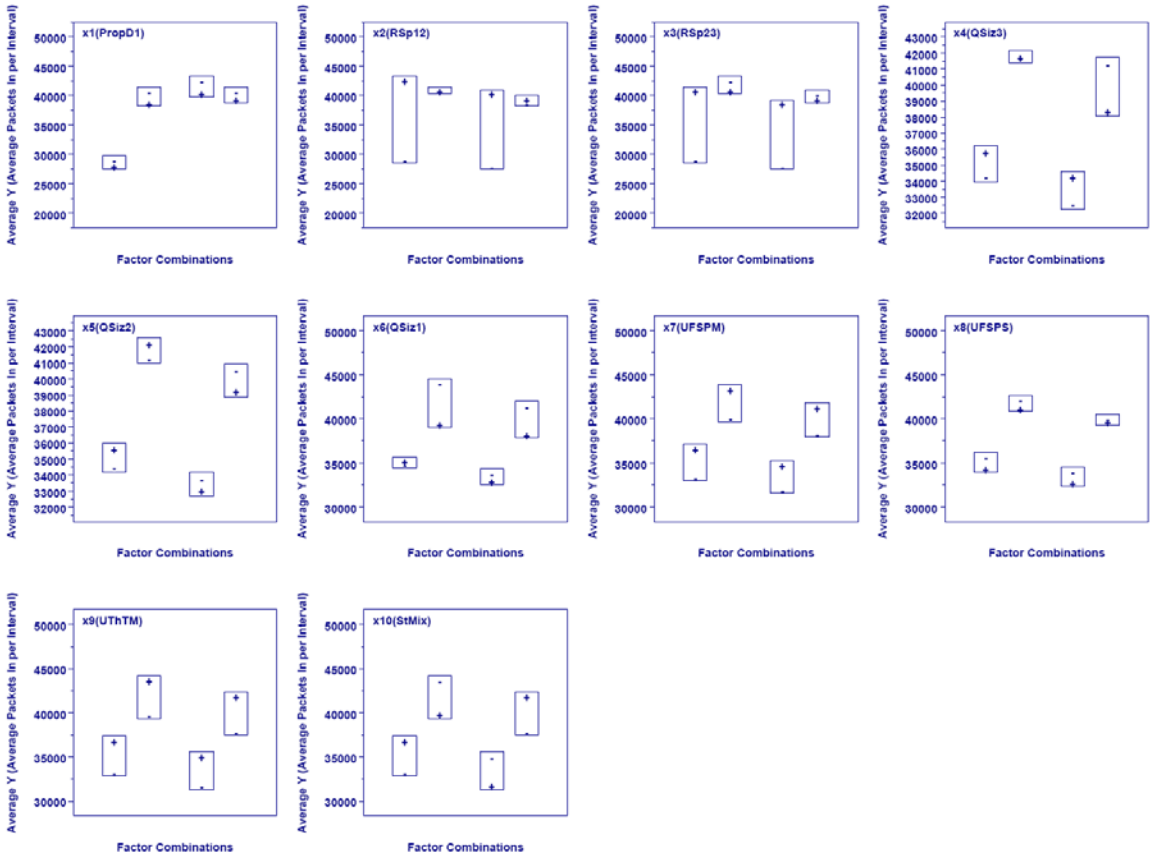

Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
2. Response = Average Packets In per Interval
Interaction Effects Matrix
Average Y (Average Packets In per Interval)
1: -1761.31
12: -112.94
13: -42.56
14: -723.44
15: -1007.2
16: 42.06
17: -191.94
18: 165.44
19: 1.31
110: 218.56
X1(PropD1)
2: 6581.19
23: -6265.31
24: -1513.94
25: -190.19
26: -1839.69
27: 34.31
28: 371.44
29: 218.56
210: 1.31
X2(RSp12)
3: 4931.56
34: 698.94
35: 26.69
36: -766.56
37: -86.06
38: 218.56
39: 371.44
310: 165.44
X3(RSp23)
4: 68.94
45: 118.06
46: 475.31
47: 218.56
48: -86.06
49: 34.31
410: -191.94
X4(QSiz3)
5: -33.56
56: 218.56
57: 475.31
58: -766.56
59: -1839.69
510: 42.06
X5(QSiz2)
6: -2135.31
67: 118.06
68: 26.69
69: -190.19
610: -1007.2
X6(QSiz1)
7: 3008.94
78: 698.94
79: -1513.94
710: -723.44
X7(UFSPM)
8: -1052.94
89: -6265.31
810: -42.56
X8(UFSPS)
9: 3665.44
910: -112.94
X9(UThTM)
10: 53.69
X10(StMix)

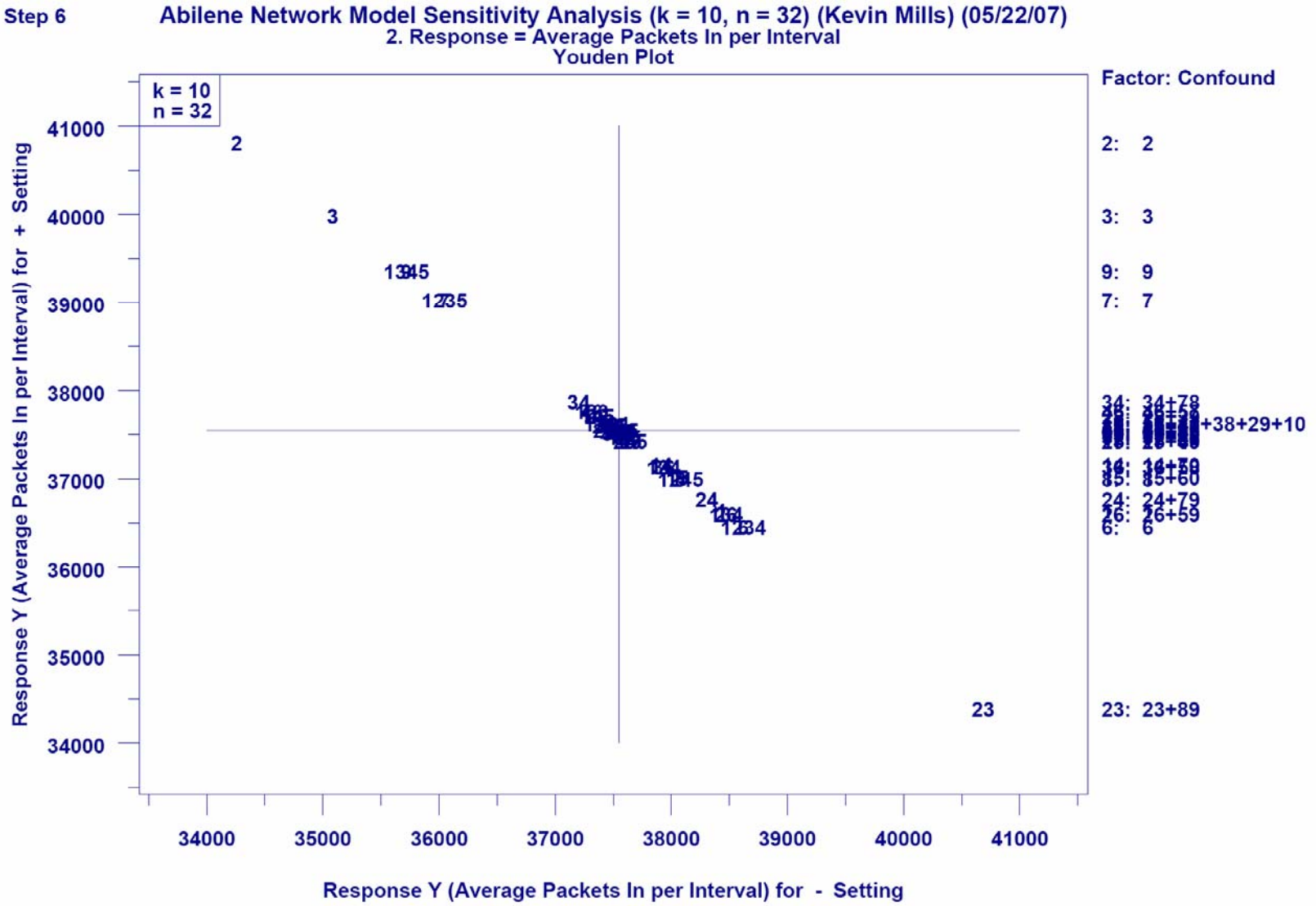
Step 5

Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)

2. Response = Average Packets In per Interval

Block Plots



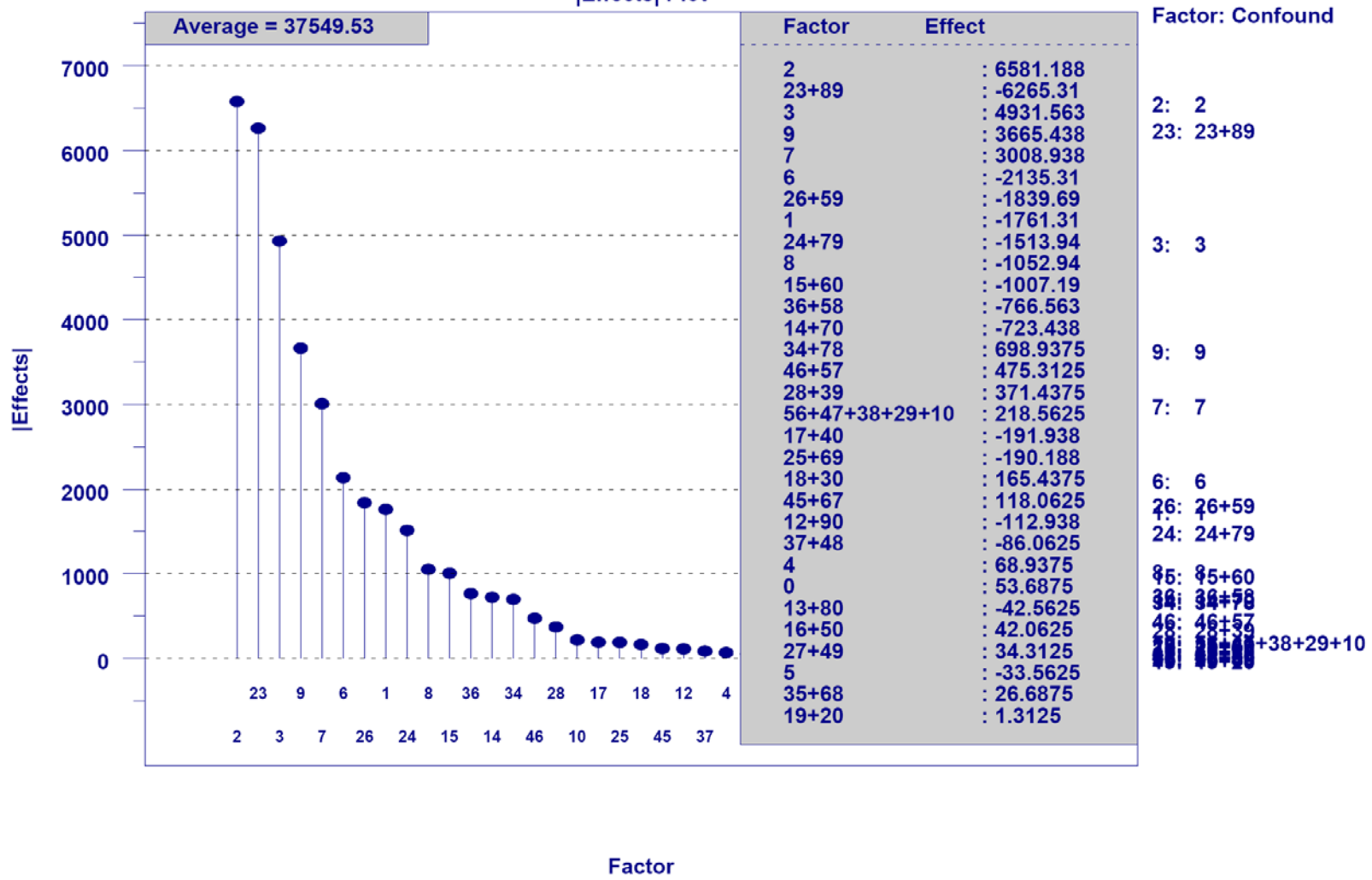

Step 6
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
2. Response = Average Packets In per Interval
Youden Plot
k = 10
n = 32
Factor: Confound
2: 2
3: 3
9: 9
7: 7
34: 34+78
+38+29+10
14: 14+79
85: 85+60
24: 24+79
26: 26+59
6: 6
23: 23+89
Response Y (Average Packets In per Interval) for + Setting
Response Y (Average Packets In per Interval) for - Setting
41000
40000
39000
38000
37000
36000
35000
34000

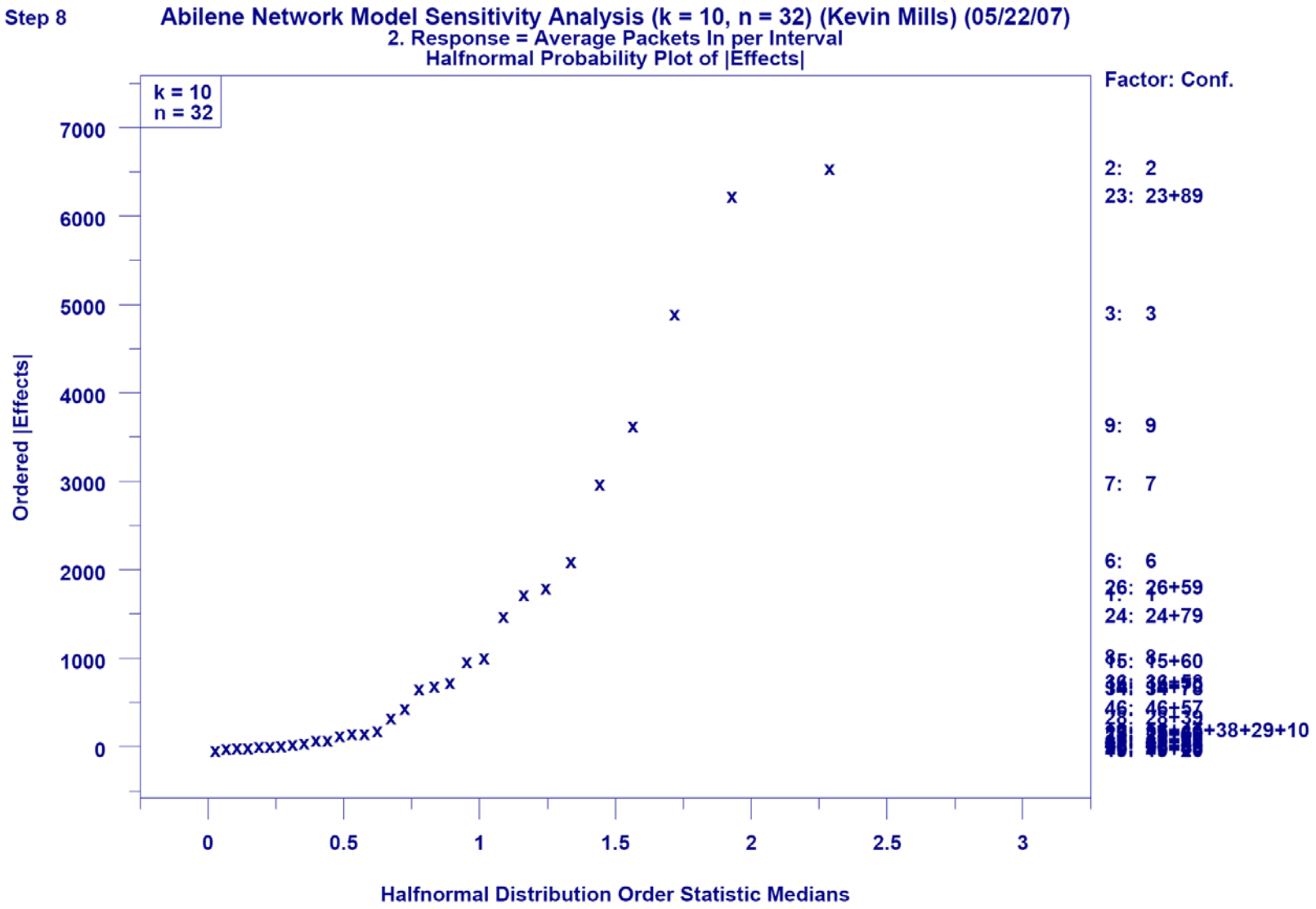
Step 7

Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)

