BAYESIALAB

Key Drivers Analysis & Optimization Based on Consumer Survey Data

BAYESIALAB

Hello

my name is

Stefan Conrady

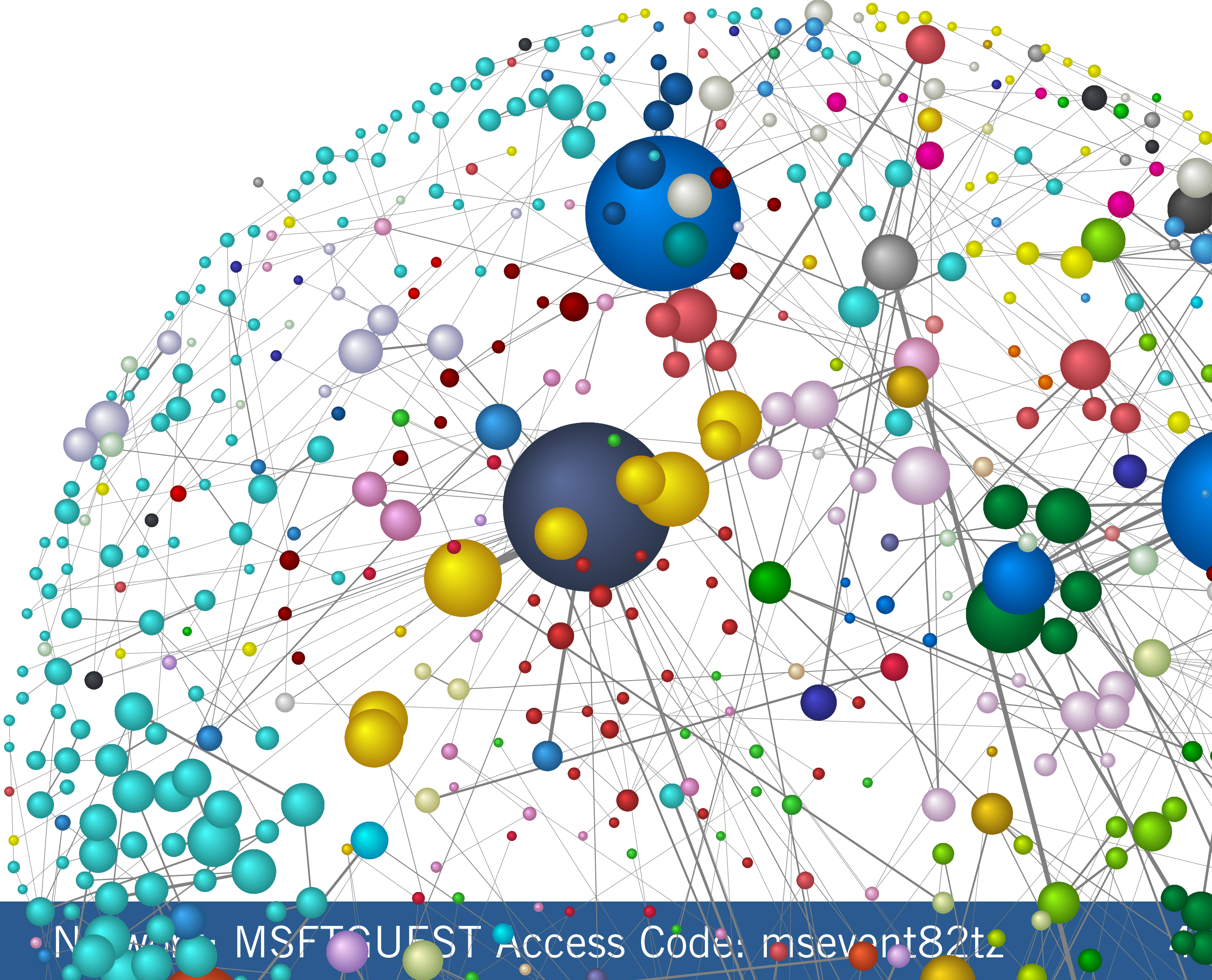
BAYESIA

Your Decision Partner

Co-founded in 2001

by Dr. Lionel Jouffe &

Dr. Paul Munteanu

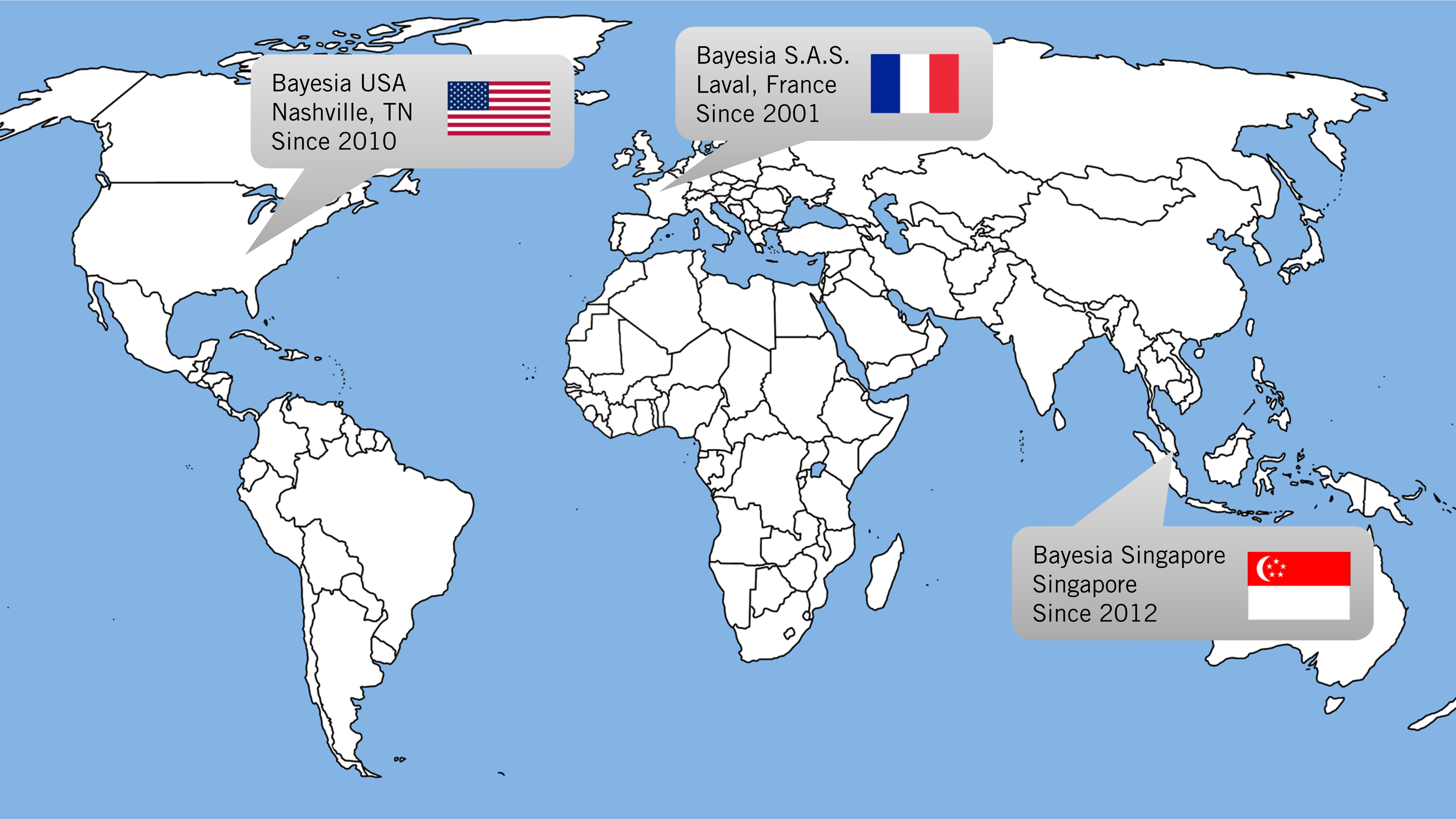


stefan.conrady@bayesia.us

Network: MSFTGUEST Access Code: msevent82tz

The BayesiaLab Software Platform

U.S. ARMY
NASA
Booz | Allen | Hamilton
Georgetown University
Dassault Aviation
The pert Group
Lockheed Martin
bp
La Poste
ArcelorMittal
groupm
WPP
gsk GlaxoSmithKline
University of Virginia
Renault
sodexo
Unilever
DELL
Lilly
Mu Sigma DO THE MATH
EADS
Holiday Inn
SONY
IHG InterContinental Hotels Group
synovate Research reinvented
SOCIETE GENERALE
STANFORD UNIVERSITY
BBDO
HYATT
GfK
Nestlé
Fractal
NTT
MAi
Firmenich
National Analysts Worldwide Research & Consulting
SAMSUNG
france telecom
Rutgers
Cargill
eDF
Ipsos
McGill
SNCF
P&G
CDC
eni
Hilton Hotels & Resorts
Lancaster University
VirginiaTech Invent the Future
orange
AIRBUS
NISSAN
DGA
SAINT-GOBAIN
tns
PDK
IMRB international
Rush University
Microsoft
VA
Team Detroit
sanofi pasteur
Smucker's
MillwardBrown
American Diabetes Association. Cure • Care • Commitment
PENNSTATE
ACXIOM
Deloitte.
cancer care ontario | action cancer ontario
UCLA
L'ORÉAL
Rotman University of Toronto
intel
AIRFRANCE
Neiman Marcus
repères
Vanderbilt University
TOTAL
SAFRAN Turbomeca
PSA PEUGEOT CITROËN
MED SOLUTION
LSU Louisiana State University
nielsen
OmnicomGroup
Capgemini


Bayesia USA
Nashville, TN
Since 2010
Bayesia S.A.S.
Laval, France
Since 2001
Bayesia Singapore
Singapore
Since 2012

Seminar Series

2016/17 BayesiaLab Lecture Program

- Marketing Mix Modeling and Optimization
- **Key Drivers Analysis and Optimization**
- Knowledge Elicitation and Reasoning
- Bayesian Networks—Artificial Intelligence for Research, Analytics, and Reasoning

Today's Agenda

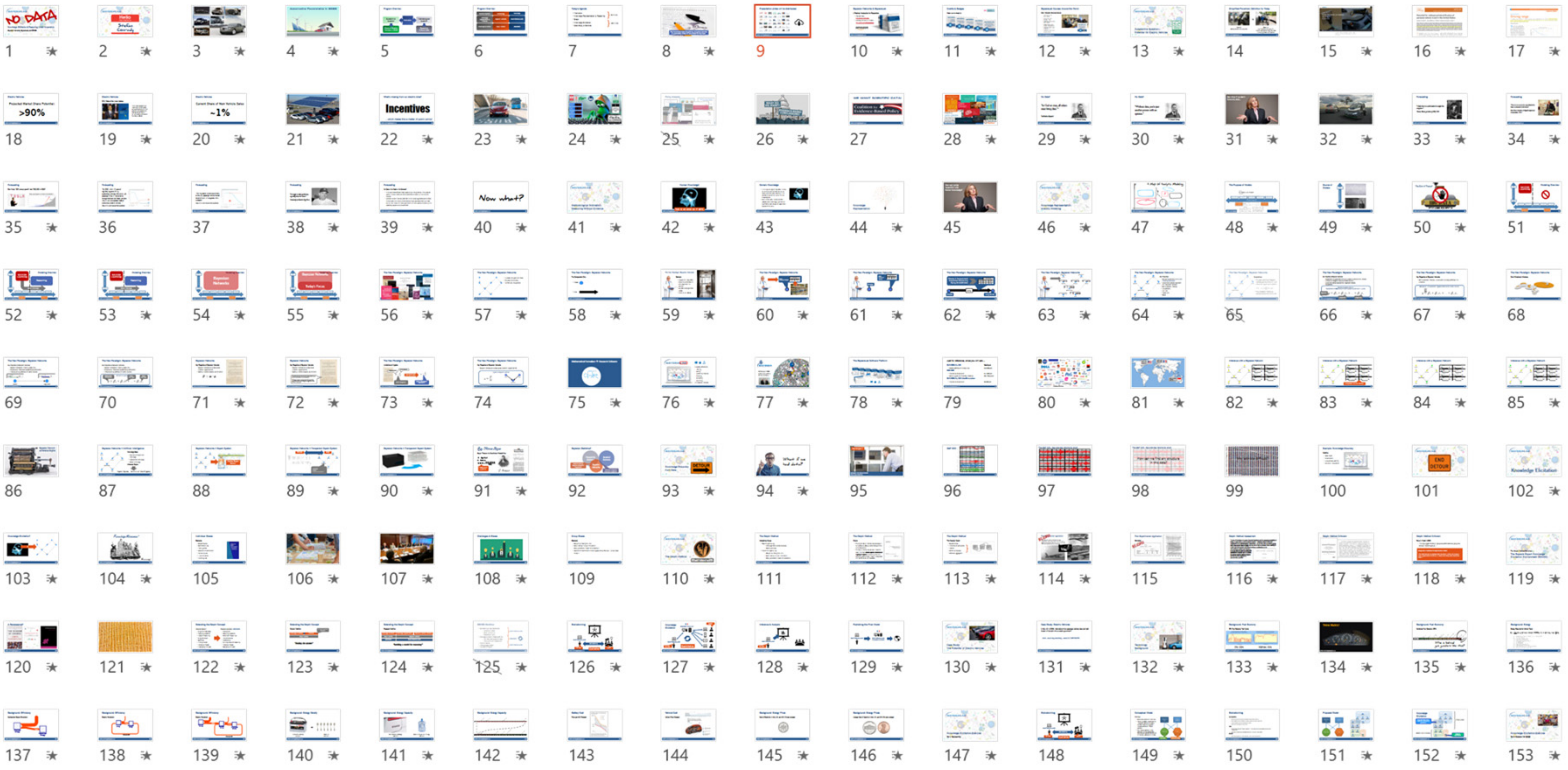
- An Overview of Analytic Modeling
- The Bayesian Network Paradigm
- Key Drivers Analysis
    - Conceptual Challenges
    - Statistical Challenges
- Case Study: Auto Buyer Satisfaction Survey
    - Building a Probabilistic Structural Equation Model for Key Driver Analysis with BayesiaLab
    - Optimization of Key Drivers

1 hour

1 hour

1.5 hours

Presentation slides will be available



Bayesian Networks & BayesiaLab

A Practical Introduction for Researchers

- Free download: www.bayesia.com/book
- Hardcopy available on Amazon: http://amzn.com/0996533303

Credits & Badges

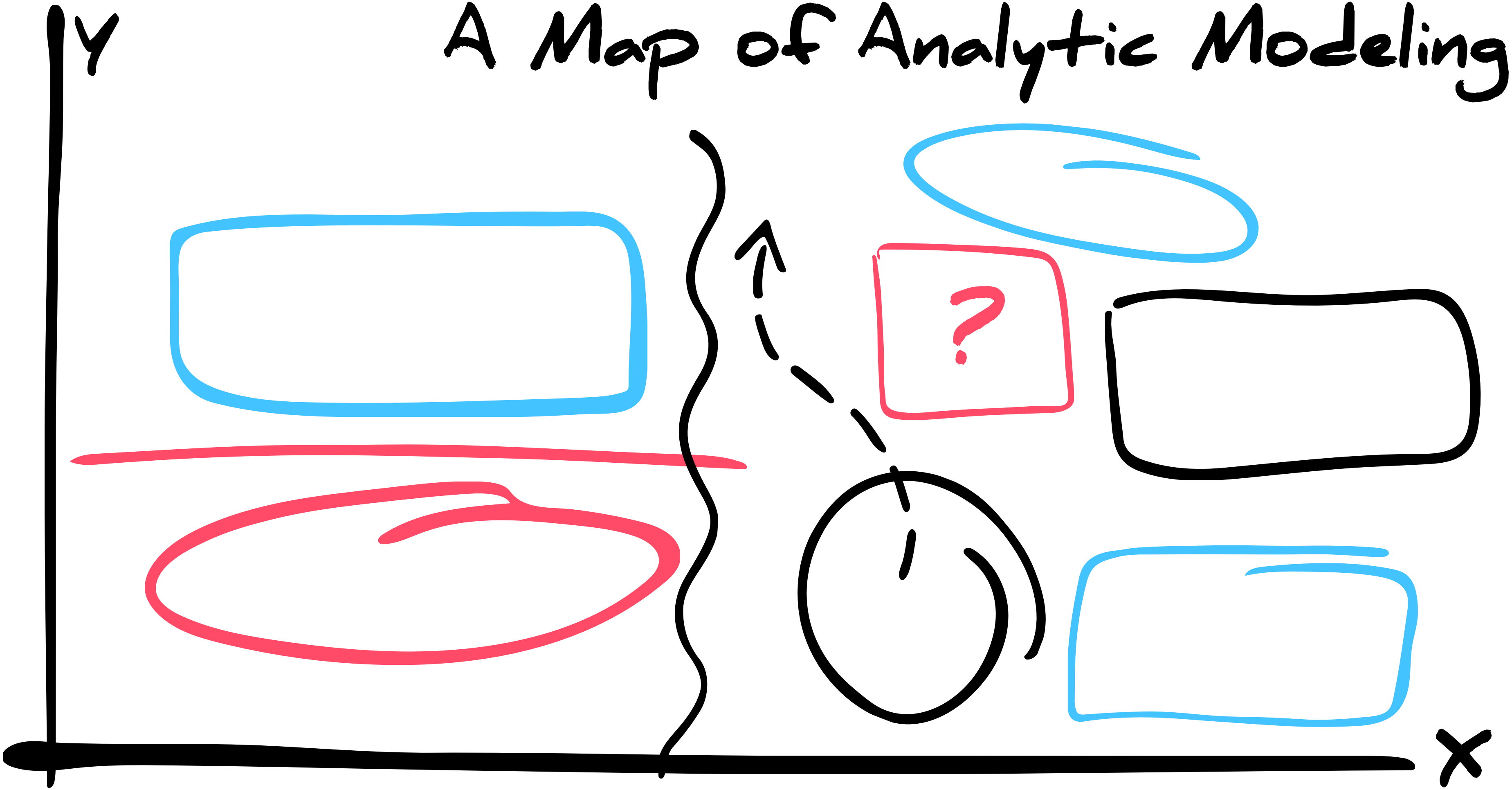
Make sure to check in!

BayesiaLab Courses Around the World

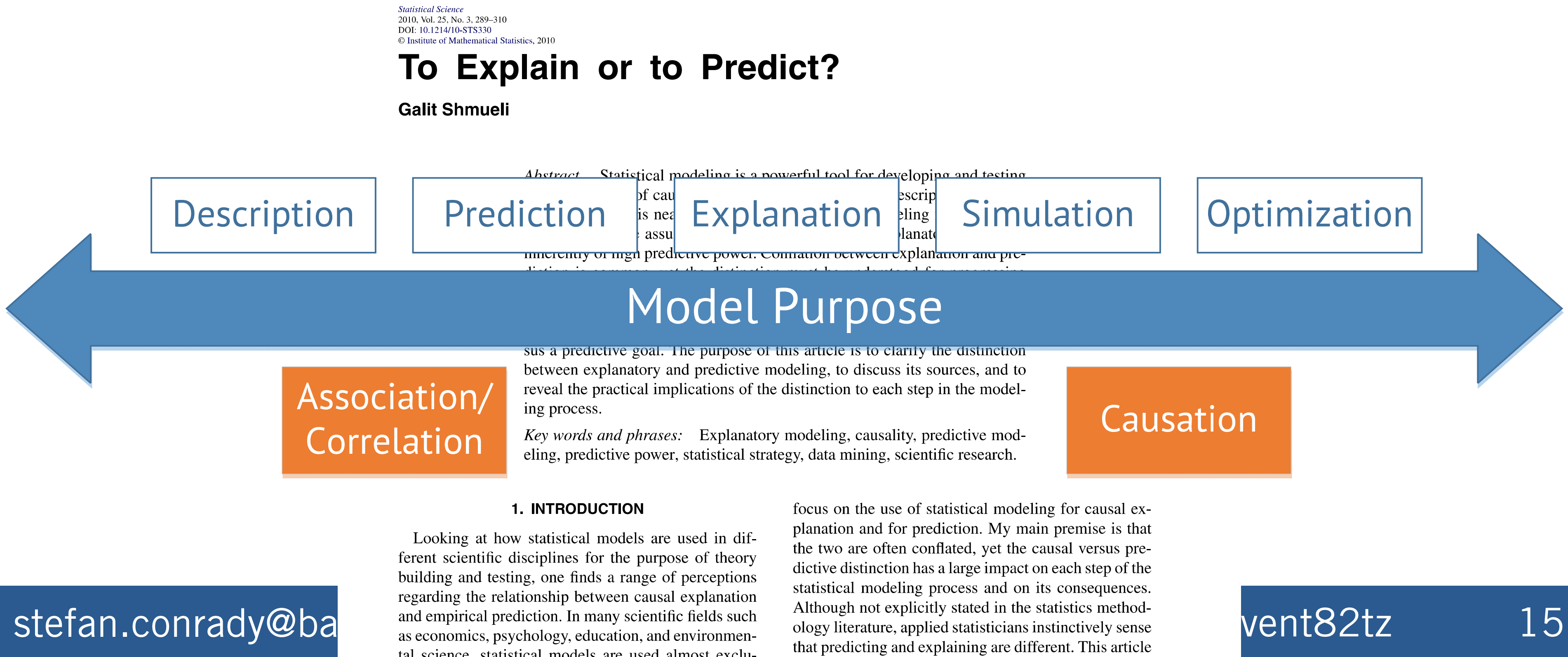
3-Day Introductory BayesiaLab Courses

- June 13-15, 2017
  Paris, France
- June 27-29, 2017
  Chicago, Illinois
- September 6-8, 2017
  Redmond, Washington
- September 25-27, 2017
  Paris, France
- October 24-26, 2017
  Durham, North Carolina
- November 20–22, 2017
  Singapore
- November 27–29, 2017
  Sydney, Australia

A Map of Analytic Modeling



The Purpose of Models


Statistical Science
2010, Vol. 25, No. 3, 289–310
DOI: 10.1214/10-STS330

To Explain or to Predict?

Galit Shmueli

Abstract. Statistical modeling is a powerful tool for developing and testing ... of cau ... escrip ... is nea ... eling ... assu ... lanat ... inherently of high predictive power. Conflation between explanation and pre- diction is common, yet the distinction must be understood for progressing ... sus a predictive goal. The purpose of this article is to clarify the distinction between explanatory and predictive modeling, to discuss its sources, and to reveal the practical implications of the distinction to each step in the model- ing process.

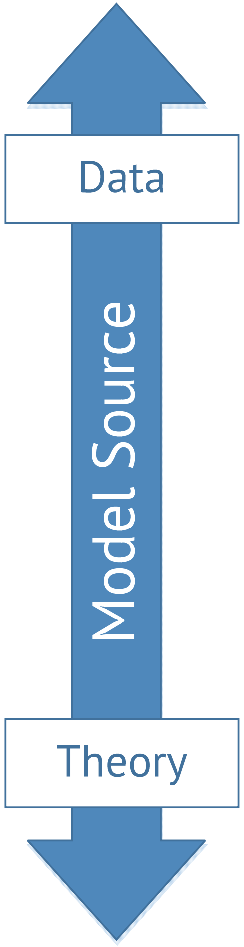
Key words and phrases: Explanatory modeling, causality, predictive mod- eling, predictive power, statistical strategy, data mining, scientific research.

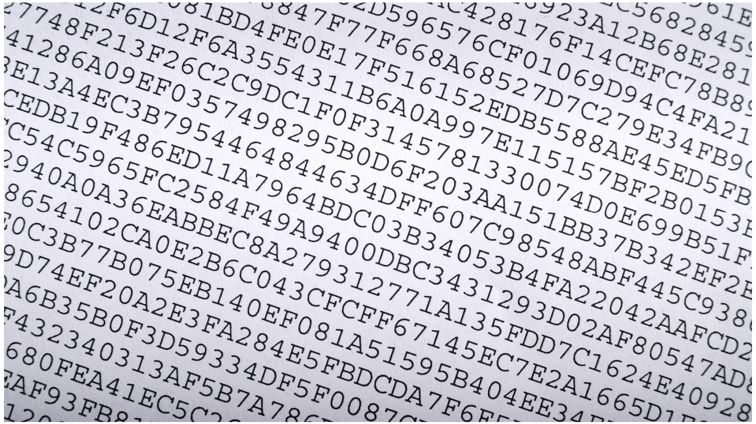
1. INTRODUCTION

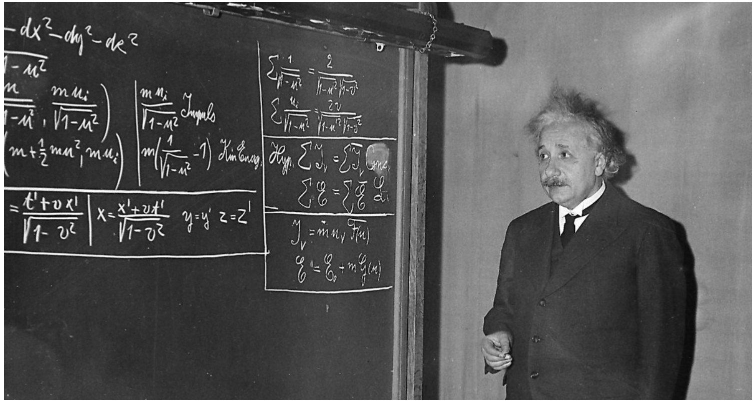
Looking at how statistical models are used in dif- ferent scientific disciplines for the purpose of theory building and testing, one finds a range of perceptions regarding the relationship between causal explanation and empirical prediction. In many scientific fields such as economics, psychology, education, and environmen- tal science, statistical models are used almost exclu-

focus on the use of statistical modeling for causal ex- planation and for prediction. My main premise is that the two are often conflated, yet the causal versus pre- dictive distinction has a large impact on each step of the statistical modeling process and on its consequences. Although not explicitly stated in the statistics method- ology literature, applied statisticians instinctively sense that predicting and explaining are different. This article

Source of Models

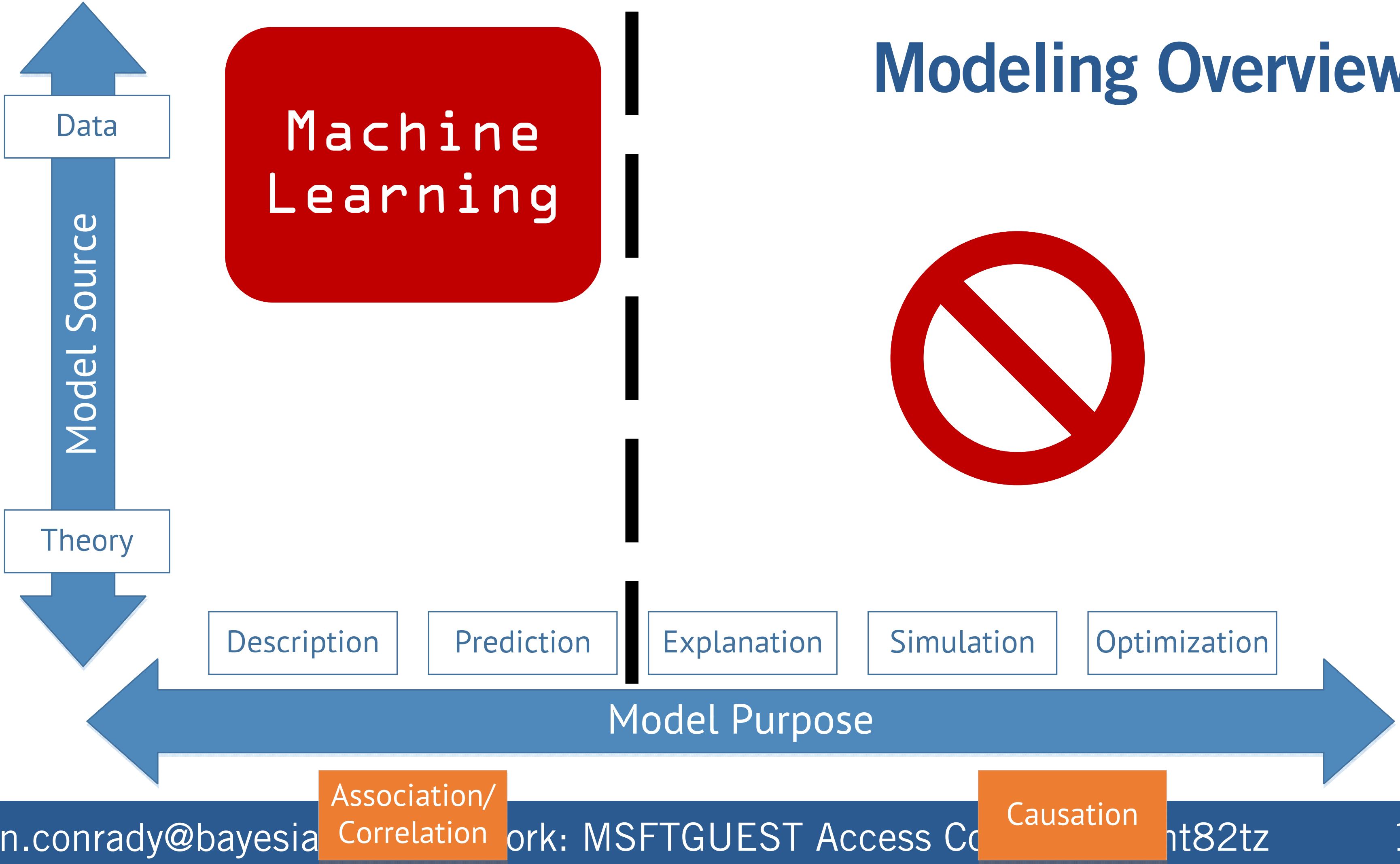






The End of Theory?

Modeling Overview



Why does this matter?

Key Drivers Analysis & Optimization Based on Consumer Opinion Survey Data

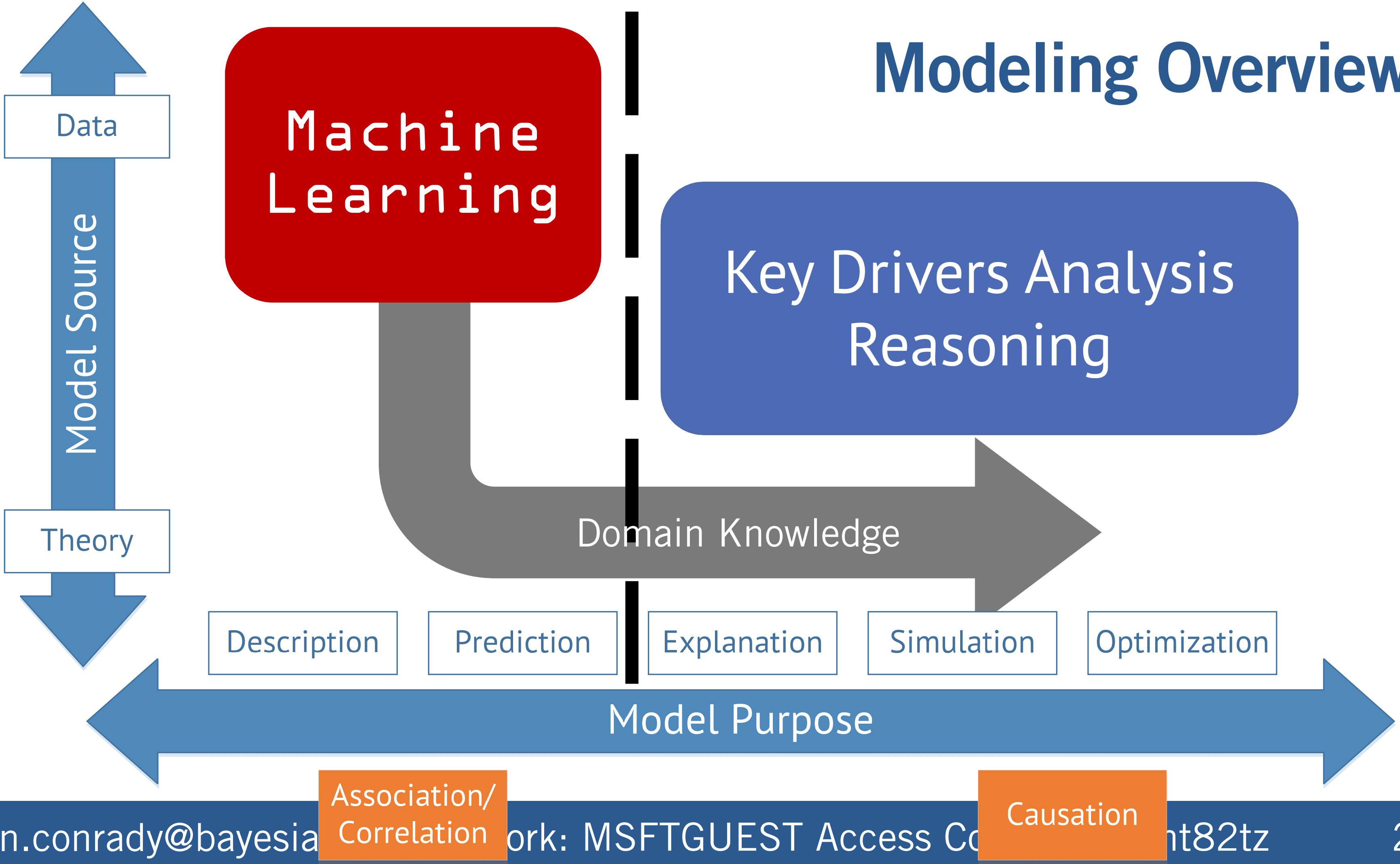
A Definition:

"A key driver analysis investigates the relationships between potential drivers and customer behavior such as the likelihood of a positive recommendation, overall satisfaction, or propensity to buy a product."

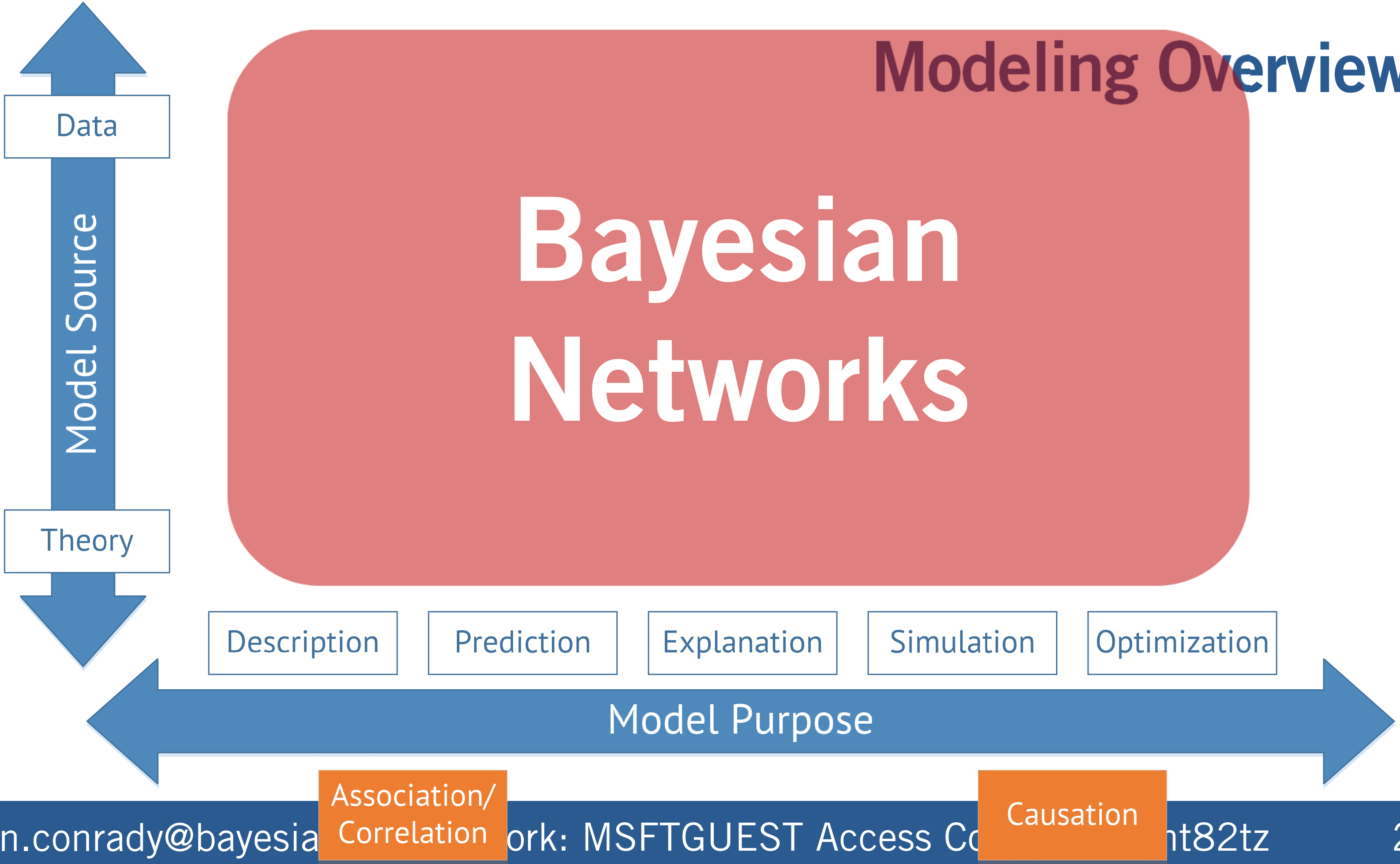
Source: https://select-statistics.co.uk/blog/key-driver-analysis/

select
statistical services

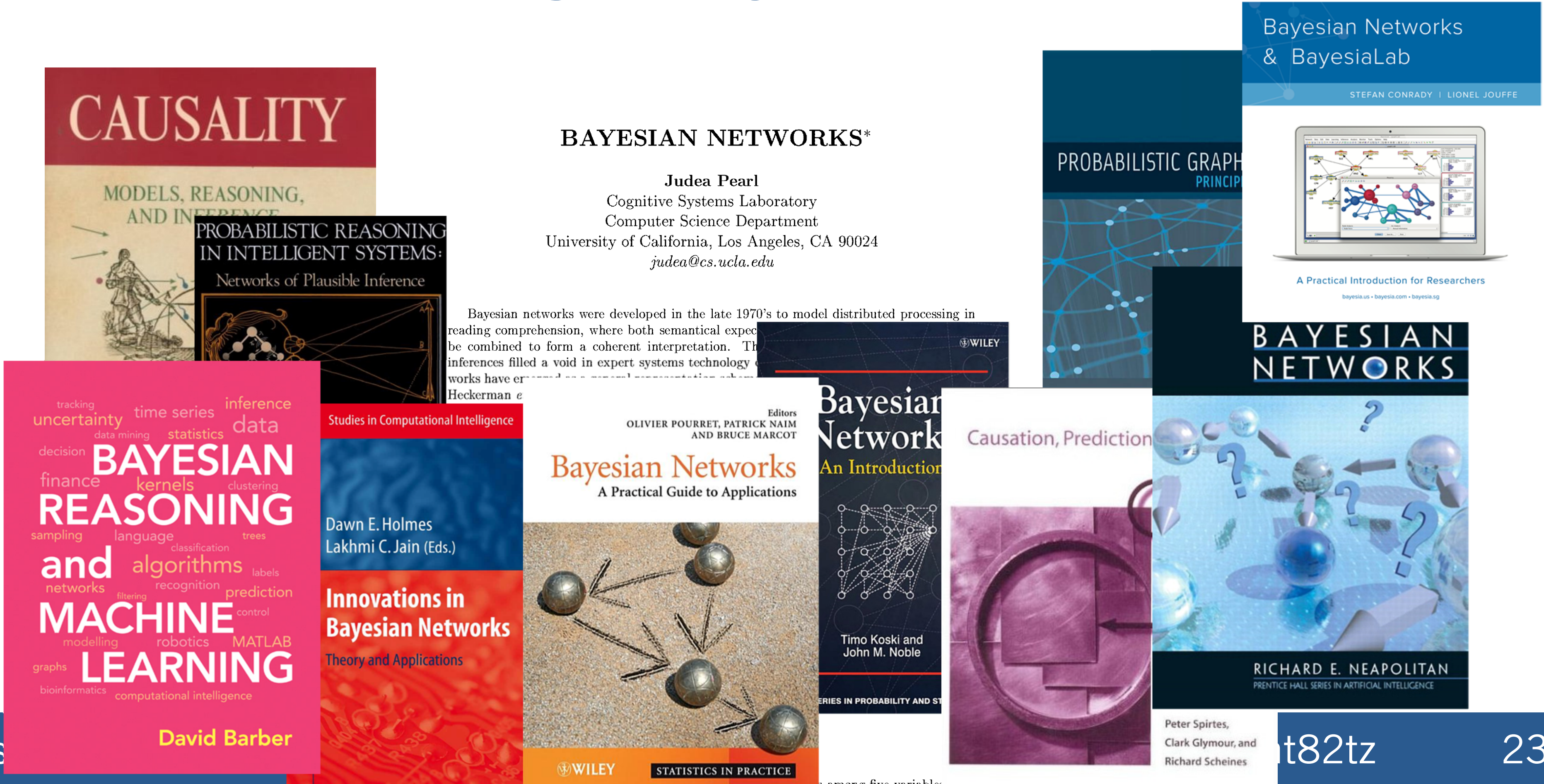
Modeling Overview



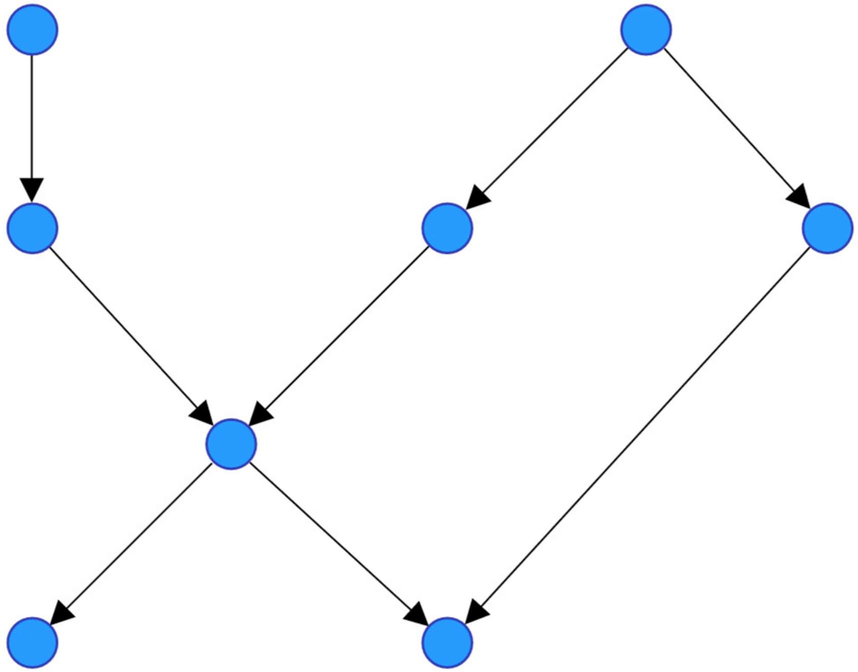
Modeling Overview



The New Paradigm: Bayesian Networks



The New Paradigm: Bayesian Networks



- A probabilistic graphical model.
- The graph is the model.
- No formulas, no equations!

The New Paradigm: Bayesian Networks

Two Components Only:

- Node 

- Arc 

The New Paradigm: Bayesian Networks

Example

- A specialist in respiratory medicine summarizes his knowledge about his patients.
- Lauritzen & Spiegelhalter (1988)
- Fenton & Neil (2013)

The New Paradigm: Bayesian Networks

Node:
Variable of Interest

Smoker	
TRUE	FALSE
50%	50%

The New Paradigm: Bayesian Networks

Node:
Variable of
Interest

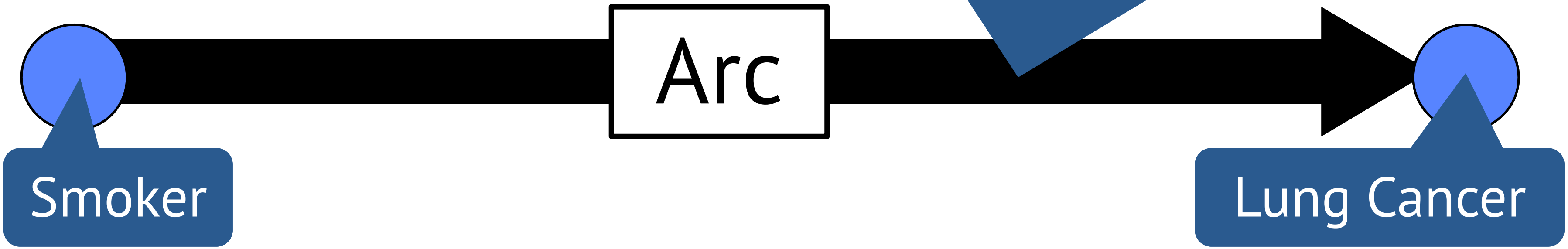
Lung Cancer	
TRUE	FALSE
5.5%	94.5%

Smoker

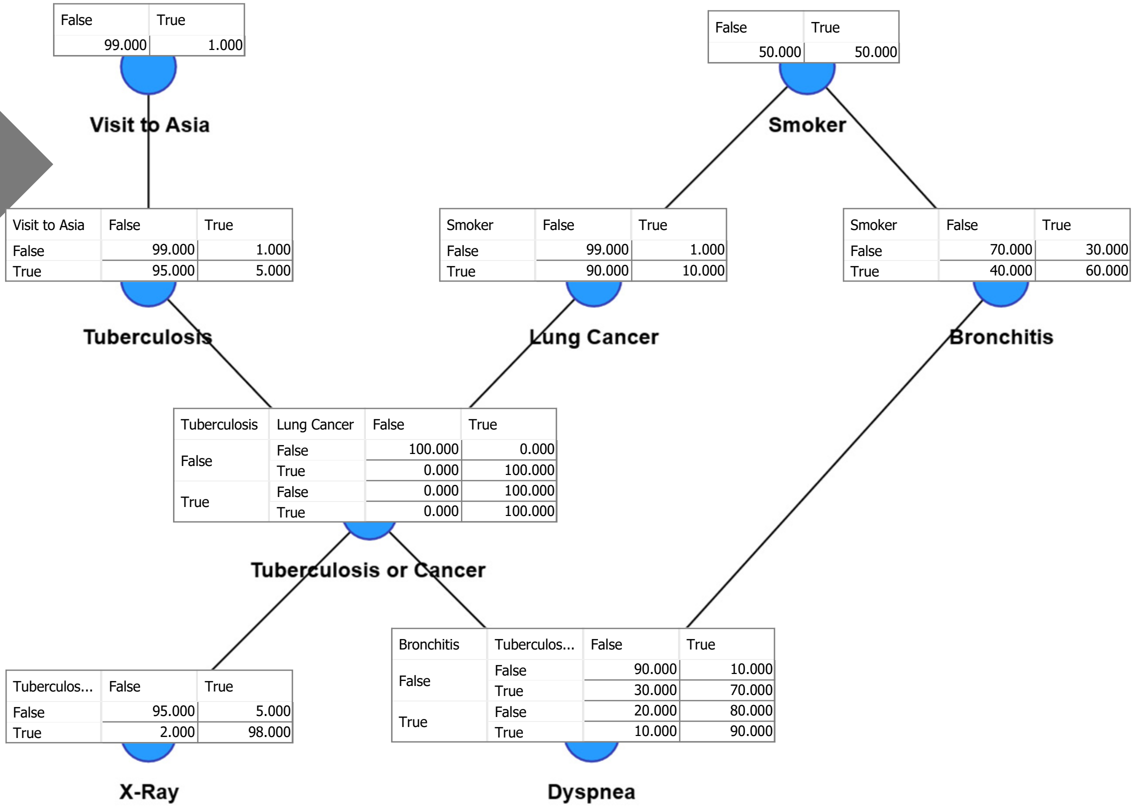
The New Paradigm: Bayesian Networks

Discrete & Nonparametric
Probabilistic Relationship
P(Lung Cancer|Smoker)

	Lung Cancer	
Smoker	FALSE	TRUE
FALSE	99%	1%
TRUE	90%	10%



The New Paradigm: Bayesian Networks



False	True
99.000	1.000

False	True
50.000	50.000

Visit to Asia	False	True
False	99.000	1.000
True	95.000	5.000

Smoker	False	True
False	99.000	1.000
True	90.000	10.000

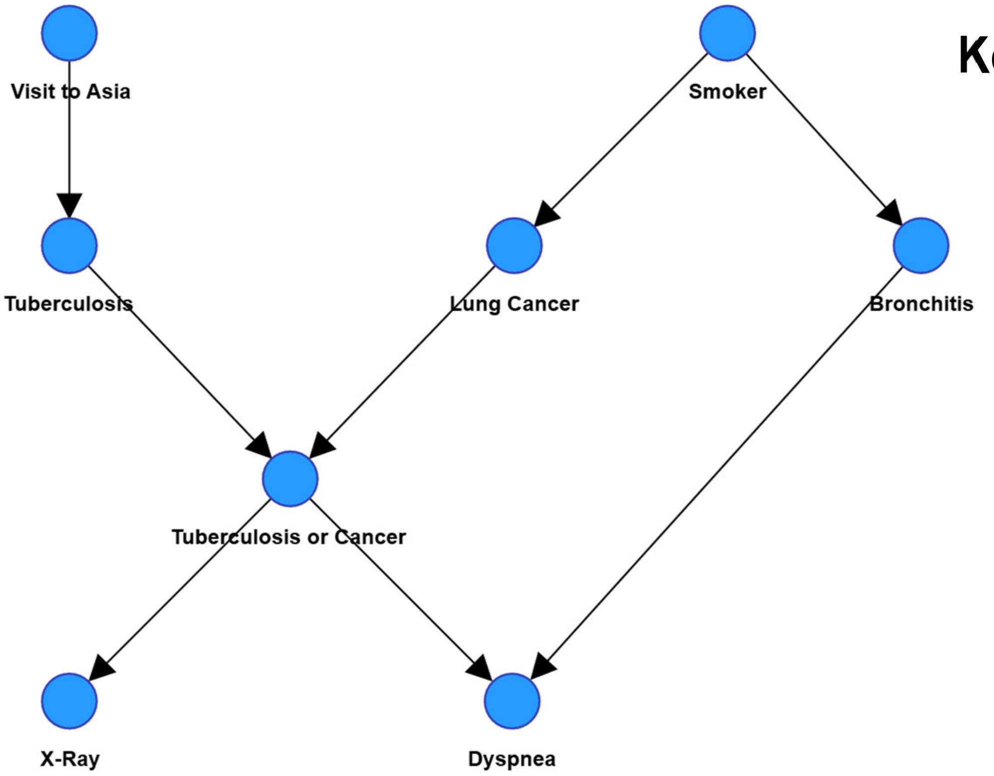
Smoker	False	True
False	70.000	30.000
True	40.000	60.000

Tuberculosis	Lung Cancer	False	True
False	False	100.000	0.000
	True	0.000	100.000
True	False	0.000	100.000
	True	0.000	100.000

Tuberculos...	False	True
False	95.000	5.000
True	2.000	98.000

Bronchitis	Tuberculos...	False	True
False	False	90.000	10.000
	True	30.000	70.000
True	False	20.000	80.000
	True	10.000	90.000

The New Paradigm: Bayesian Networks



Key Properties

- Compact representation of the **Joint Probability Distribution**
- No distinction between dependent and independent variables
- Omni-directional Inference
- Nonparametric
- Nonlinear
- Probabilistic
- Causal

The New Paradigm: Bayesian Networks

Key Properties of Bayesian Networks

- Representation (or approximation) of the joint probability distribution of all variables.
- Numerical and categorical variables are treated identically.
- No distinction between dependent and independent variables.
- Nonparametric.