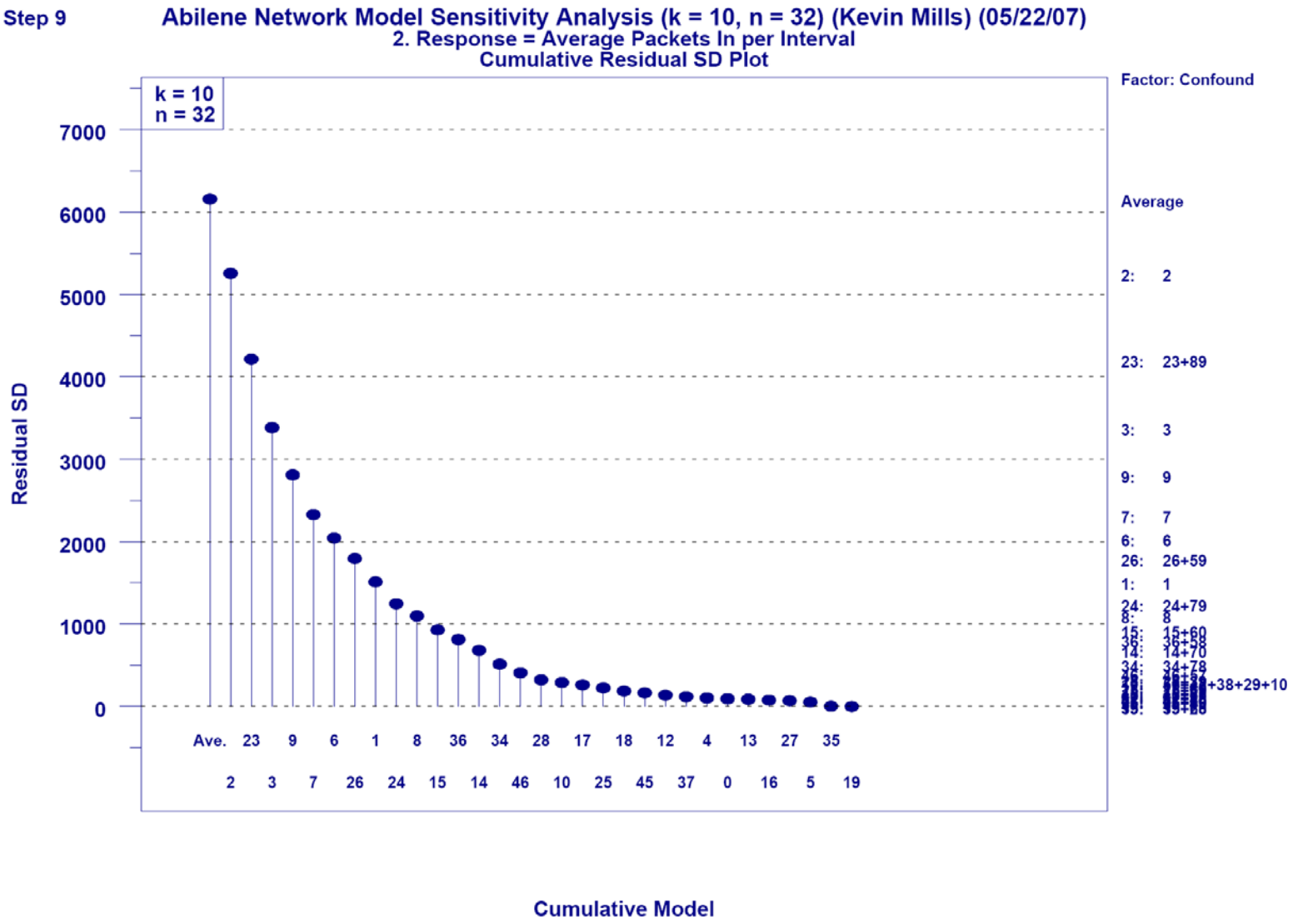
2. Response = Average Packets In per Interval

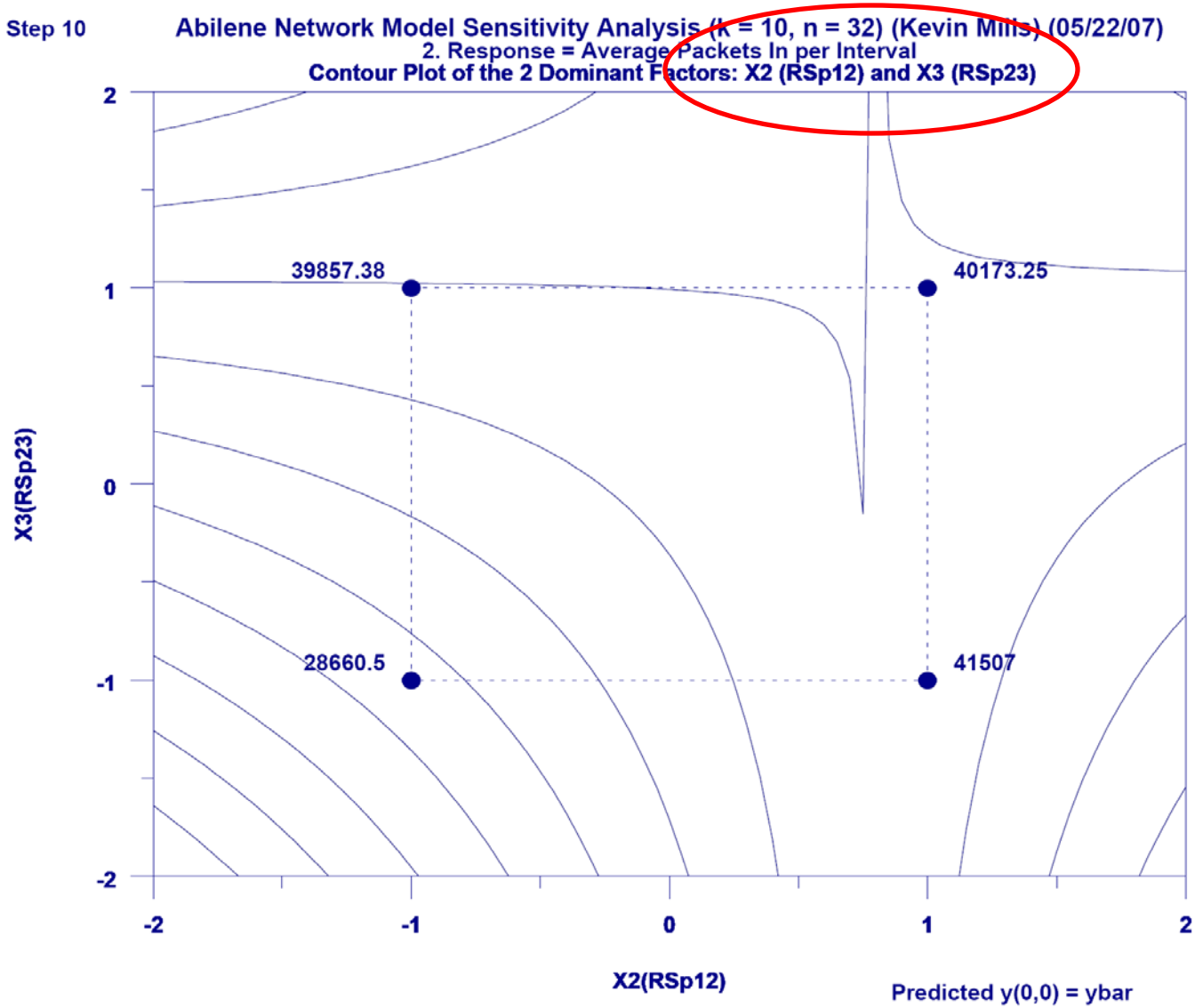
|Effects| Plot



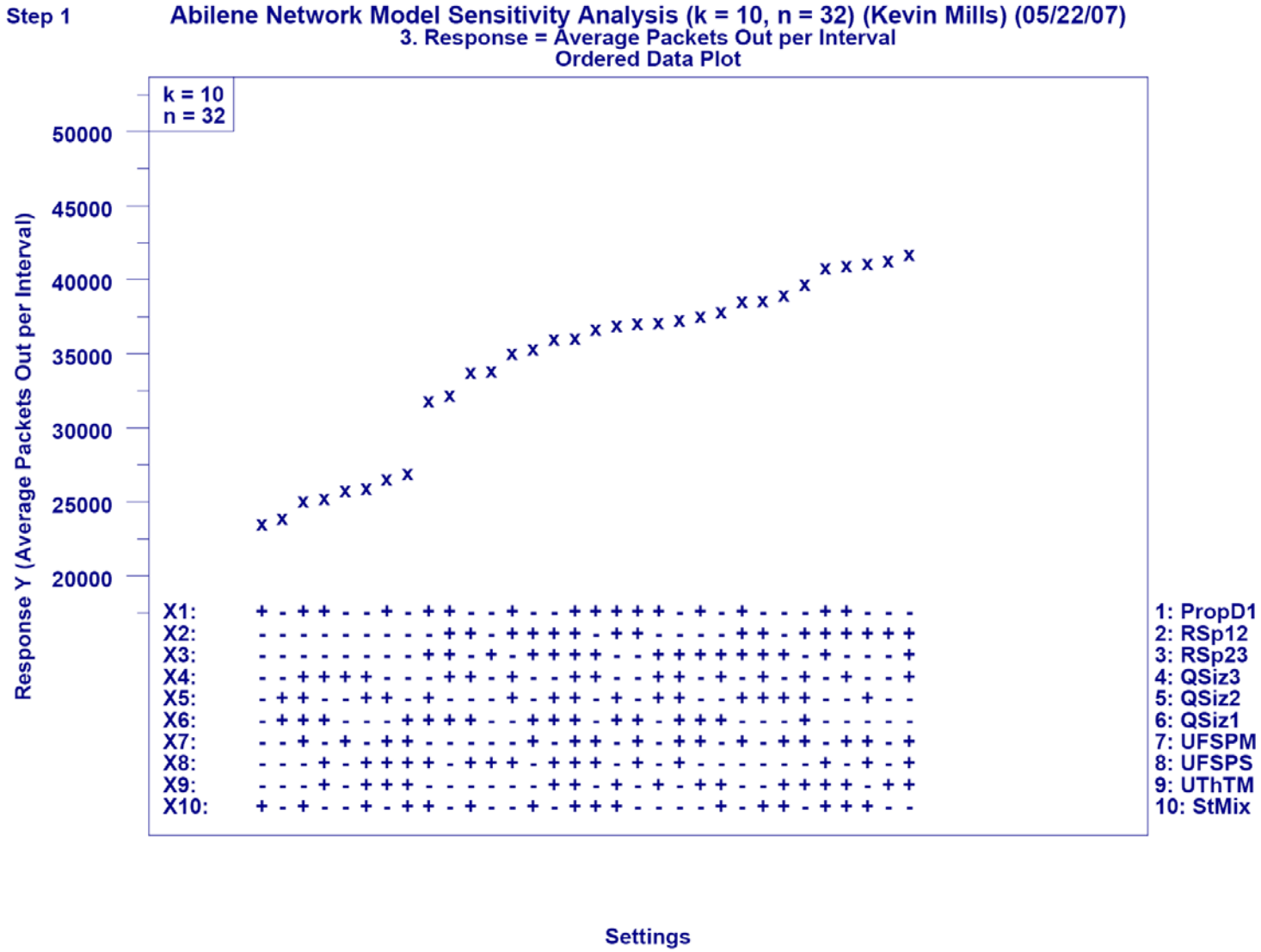

Step 8
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
2. Response = Average Packets In per Interval
Halfnormal Probability Plot of |Effects|
k = 10
n = 32
Factor: Conf.
2: 2
23: 23+89
3: 3
9: 9
7: 7
6: 6
26: 26+59
24: 24+79
46: 46+57
+38+29+10
Ordered |Effects|
7000
6000
5000
4000
3000
2000
1000
0
0
0.5
1
1.5
2
2.5
3
Halfnormal Distribution Order Statistic Medians

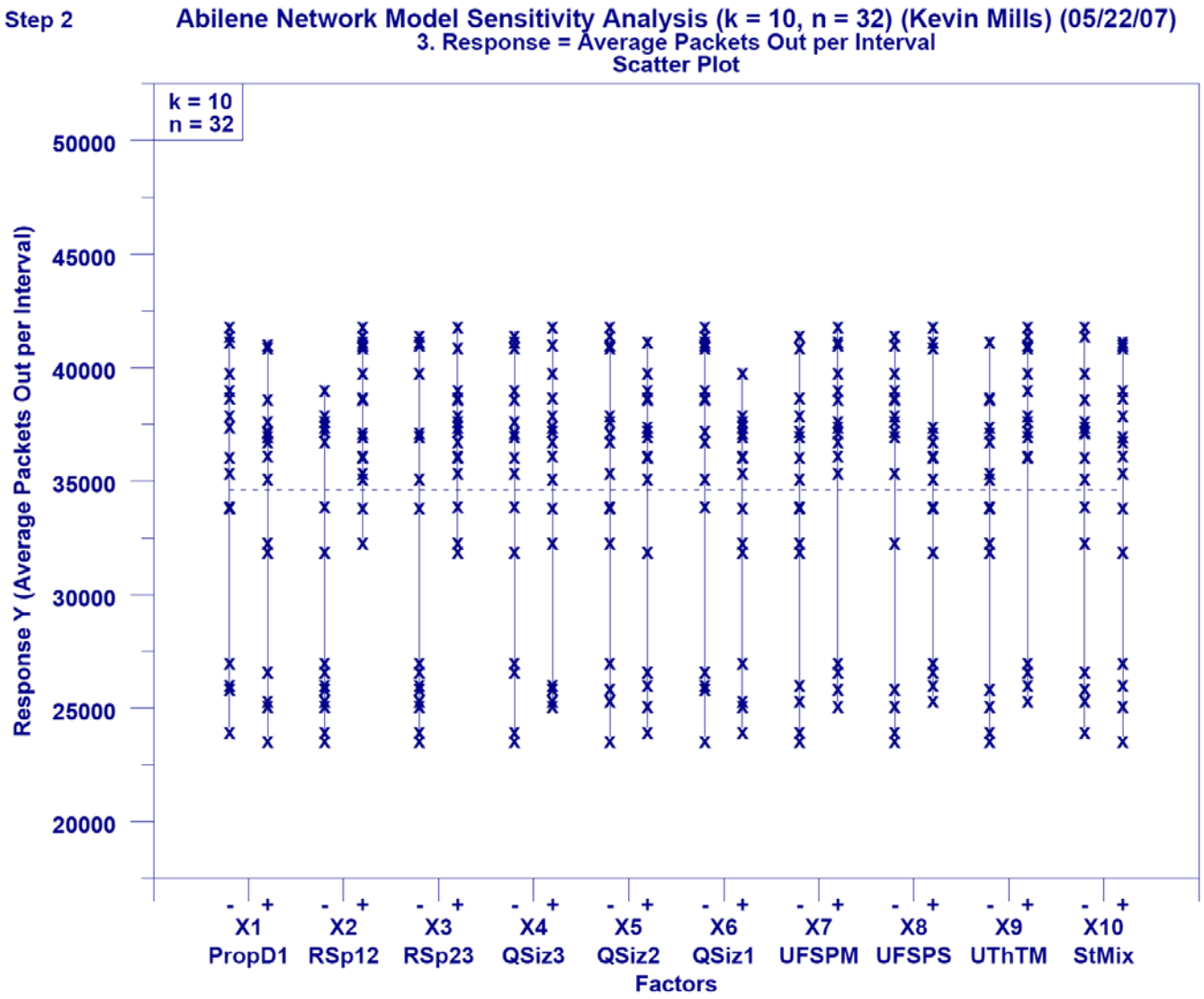
Step 9


Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
2. Response = Average Packets In per Interval
Cumulative Residual SD Plot
k = 10
n = 32
Residual SD
7000
6000
5000
4000
3000
2000
1000
0
Ave. 23 9 6 1 8 36 34 28 17 18 12 4 13 27 35
2 3 7 26 24 15 14 46 10 25 45 37 0 16 5 19
Cumulative Model
Factor: Confound
Average
2: 2
23: 23+89
3: 3
9: 9
7: 7
6: 6
26: 26+59
1: 1
24: 24+79
8: 8
15: 15+60
36: 36+58
14: 14+70
34: 34+78
+38+29+10