Compare to algebraic formula:
Representation of **one** variable of the joint probability distribution, i.e. y=f(x)

Dependent

$$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n$$

Independent

Independent

The New Paradigm: Bayesian Networks

Key Properties of Bayesian Networks

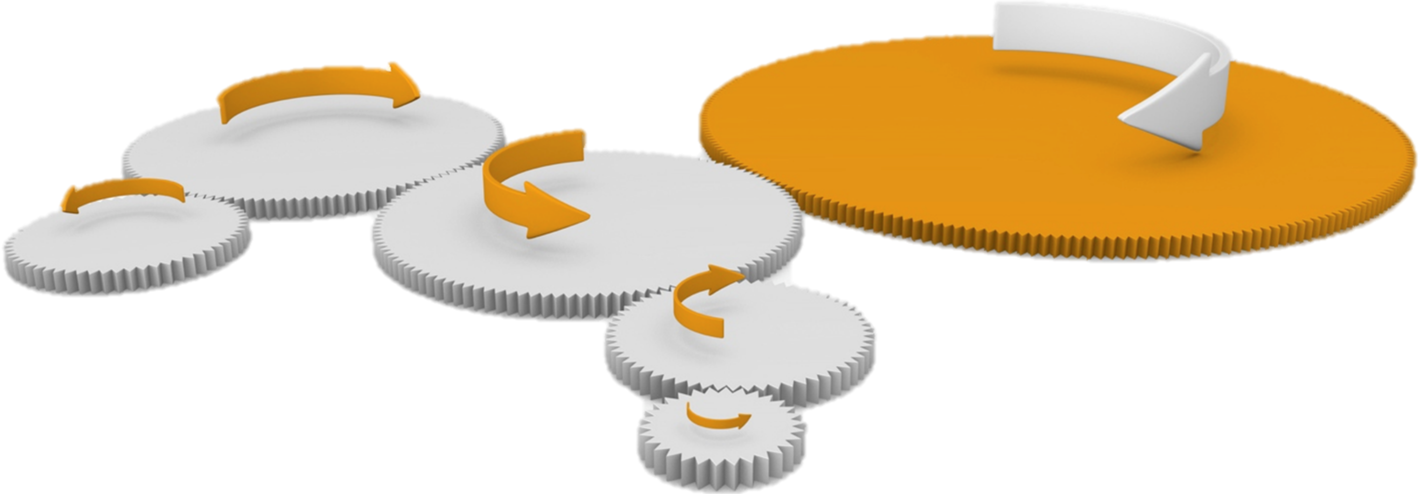
- Omni-directional Inference, i.e. evaluation is always performed in all directions.

Compare to "uni-directional" algebraic formula and human intuition

$$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n$$

The New Paradigm: Bayesian Networks

Omni-Directional Inference



The New Paradigm: Bayesian Networks

Key Properties of Bayesian Networks

- Bayesian networks are inherently probabilistic.
- Evidence and inference are represented as distributions.
- Inference can be performed with partial evidence.

The New Paradigm: Bayesian Networks

Key Properties of Bayesian Networks

- Bayesian networks are inherently probabilistic.
- Evidence and inference are represented by distributions.
- Inference can be performed with partial evidence.

Compare to algebra

Deterministic Point Estimate

Single Value Input

Single Value Input

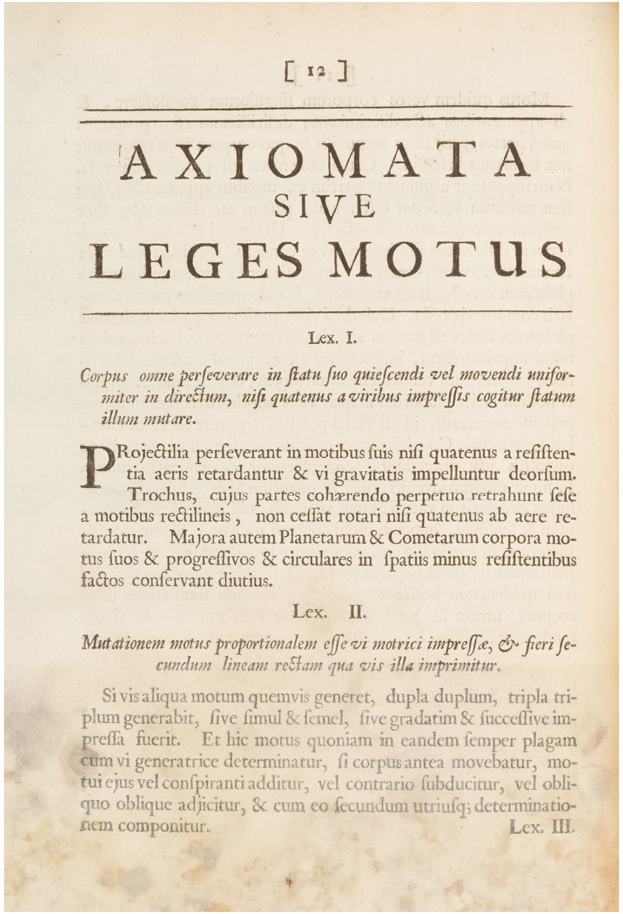
$$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n$$

Bayesian Networks

Key Properties of Bayesian Networks

- Bayesian networks can encode causal direction, algebra cannot.
- Example: Newton's Second Law of Motion

$$F = m \cdot a$$



[12]

AXIOMATA
SIVE
LEGES MOTUS

Lex. I.

Corpus omne perſeverare in ſtatu ſuo quieſcendi vel movendi uniformiter in directum, niſi quatenus a viribus impreſſis cogitur ſtatum illum mutare.

Projectilia perſeverant in motibus ſuis niſi quatenus a reſiſtentia aeris retardantur & vi gravitatis impelluntur deorſum. Trochus, cujus partes cohærendo perpetuo retrahunt ſeſe a motibus rectilineis, non ceſſat rotari niſi quatenus ab aere retardatur. Majora autem Planetarum & Cometarum corpora motus ſuos & progreſſivos & circulares in ſpatiis minus reſiſtentibus factos conſervant diutius.

Lex. II.

Mutationem motus proportionalem eſſe vi motrici impreſſæ, & fieri ſecundum lineam rectam qua vis illa imprimitur.

Si vis aliqua motum quemvis generet, dupla duplum, tripla triplum generabit, ſive ſimul & ſemel, ſive gradatim & ſucceſſive impreſſa fuerit. Et hic motus quoniam in eandem ſemper plagam cum vi generatrice determinatur, ſi corpus antea movebatur, motui ejus vel conſpiranti additur, vel contrario ſubducitur, vel oblique adjicitur, & cum eo ſecundum utriuſq; determinationem componitur.

Lex. III.

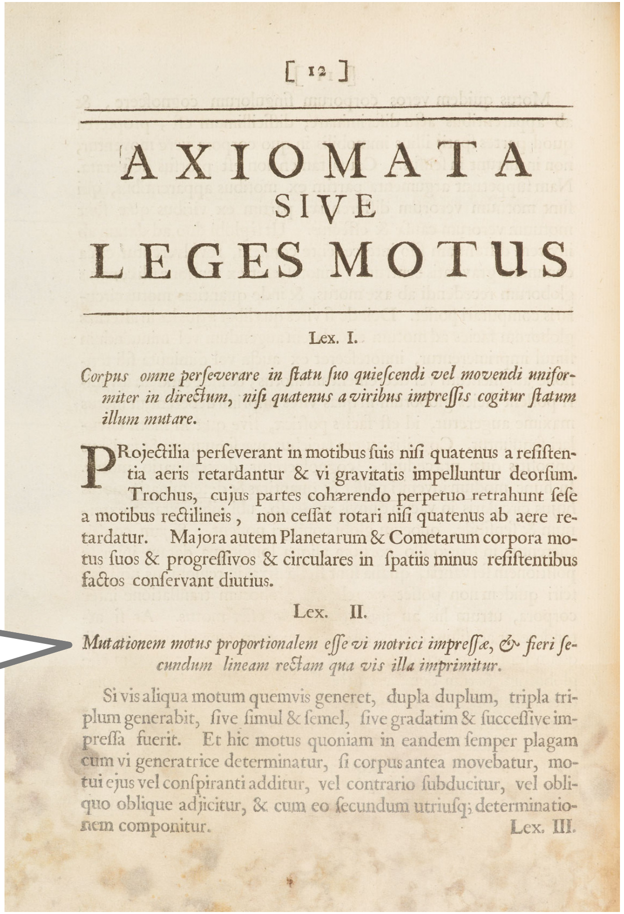
Bayesian Networks

Key Properties of Bayesian Networks

- Bayesian networks can encode causal direction, algebra cannot.
- Example: Newton's Second Law of Motion

"Mutationem motus proportionalem esse vi motrici impressæ, & fieri secundum lineam rectam qua vis illa imprimitur."

"A change in motion is proportional to the motive force impressed and takes place along the straight line in which that force is impressed."



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AXIOMATA
SIVE
LEGES MOTUS

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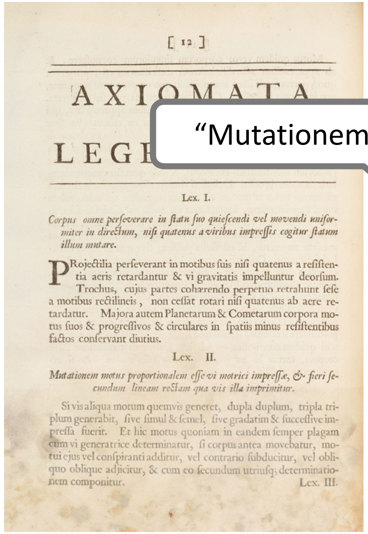
Lex. III.

The New Paradigm: Bayesian Networks

Limitations of Algebra



[12]

AXIOMATA

LEGE

Lex. I.

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Lex. III.

"Mutationem motus"

"vi motrici impressae"

$$a = \frac{F}{m}$$

Causal Assignment

solving for *mass*

$$m = \frac{F}{a}$$

Causal Interpretation
Not Possible

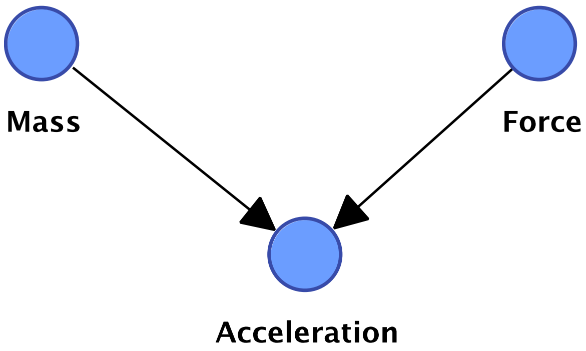
The New Paradigm: Bayesian Networks

Key Properties of Bayesian Networks

- Bayesian networks can encode causal direction, algebra cannot.

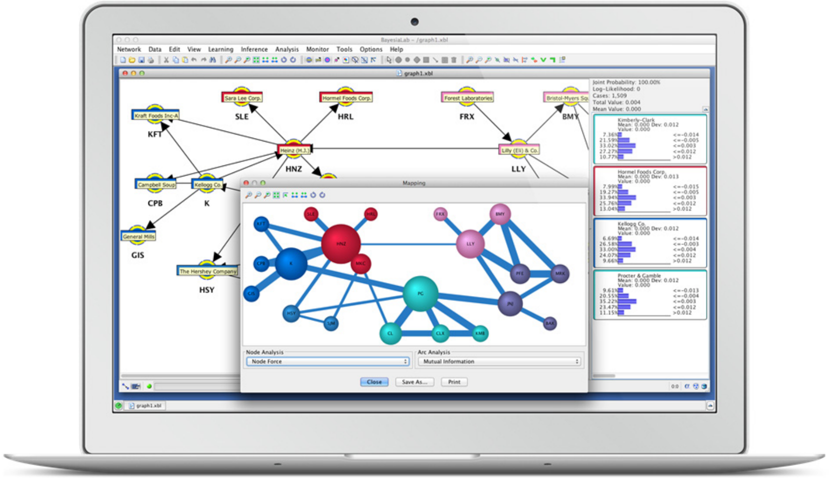
Algebra vs. Bayesian Network

$$a = \frac{F}{m}$$

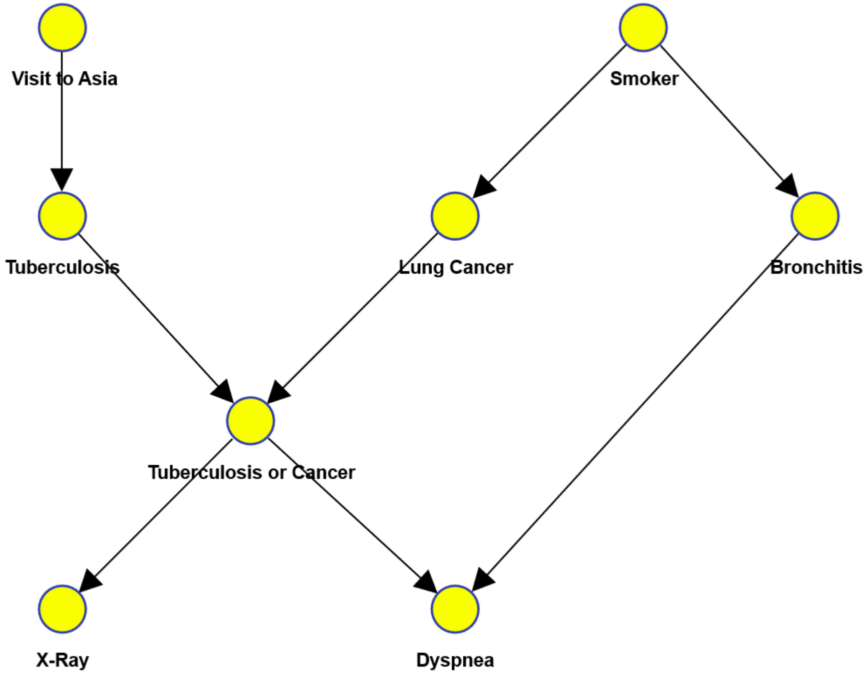


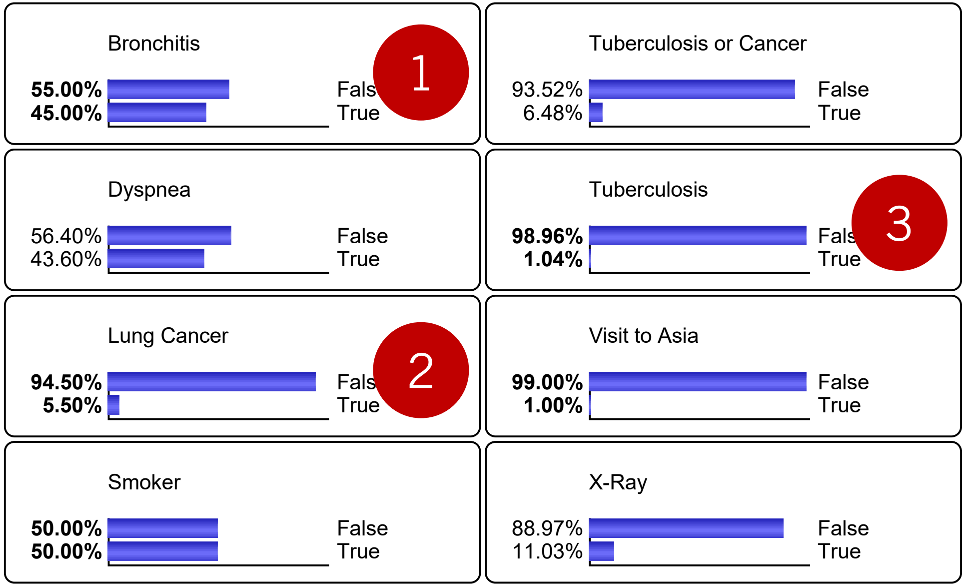

QUESTIONS

Inference with a Bayesian Network & BayesiaLab

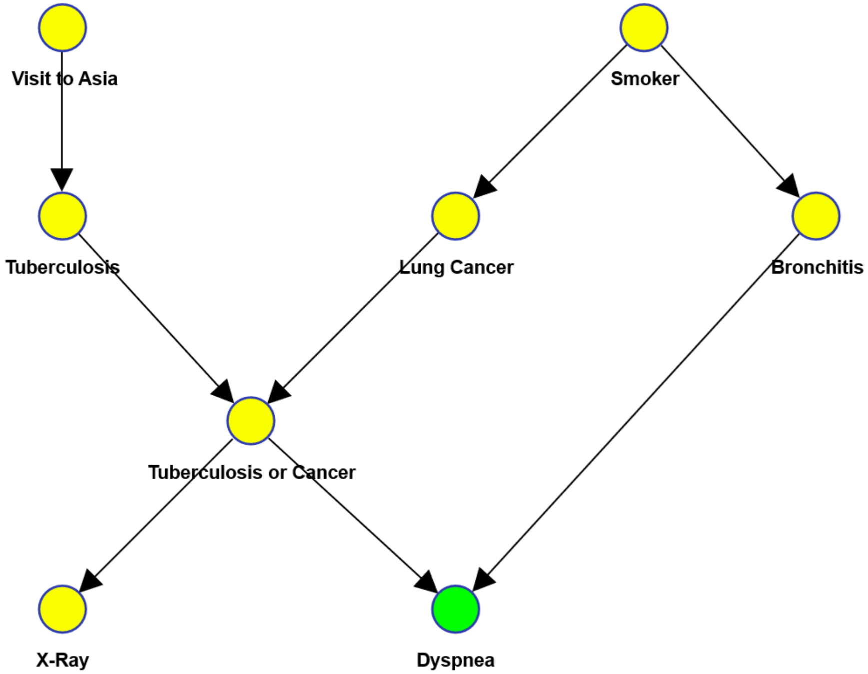


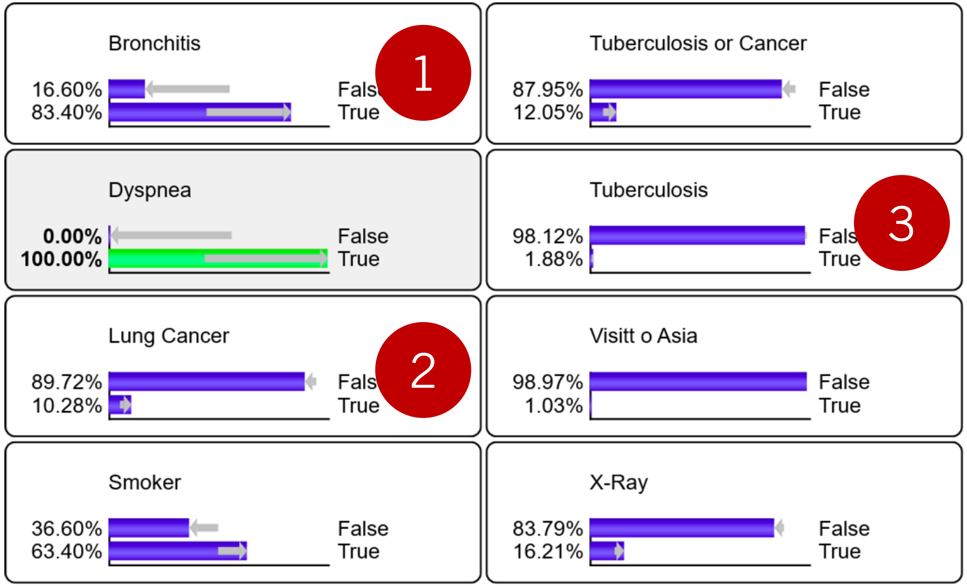
Inference with a Bayesian Network



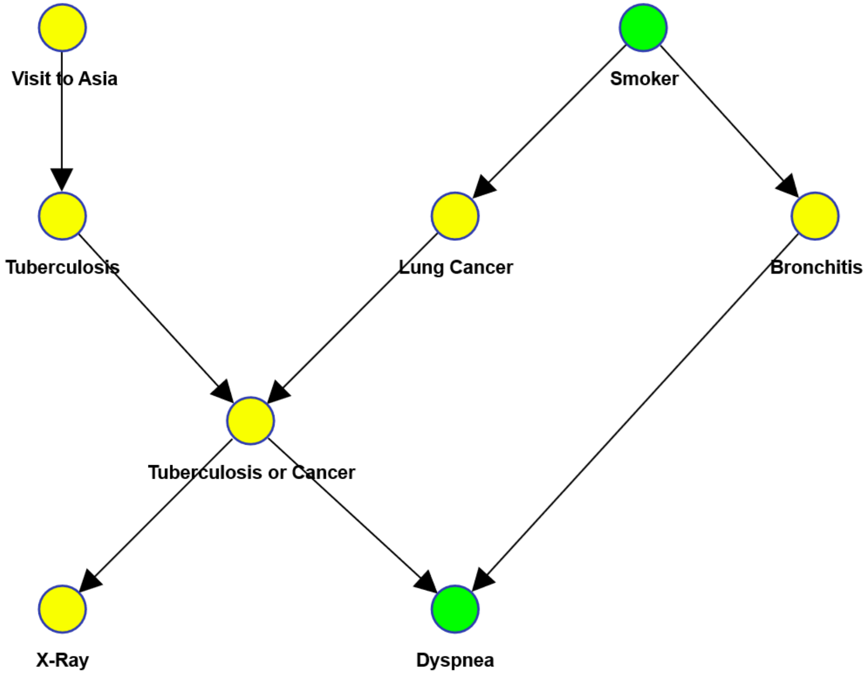


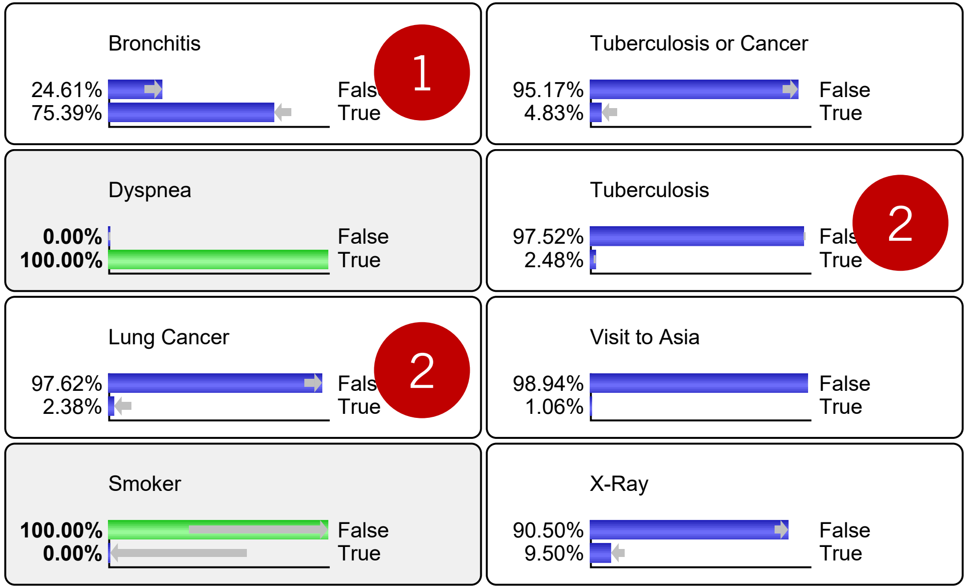
Inference with a Bayesian Network





Inference with a Bayesian Network





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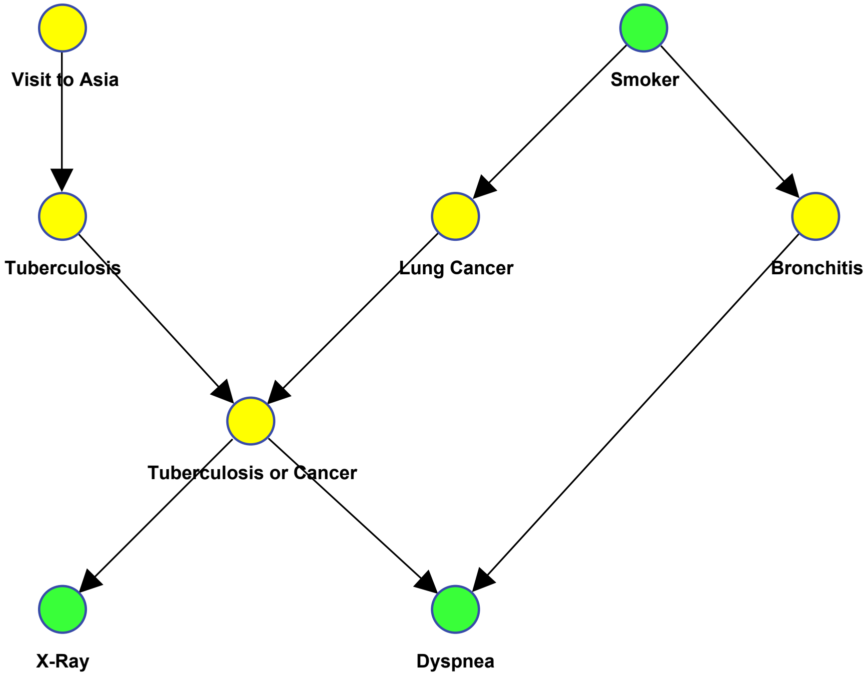
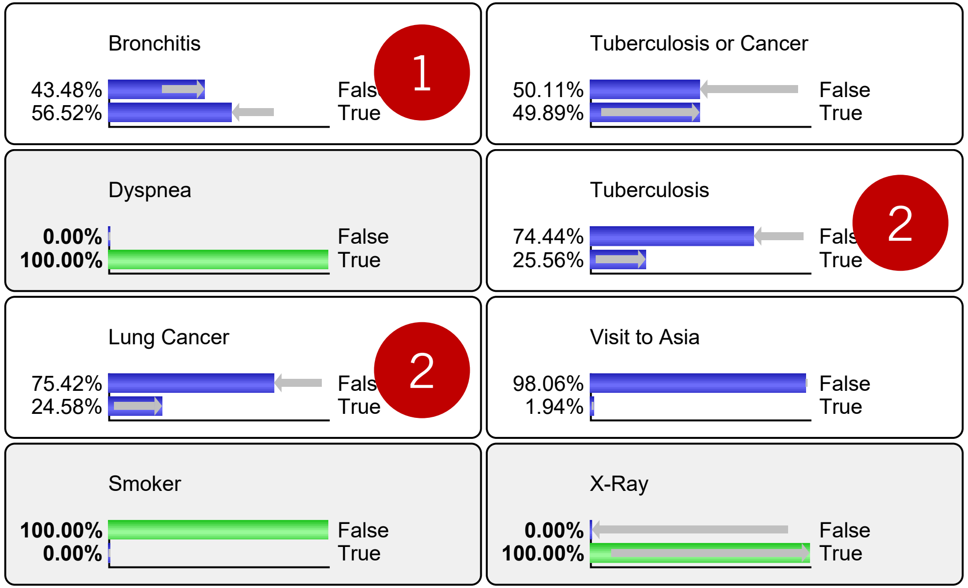
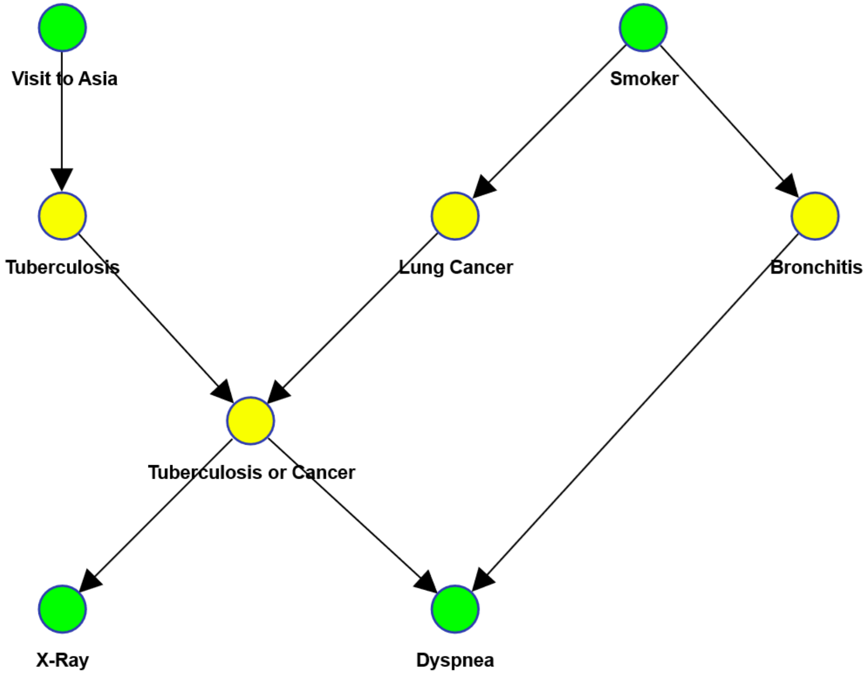
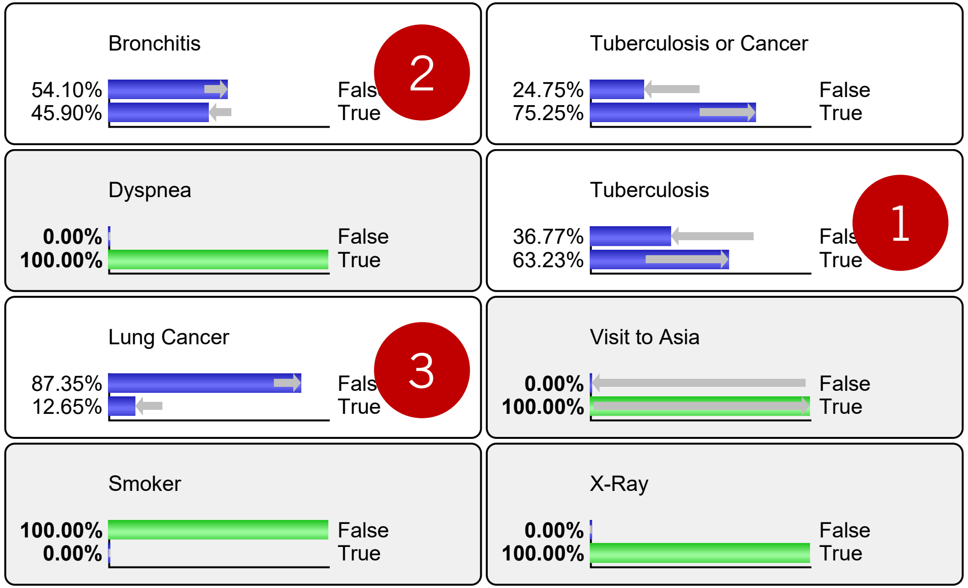


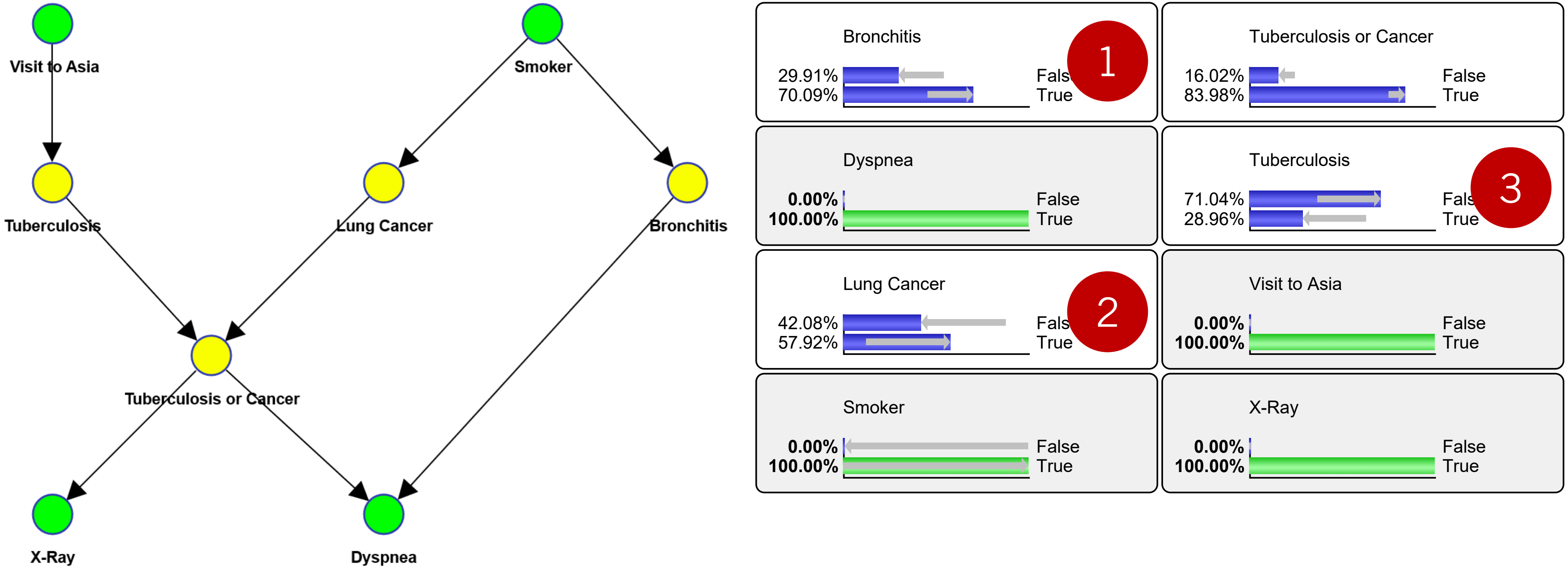


Inference with a Bayesian Network

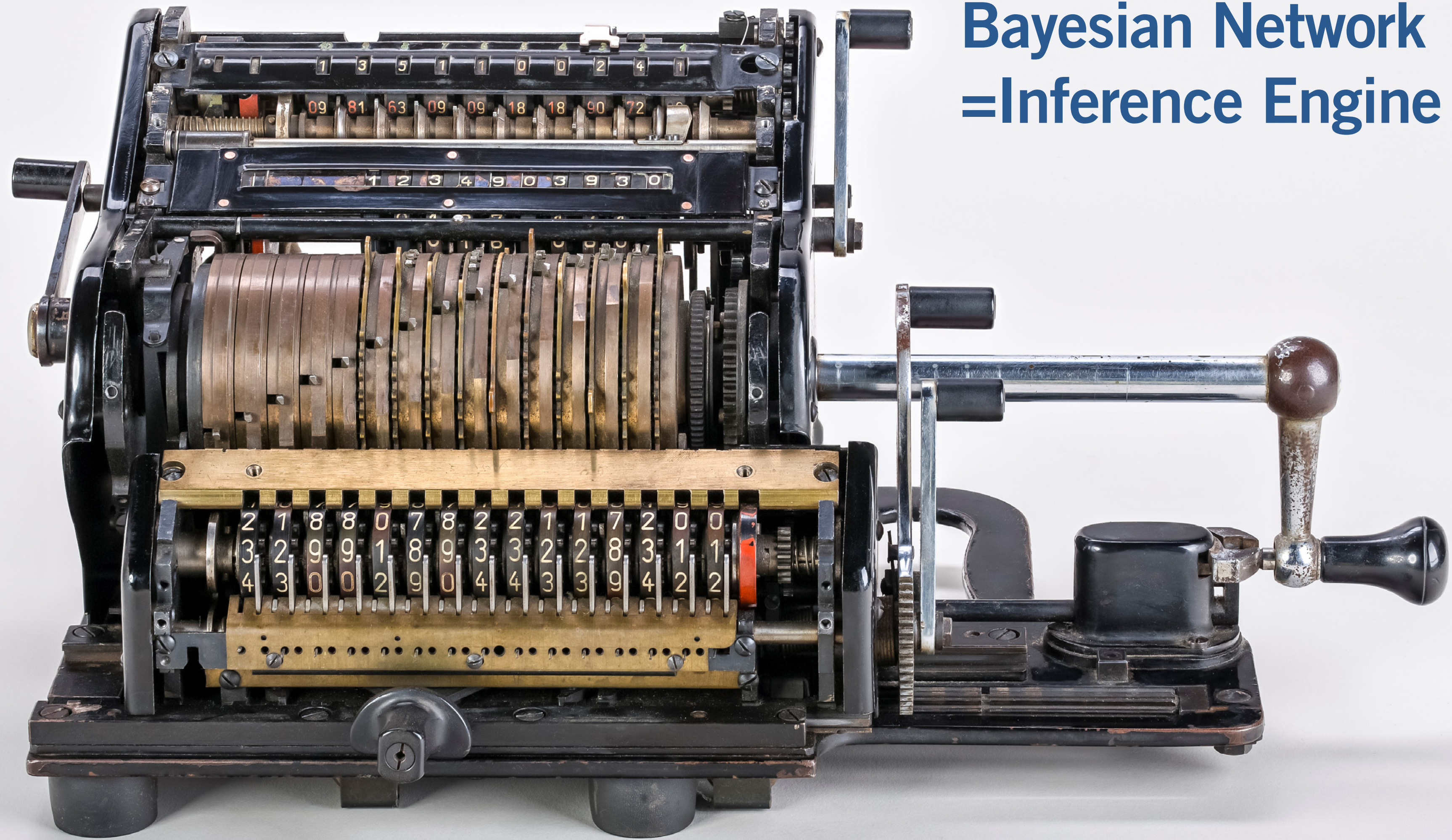




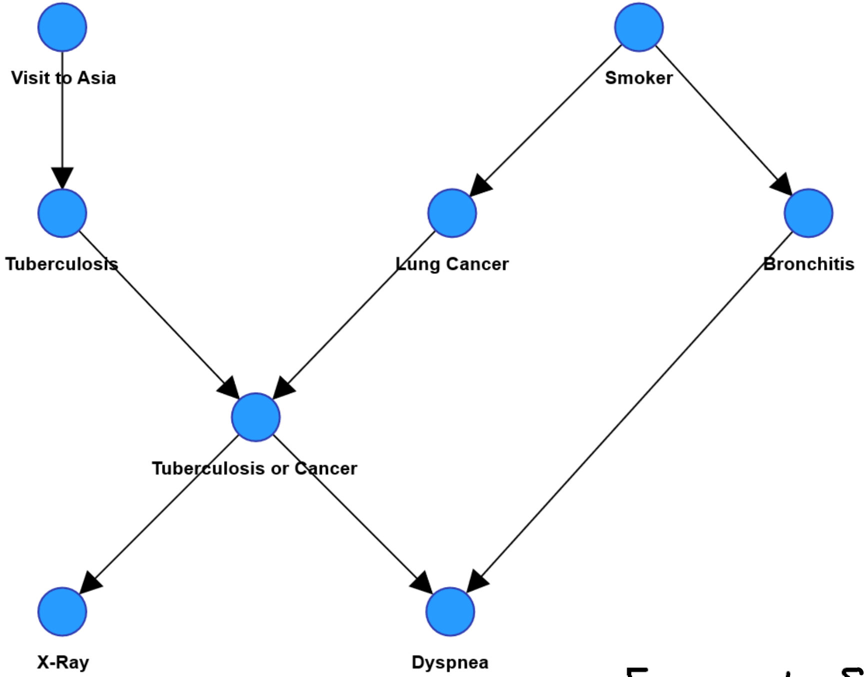
Inference with a Bayesian Network



Bayesian Network
=Inference Engine



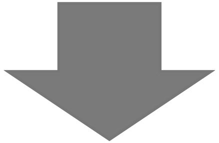
Bayesian Networks = Artificial Intelligence



Knowledge Base

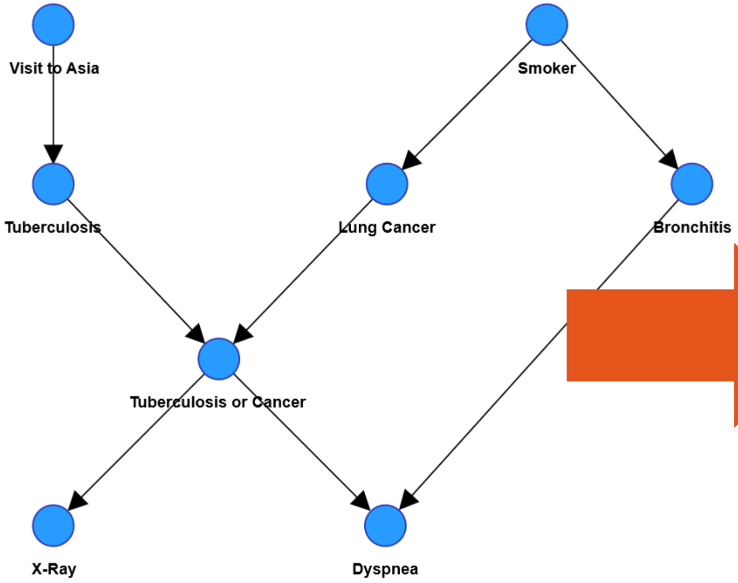
- Declarative/Propositional Knowledge
- Associational Knowledge
- Causal Knowledge

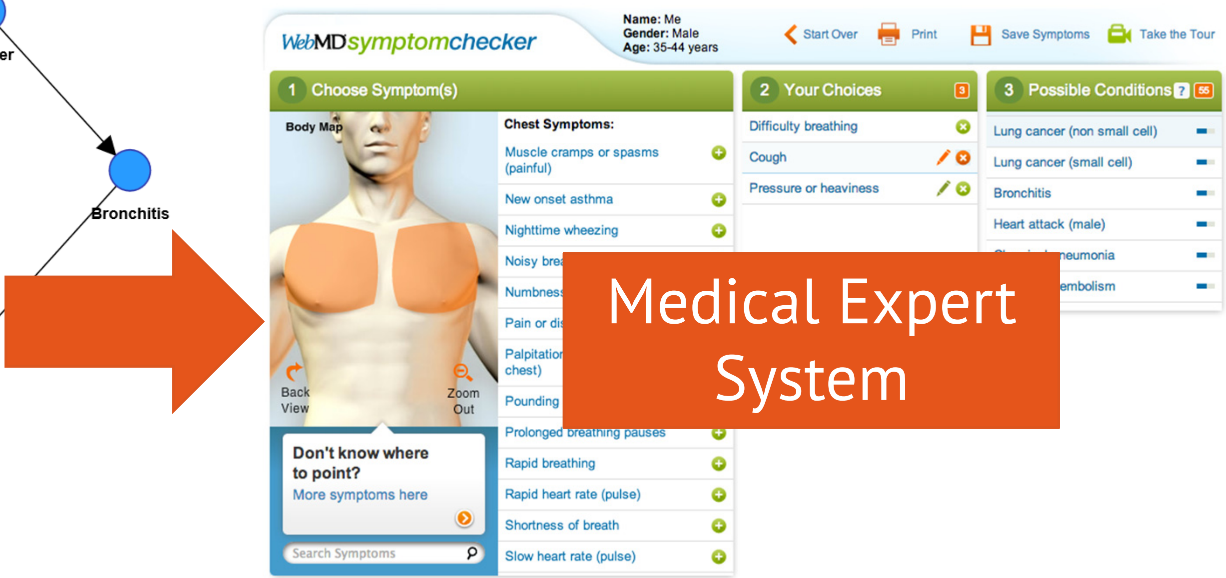
Inference Engine



Expert System - Artificial Intelligence

Bayesian Networks = Expert System



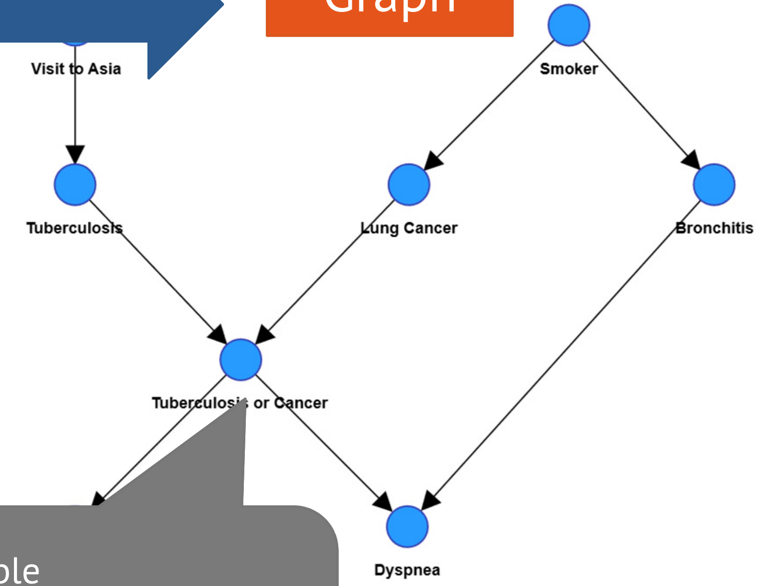


Bayesian Networks = Transparent Expert System

Formula

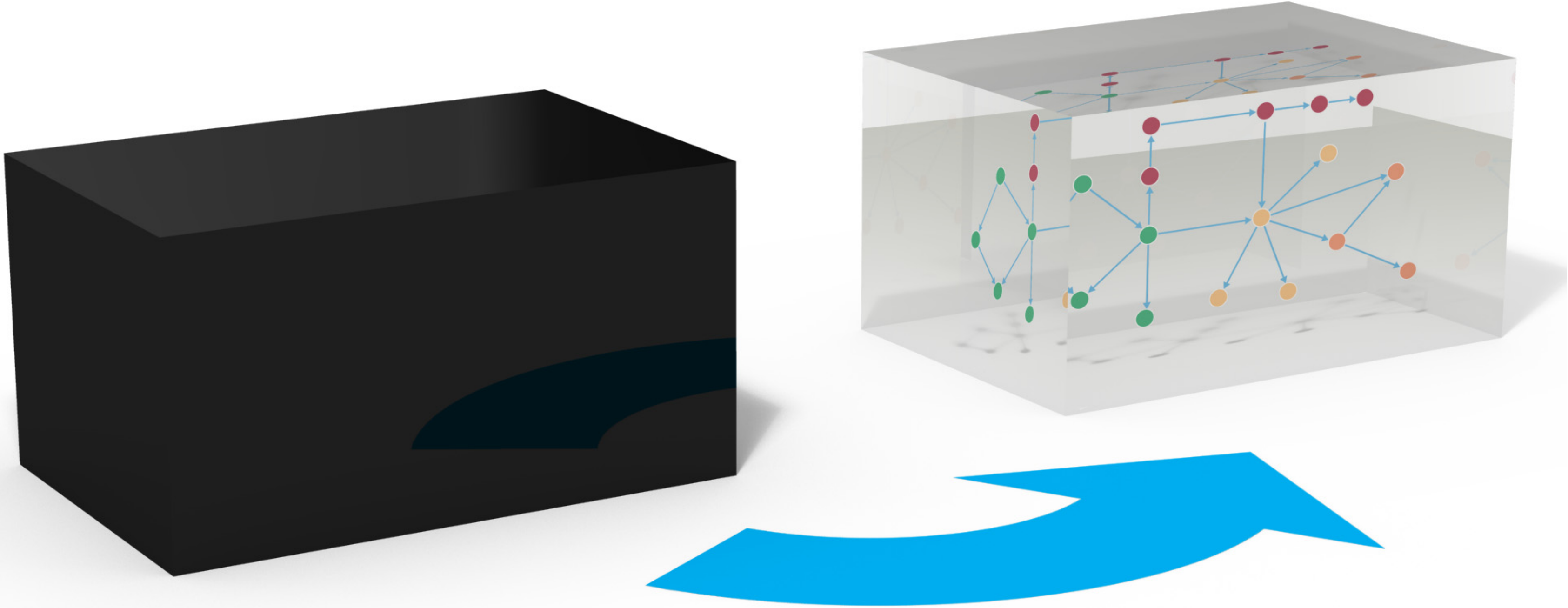
Graph

$$\overbrace{\frac{dI^{MT}_{F3}}{dt}}^{\text{Change in F3 infecteds on treatment}} = \overbrace{\tau^{MT}_{F2} I^{MT}_{F2}}^{\text{Progress from F2 during treatment}} + \overbrace{\eta_{F3} I^{M}_{F3}}^{\text{Commenced treatment (F3)}} - \left(\overbrace{\mu}^{\text{Background death}} + \overbrace{\mu_D}^{\text{Drug-related death}} + \overbrace{\xi}^{\text{Exit rate}} + \overbrace{\lambda_{HIV}}^{\text{Force of HIV infection}} + \overbrace{(1-\gamma^{M}_{F3})\nu^{M}_{F}}^{\text{Cease treatment (F3)}} + \overbrace{\gamma^{M}_{F3}\nu^{M}_{F}}^{\text{Viral clearance on treatment (F3)}} + \overbrace{\tau^{MT}_{F3}}^{\text{Progress to F4 during treatment}} \right) I^{MT}_{F3}$$



- Interpretable
- Transparent
- Intuitive
- Less “cognitive overhead”

Bayesian Networks = Transparent Expert System



Rev. Thomas Bayes

1763
PHILOSOPHICAL
TRANSACTIONS

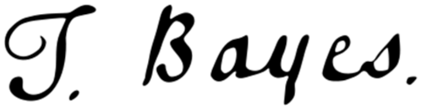
Bayes' Theorem for Conditional Probabilities

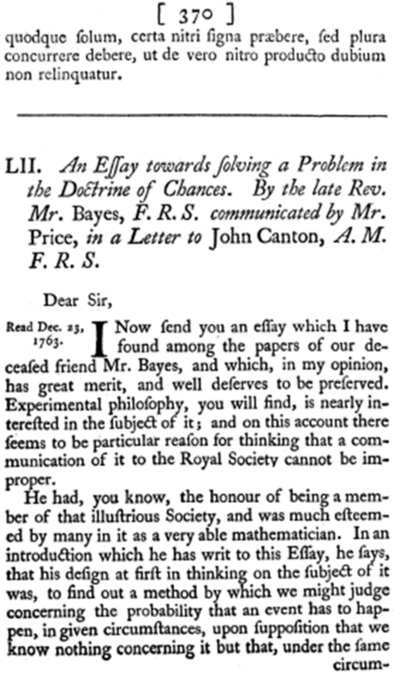
H: *Hypothesis*

E: *Evidence*

$$P(H \mid E) = \frac{P(E \mid H)\,P(H)}{P(E)}$$

"Probability of H given E"





[370]

quodque ſolum, certa nitri ſigna præbere, ſed plura concurrere debere, ut de vero nitro producto dubium non relinquatur.