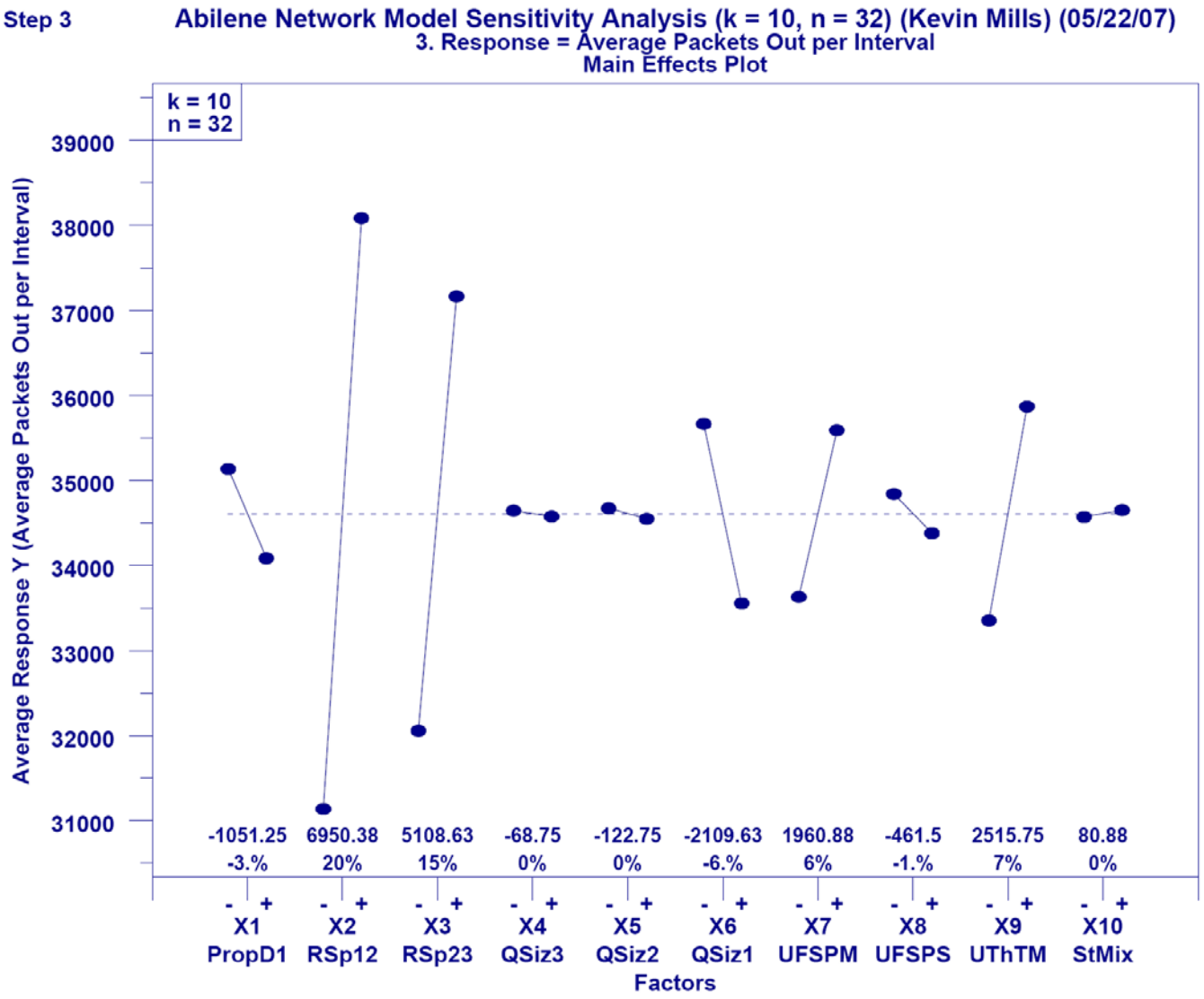

Step 10
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
2. Response = Average Packets In per Interval
Contour Plot of the 2 Dominant Factors: X2 (RSp12) and X3 (RSp23)
39857.38
40173.25
28660.5
41507
X3(RSp23)
X2(RSp12)
2
1
0
-1
-2
-2
-1
0
1
2
Predicted y(0,0) = ybar = 37549.53

Response 3:
Average Packets Out per Interval

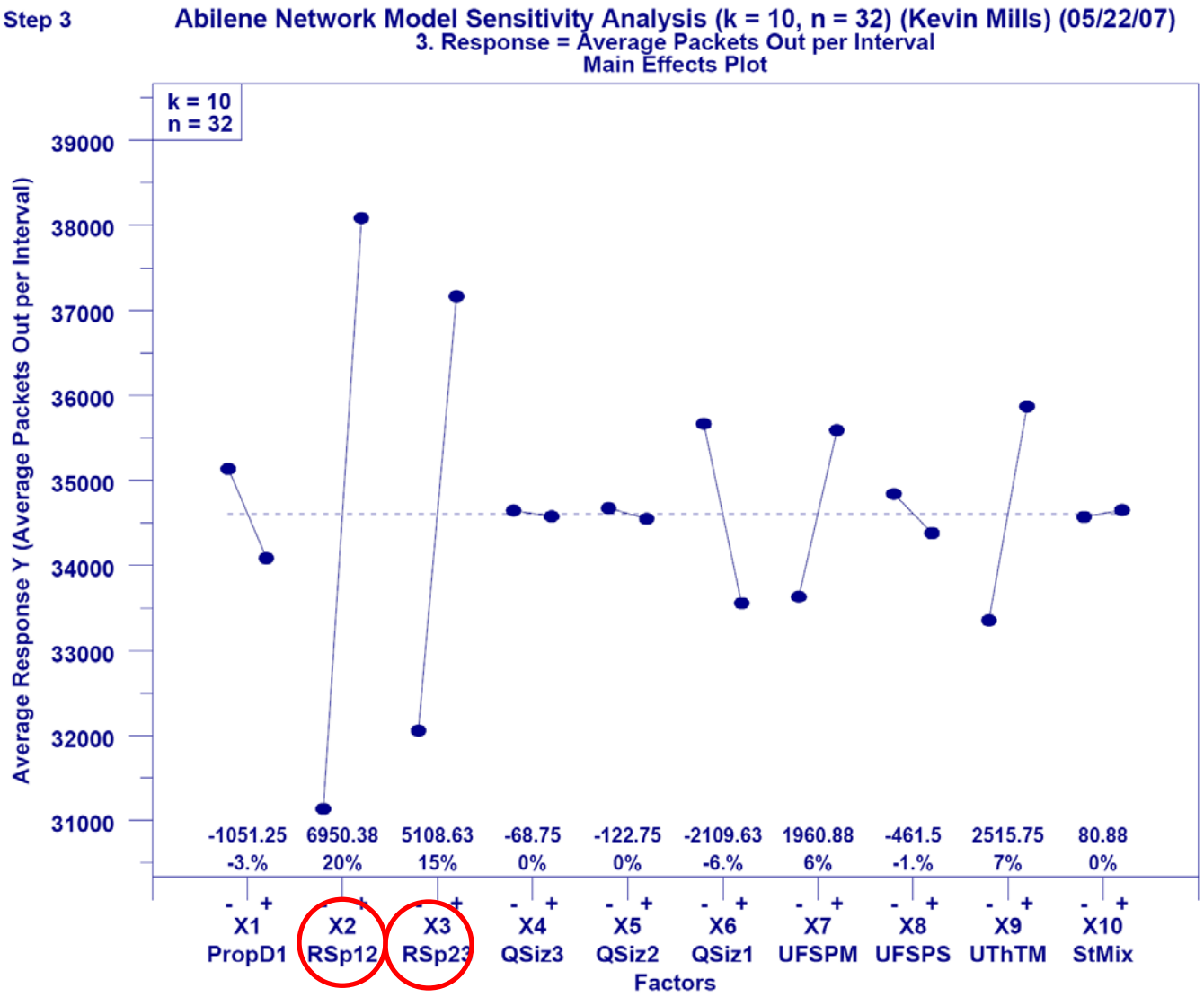

Step 1
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
3. Response = Average Packets Out per Interval
Ordered Data Plot
k = 10
n = 32
Response Y (Average Packets Out per Interval)
50000
45000
40000
35000
30000
25000
20000
X1: + - + + - - + - + + - - + - - + + + + + - + - + - - - + + - - -
X2: - - - - - - - - - + + - + + + + - + + - - - - + + - + + + + + +
X3: - - - - - - - - + + - + - + + + + - - + + + + + + + - + - - - +
X4: - - + + + + - - - + + - + - - + + - - + + - + - + - + - + - - +
X5: - + + - - + + - + - - - + - + + - + + - - + + + + - - + - - -
X6: - + + + - - - + + + + - - + + + - + + - + + + - - - + - - - - -
X7: - - + - + - + + - - - - - + - + + - + - + + - + - + + - + + - +
X8: - - - + - + + + + - + + + - + + + - + - + - - - - - - + - + - +
X9: - - - + - + + + - - - - - - + + - + - + - + - + + - - + + + + - + +
X10: + - + - - + - + + - + - - + - + + + - - - - + - + + - + + + - -
1: PropD1
2: RSp12
3: RSp23
4: QSiz3
5: QSiz2
6: QSiz1
7: UFSPM
8: UFSPS
9: UThTM
10: StMix
Settings


Step 2
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
3. Response = Average Packets Out per Interval
Scatter Plot
k = 10
n = 32
Response Y (Average Packets Out per Interval)
50000
45000
40000
35000
30000
25000
20000
- + - + - + - + - + - + - + - + - + - +
X1 PropD1
X2 RSp12
X3 RSp23
X4 QSiz3
X5 QSiz2
X6 QSiz1
X7 UFSPM
X8 UFSPS
X9 UThTM
X10 StMix
Factors

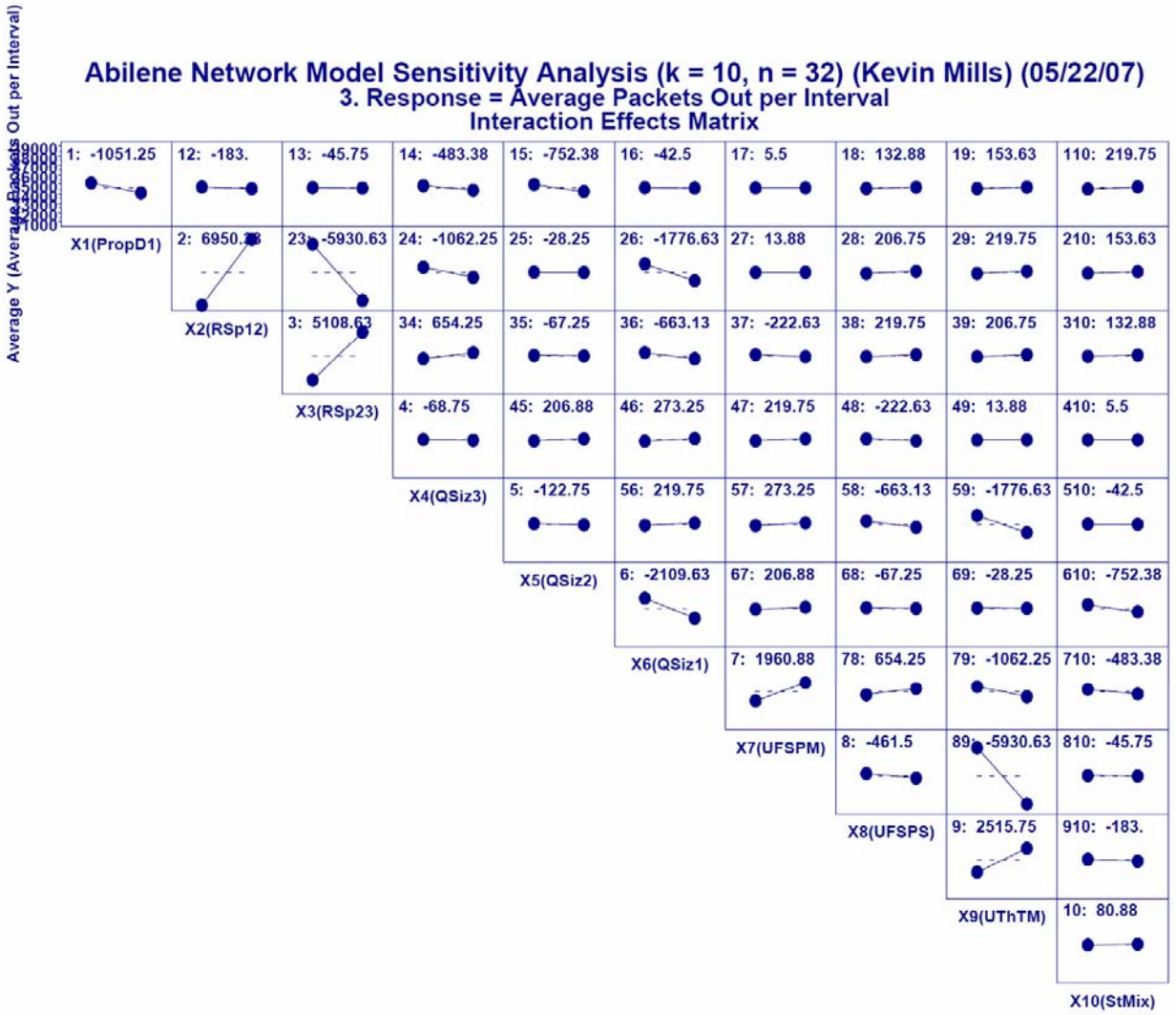
Step 3


Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
3. Response = Average Packets Out per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Packets Out per Interval)
39000
38000
37000
36000
35000
34000
33000
32000
31000
-1051.25
-3.%
6950.38
20%
5108.63
15%
-68.75
0%
-122.75
0%
-2109.63
-6.%
1960.88
6%
-461.5
-1.%
2515.75
7%
80.88
0%
- +
X1
PropD1
X2
RSp12
X3
RSp23
X4
QSiz3
X5
QSiz2
X6
QSiz1
X7
UFSPM
X8
UFSPS
X9
UThTM
X10
StMix
Factors

Step 3


Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
3. Response = Average Packets Out per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Packets Out per Interval)
39000
38000
37000
36000
35000
34000
33000
32000
31000
-1051.25
-3.%
6950.38
20%
5108.63
15%
-68.75
0%
-122.75
0%
-2109.63
-6.%
1960.88
6%
-461.5
-1.%
2515.75
7%
80.88
0%
X1
PropD1
X2
RSp12
X3
RSp23
X4
QSiz3
X5
QSiz2
X6
QSiz1
X7
UFSPM
X8
UFSPS
X9
UThTM
X10
StMix
Factors

Step 4

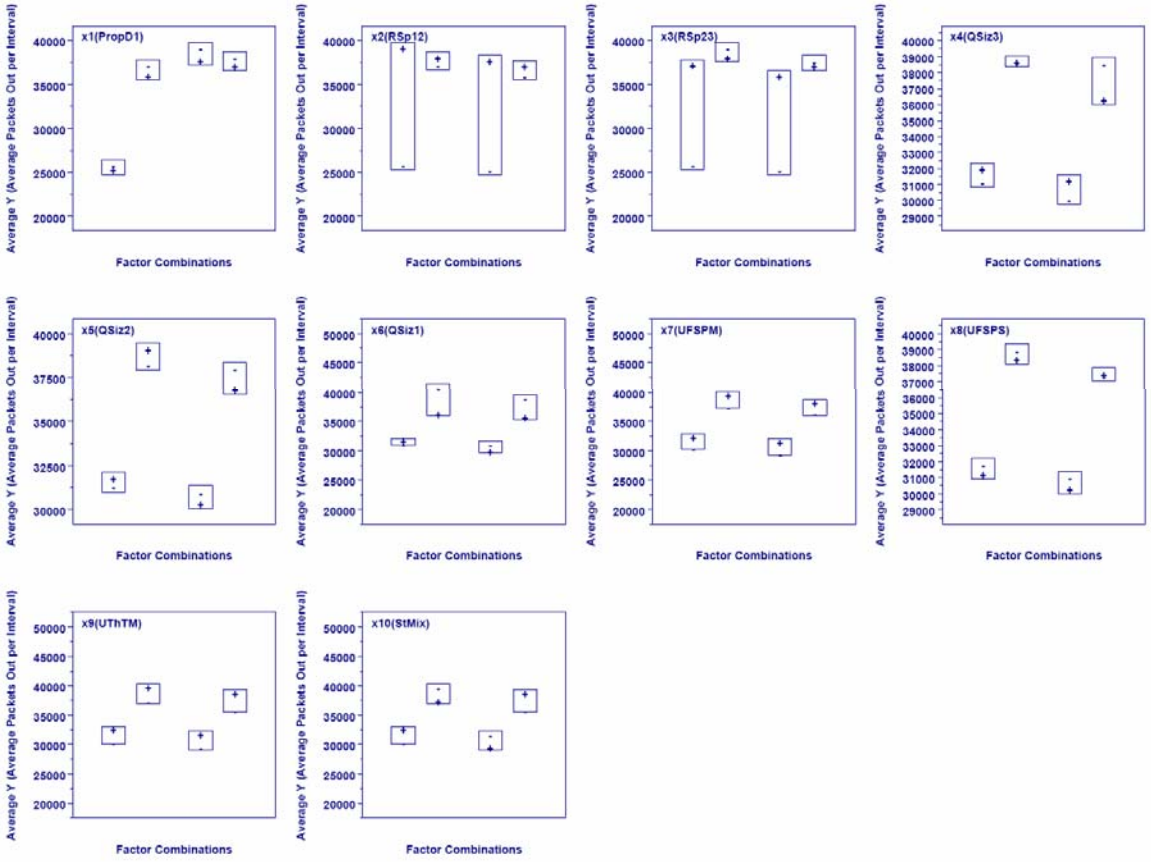

Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
3. Response = Average Packets Out per Interval
Interaction Effects Matrix
Average Y (Average Packets Out per Interval)
1: -1051.25
12: -183.
13: -45.75
14: -483.38
15: -752.38
16: -42.5
17: 5.5
18: 132.88
19: 153.63
110: 219.75
X1(PropD1)
2: 6950.38
23: -5930.63
24: -1062.25
25: -28.25
26: -1776.63
27: 13.88
28: 206.75
29: 219.75
210: 153.63
X2(RSp12)
3: 5108.63
34: 654.25
35: -67.25
36: -663.13
37: -222.63
38: 219.75
39: 206.75
310: 132.88
X3(RSp23)
4: -68.75
45: 206.88
46: 273.25
47: 219.75
48: -222.63
49: 13.88
410: 5.5
X4(QSiz3)
5: -122.75
56: 219.75
57: 273.25
58: -663.13
59: -1776.63
510: -42.5
X5(QSiz2)
6: -2109.63
67: 206.88
68: -67.25
69: -28.25
610: -752.38
X6(QSiz1)
7: 1960.88
78: 654.25
79: -1062.25
710: -483.38
X7(UFSPM)
8: -461.5
89: -5930.63
810: -45.75
X8(UFSPS)
9: 2515.75
910: -183.
X9(UThTM)
10: 80.88
X10(StMix)