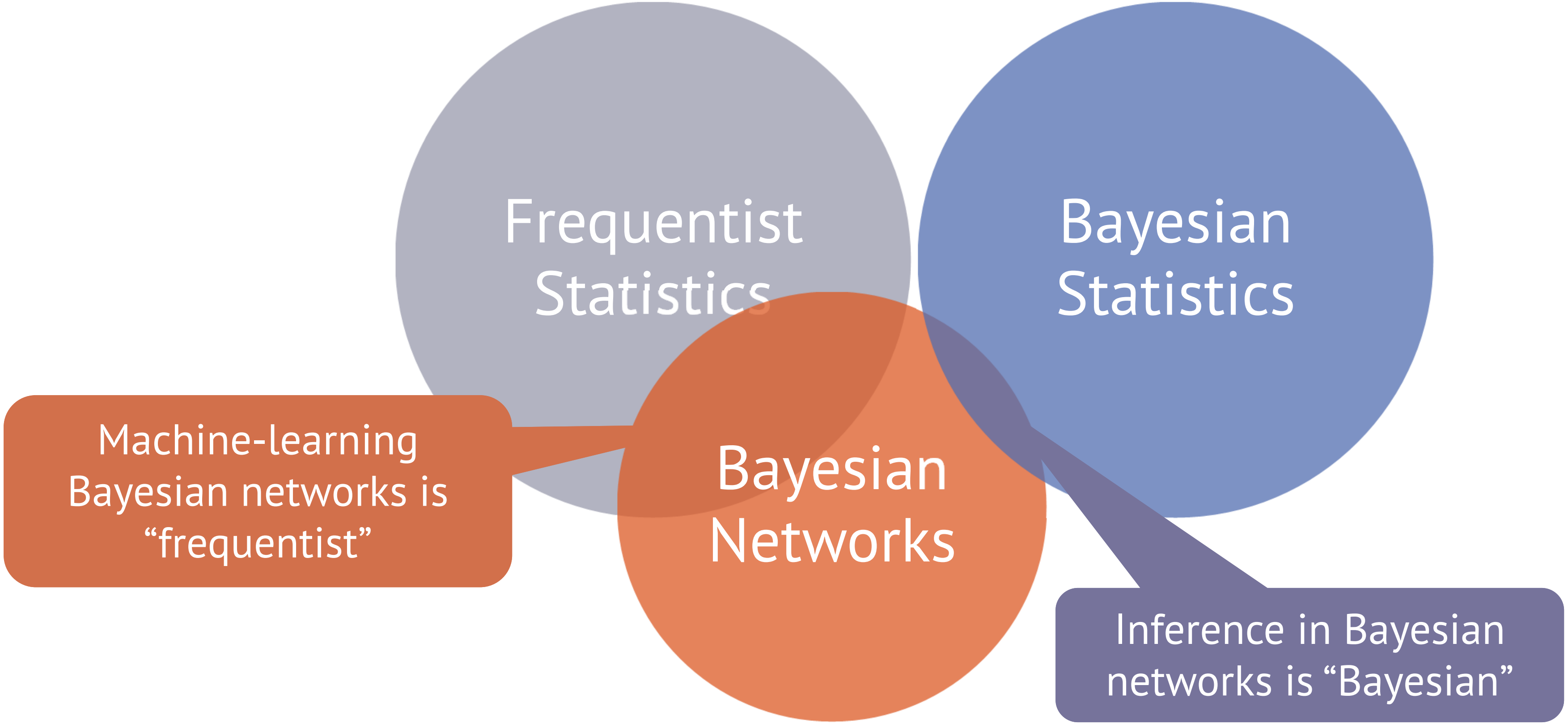
LII. *An Eſſay towards ſolving a Problem in the Doctrine of Chances. By the late Rev.* Mr. Bayes, *F. R. S. communicated by* Mr. Price, *in a Letter to* John Canton, *A. M. F. R. S.*

Dear Sir,

Read Dec. 23, 1763. I Now ſend you an eſſay which I have found among the papers of our deceaſed friend Mr. Bayes, and which, in my opinion, has great merit, and well deſerves to be preſerved. Experimental philoſophy, you will find, is nearly intereſted in the ſubject of it; and on this account there ſeems to be particular reaſon for thinking that a communication of it to the Royal Society cannot be improper.

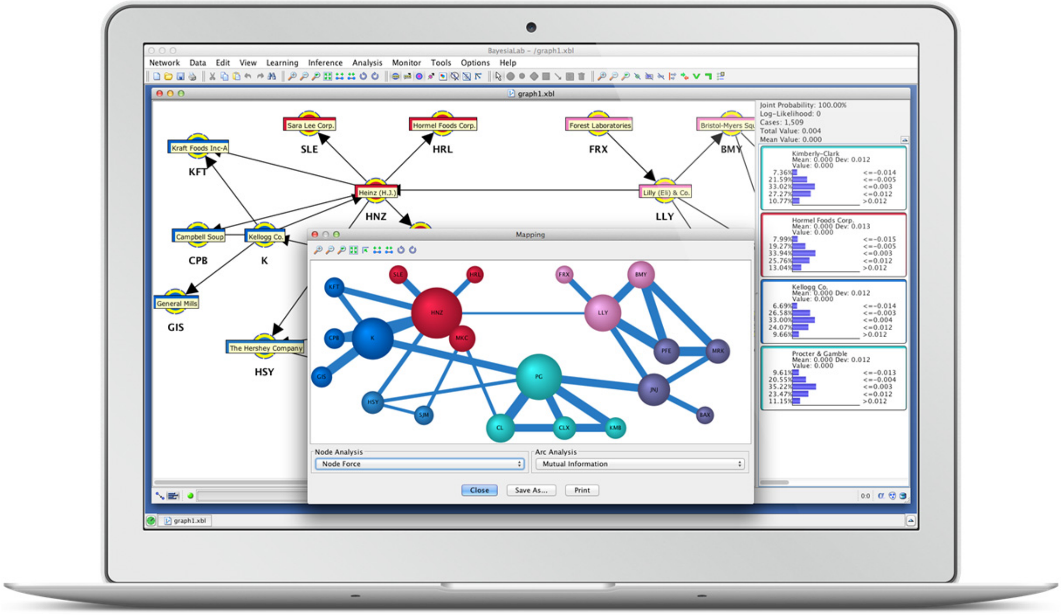
He had, you know, the honour of being a member of that illuſtrious Society, and was much eſteemed by many in it as a very able mathematician. In an introduction which he has writ to this Eſſay, he ſays, that his deſign at firſt in thinking on the ſubject of it was, to find out a method by which we might judge concerning the probability that an event has to happen, in given circumſtances, upon ſuppoſition that we know nothing concerning it but that, under the ſame circum-

Bayesian Statistics?



Sounds great, but how can I get a Bayesian Network?

BAYESIALAB

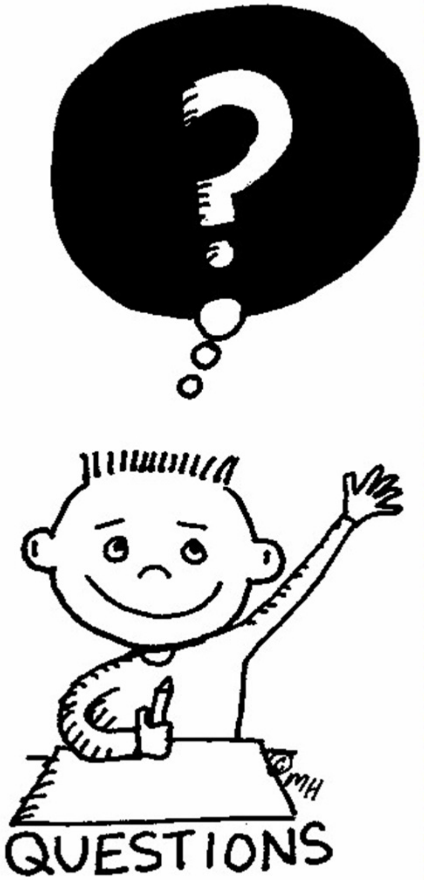


A desktop software for:

- learning
- editing
- performing inference
- analyzing
- simulating
- optimizing

with Bayesian networks.

Mathematical Formalism → Research Software


?
©MH
QUESTIONS

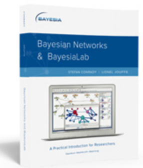
Key Drivers Analysis & Optimization Based on Consumer Survey Data

Example: Auto Buyer Satisfaction Study

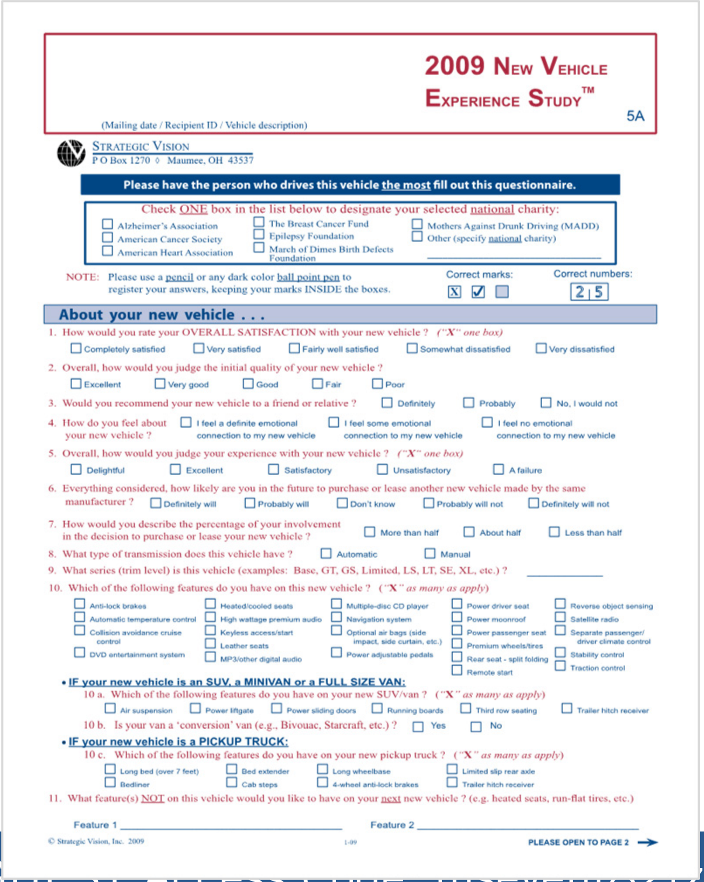
Strategic Vision

New Vehicle Experience Study™

- 200,000+ records
- 1,000+ variables



Compare to Chapter 8 Perfume Study



2009 New Vehicle Experience Study™

5A

(Mailing date / Recipient ID / Vehicle description)

Strategic Vision
P O Box 1270 ◊ Maumee, OH 43537

Please have the person who drives this vehicle the most fill out this questionnaire.

Check ONE box in the list below to designate your selected national charity:

- ☐ Alzheimer's Association
- ☐ American Cancer Society
- ☐ American Heart Association
- ☐ The Breast Cancer Fund
- ☐ Epilepsy Foundation
- ☐ March of Dimes Birth Defects Foundation
- ☐ Mothers Against Drunk Driving (MADD)
- ☐ Other (specify national charity) ____________

NOTE: Please use a pencil or any dark color ball point pen to register your answers, keeping your marks INSIDE the boxes.

Correct marks: ☒ ☑ ■ Correct numbers: 2 5

About your new vehicle . . .

1. How would you rate your OVERALL SATISFACTION with your new vehicle ? *("X" one box)*
   ☐ Completely satisfied ☐ Very satisfied ☐ Fairly well satisfied ☐ Somewhat dissatisfied ☐ Very dissatisfied
2. Overall, how would you judge the initial quality of your new vehicle ?
   ☐ Excellent ☐ Very good ☐ Good ☐ Fair ☐ Poor
3. Would you recommend your new vehicle to a friend or relative ? ☐ Definitely ☐ Probably ☐ No, I would not
4. How do you feel about your new vehicle ? ☐ I feel a definite emotional connection to my new vehicle ☐ I feel some emotional connection to my new vehicle ☐ I feel no emotional connection to my new vehicle
5. Overall, how would you judge your experience with your new vehicle ? *("X" one box)*
   ☐ Delightful ☐ Excellent ☐ Satisfactory ☐ Unsatisfactory ☐ A failure
6. Everything considered, how likely are you in the future to purchase or lease another new vehicle made by the same manufacturer ? ☐ Definitely will ☐ Probably will ☐ Don't know ☐ Probably will not ☐ Definitely will not
7. How would you describe the percentage of your involvement in the decision to purchase or lease your new vehicle ? ☐ More than half ☐ About half ☐ Less than half
8. What type of transmission does this vehicle have ? ☐ Automatic ☐ Manual
9. What series (trim level) is this vehicle (examples: Base, GT, GS, Limited, LS, LT, SE, XL, etc.) ? ____________
10. Which of the following features do you have on this new vehicle ? ("X" *as many as apply*)
    ☐ Anti-lock brakes ☐ Automatic temperature control ☐ Collision avoidance cruise control ☐ DVD entertainment system ☐ Heated/cooled seats ☐ High wattage premium audio ☐ Keyless access/start ☐ Leather seats ☐ MP3/other digital audio ☐ Multiple-disc CD player ☐ Navigation system ☐ Optional air bags (side impact, side curtain, etc.) ☐ Power adjustable pedals ☐ Power driver seat ☐ Power moonroof ☐ Power passenger seat ☐ Premium wheels/tires ☐ Rear seat - split folding ☐ Remote start ☐ Reverse object sensing ☐ Satellite radio ☐ Separate passenger/ driver climate control ☐ Stability control ☐ Traction control

- **IF your new vehicle is an SUV, a MINIVAN or a FULL SIZE VAN:**
  10 a. Which of the following features do you have on your new SUV/van ? ("X" *as many as apply*)
  ☐ Air suspension ☐ Power liftgate ☐ Power sliding doors ☐ Running boards ☐ Third row seating ☐ Trailer hitch receiver
  10 b. Is your van a 'conversion' van (e.g., Bivouac, Starcraft, etc.) ? ☐ Yes ☐ No
- **IF your new vehicle is a PICKUP TRUCK:**
  10 c. Which of the following features do you have on your new pickup truck ? ("X" *as many as apply*)
  ☐ Long bed (over 7 feet) ☐ Bedliner ☐ Bed extender ☐ Cab steps ☐ Long wheelbase ☐ 4-wheel anti-lock brakes ☐ Limited slip rear axle ☐ Trailer hitch receiver

11. What feature(s) NOT on this vehicle would you like to have on your next new vehicle ? (e.g. heated seats, run-flat tires, etc.)

Feature 1 ____________ Feature 2 ____________

 1-09 PLEASE OPEN TO PAGE 2 →

Thanks!

Strategic Vision Inc.

- Strategic Vision is a research-based consultancy with more than 35 years of experience in understanding the consumers' and constituents' decision-making systems for a variety of Fortune 100 clients, 10 Downing Street, Coca-Cola, American Airlines, Procter & Gamble, the White House and including most automotive manufacturers and many advertising agencies. The company specializes in identifying consumers' complete, motivational hierarchies, including the product attributes, personal benefits, value/emotions and images that drive perceptions and behaviors. Strategic Vision has at its core a large-scale syndicated automotive experience and "Pulse of the Customer" (POC) study that collects more than 350,000 responses annually, using over 1,500 comprehensive data points Since its foundation in 1972 and incorporation in 1989, Strategic Vision—led by company founders Darrel Edwards, Ph.D., J. Susan Johnson, Sharon Shedroff, with Alexander Edwards—has used in-depth Discovery Interviews and Value Centered Survey instruments that provide comprehensive, integrated and actionable outcomes, linking behavior to attributes to consequences to values and emotions to images.

Subset Under Study: MY2009 Midsize Sedans

- Chrysler Sebring
- Dodge Avenger
- Ford Fusion
- Chevrolet Malibu
- Kia Optima
- Honda Accord
- Nissan Altima
- Toyota Camry
- Mazda6
- Hyundai Sonata

Subset from New Vehicle Experience Survey

- 98 questions about satisfaction of features and vehicle attributes.
- 1 question about overall satisfaction (“Overall New Vehicle Experience NVES”).
- 1 categorical variable representing the vehicle model.
- 4,214 survey responses.

9.5 - Completely Satisfied
7.5 - Very Satisfied
5.5 - Fairly Well Satisfied
3.5 - Somewhat Dissatisfied
1.5 - Very Dissatisfied

Rating scale for all numerical variables

Note: This dataset is not publicly available and cannot be downloaded. For a training dataset, please see the Perfume Study in Chapter 8

BAYESIALAB

Key Drivers Analysis & Optimization Based on Consumer Survey

Oxymoron

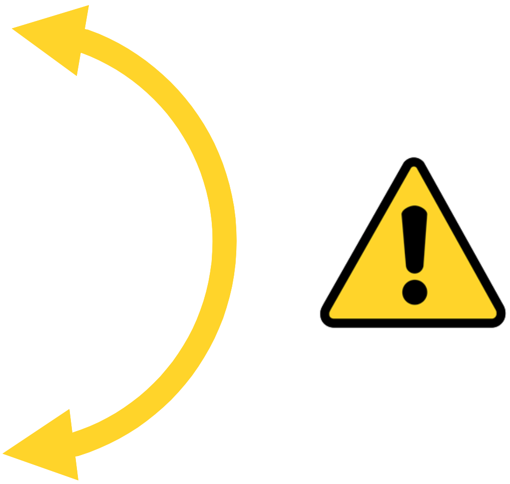
Key Drivers Analysis & Optimization
Based on Consumer Opinion Survey Data

“Driver”

- A fundamentally causal concept.
- Implies knowledge of the causal direction.

“Opinion Survey Data”

- Non-experimental data, i.e. observational data.

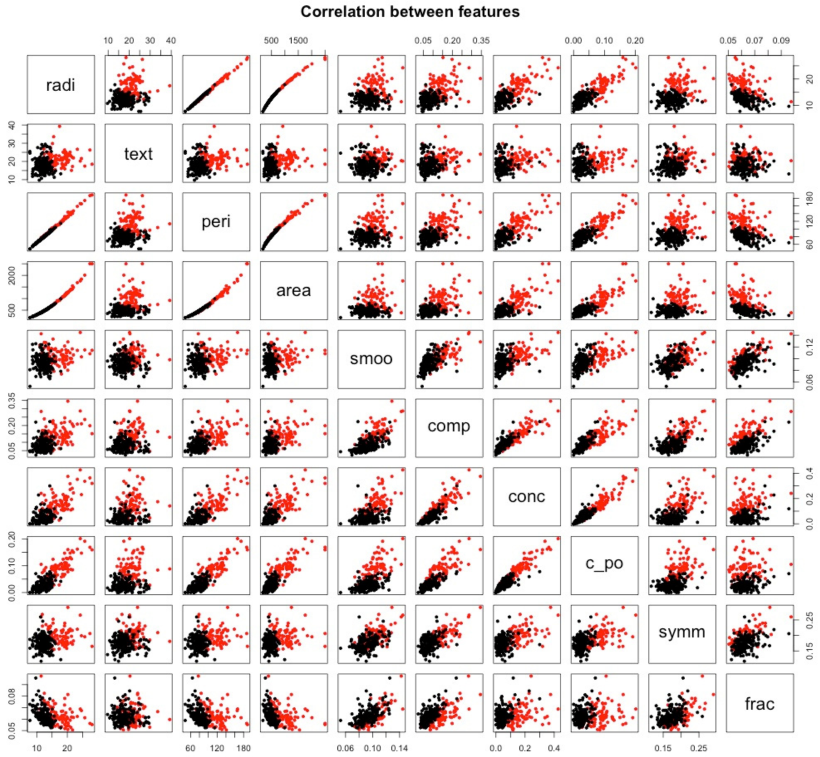


Data → Association/Correlation

Key Drivers Analysis

Why?

- Observational data only provides associations/correlations.
- A statistical model can approximate the joint probability distribution of the data produced by the domain under study.
- However, with such a statistical model we can only perform observational inference, i.e. produce predictions.




Correlation does not
equal causation!

Key Drivers Analysis & Optimization Based on Consumer Opinion Survey Data

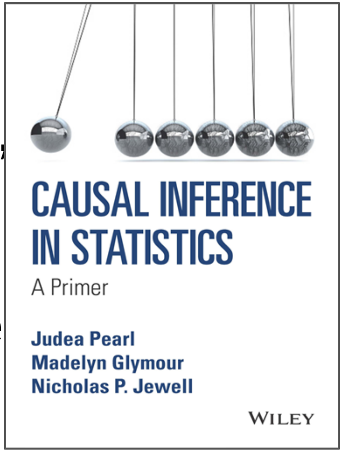
$$y=f(x)$$

ambiguous

Observational Inference (Prediction)

$$y=f(see(x))$$

“given that I see”



Causal Inference (Inte

$$y=f(do(x))$$

“given that I do”


21
14
BUST
APRIL
900
EMILY
100
RYAN
0


A

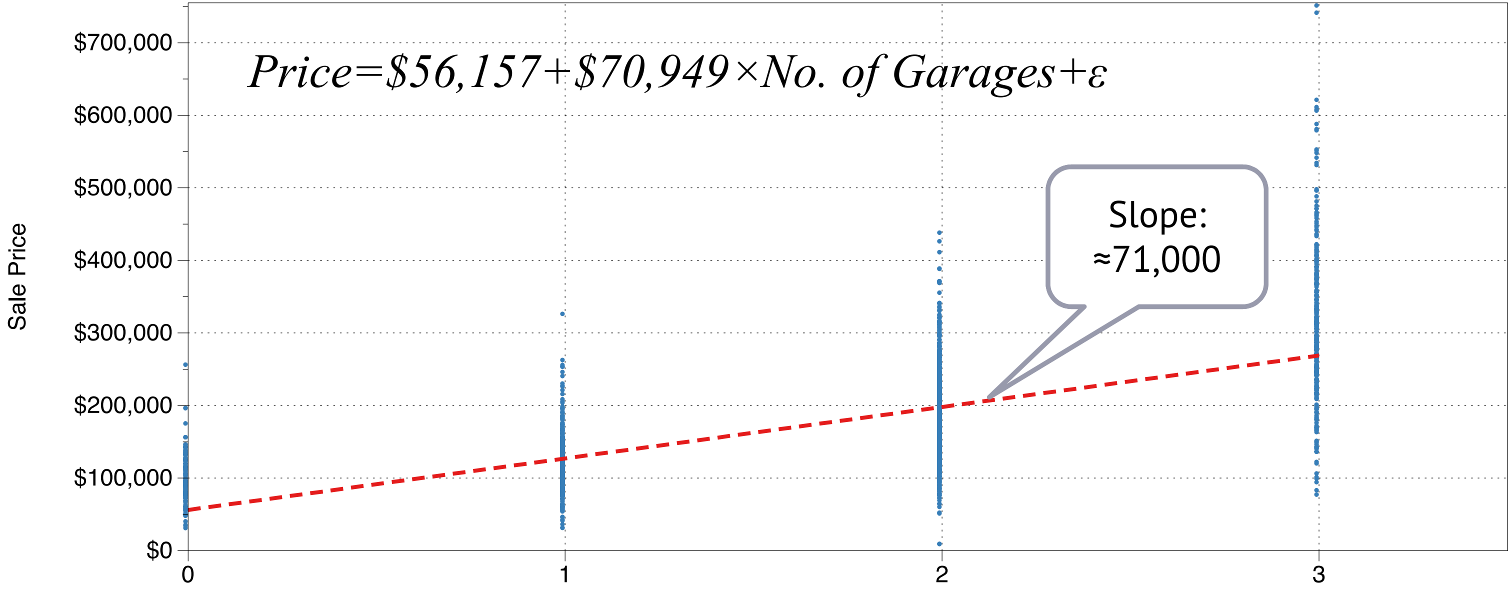

B


C

Observational vs. Causal Inference

See Chapter 5

Ames Dataset: Sale Prices of Single-Family Homes



Observational Data → Observational Inference/Prediction

Observational vs. Causal Inference

Clever Homeowner:

- “I’ll add two garages to my house and increase its value by $142,000”

Observational vs. Causal Inference

Observational vs. Causal Inference

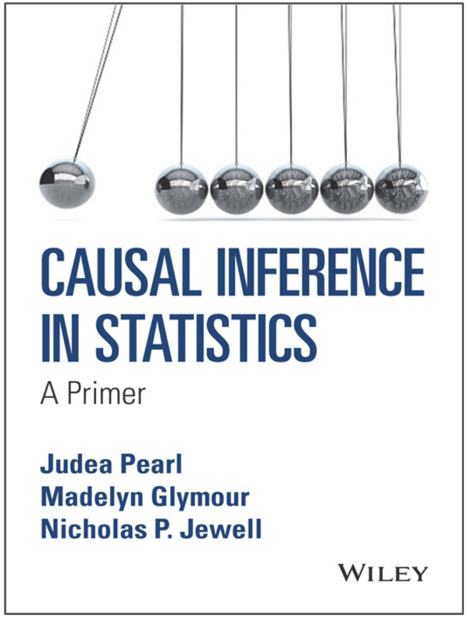
Intervention

Observational vs. Causal Inference

Observational Inference (Conditioning)

- "When we condition on a variable, we change nothing; we merely narrow our focus to the subset of cases in which the variable takes the value we are interested in. What changes, then, is our perception about of the world, not the world itself."

$$y = f(see(x))$$

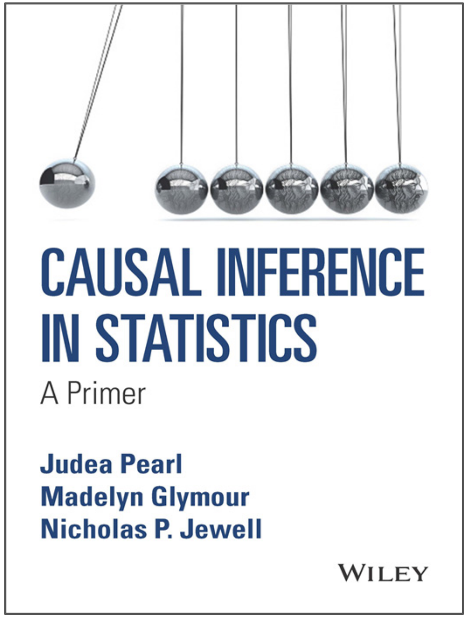


Observational vs. Causal Inference

Causal Inference (Intervention)

- "When we intervene on a variable in a system, we fix its value. We change the system, and the values of other variables often change as a result."

$$y = f(do(x))$$



Observational vs. Causal Inference

Statistical Model → Observational Inference/Prediction

- $Price = \$56{,}157 + \$70{,}949 \times No.\ of\ Garages + \varepsilon$

Regression

Causal Model → Causal Inference/Intervention

???

Observational vs. Causal Inference

Predictive Model:
Observational Inference

$$y = f(see(x))$$

Causal Model:
Causal Inference

$$y = f(do(x))$$

Key Drivers Analysis & Optimization Based on Consumer Opinion Survey Data

"Driver"

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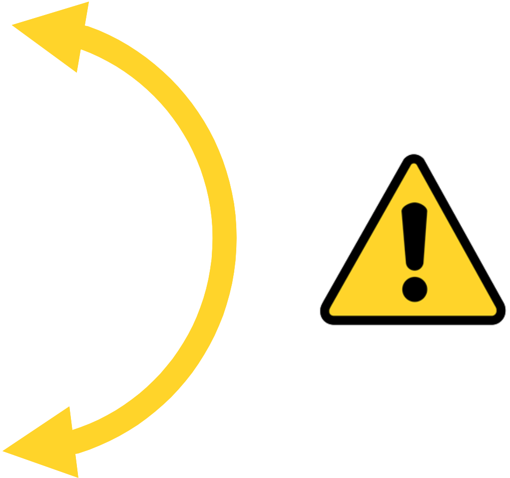
- Implies knowledge of the causal direction.

"Opinion Survey Data"

- Non-experimental data, i.e. observational data.



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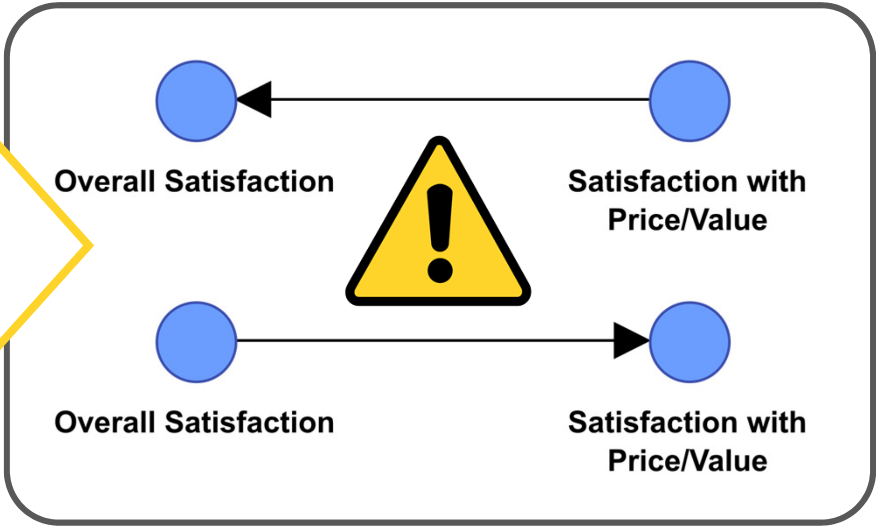


"Opinion Survey Data"

- Non-experimental data, i.e. observational data.

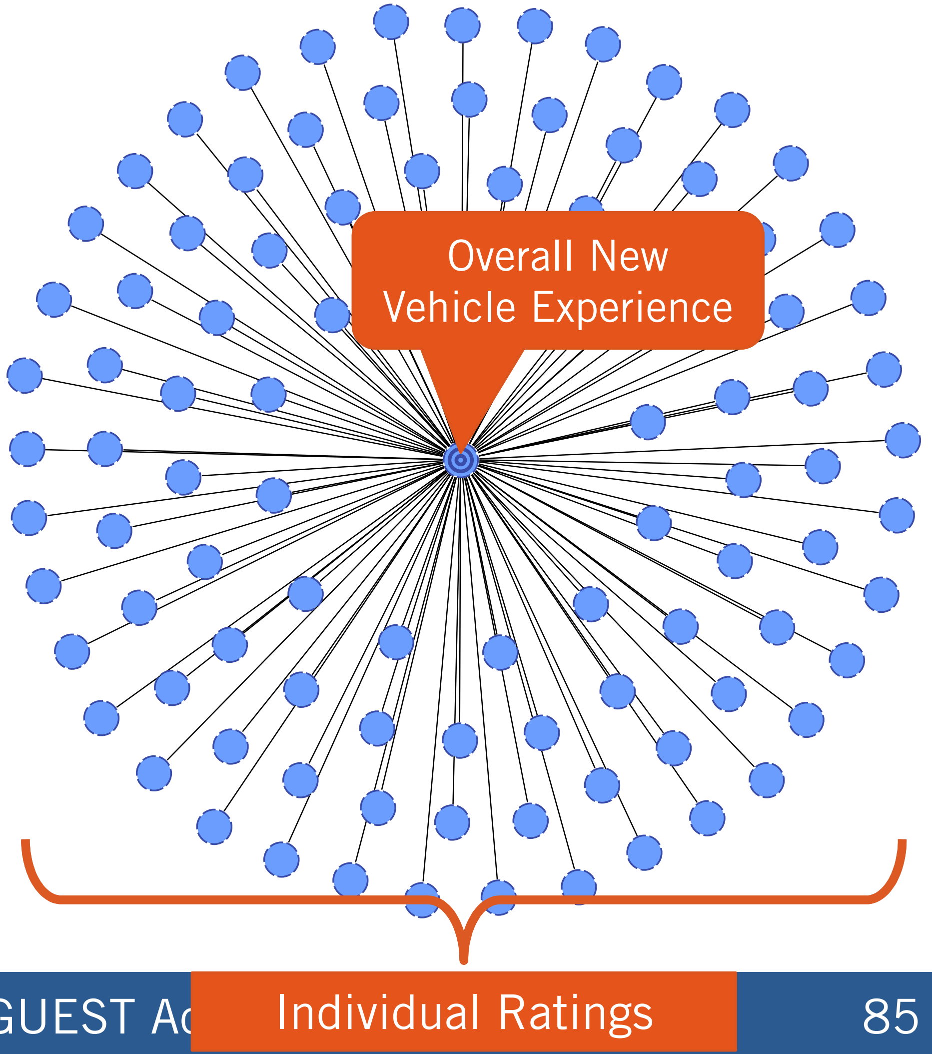
Key Drivers Analysis & Optimization
Based on Consumer Opinion Survey Data

Can we make some causal assumptions?

Causal Assumptions?

Can we make a causal assumption?

- E.g., all individual ratings ("drivers") are a cause of the overall rating?
- Yes, but what would be the causal relationships between the drivers, as they are probably not independent?



Causal Assumptions?

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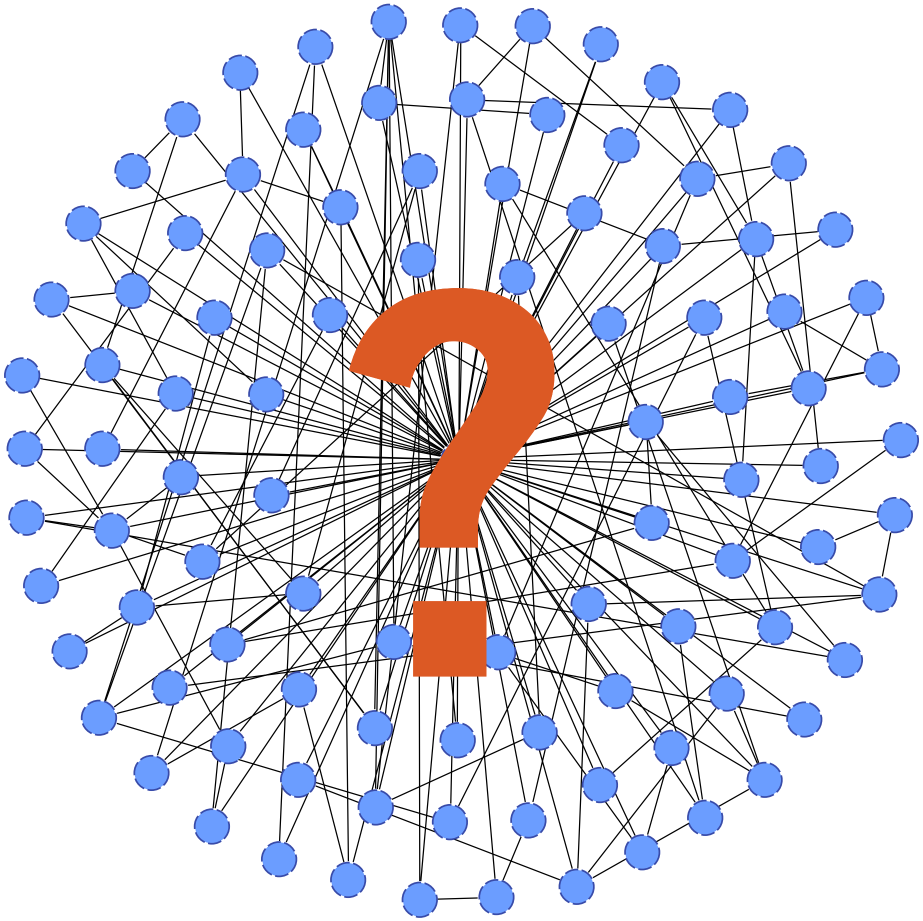
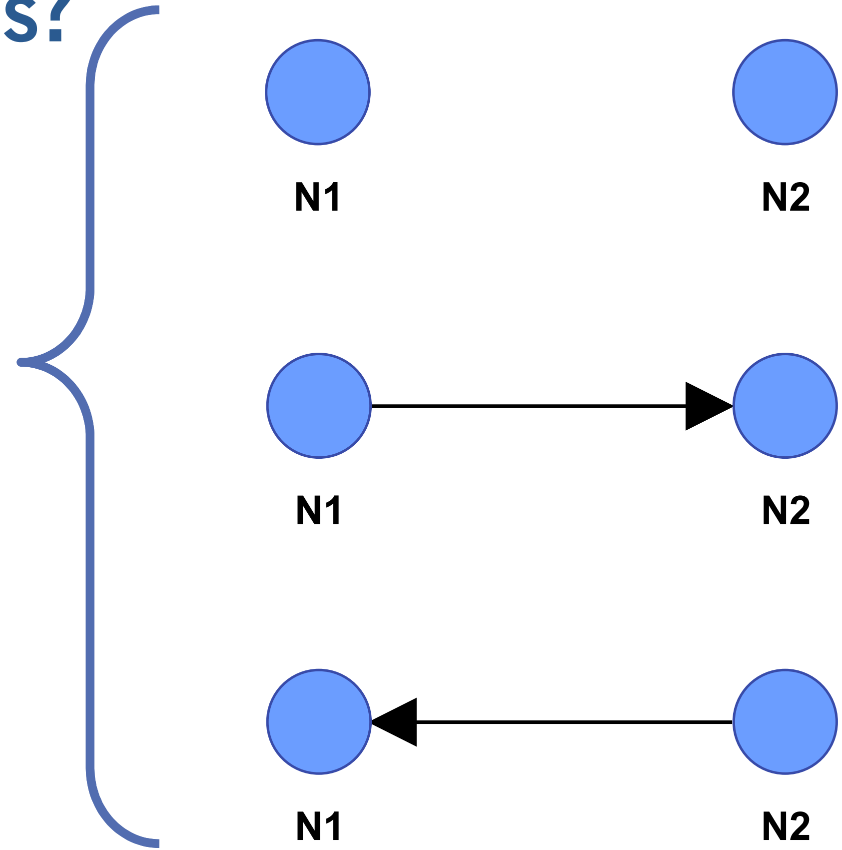


Causal Assumptions?

Number of Possible Causal Structures

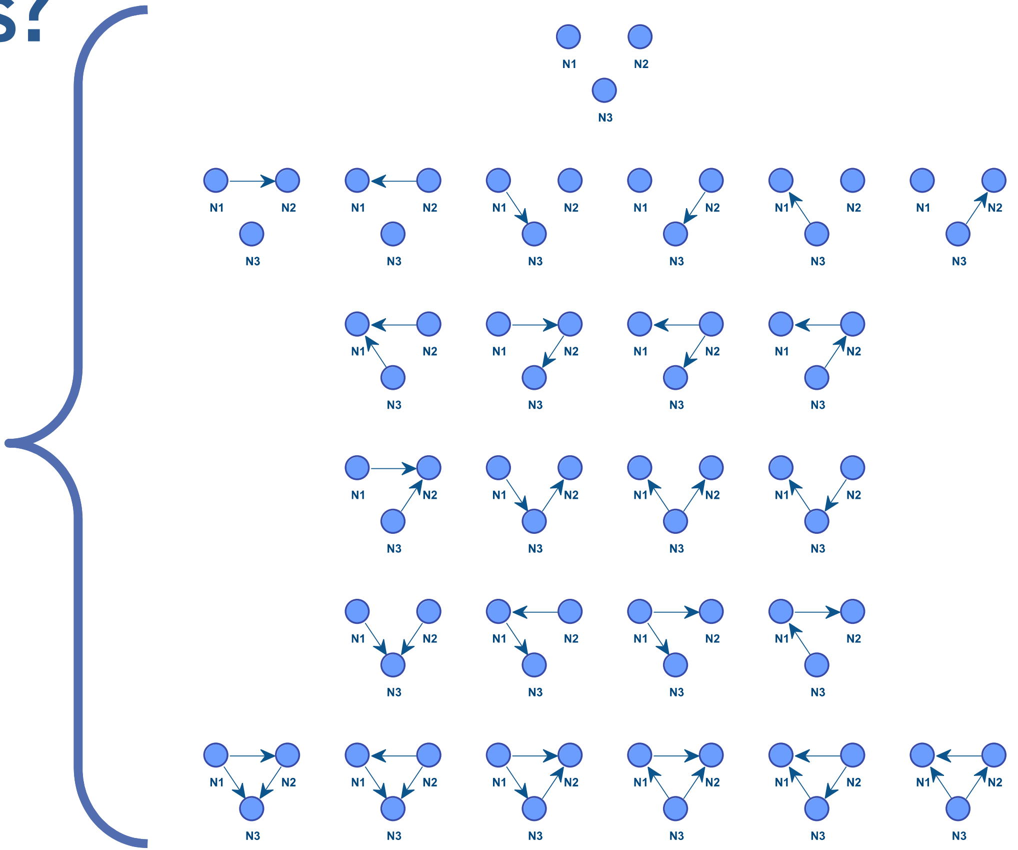
- 2 Nodes: 3



Causal Assumptions?

Number of Possible Causal Structures

- 2 Nodes: 3
- 3 Nodes: 25



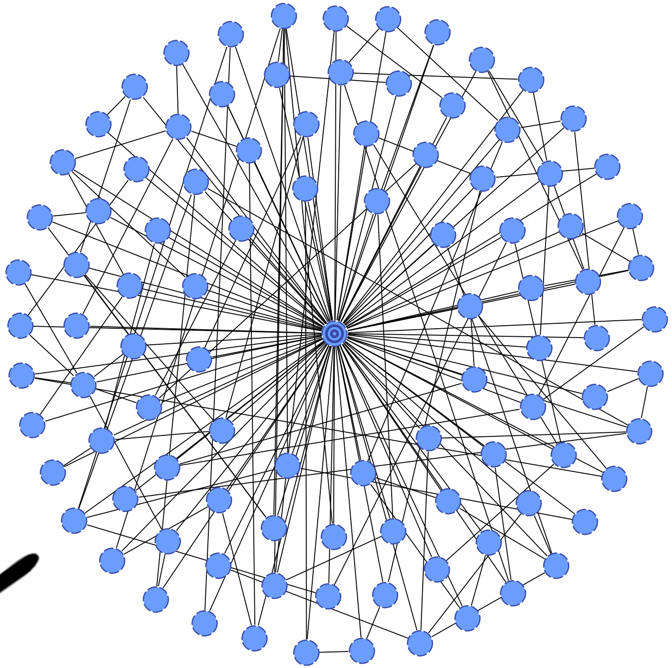
Causal Assumptions?

Number of Possible Causal Structures

- 2 Nodes: 3
- 3 Nodes: 25
- 4 Nodes: 543
- 5 Nodes: 29,281
- 6 Nodes: 3.8×10^{6}
- 7 Nodes: 1.1×10^{9}
- 8 Nodes: 7.8×10^{11}
- 9 Nodes: 1.2×10^{15}
- 10 Nodes: 4.2×10^{18}
- 11 Nodes: 3.2×10^{22}

⋮

- 100 Nodes: 1.1×10^{1631}

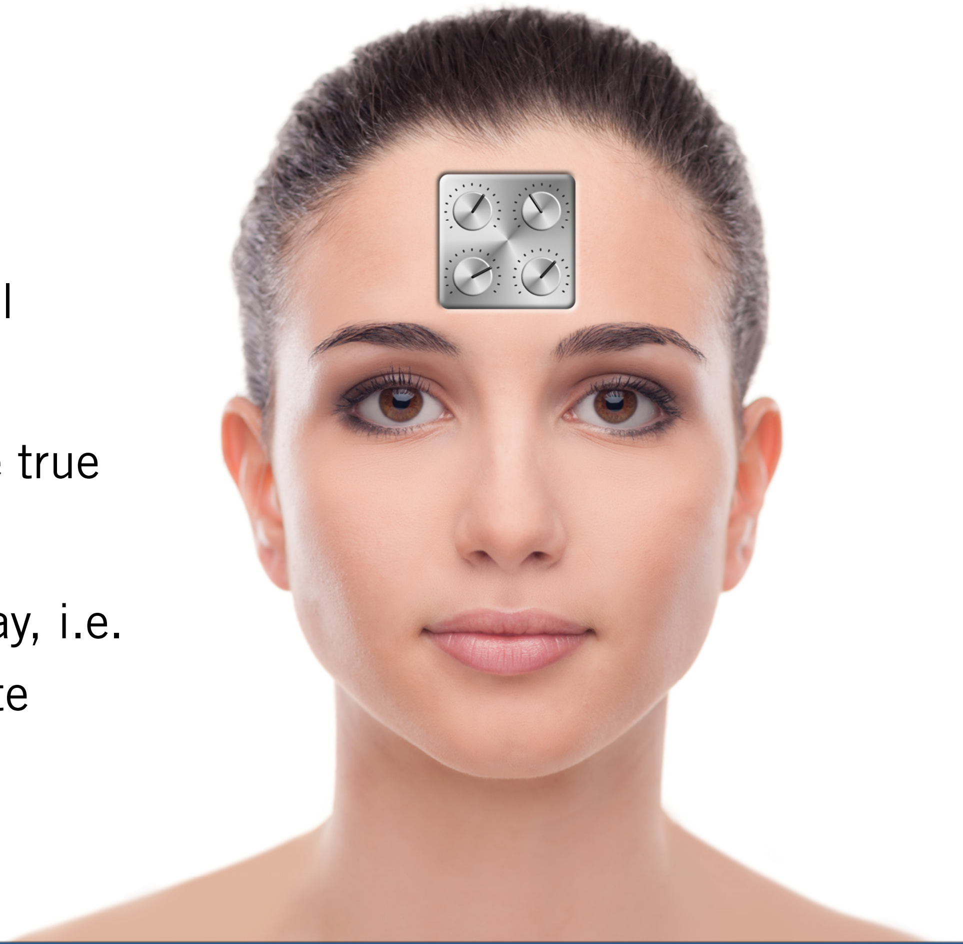


Good luck!

Causal Assumptions?

Observational Inference Only!

- We need to give up on formal causal inference because…
    - We cannot possibly know the true causal structure.
    - And, we can't "cause" anyway, i.e. we cannot directly manipulate consumer opinion.



Key Drivers Analysis & Optimization Based on Consumer Opinion Survey Data

“Driver”

- A fundamentally causal concept.
- Implies knowledge of the causal direction.

“Opinion Survey Data”

- Non-experimental data, i.e. observational data.

“Optimization”

- Measured variables cannot be directly manipulated.
- Multitude of subjects.
- No natural constraints.

causality?

optimization?