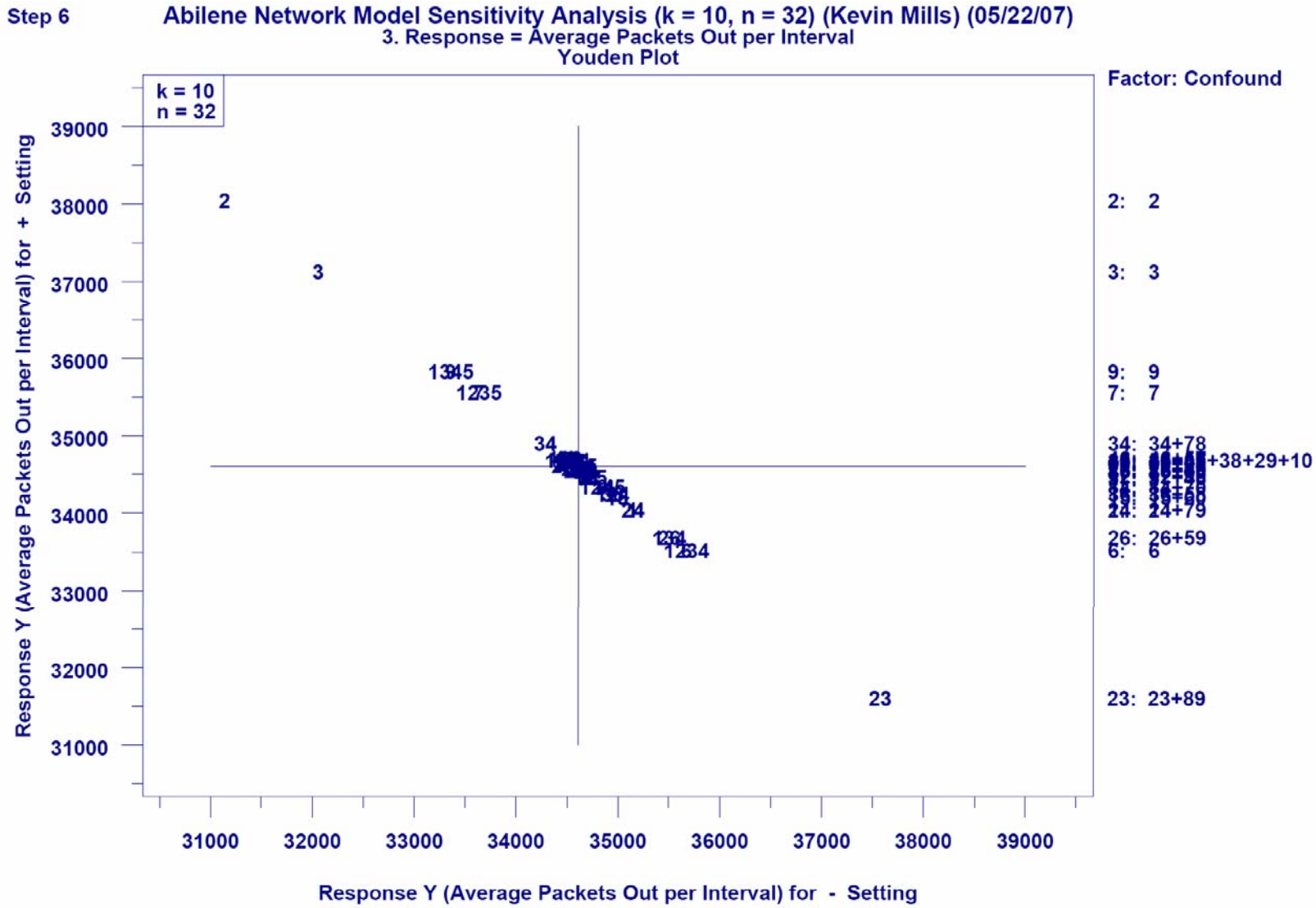
Step 5

Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)

3. Response = Average Packets Out per Interval

Block Plots



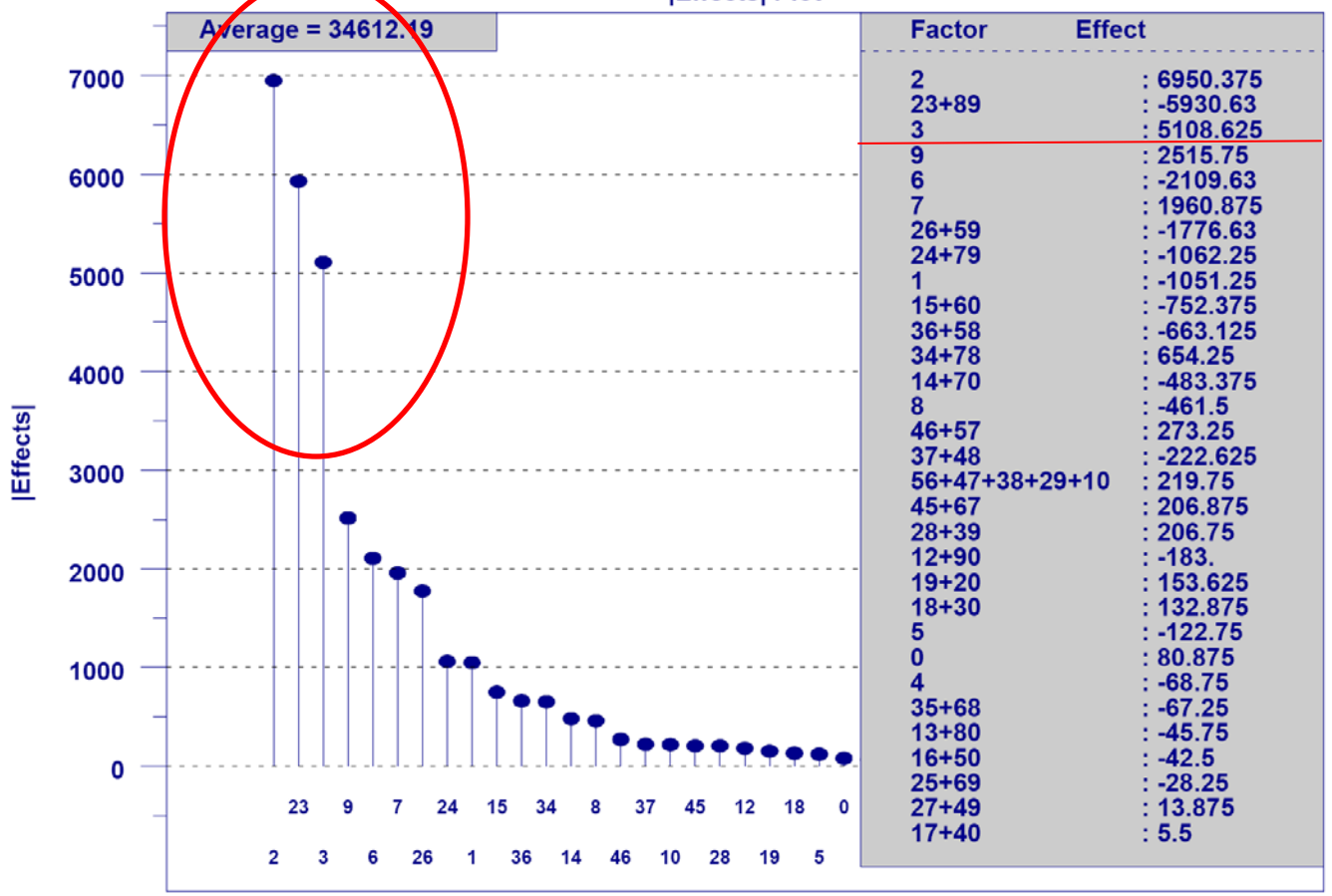

Step 6
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
3. Response = Average Packets Out per Interval
Youden Plot
k = 10
n = 32
Factor: Confound
2: 2
3: 3
9: 9
7: 7
34: 34+78
+38+29+10
24: 24+79
26: 26+59
6: 6
23: 23+89
Response Y (Average Packets Out per Interval) for + Setting
Response Y (Average Packets Out per Interval) for - Setting
39000
38000
37000
36000
35000
34000
33000
32000
31000

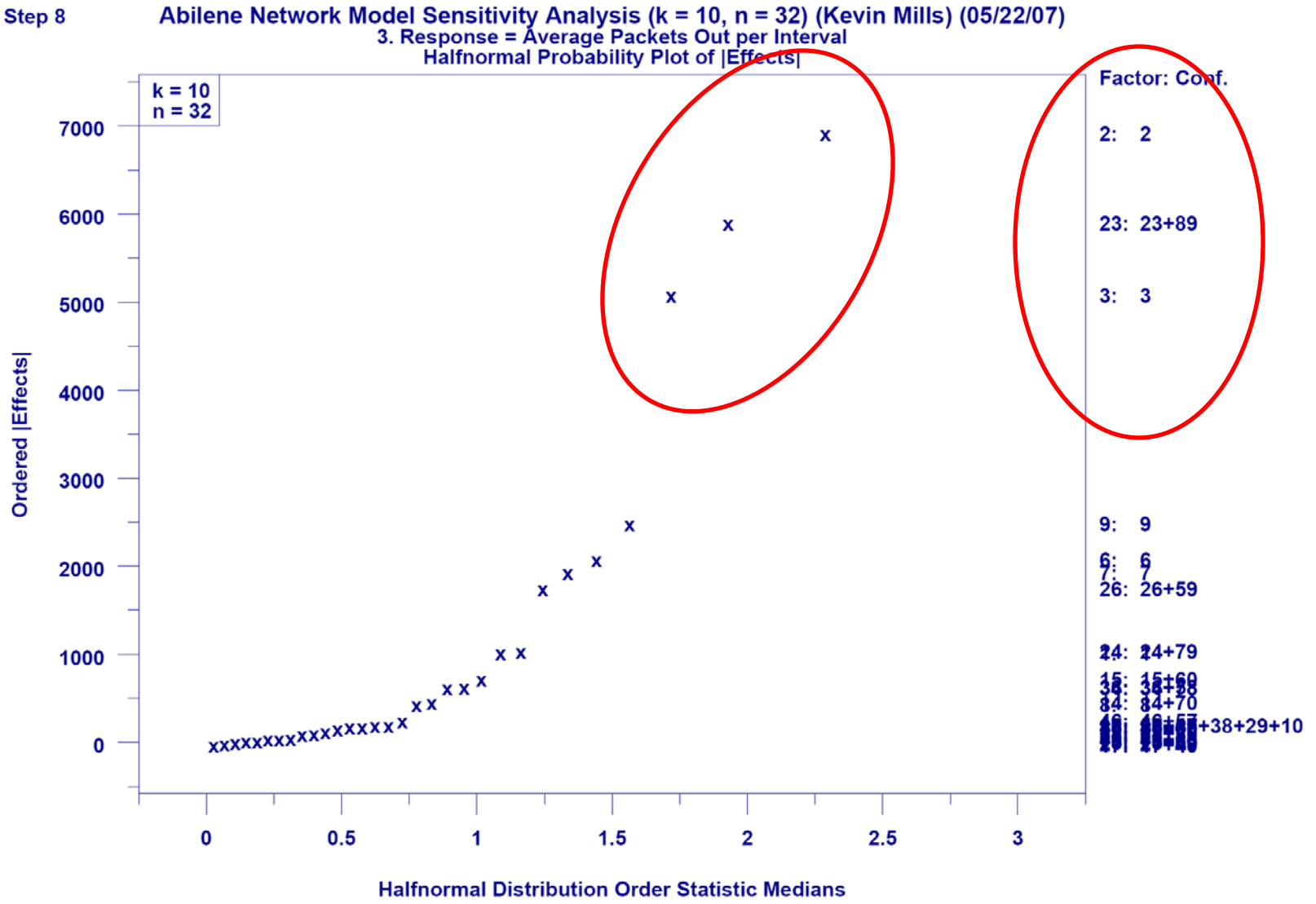
Step 7

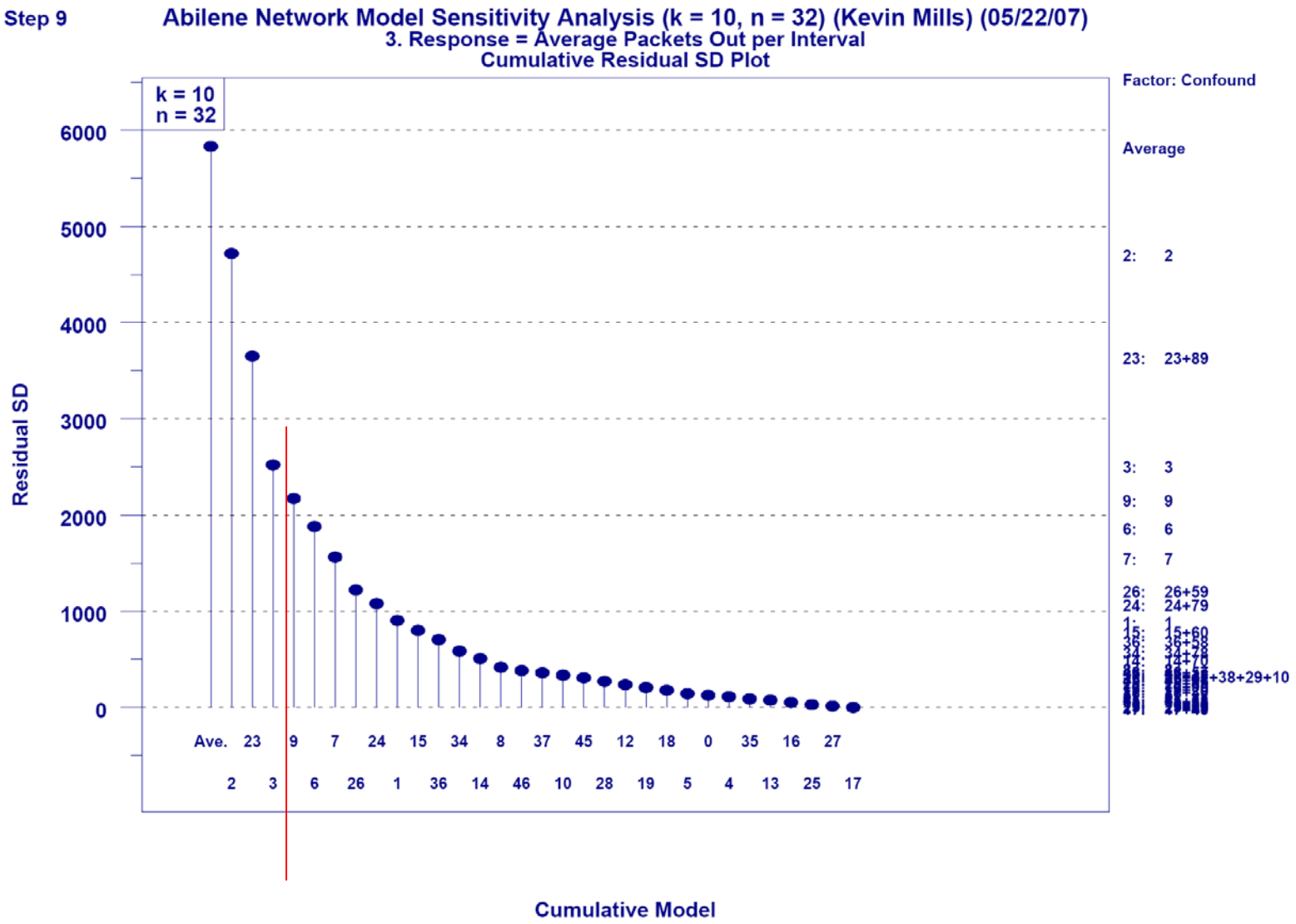
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)

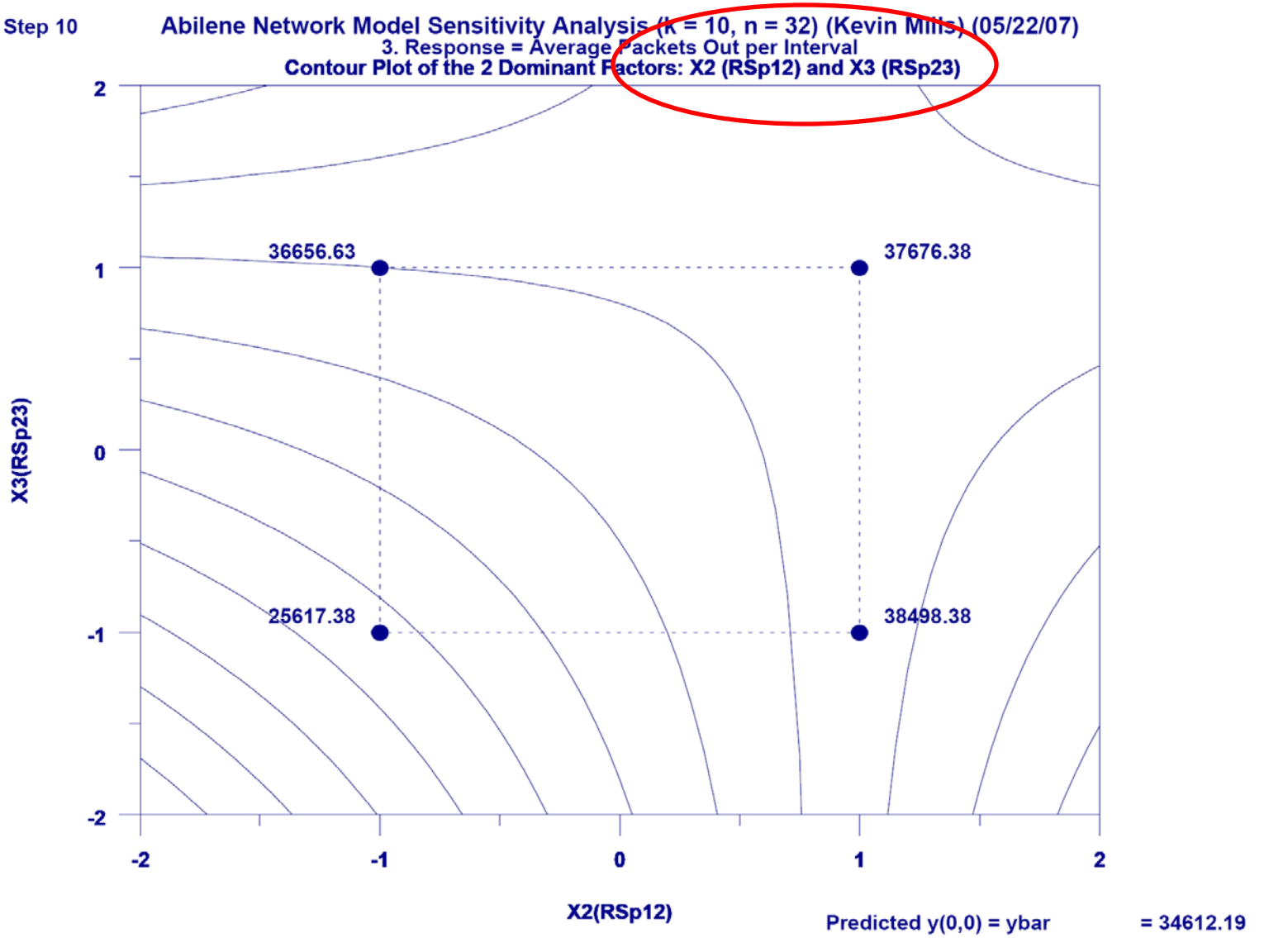
3. Response = Average Packets Out per Interval

|Effects| Plot

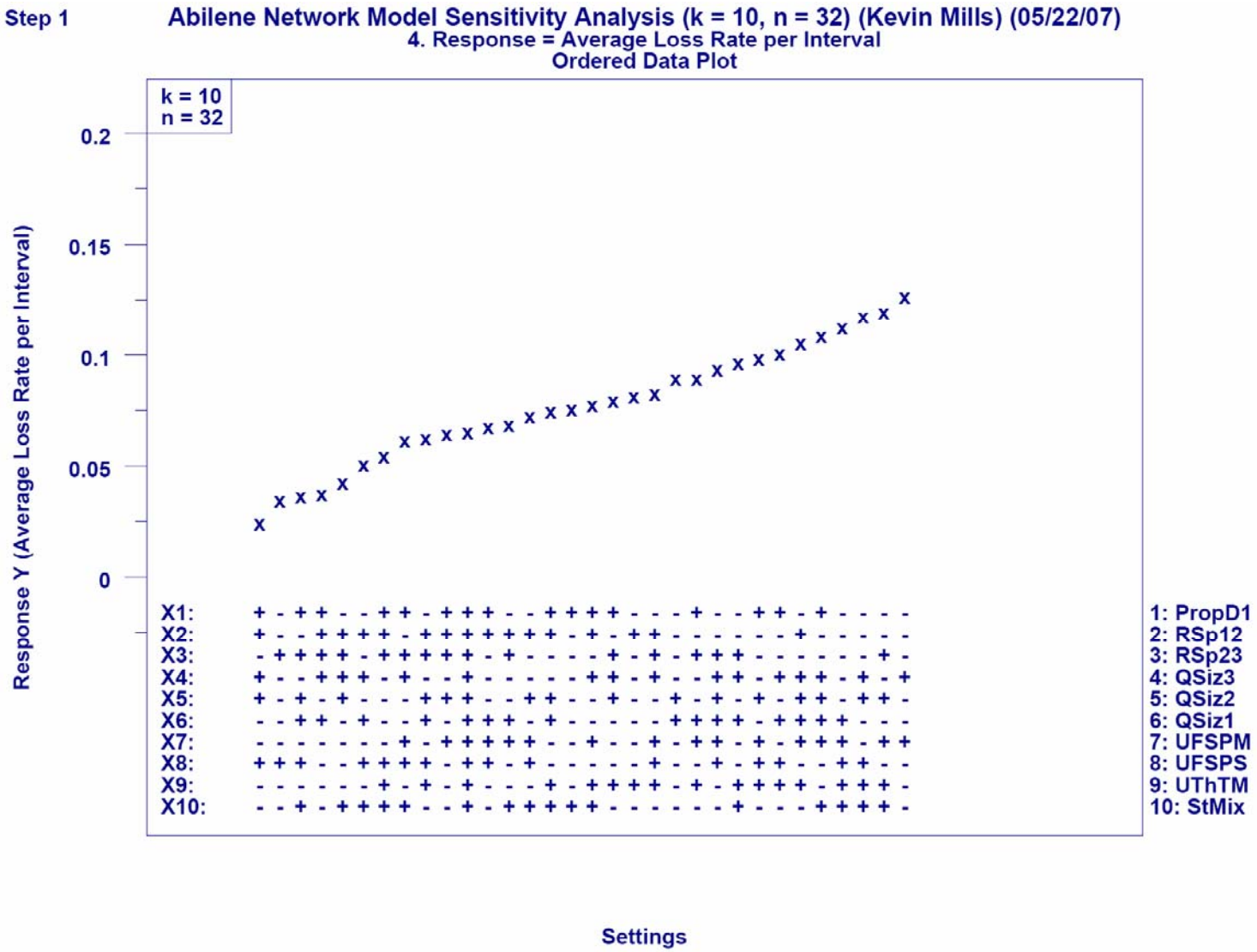


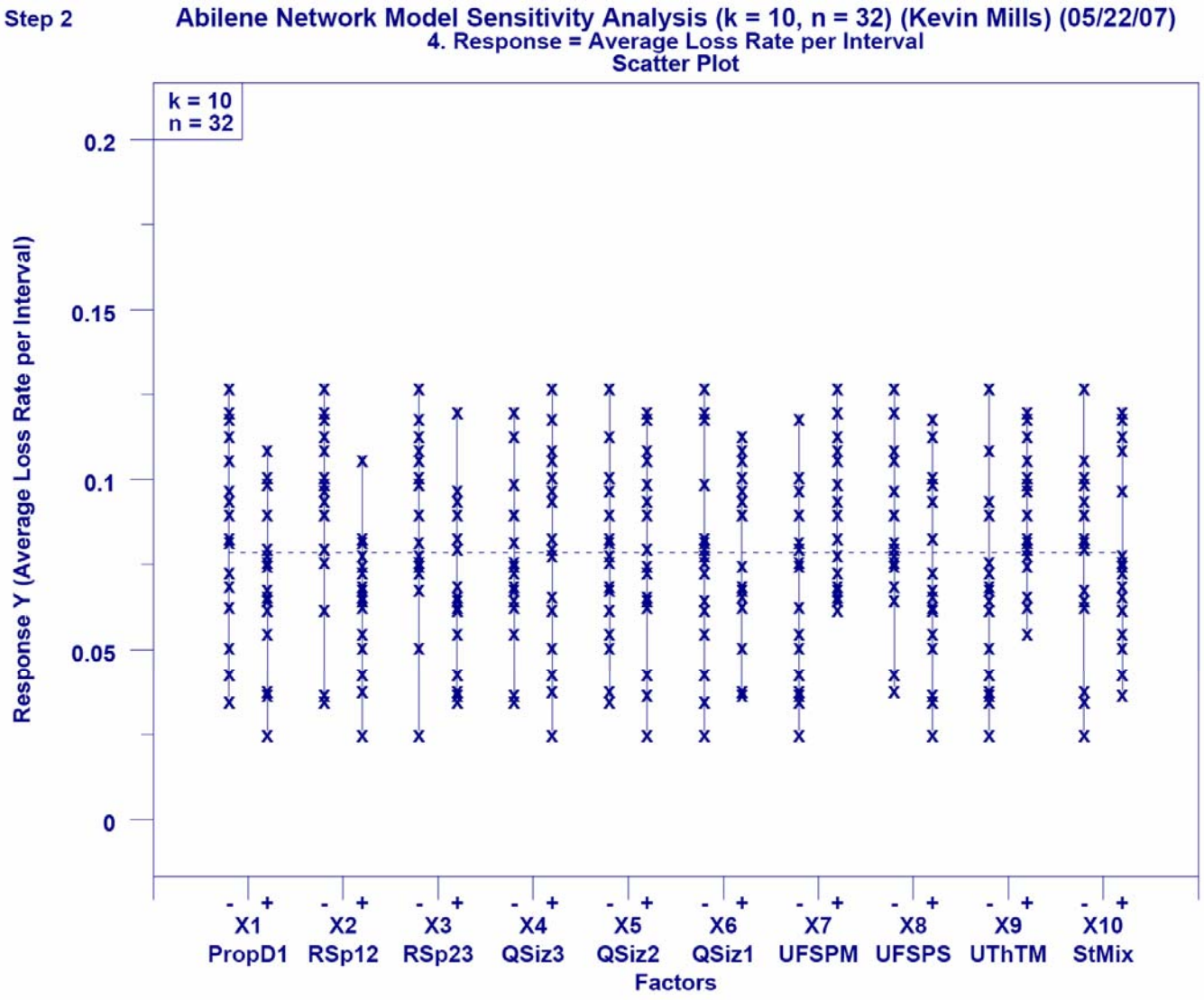

Step 8
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
3. Response = Average Packets Out per Interval
Halfnormal Probability Plot of |Effects|
k = 10
n = 32
Factor: Conf.
2: 2
23: 23+89
3: 3
9: 9
6: 6
7: 7
26: 26+59
24: 24+79
15: 15+69
38: 38+28
34: 34+70
+38+29+10
Ordered |Effects|
7000
6000
5000
4000
3000
2000
1000
0
0
0.5
1
1.5
2
2.5
3
Halfnormal Distribution Order Statistic Medians

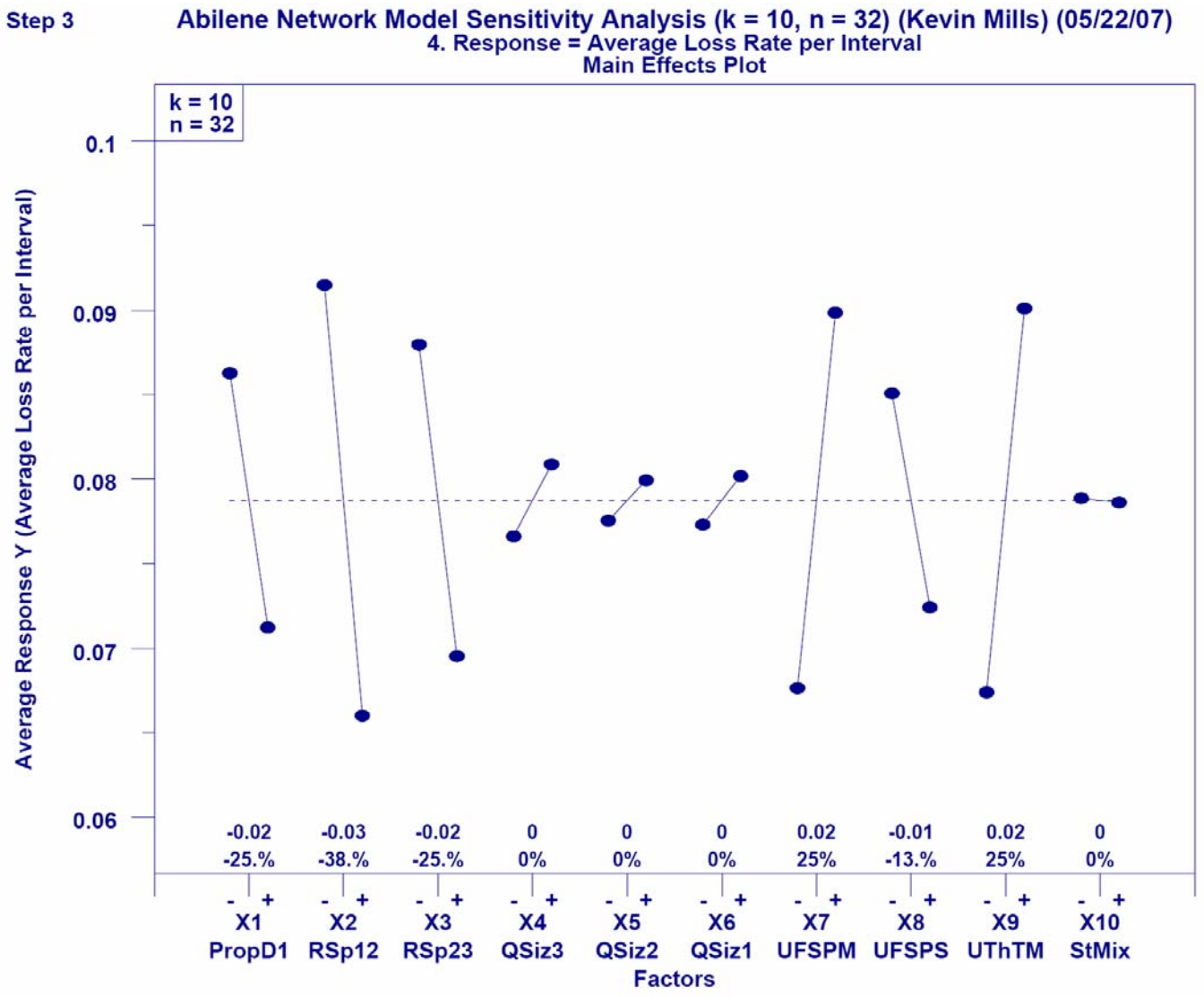

Step 9
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
3. Response = Average Packets Out per Interval
Cumulative Residual SD Plot
k = 10
n = 32
Residual SD
6000
5000
4000
3000
2000
1000
0
Ave. 23 9 7 24 15 34 8 37 45 12 18 0 35 16 27
2 3 6 26 1 36 14 46 10 28 19 5 4 13 25 17
Cumulative Model
Factor: Confound
Average
2: 2
23: 23+89
3: 3
9: 9
6: 6
7: 7
26: 26+59
24: 24+79
+38+29+10