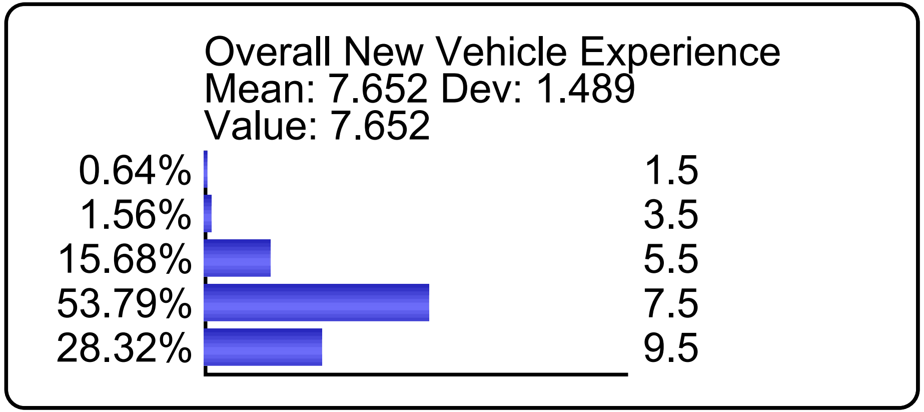
Key Drivers Analysis & Optimization Based on Consumer Opinion Survey Data

Statistical Problems

Statistical Challenges in Key Drivers Analysis

Estimation Challenges

- Small Variance
    - Only ~2% of all ratings are below "Fairly Well Satisfied"

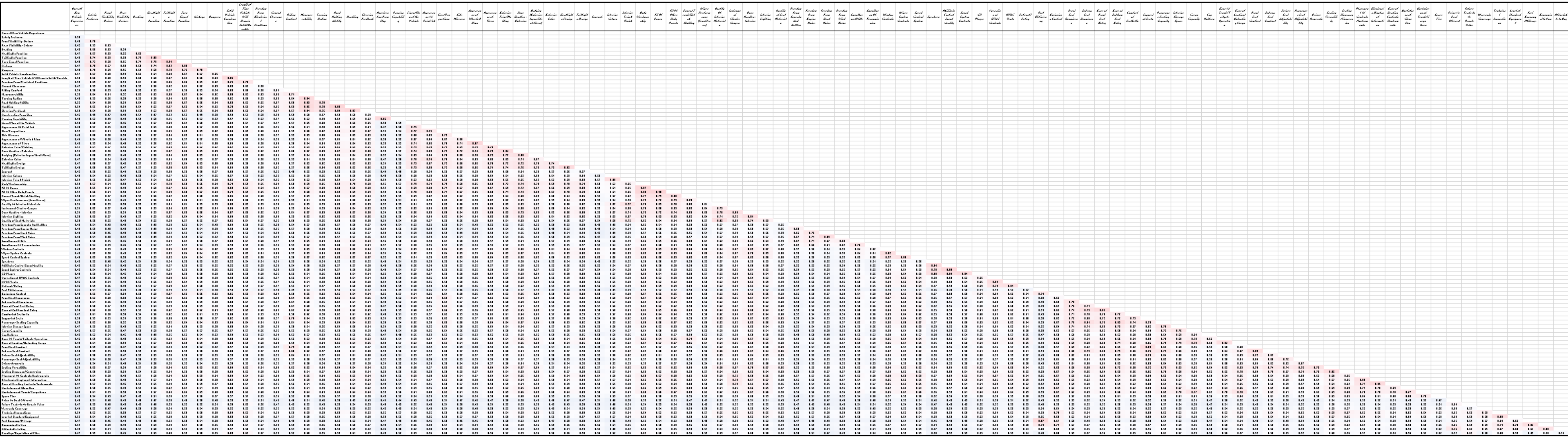



Airbags
Mean: 8.148 Dev: 1.371
Value: 8.148
0.15% 0.11% 11.32% 44.03% 44.39%
1.5 3.5 5.5 7.5 9.5
Length of Time Vehicle Will Remain S...
Mean: 7.758 Dev: 1.572
Value: 7.758
0.32% 1.18% 19.82% 42.67% 36.02%
1.5 3.5 5.5 7.5 9.5
Lines/Flow of the Vehicle
Mean: 8.194 Dev: 1.385
Value: 8.194
0.02% 0.56% 10.84% 41.83% 46.74%
1.5 3.5 5.5 7.5 9.5
Taillights Design
Mean: 8.129 Dev: 1.416
Value: 8.129
0.09% 0.42% 12.51% 41.94% 45.04%
1.5 3.5 5.5 7.5 9.5
Door Handles - Interior
Mean: 7.907 Dev: 1.475
Value: 7.907
0.06% 0.74% 16.50% 44.18% 38.52%
1.5 3.5 5.5 7.5 9.5
Speed Control System
Mean: 7.997 Dev: 1.482
Value: 7.997
0.15% 1.17% 13.68% 43.64% 41.35%
1.5 3.5 5.5 7.5 9.5
2nd row Seat Roominess
Mean: 7.751 Dev: 1.612
Value: 7.751
0.36% 1.60% 20.01% 41.18% 36.85%
1.5 3.5 5.5 7.5 9.5
Front Seat Comfort
Mean: 7.771 Dev: 1.700
Value: 7.771
0.80% 3.19% 15.90% 41.87% 38.24%
1.5 3.5 5.5 7.5 9.5
Usefulness of Trunk/Cargo Area
Mean: 7.889 Dev: 1.559
Value: 7.889
0.47% 1.49% 15.27% 43.67% 39.11%
1.5 3.5 5.5 7.5 9.5
Overall New Vehicle Experience
Mean: 7.651 Dev: 1.490
Value: 7.651
0.65% 1.56% 15.69% 53.79% 28.32%
1.5 3.5 5.5 7.5 9.5
Freedom From Electrical Problems
Mean: 7.890 Dev: 1.523
Value: 7.890
0.28% 1.08% 16.25% 43.68% 38.72%
1.5 3.5
Appearance Of Paint Job
Mean: 8.300 Dev: 1.416
Value: 8.300
0.23% 0.60%
1.5 3.5
Sunroof
Mean: 8.258 Dev: 1.458
Value: 8.258
0.83% 0.41%
1.5 3.5
Interior Lighting
Mean: 7.957 Dev: 1.519
Value: 7.957
0.21% 1.12%
1.5 3.5
Speakers
Mean: 7.814 Dev: 1.615
Value: 7.814
0.63% 1.86%
1.5 3.5
Ease of Front Seat Entry
Mean: 7.682 Dev: 1.769
Value: 7.682
1.14% 3.36%
1.5 3.5
2nd row Seat Comfort
Mean: 7.702 Dev: 1.599
Value: 7.702
0.25% 1.96%
1.5 3.5 5.5 7.5 9.5
Spare Tire
Mean: 7.423 Dev: 1.767
Value: 7.423
1.16% 2.52% 26.47% 38.69% 31.16%
1.5 3.5 5.5 7.5 9.5
Safety Features
Mean: 8.095 Dev: 1.390
Value: 8.095
0.31% 0.37% 10.72% 46.45% 42.14%
1.5 3.5 5.5 7.5 9.5
Ground Clearance
Mean: 7.649 Dev: 1.618
Value: 7.649
0.45% 2.23% 19.87% 44.29% 33.15%
r Seat Adjustability
n: 7.842 Dev: 1.645
e: 7.842
1.5 3.5 5.5 7.5 9.5
Price Or Deal Offered
Mean: 7.500 Dev: 1.735
Value: 7.500
0.74% 3.01% 24.15% 39.71% 32.39%
1.5 3.5 5.5 7.5 9.5
Front Visibility - Driver
Mean: 8.039 Dev: 1.500
Value: 8.039
0.64% 1.18% 10.89% 45.17% 42.12%
1.5 3.5 5.5 7.5 9.5
Riding Comfort
Mean: 7.906 Dev: 1.564
Value: 7.906
0.47% 1.45% 15.27% 42.91% 39.90%
enger Seat Adjustability
n: 7.346 Dev: 1.791
e: 7.346
1.5 3.5 5.5 7.5 9.5
Future Trade-In Or Resale Value
Mean: 7.230 Dev: 1.694
Value: 7.230
0.49% 3.14% 31.18% 39.76% 25.43%
1.5 3.5 5.5 7.5 9.5
Rear Visibility - Driver
Mean: 7.280 Dev: 1.851
Value: 7.280
0.81% 6.58% 24.32% 39.37% 28.92%
1.5 3.5 5.5 7.5 9.5
Maneuverability
Mean: 8.045 Dev: 1.406
Value: 8.045
0.05% 0.59% 12.76% 45.29% 41.32%
r Armrests
n: 7.436 Dev: 1.773
e: 7.436
1.5 3.5 5.5 7.5 9.5
Warranty Coverage
Mean: 7.562 Dev: 1.697
Value: 7.562
0.37% 2.61% 24.43% 38.75% 33.84%
1.5 3.5 5.5 7.5 9.5
Braking
Mean: 8.124 Dev: 1.391
Value: 8.124
0.23% 0.55% 10.42% 45.39% 43.41%
1.5 3.5 5.5 7.5 9.5
Turning Radius
Mean: 7.924 Dev: 1.476
Value: 7.924
0.05% 0.86% 15.99% 44.06% 39.04%
ing Versatility
n: 7.552 Dev: 1.634
e: 7.552
1.5 3.5 5.5 7.5 9.5
Technical Innovations
Mean: 7.509 Dev: 1.595
Value: 7.509
0.26% 1.54% 25.39% 43.11% 29.71%
1.5 3.5 5.5 7.5 9.5
Headlights Function
Mean: 8.092 Dev: 1.475
Value: 8.092
0.39% 1.07% 11.20% 43.24% 44.10%
1.5 3.5 5.5 7.5 9.5
Road Holding Ability
Mean: 8.018 Dev: 1.433
Value: 8.018
0.03% 0.99% 12.89% 45.21% 40.88%
ing Stowaway/Conversion
n: 7.508 Dev: 1.670
e: 7.508
1.5 3.5 5.5 7.5 9.5
Level of Standard Equipment
Mean: 7.618 Dev: 1.592
Value: 7.618
0.30% 2.01% 21.12% 44.66% 31.92%
1.5 3.5 5.5 7.5 9.5
Taillights Function
Mean: 8.147 Dev: 1.360
Value: 8.147
0.25% 0.19% 10.11% 45.87% 43.58%
1.5 3.5 5.5 7.5 9.5
Handling
Mean: 8.106 Dev: 1.389
Value: 8.106
0.05% 0.54% 11.66% 44.59% 43.17%
ement Of Controls/Instruments
n: 7.890 Dev: 1.552
e: 7.890
1.5 3.5 5.5 7.5 9.5
Fuel Economy/Mileage
Mean: 7.417 Dev: 1.753
Value: 7.417
0.92% 4.36% 21.99% 43.41% 29.32%
1.5 3.5 5.5 7.5 9.5
Turn Signal Function
Mean: 8.203 Dev: 1.324
Value: 8.203
0.15% 0.14% 9.21% 45.40% 45.09%
1.5 3.5 5.5 7.5 9.5
Steering Feedback
Mean: 8.018 Dev: 1.453
Value: 8.018
0.10% 1.28% 12.35% 45.17% 41.10%
ronic Display of Information
n: 7.921 Dev: 1.562
e: 7.921
1.5 3.5 5.5 7.5 9.5
Economical to Own
Mean: 7.568 Dev: 1.655
Value: 7.568
0.42% 2.54% 22.49% 42.34% 32.22%
1.5 3.5 5.5 7.5 9.5
Bumpers
Mean: 7.926 Dev: 1.516
Value: 7.926
0.40% 1.00% 14.95% 44.20% 39.46%
1.5 3.5 5.5 7.5 9.5
Acceleration From Stop
Mean: 7.457 Dev: 1.636
Value: 7.457
0.16% 2.92% 24.88% 43.03% 29.02%
of Reading Controls/Instruments
n: 7.884 Dev: 1.651
e: 7.884
1.5 3.5 5.5 7.5 9.5
Affordable to Buy
Mean: 7.491 Dev: 1.702
Value: 7.491
0.50% 3.20% 23.80% 41.22% 31.28%
1.5 3.5 5.5 7.5 9.5
Solid Vehicle Construction
Mean: 7.988 Dev: 1.459
Value: 7.988
0.20% 1.01% 13.16% 45.43% 40.20%
1.5 3.5 5.5 7.5 9.5
Passing Capability
Mean: 7.605 Dev: 1.576
Value: 7.605
0.13% 1.99% 21.79% 44.65% 31.43%
1.5 3.5 5.5 7.5 9.5
Headlights Design
Mean: 8.179 Dev: 1.420
Value: 8.179
0.04% 0.61% 11.91% 40.25% 47.18%
1.5 3.5 5.5 7.5 9.5
Instrument Cluster Gauges
Mean: 7.936 Dev: 1.531
Value: 7.936
0.22% 1.35% 15.42% 42.43% 40.58%
1.5 3.5 5.5 7.5 9.5
Wiper System Controls
Mean: 8.050 Dev: 1.425
Value: 8.050
0.03% 1.06% 12.04% 45.12% 41.76%
1.5 3.5 5.5 7.5 9.5
Front Seat Roominess
Mean: 7.986 Dev: 1.575
Value: 7.986
0.44% 1.79% 13.79% 40.98% 43.00%
1.5 3.5 5.5 7.5 9.5
Ease of Loading/Unloading Cargo
Mean: 7.826 Dev: 1.602
Value: 7.826
0.65% 1.81% 15.97% 43.74% 37.84%
1.5 3.5 5.5 7.5 9.5
Usefulness of Glove Box
Mean: 7.680 Dev: 1.689
Value: 7.680
1.07% 1.73% 19.93% 41.66% 35.61%
1.5 3.5 5.5 7.5 9.5
Prestige/Reputation of Mfr.
Mean: 7.953 Dev: 1.512
Value: 7.953
0.50% 0.76% 14.57% 43.95% 40.23%
1.5 3.5 5.5 7.5 9.5

Statistical Challenges in Key Drivers Analysis

Estimation Challenges (cont'd)

- High-dimensional Multi-Collinearity



Statistical Challenges in Key Drivers Analysis

Estimation Challenges (cont'd)

- Multi-Collinearity
- Slopes of curves are nearly identical.

Key Drivers Analysis

How about a regression?

Key Drivers Analysis

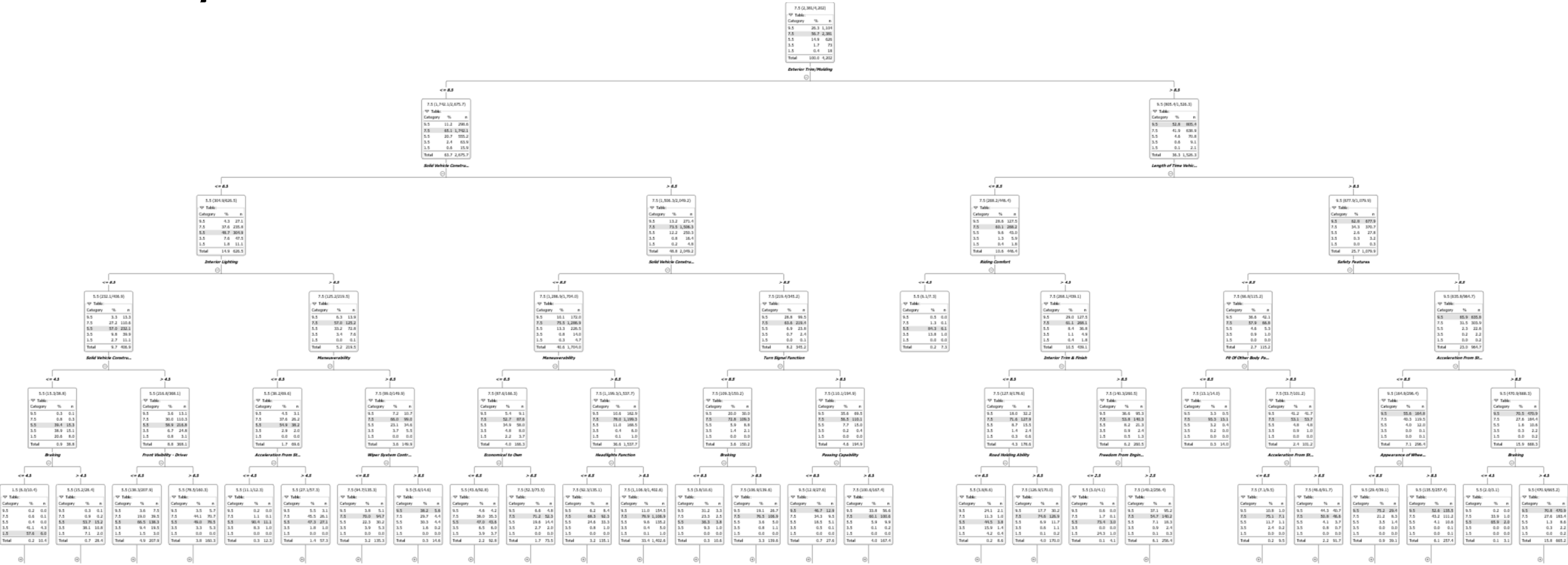
How about…

- Neural Networks
- Decision Trees
- Random Forests
- Ensemble Models
- Etc.

Great predictive performance, but difficult interpretability

Key Drivers Analysis

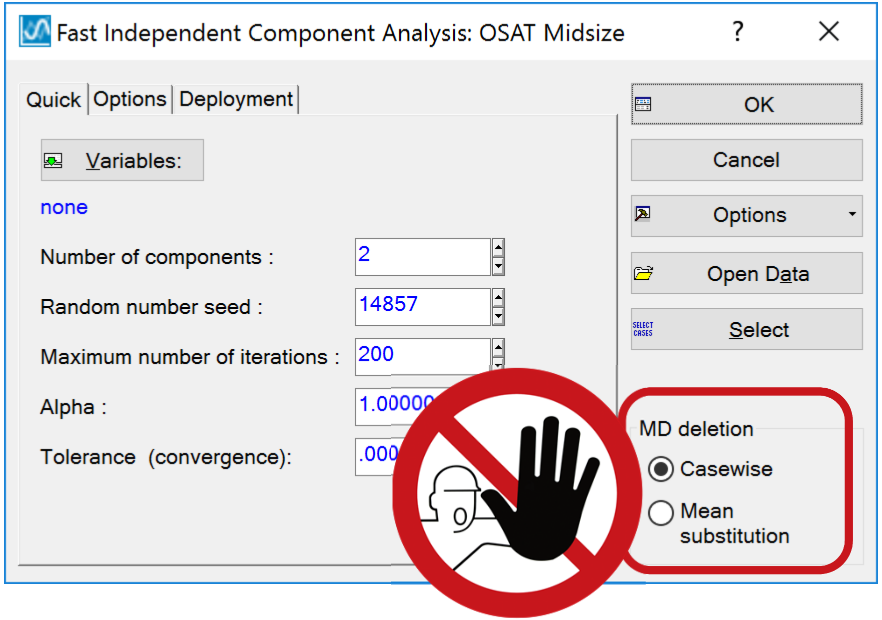
Example: Decision Tree



Statistical Challenges in Key Drivers Analysis

Estimation Challenges (cont'd)

- Missing Values
  - 5% of all data points are missing (21,110).
  - 77% of survey response contain at least one missing value.



Summary of Challenges

Conceptual Challenges

- "Driver"
  - A fundamentally causal concept.

Create a Non-Causal Model

  - direction, which we don't have.
- "Opinion Survey Data"
  - Non-experimental data.
- "Optimization"

Derive Constraints

  - Multitude of subjects.

Simulate Scenarios

  - No natural constraints.

Statistical Challenges

Leverage Information Theory

- Small variance
- Many dimensions

Find Factors

- Multi-collinearity
- Nonlinearity

Machine-Learn a Bayesian Network

- Missing Values

Building a Probabilistic Structural Equation Model

Key Drivers Analysis

Proposed Workflow

- Perform Factor Analysis
    - A machine-learned Bayesian network structure produces intuitive clusters for factor induction.
- Build a Non-Causal Probabilistic Structural Equation Model
    - A Probabilistic Structural Equation Model with a Bayesian network does not require causal assumptions, which we don't have.
- Perform Optimization
    - The explicit representation of the joint probability in a Bayesian network provides natural constraints for optimization.

Key Drivers Analysis

Practical Advantages of Using Bayesian Networks

- We can utilize information-theoretic measures for learning structure and quantifying relationships.
- We can “embrace” collinearity instead of suppressing it as a nuisance.
- Without parametric constraints, we have no problems with potential nonlinearity.
- We can easily handle missing values.

Key Drivers Analysis

Nomenclature

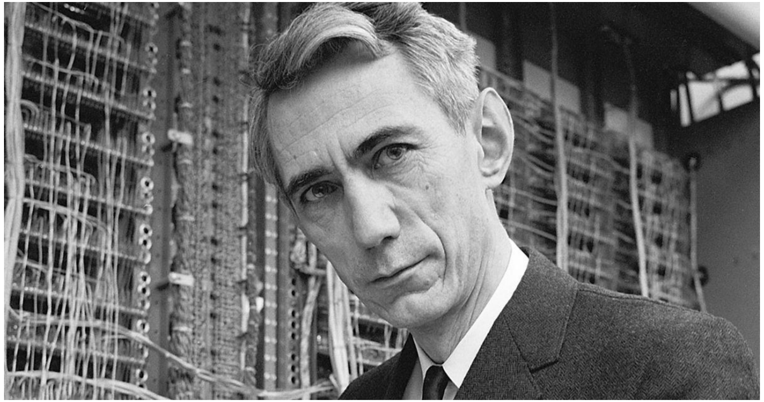
- We are trying to induce factors that can summarize multiple manifest variables.
- A factor is often referred to as a latent variable, as opposed to an observed, manifest variable.
- As such, factors do not exist, they are merely theoretical constructs.
- Creating factors is a variable reduction technique (compare to Factor Analysis, Principal Components Analysis, etc.)

Information Theory

Information-Theoretic Measures

- Entropy
- Mutual Information
- Arc Force (Kullback-Leibler Divergence)

See Chapter 5



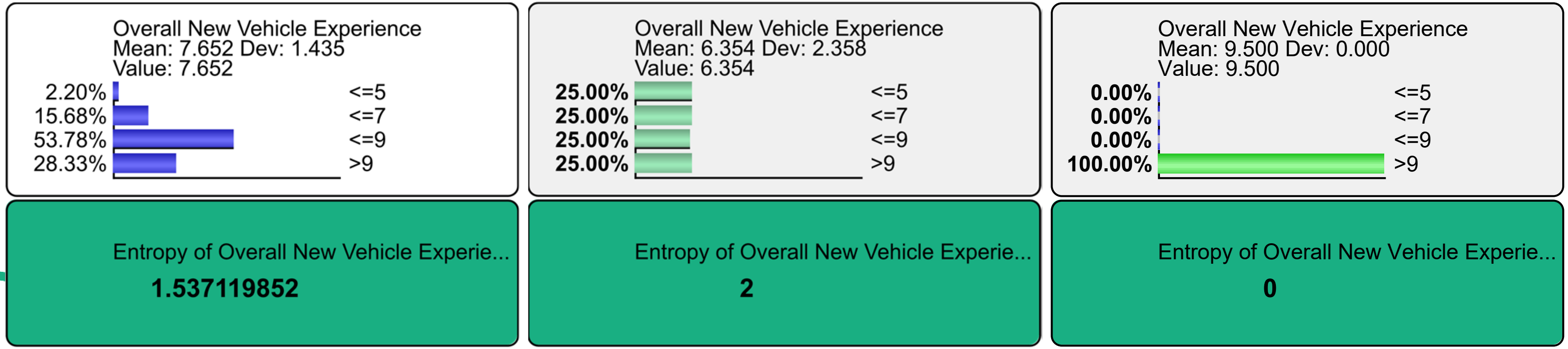
Claude Shannon (1916-2001)

Information Theory

Entropy: a measure of "uncertainty"

$$H(X) = -\sum_{x \in X} P(x) \log_2 P(x)$$

$$H(Overall\ NVE) = 1.54$$

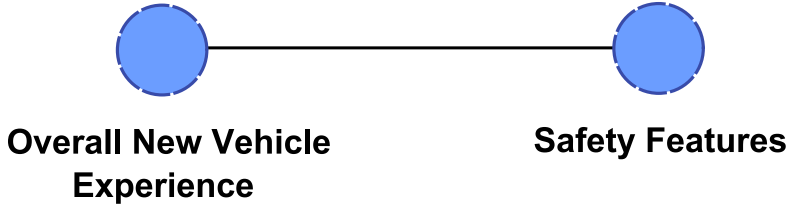


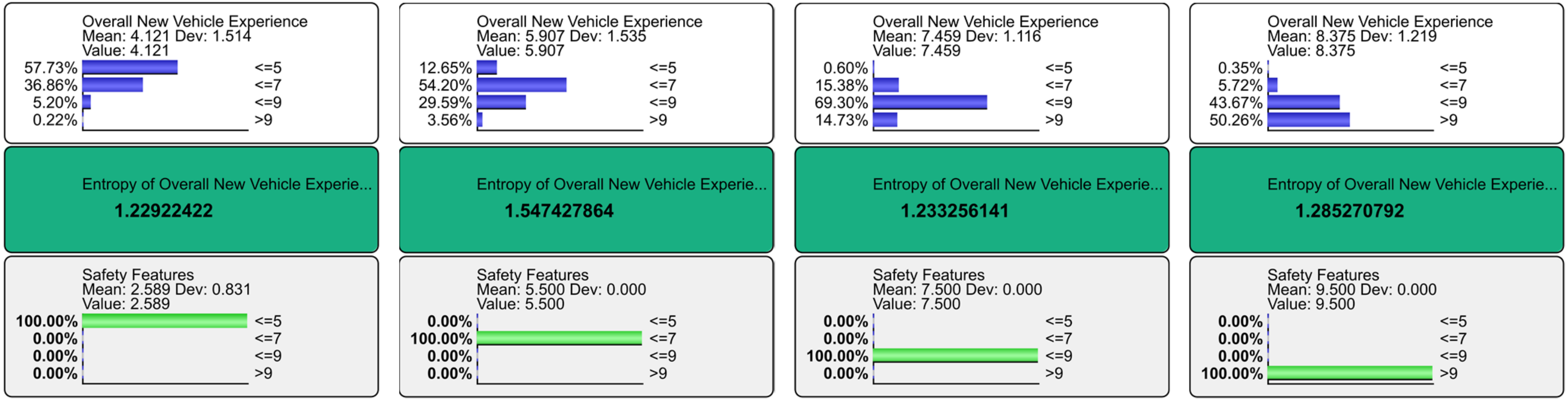
Marginal Entropy Maximal Entropy Minimal Entropy