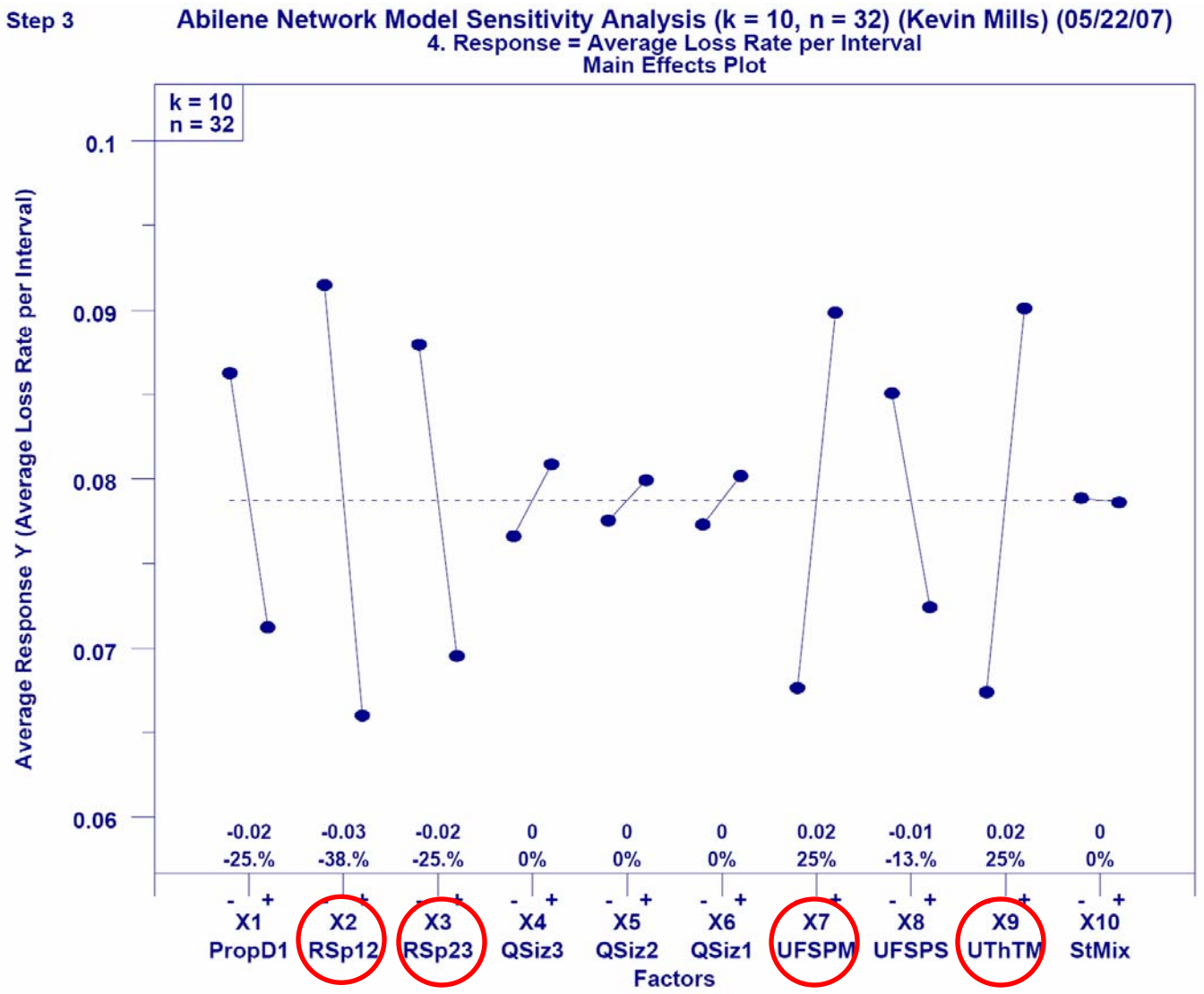

Step 10
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
3. Response = Average Packets Out per Interval
Contour Plot of the 2 Dominant Factors: X2 (RSp12) and X3 (RSp23)
36656.63
37676.38
25617.38
38498.38
X3(RSp23)
X2(RSp12)
2
1
0
-1
-2
-2
-1
0
1
2
Predicted y(0,0) = ybar = 34612.19

Response 4:
Average Loss per Interval

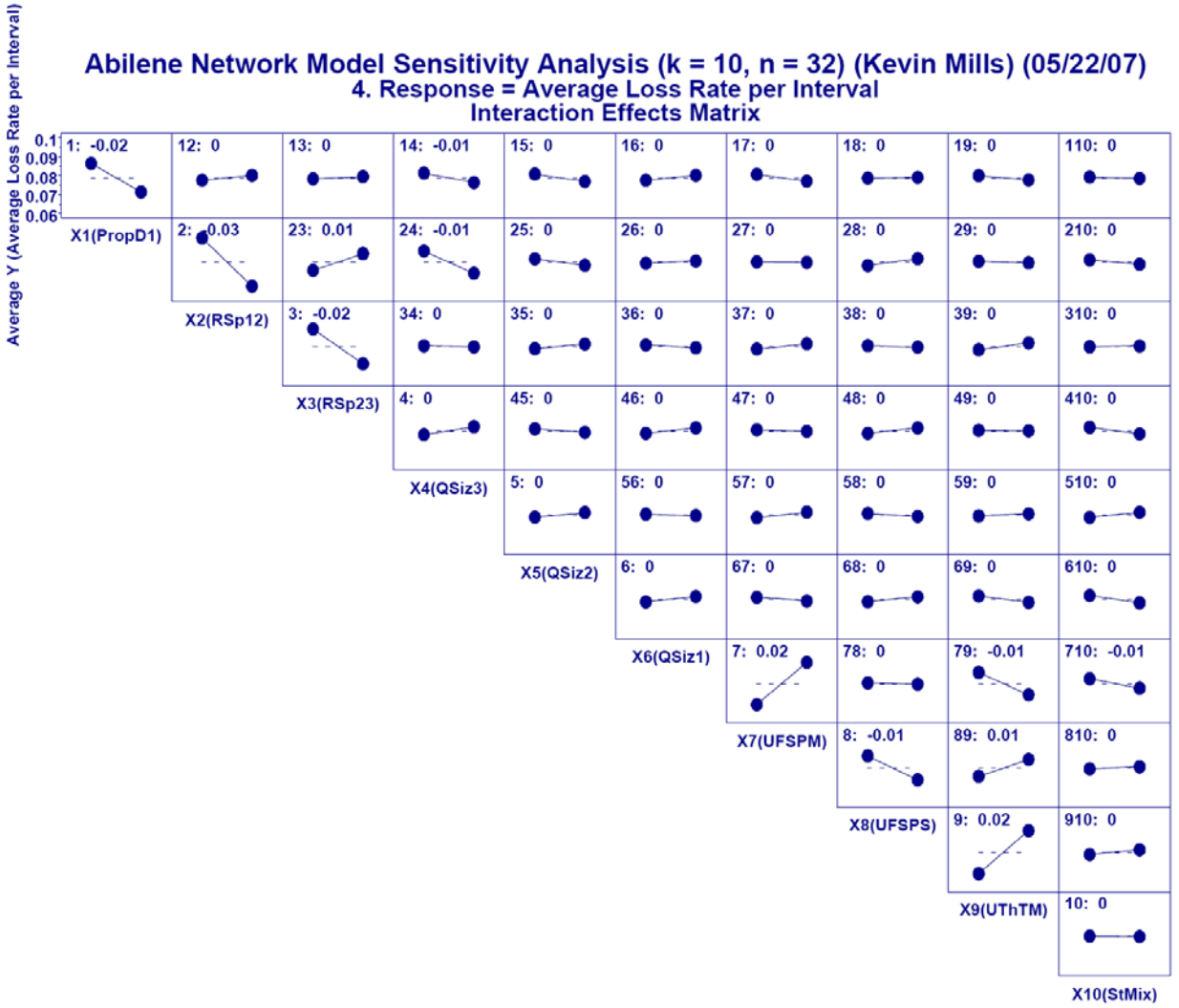

Step 1
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
4. Response = Average Loss Rate per Interval
Ordered Data Plot
k = 10
n = 32
Response Y (Average Loss Rate per Interval)
0.2
0.15
0.1
0.05
0
X1:
X2:
X3:
X4:
X5:
X6:
X7:
X8:
X9:
X10:
1: PropD1
2: RSp12
3: RSp23
4: QSiz3
5: QSiz2
6: QSiz1
7: UFSPM
8: UFSPS
9: UThTM
10: StMix
Settings


Step 2
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
4. Response = Average Loss Rate per Interval
Scatter Plot
k = 10
n = 32
Response Y (Average Loss Rate per Interval)
0.2
0.15
0.1
0.05
0
- + - + - + - + - + - + - + - + - + - +
X1 PropD1
X2 RSp12
X3 RSp23
X4 QSiz3
X5 QSiz2
X6 QSiz1
X7 UFSPM
X8 UFSPS
X9 UThTM
X10 StMix
Factors


Step 3
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
4. Response = Average Loss Rate per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Loss Rate per Interval)
0.1
0.09
0.08
0.07
0.06
-0.02
-25.%
-0.03
-38.%
-0.02
-25.%
0
0%
0
0%
0
0%
0.02
25%
-0.01
-13.%
0.02
25%
0
0%
X1
PropD1
X2
RSp12
X3
RSp23
X4
QSiz3
X5
QSiz2
X6
QSiz1
X7
UFSPM
X8
UFSPS
X9
UThTM
X10
StMix
Factors


Step 3
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
4. Response = Average Loss Rate per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Loss Rate per Interval)
0.1
0.09
0.08
0.07
0.06
-0.02
-25.%
-0.03
-38.%
-0.02
-25.%
0
0%
0
0%
0
0%
0.02
25%
-0.01
-13.%
0.02
25%
0
0%
X1
PropD1
X2
RSp12
X3
RSp23
X4
QSiz3
X5
QSiz2
X6
QSiz1
X7
UFSPM
X8
UFSPS
X9
UThTM
X10
StMix
Factors

Step 4

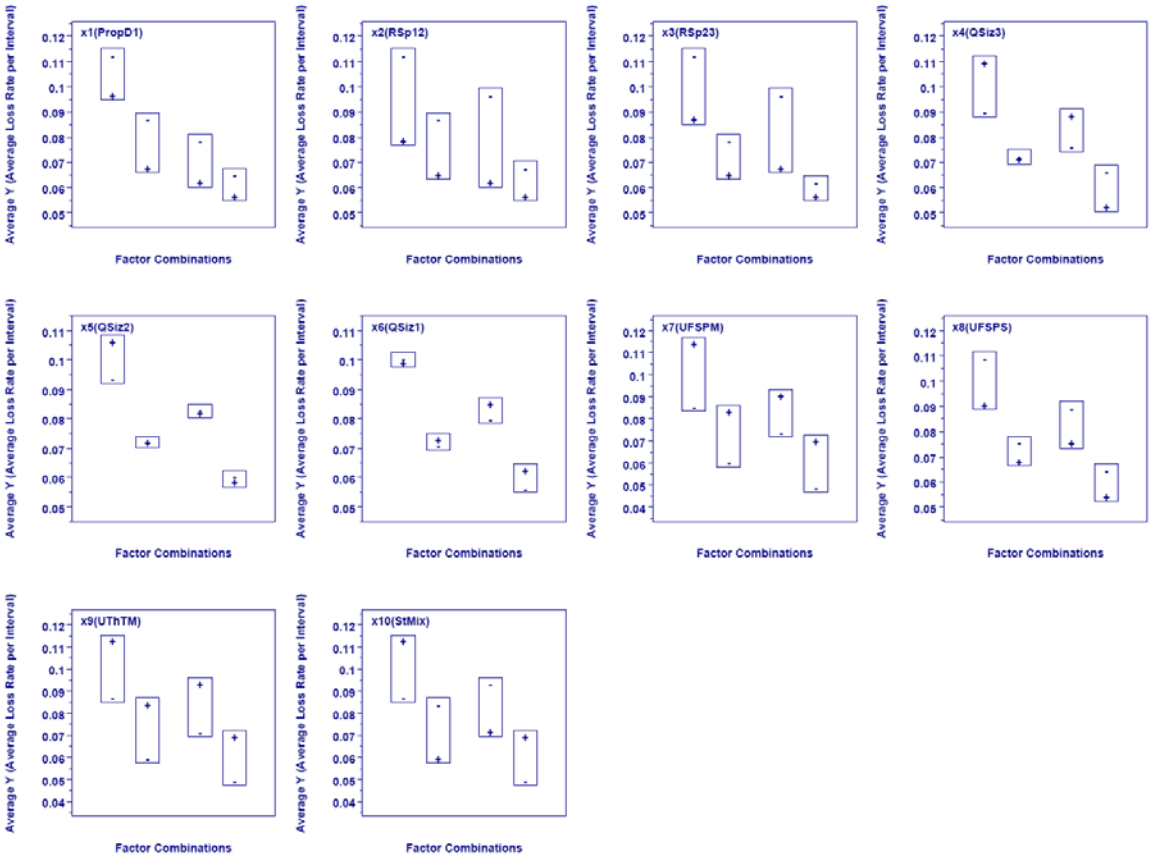

Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
4. Response = Average Loss Rate per Interval
Interaction Effects Matrix
Average Y (Average Loss Rate per Interval)
0.1
0.09
0.08
0.07
0.06
1: -0.02
12: 0
13: 0
14: -0.01
15: 0
16: 0
17: 0
18: 0
19: 0
110: 0
X1(PropD1)
2: 0.03
23: 0.01
24: -0.01
25: 0
26: 0
27: 0
28: 0
29: 0
210: 0
X2(RSp12)
3: -0.02
34: 0
35: 0
36: 0
37: 0
38: 0
39: 0
310: 0
X3(RSp23)
4: 0
45: 0
46: 0
47: 0
48: 0
49: 0
410: 0
X4(QSiz3)
5: 0
56: 0
57: 0
58: 0
59: 0
510: 0
X5(QSiz2)
6: 0
67: 0
68: 0
69: 0
610: 0
X6(QSiz1)
7: 0.02
78: 0
79: -0.01
710: -0.01
X7(UFSPM)
8: -0.01
89: 0.01
810: 0
X8(UFSPS)
9: 0.02
910: 0
X9(UThTM)
10: 0
X10(StMix)

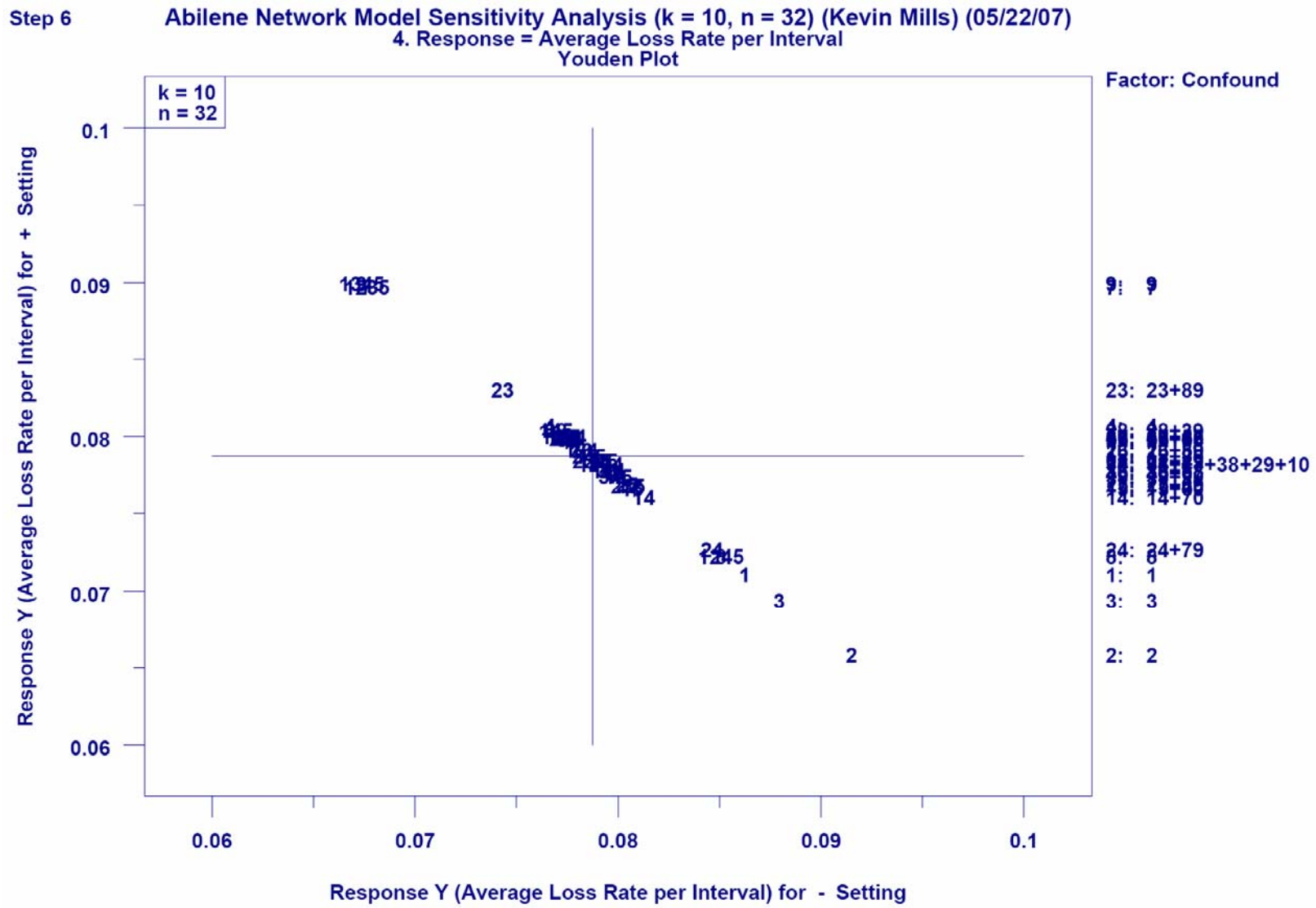
Step 5

Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)

4. Response = Average Loss Rate per Interval

Block Plots



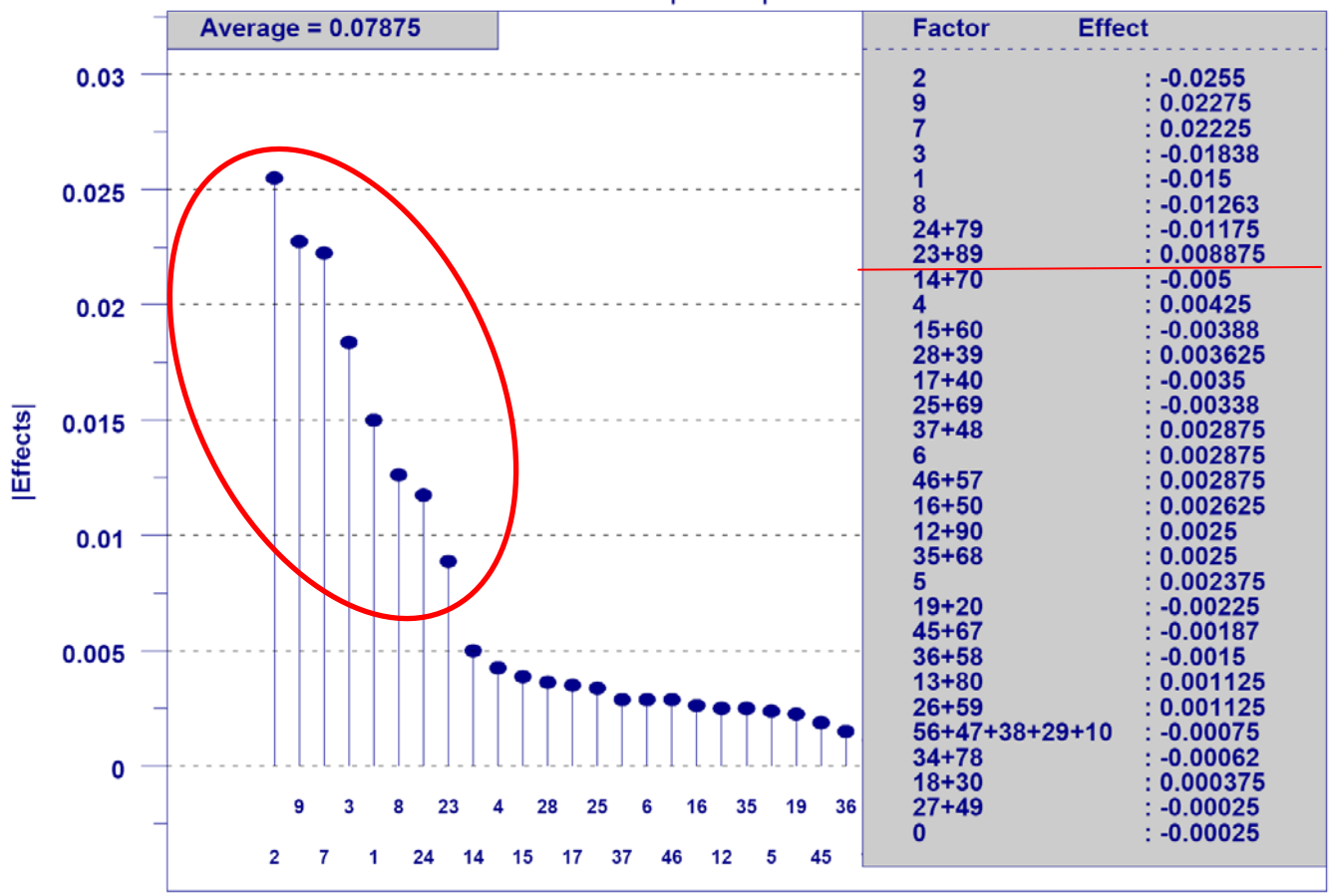

Step 6
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
4. Response = Average Loss Rate per Interval
Youden Plot
k = 10
n = 32
Factor: Confound
Response Y (Average Loss Rate per Interval) for + Setting
Response Y (Average Loss Rate per Interval) for - Setting
0.1
0.09
0.08
0.07
0.06
0.06
0.07
0.08
0.09
0.1
23
14
24
1
3
2
9: 9
23: 23+89
24: 24+79
6: 6
1: 1
3: 3
2: 2
+38+29+10

Step 7

Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)

4. Response = Average Loss Rate per Interval

|Effects| Plot

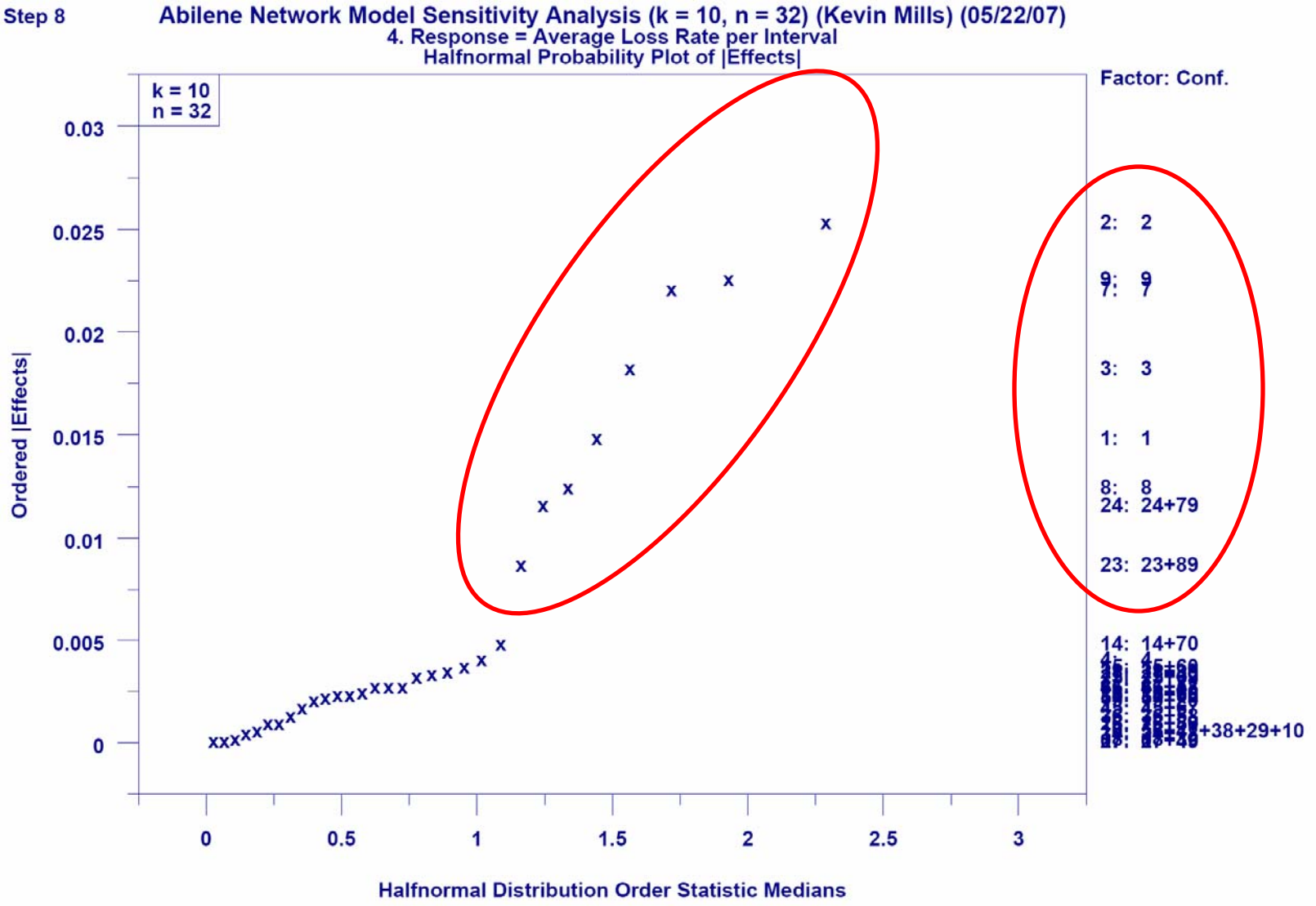


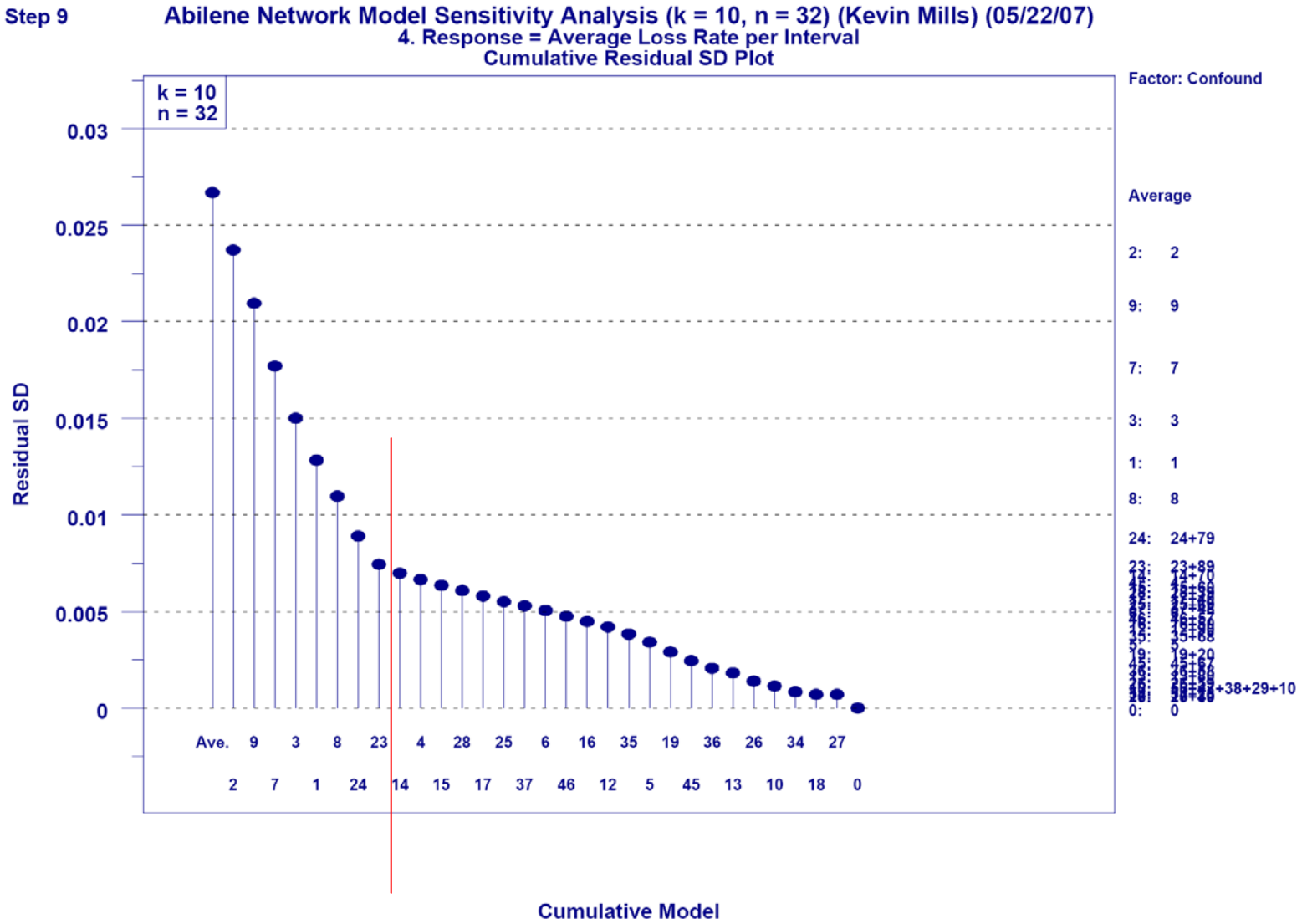
Factor	Effect
2	: -0.0255
9	: 0.02275
7	: 0.02225
3	: -0.01838
1	: -0.015
8	: -0.01263
24+79	: -0.01175
23+89	: 0.008875
14+70	: -0.005
4	: 0.00425
15+60	: -0.00388
28+39	: 0.003625
17+40	: -0.0035
25+69	: -0.00338
37+48	: 0.002875
6	: 0.002875
46+57	: 0.002875
16+50	: 0.002625
12+90	: 0.0025
35+68	: 0.0025
5	: 0.002375
19+20	: -0.00225
45+67	: -0.00187
36+58	: -0.0015
13+80	: 0.001125
26+59	: 0.001125
56+47+38+29+10	: -0.00075
34+78	: -0.00062
18+30	: 0.000375
27+49	: -0.00025
0	: -0.00025

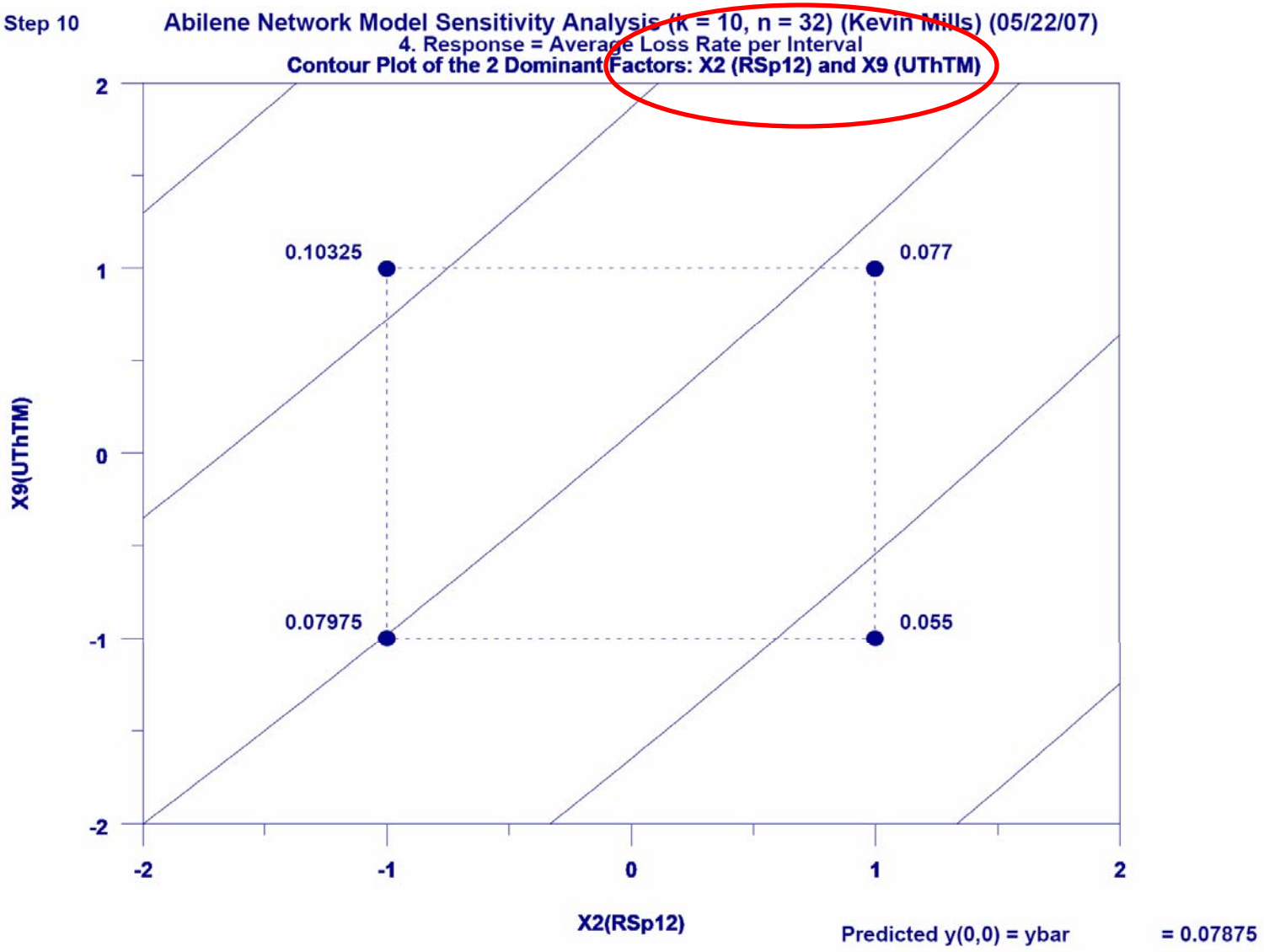
Factor: Confound

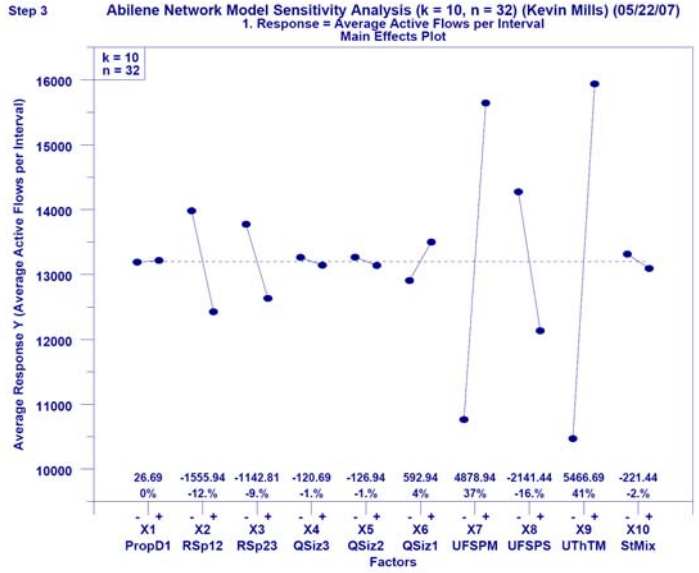
2: 2
9: 9
7: 7
3: 3
1: 1
8: 8
24: 24+79
23: 23+89
14: 14+70
+38+29+10

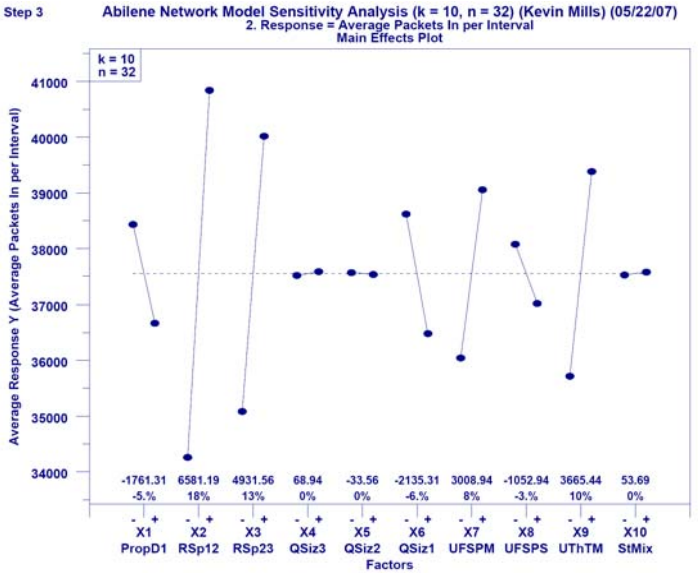
Factor

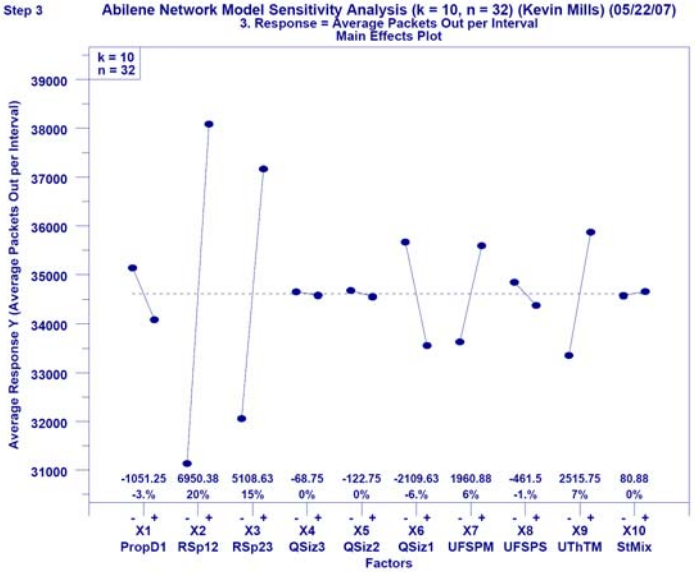

Step 8
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
4. Response = Average Loss Rate per Interval
Halfnormal Probability Plot of |Effects|
k = 10
n = 32
Factor: Conf.
Ordered |Effects|
0.03
0.025
0.02
0.015
0.01
0.005
0
0
0.5
1
1.5
2
2.5
3
Halfnormal Distribution Order Statistic Medians
2: 2
9: 9
7: 7
3: 3
1: 1
8: 8
24: 24+79
23: 23+89
14: 14+70
+38+29+10

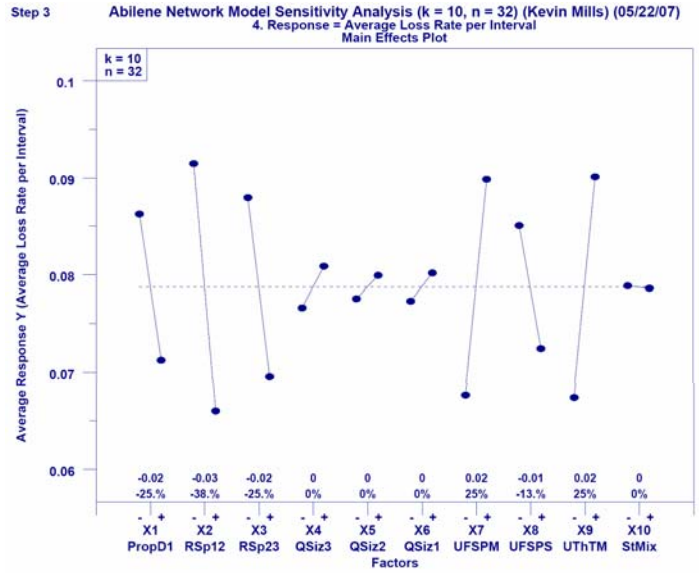

Step 9
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
4. Response = Average Loss Rate per Interval
Cumulative Residual SD Plot
k = 10
n = 32
Residual SD
0.03
0.025
0.02
0.015
0.01
0.005
0
Ave. 9 3 8 23 4 28 25 6 16 35 19 36 26 34 27
2 7 1 24 14 15 17 37 46 12 5 45 13 10 18 0
Cumulative Model
Factor: Confound
Average
2: 2
9: 9
7: 7
3: 3
1: 1
8: 8
24: 24+79
0: 0

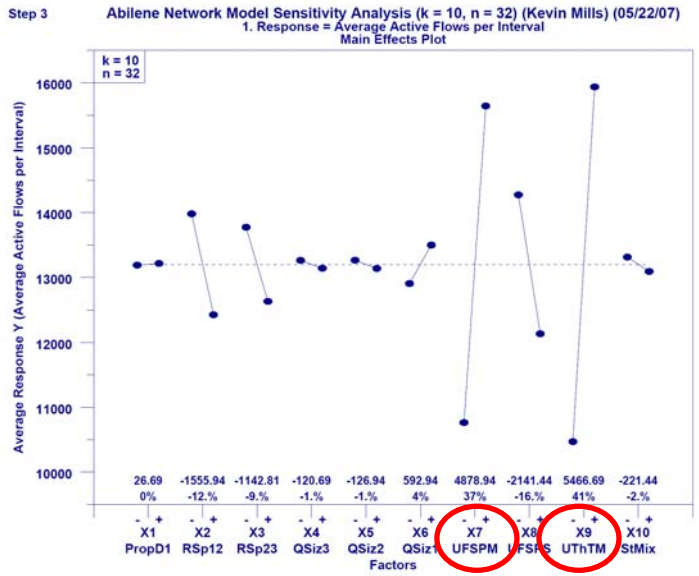

Step 10
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
4. Response = Average Loss Rate per Interval
Contour Plot of the 2 Dominant Factors: X2 (RSp12) and X9 (UThTM)
0.10325
0.077
0.07975
0.055
X9(UThTM)
X2(RSp12)
2
1
0
-1
-2
Predicted y(0,0) = ybar = 0.07875

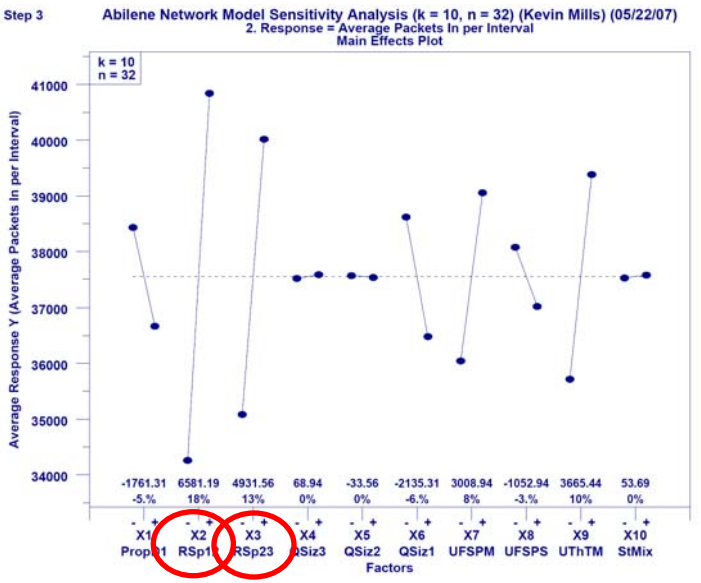

Step 3
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Active Flows per Interval)
16000
15000
14000
13000
12000
11000
10000
26.69 0%
-1555.94 -12.%
-1142.81 -9.%
-120.69 -1.%
-126.94 -1.%
592.94 4%
4878.94 37%
-2141.44 -16.%
5466.69 41%
-221.44 -2.%
X1 PropD1
X2 RSp12
X3 RSp23
X4 QSiz3
X5 QSiz2
X6 QSiz1
X7 UFSPM
X8 UFSPS
X9 UThTM
X10 StMix
Factors

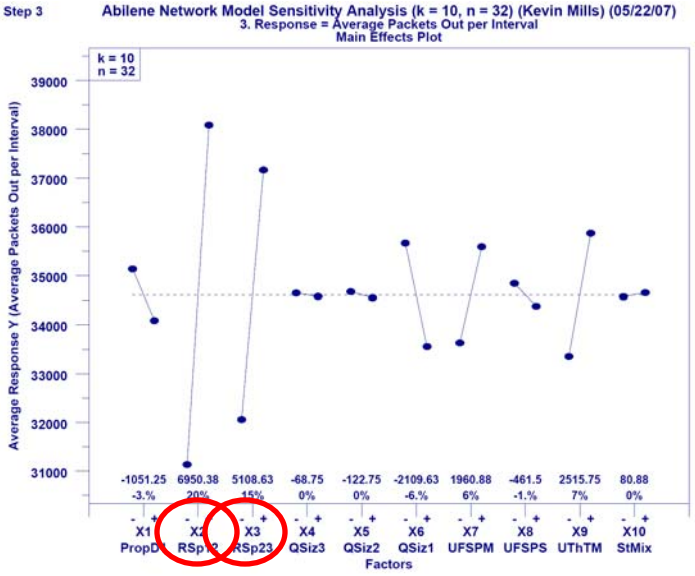

Step 3
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
2. Response = Average Packets In per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Packets In per Interval)
41000
40000
39000
38000
37000
36000
35000
34000
-1761.31 -5.%
6581.19 18%
4931.56 13%
68.94 0%
-33.56 0%
-2135.31 -6.%
3008.94 8%
-1052.94 -3.%
3665.44 10%
53.69 0%
X1 PropD1
X2 RSp12
X3 RSp23
X4 QSiz3
X5 QSiz2
X6 QSiz1
X7 UFSPM
X8 UFSPS
X9 UThTM
X10 StMix
Factors

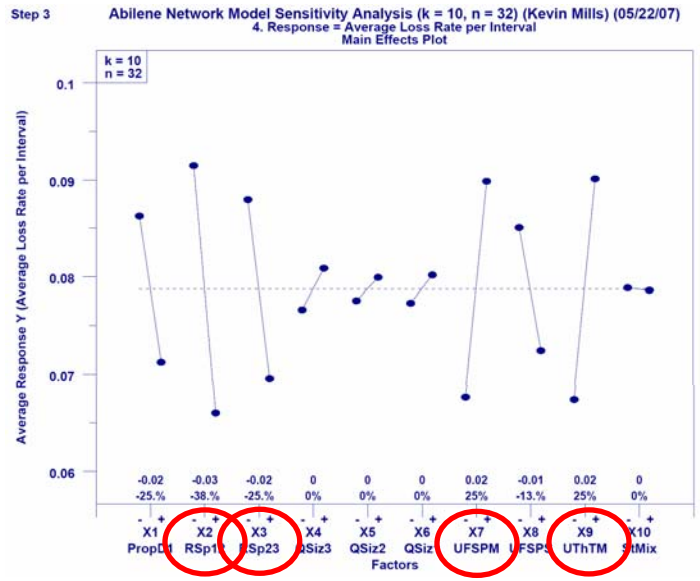

Step 3
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
3. Response = Average Packets Out per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Packets Out per Interval)
39000
38000
37000
36000
35000
34000
33000
32000
31000
-1051.25 -3.%
6950.38 20%
5108.63 15%
-68.75 0%
-122.75 0%
-2109.63 -6.%
1960.88 6%
-461.5 -1.%
2515.75 7%
80.88 0%
X1 PropD1
X2 RSp12
X3 RSp23
X4 QSiz3
X5 QSiz2
X6 QSiz1
X7 UFSPM
X8 UFSPS
X9 UThTM
X10 StMix
Factors


Step 3
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
4. Response = Average Loss Rate per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Loss Rate per Interval)
0.1
0.09
0.08
0.07
0.06
-0.02 -25.%
-0.03 -38.%
-0.02 -25.%
0 0%
0 0%
0 0%
0.02 25%
-0.01 -13.%
0.02 25%
0 0%
X1 PropD1
X2 RSp12
X3 RSp23
X4 QSiz3
X5 QSiz2
X6 QSiz1
X7 UFSPM
X8 UFSPS
X9 UThTM
X10 StMix
Factors


Step 3
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
1. Response = Average Active Flows per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Active Flows per Interval)
16000
15000
14000
13000
12000
11000
10000
26.69 0%
-1555.94 -12.%
-1142.81 -9.%
-120.69 -1.%
-126.94 -1.%
592.94 4%
4878.94 37%
-2141.44 -16.%
5466.69 41%
-221.44 -2.%
X1 PropD1
X2 RSp12
X3 RSp23
X4 QSiz3
X5 QSiz2
X6 QSiz1
X7 UFSPM
X8
X9 UThTM
X10 StMix
Factors


Step 3
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
2. Response = Average Packets In per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Packets In per Interval)
41000
40000
39000
38000
37000
36000
35000
34000
-1761.31 -5.%
6581.19 18%
4931.56 13%
68.94 0%
-33.56 0%
-2135.31 -6.%
3008.94 8%
-1052.94 -3.%
3665.44 10%
53.69 0%
X1
X2 RSp1
X3 RSp23
X4 QSiz3
X5 QSiz2
X6 QSiz1
X7 UFSPM
X8 UFSPS
X9 UThTM
X10 StMix
Factors


Step 3
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
3. Response = Average Packets Out per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Packets Out per Interval)
39000
38000
37000
36000
35000
34000
33000
32000
31000
-1051.25 -3.%
6950.38 20%
5108.63 15%
-68.75 0%
-122.75 0%
-2109.63 -6.%
1960.88 6%
-461.5 -1.%
2515.75 7%
80.88 0%
X1
X2
X3 RSp23
X4 QSiz3
X5 QSiz2
X6 QSiz1
X7 UFSPM
X8 UFSPS
X9 UThTM
X10 StMix
Factors


Step 3
Abilene Network Model Sensitivity Analysis (k = 10, n = 32) (Kevin Mills) (05/22/07)
4. Response = Average Loss Rate per Interval
Main Effects Plot
k = 10
n = 32
Average Response Y (Average Loss Rate per Interval)
0.1
0.09
0.08
0.07
0.06
-0.02 -25.%
-0.03 -38.%
-0.02 -25.%
0 0%
0 0%
0 0%
0.02 25%
-0.01 -13.%
0.02 25%
0 0%
X1
X2 RSp1
X3 RSp23
X4 QSiz3
X5 QSiz2
X6 QSiz
X7 UFSPM
X8
X9 UThTM
X10
Factors

Conclusion

1. *Network Goal: insight & understanding*
2. *Structured Stat approach provides a path for network science*
3. *DEX is critically important component*
4. *To achieve insight: Step 1= Sensitivity Analysis*
5. *2^{k-p} fractional factorial designs potent & efficient*
6. *Insight: Flows from accompanying 10-step graphical analysis*