Information Theory

Conditional Entropy

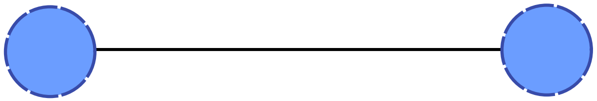
H(Overall NVE | Safety Features)





Information Theory

Mutual Information

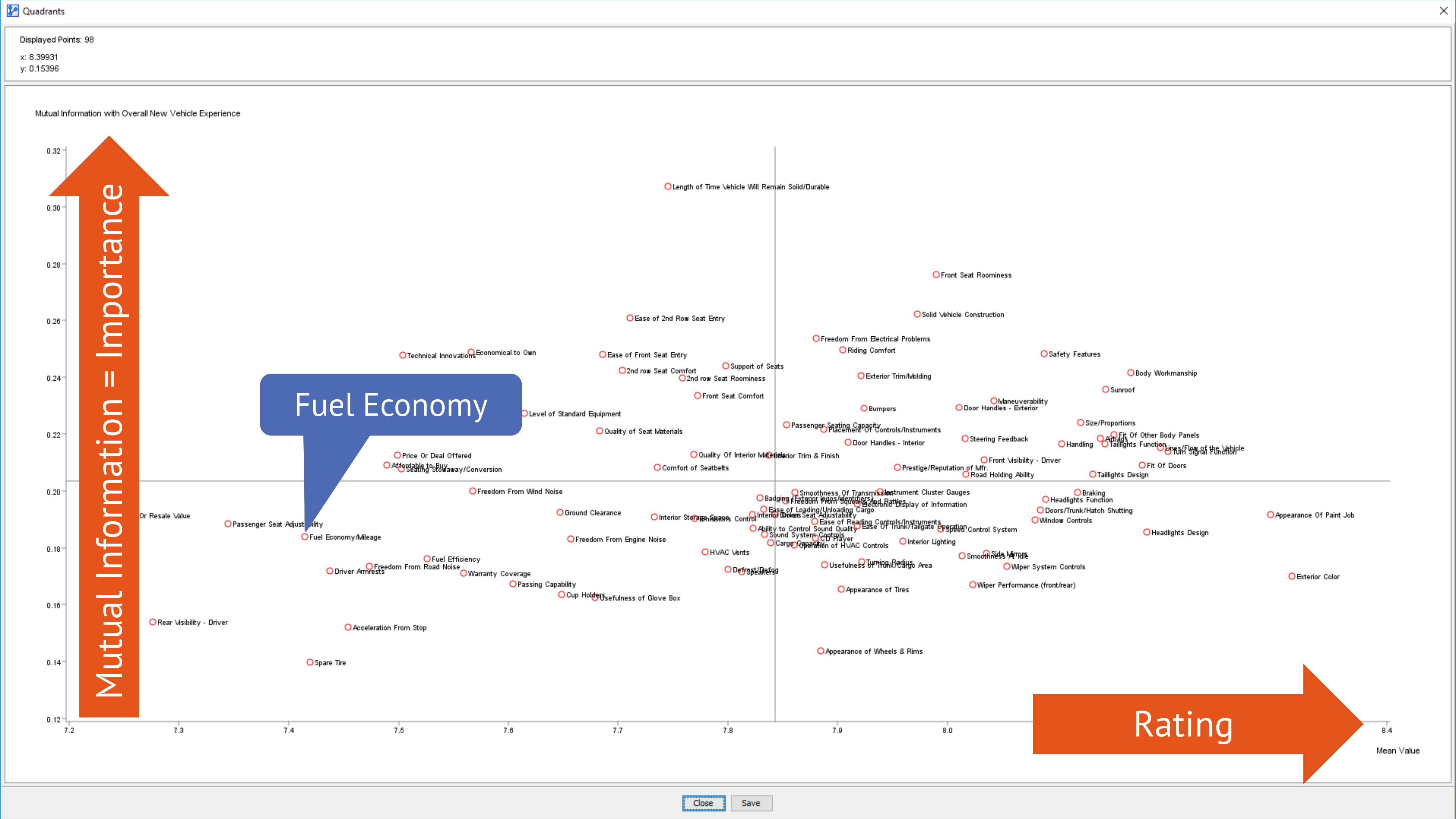


Overall New Vehicle Experience

Safety Features

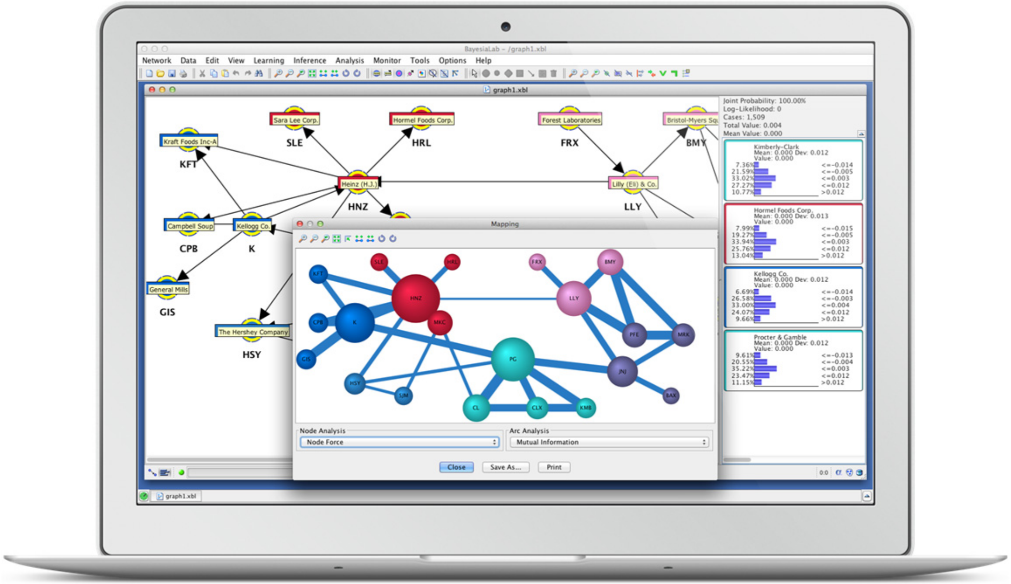
$$\underbrace{I(Overall\ NVE,\ Safety\ Features)}_{\text{Mutual Information}} = \underbrace{H(Overall\ NVE)}_{\text{Marginal Entropy}} - \underbrace{H(Overall\ NVE \mid Safety\ Features)}_{\text{Conditional Entropy}}$$

Airbags
Mean: 8.148 Dev: 1.371
Value: 8.148
0.15% 1.5
0.11% 3.5
11.32% 5.5
44.03% 7.5
44.39% 9.5
Length of Time Vehicle Will Remain S...
Mean: 7.758 Dev: 1.572
Value: 7.758
0.32% 1.5
1.18% 3.5
19.82% 5.5
42.67% 7.5
36.02% 9.5
Lines/Flow of the Vehicle
Mean: 8.194 Dev: 1.385
Value: 8.194
0.02% 1.5
0.56% 3.5
10.84% 5.5
41.83% 7.5
46.74% 9.5
Taillights Design
Mean: 8.129 Dev: 1.416
Value: 8.129
0.09% 1.5
0.42% 3.5
12.51% 5.5
41.94% 7.5
45.04% 9.5
Door Handles - Interior
Mean: 7.907 Dev: 1.475
Value: 7.907
0.06% 1.5
0.74% 3.5
16.50% 5.5
44.18% 7.5
38.52% 9.5
Speed Control System
Mean: 7.997 Dev: 1.482
Value: 7.997
0.15% 1.5
1.17% 3.5
13.68% 5.5
43.64% 7.5
41.35% 9.5
2nd row Seat Roominess
Mean: 7.751 Dev: 1.612
Value: 7.751
0.36% 1.5
1.60% 3.5
20.01% 5.5
41.18% 7.5
36.85% 9.5
Front Seat Comfort
Mean: 7.771 Dev: 1.700
Value: 7.771
0.80% 1.5
3.19% 3.5
15.90% 5.5
41.87% 7.5
38.24% 9.5
Usefulness of Trunk/Cargo Area
Mean: 7.889 Dev: 1.559
Value: 7.889
0.47% 1.5
1.49% 3.5
15.27% 5.5
43.67% 7.5
39.11% 9.5
Overall New Vehicle Experience
Mean: 7.651 Dev: 1.490
Value: 7.651
0.65% 1.5
1.56% 3.5
15.69% 5.5
53.79% 7.5
28.32% 9.5
Freedom From Electrical Problems
Mean: 7.890 Dev: 1.523
Value: 7.890
0.28% 1.5
1.08% 3.5
16.25% 5.5
43.68% 7.5
38.72% 9.5
Appearance Of Paint Job
Mean: 8.300 Dev: 1.416
Value: 8.300
0.23% 1.5
0.60% 3.5
9.91% 5.5
37.46% 7.5
51.81% 9.5
Sunroof
Mean: 8.258 Dev: 1.458
Value: 8.258
0.83% 1.5
0.41% 3.5
8.60% 5.5
40.35% 7.5
49.81% 9.5
Interior Lighting
Mean: 7.957 Dev: 1.519
Value: 7.957
0.21% 1.5
1.12% 3.5
15.39% 5.5
42.13% 7.5
41.14% 9.5
Speakers
Mean: 7.814 Dev: 1.615
Value: 7.814
0.63% 1.5
1.86% 3.5
16.63% 5.5
42.94% 7.5
37.94% 9.5
Ease of Front Seat Entry
Mean: 7.682 Dev: 1.769
Value: 7.682
1.14% 1.5
3.36% 3.5
18.02% 5.5
40.21% 7.5
37.27% 9.5
2nd row Seat Comfort
Mean: 7.702 Dev: 1.599
Value: 7.702
0.25% 1.5
1.96% 3.5
20.06% 5.5
42.92% 7.5
34.82% 9.5
Spare Tire
Mean: 7.423 Dev: 1.767
Value: 7.423
1.16% 1.5
2.52% 3.5
26.47% 5.5
38.69% 7.5
31.16% 9.5
Safety Features
Mean: 8.095 Dev: 1.390
Value: 8.095
0.31% 1.5
0.37% 3.5
10.72% 5.5
46.45% 7.5
42.14% 9.5
Ground Clearance
Mean: 7.649 Dev: 1.618
Value: 7.649
0.45% 1.5
2.23% 3.5
19.87% 5.5
44.29% 7.5
33.15% 9.5
Size/Proportions
Mean: 8.120 Dev: 1.443
Value: 8.120
0.16% 1.5
0.70% 3.5
12.27% 5.5
41.71% 7.5
45.16% 9.5
Interior Colors
Mean: 7.825 Dev: 1.634
Value: 7.825
0.50% 1.5
1.63% 3.5
18.69% 5.5
39.49% 7.5
39.70% 9.5
Quality of Seat Materials
Mean: 7.681 Dev: 1.644
Value: 7.681
0.50% 1.5
2.15% 3.5
20.19% 5.5
42.12% 7.5
35.04% 9.5
Ability to Control Sound Quality
Mean: 7.827 Dev: 1.622
Value: 7.827
0.46% 1.5
2.14% 3.5
16.90% 5.5
41.61% 7.5
38.90% 9.5
Ease of 2nd Row Seat Entry
Mean: 7.707 Dev: 1.620
Value: 7.707
0.30% 1.5
2.05% 3.5
20.22% 5.5
41.87% 7.5
35.57% 9.5
Driver Seat Adjustability
Mean: 7.842 Dev: 1.645
Value: 7.842
0.48% 1.5
2.26% 3.5
17.07% 5.5
40.07% 7.5
40.12% 9.5
Price Or Deal Offered
Mean: 7.500 Dev: 1.735
Value: 7.500
0.74% 1.5
3.01% 3.5
24.15% 5.5
39.71% 7.5
32.39% 9.5
Front Visibility - Driver
Mean: 8.039 Dev: 1.500
Value: 8.039
0.64% 1.5
1.18% 3.5
10.89% 5.5
45.17% 7.5
42.12% 9.5
Riding Comfort
Mean: 7.906 Dev: 1.564
Value: 7.906
0.47% 1.5
1.45% 3.5
15.27% 5.5
42.91% 7.5
39.90% 9.5
Side Mirrors
Mean: 8.036 Dev: 1.485
Value: 8.036
0.36% 1.5
0.92% 3.5
12.86% 5.5
43.33% 7.5
42.54% 9.5
Interior Trim & Finish
Mean: 7.836 Dev: 1.625
Value: 7.836
0.54% 1.5
1.20% 3.5
19.17% 5.5
39.12% 7.5
39.97% 9.5
Freedom From Squeaks And Rattles
Mean: 7.851 Dev: 1.649
Value: 7.851
0.43% 1.5
2.78% 3.5
15.87% 5.5
40.65% 7.5
40.27% 9.5
Sound System Controls
Mean: 7.836 Dev: 1.575
Value: 7.836
0.28% 1.5
2.06% 3.5
16.16% 5.5
43.59% 7.5
37.90% 9.5
Comfort of Seatbelts
Mean: 7.733 Dev: 1.632
Value: 7.733
0.67% 1.5
2.02% 3.5
18.06% 5.5
43.47% 7.5
35.78% 9.5
Passenger Seat Adjustability
Mean: 7.346 Dev: 1.791
Value: 7.346
1.08% 1.5
3.29% 3.5
27.93% 5.5
37.68% 7.5
30.03% 9.5
Future Trade-In Or Resale Value
Mean: 7.230 Dev: 1.694
Value: 7.230
0.49% 1.5
3.14% 3.5
31.18% 5.5
39.76% 7.5
25.43% 9.5
Rear Visibility - Driver
Mean: 7.280 Dev: 1.851
Value: 7.280
0.81% 1.5
6.58% 3.5
24.32% 5.5
39.37% 7.5
28.92% 9.5
Maneuverability
Mean: 8.045 Dev: 1.406
Value: 8.045
0.05% 1.5
0.59% 3.5
12.76% 5.5
45.29% 7.5
41.32% 9.5
Appearance of Wheels & Rims
Mean: 7.883 Dev: 1.552
Value: 7.883
0.11% 1.5
0.78% 3.5
19.37% 5.5
39.34% 7.5
40.40% 9.5
Body Workmanship
Mean: 8.165 Dev: 1.353
Value: 8.165
0.22% 1.5
0.22% 3.5
9.81% 5.5
45.61% 7.5
44.15% 9.5
Freedom From Engine Noise
Mean: 7.656 Dev: 1.690
Value: 7.656
0.94% 1.5
2.19% 3.5
19.91% 5.5
42.05% 7.5
34.91% 9.5
CD Player
Mean: 7.887 Dev: 1.496
Value: 7.887
0.12% 1.5
1.22% 3.5
15.80% 5.5
44.91% 7.5
37.95% 9.5
Support of Seats
Mean: 7.795 Dev: 1.592
Value: 7.795
0.47% 1.5
2.10% 3.5
16.28% 5.5
44.50% 7.5
36.65% 9.5
Driver Armrests
Mean: 7.436 Dev: 1.773
Value: 7.436
1.20% 1.5
3.05% 3.5
24.60% 5.5
40.06% 7.5
31.09% 9.5
Warranty Coverage
Mean: 7.562 Dev: 1.697
Value: 7.562
0.37% 1.5
2.61% 3.5
24.43% 5.5
38.75% 7.5
33.84% 9.5
Braking
Mean: 8.124 Dev: 1.391
Value: 8.124
0.23% 1.5
0.55% 3.5
10.42% 5.5
45.39% 7.5
43.41% 9.5
Turning Radius
Mean: 7.924 Dev: 1.476
Value: 7.924
0.05% 1.5
0.86% 3.5
15.99% 5.5
44.06% 7.5
39.04% 9.5
Appearance of Tires
Mean: 7.902 Dev: 1.515
Value: 7.902
0.04% 1.5
0.51% 3.5
18.88% 5.5
40.46% 7.5
40.11% 9.5
Fit Of Doors
Mean: 8.177 Dev: 1.380
Value: 8.177
0.16% 1.5
0.45% 3.5
10.32% 5.5
43.56% 7.5
45.52% 9.5
Freedom From Road Noise
Mean: 7.473 Dev: 1.744
Value: 7.473
0.81% 1.5
3.37% 3.5
23.72% 5.5
40.55% 7.5
31.54% 9.5
Operation of HVAC Controls
Mean: 7.857 Dev: 1.564
Value: 7.857
0.20% 1.5
1.70% 3.5
16.92% 5.5
42.40% 7.5
38.77% 9.5
Passenger Seating Capacity
Mean: 7.850 Dev: 1.502
Value: 7.850
0.23% 1.5
0.46% 3.5
18.25% 5.5
43.73% 7.5
37.33% 9.5
Seating Versatility
Mean: 7.552 Dev: 1.634
Value: 7.552
0.45% 1.5
1.30% 3.5
25.49% 5.5
40.70% 7.5
32.06% 9.5
Technical Innovations
Mean: 7.509 Dev: 1.595
Value: 7.509
0.26% 1.5
1.54% 3.5
25.39% 5.5
43.11% 7.5
29.71% 9.5
Headlights Function
Mean: 8.092 Dev: 1.475
Value: 8.092
0.39% 1.5
1.07% 3.5
11.20% 5.5
43.24% 7.5
44.10% 9.5
Road Holding Ability
Mean: 8.018 Dev: 1.433
Value: 8.018
0.03% 1.5
0.99% 3.5
12.89% 5.5
45.21% 7.5
40.88% 9.5
Exterior Trim/Molding
Mean: 7.924 Dev: 1.562
Value: 7.924
0.29% 1.5
0.97% 3.5
17.51% 5.5
39.72% 7.5
41.51% 9.5
Fit Of Other Body Panels
Mean: 8.152 Dev: 1.389
Value: 8.152
0.23% 1.5
0.50% 3.5
10.23% 5.5
44.50% 7.5
44.54% 9.5
Freedom From Wind Noise
Mean: 7.566 Dev: 1.707
Value: 7.566
0.69% 1.5
3.05% 3.5
21.55% 5.5
41.68% 7.5
33.04% 9.5
HVAC Vents
Mean: 7.776 Dev: 1.583
Value: 7.776
0.09% 1.5
2.14% 3.5
18.44% 5.5
42.55% 7.5
36.78% 9.5
Interior Storage Space
Mean: 7.731 Dev: 1.667
Value: 7.731
0.51% 1.5
2.06% 3.5
20.35% 5.5
39.49% 7.5
37.59% 9.5
Seating Stowaway/Conversion
Mean: 7.508 Dev: 1.670
Value: 7.508
0.72% 1.5
1.21% 3.5
26.73% 5.5
39.65% 7.5
31.69% 9.5
Level of Standard Equipment
Mean: 7.618 Dev: 1.592
Value: 7.618
0.30% 1.5
2.01% 3.5
21.12% 5.5
44.66% 7.5
31.92% 9.5
Taillights Function
Mean: 8.147 Dev: 1.360
Value: 8.147
0.25% 1.5
0.19% 3.5
10.11% 5.5
45.87% 7.5
43.58% 9.5
Handling
Mean: 8.106 Dev: 1.389
Value: 8.106
0.05% 1.5
0.54% 3.5
11.66% 5.5
44.59% 7.5
43.17% 9.5
Door Handles - Exterior
Mean: 8.011 Dev: 1.495
Value: 8.011
0.20% 1.5
0.45% 3.5
15.86% 5.5
40.57% 7.5
42.92% 9.5
Doors/Trunk/Hatch Shutting
Mean: 8.084 Dev: 1.482
Value: 8.084
0.23% 1.5
1.40% 3.5
11.54% 5.5
42.60% 7.5
44.23% 9.5
Smoothness At Idle
Mean: 8.019 Dev: 1.478
Value: 8.019
0.35% 1.5
0.93% 3.5
12.82% 5.5
44.21% 7.5
41.69% 9.5
Defrost/Defog
Mean: 7.797 Dev: 1.552
Value: 7.797
0.23% 1.5
1.14% 3.5
18.97% 5.5
42.85% 7.5
36.81% 9.5
Cargo Capacity
Mean: 7.833 Dev: 1.637
Value: 7.833
0.52% 1.5
1.85% 3.5
17.87% 5.5
39.95% 7.5
39.80% 9.5
Placement Of Controls/Instruments
Mean: 7.890 Dev: 1.552
Value: 7.890
0.31% 1.5
1.67% 3.5
15.38% 5.5
43.48% 7.5
39.16% 9.5
Fuel Economy/Mileage
Mean: 7.417 Dev: 1.753
Value: 7.417
0.92% 1.5
4.36% 3.5
21.99% 5.5
43.41% 7.5
29.32% 9.5
Turn Signal Function
Mean: 8.203 Dev: 1.324
Value: 8.203
0.15% 1.5
0.14% 3.5
9.21% 5.5
45.40% 7.5
45.09% 9.5
Steering Feedback
Mean: 8.018 Dev: 1.453
Value: 8.018
0.10% 1.5
1.28% 3.5
12.35% 5.5
45.17% 7.5
41.10% 9.5
Badging (Exterior logos/identifiers)
Mean: 7.835 Dev: 1.585
Value: 7.835
0.26% 1.5
0.71% 3.5
20.76% 5.5
38.57% 7.5
39.70% 9.5
Wiper Performance (front/rear)
Mean: 8.021 Dev: 1.495
Value: 8.021
0.11% 1.5
1.26% 3.5
13.86% 5.5
42.00% 7.5
42.77% 9.5
Smoothness Of Transmission
Mean: 7.863 Dev: 1.568
Value: 7.863
0.40% 1.5
1.48% 3.5
16.48% 5.5
42.87% 7.5
38.78% 9.5
Fuel Efficiency
Mean: 7.532 Dev: 1.726
Value: 7.532
0.71% 1.5
3.15% 3.5
22.73% 5.5
40.65% 7.5
32.75% 9.5
Cup Holders
Mean: 7.644 Dev: 1.770
Value: 7.644
0.97% 1.5
3.58% 3.5
19.27% 5.5
39.62% 7.5
36.56% 9.5
Electronic Display of Information
Mean: 7.921 Dev: 1.562
Value: 7.921
0.34% 1.5
2.02% 3.5
14.07% 5.5
43.39% 7.5
40.18% 9.5
Economical to Own
Mean: 7.568 Dev: 1.655
Value: 7.568
0.42% 1.5
2.54% 3.5
22.49% 5.5
42.34% 7.5
32.22% 9.5
Bumpers
Mean: 7.926 Dev: 1.516
Value: 7.926
0.40% 1.5
1.00% 3.5
14.95% 5.5
44.20% 7.5
39.46% 9.5
Acceleration From Stop
Mean: 7.457 Dev: 1.636
Value: 7.457
0.16% 1.5
2.92% 3.5
24.88% 5.5
43.03% 7.5
29.02% 9.5
Exterior Color
Mean: 8.314 Dev: 1.385
Value: 8.314
0.06% 1.5
0.57% 3.5
9.81% 5.5
37.72% 7.5
51.83% 9.5
Quality Of Interior Materials
Mean: 7.766 Dev: 1.546
Value: 7.766
0.24% 1.5
1.71% 3.5
17.53% 5.5
45.53% 7.5
34.99% 9.5
Window Controls
Mean: 8.078 Dev: 1.422
Value: 8.078
0.15% 1.5
0.88% 3.5
11.43% 5.5
44.96% 7.5
42.57% 9.5
Emissions Control
Mean: 7.779 Dev: 1.512
Value: 7.779
0.15% 1.5
0.30% 3.5
20.79% 5.5
42.97% 7.5
35.79% 9.5
Ease Of Trunk/Tailgate Operation
Mean: 7.915 Dev: 1.590
Value: 7.915
0.38% 1.5
2.28% 3.5
14.30% 5.5
42.32% 7.5
40.73% 9.5
Ease of Reading Controls/Instruments
Mean: 7.884 Dev: 1.651
Value: 7.884
0.72% 1.5
2.82% 3.5
13.51% 5.5
42.41% 7.5
40.54% 9.5
Affordable to Buy
Mean: 7.491 Dev: 1.702
Value: 7.491
0.50% 1.5
3.20% 3.5
23.80% 5.5
41.22% 7.5
31.28% 9.5
Solid Vehicle Construction
Mean: 7.988 Dev: 1.459
Value: 7.988
0.20% 1.5
1.01% 3.5
13.16% 5.5
45.43% 7.5
40.20% 9.5
Passing Capability
Mean: 7.605 Dev: 1.576
Value: 7.605
0.13% 1.5
1.99% 3.5
21.79% 5.5
44.65% 7.5
31.43% 9.5
Headlights Design
Mean: 8.179 Dev: 1.420
Value: 8.179
0.04% 1.5
0.61% 3.5
11.91% 5.5
40.25% 7.5
47.18% 9.5
Instrument Cluster Gauges
Mean: 7.936 Dev: 1.531
Value: 7.936
0.22% 1.5
1.35% 3.5
15.42% 5.5
42.43% 7.5
40.58% 9.5
Wiper System Controls
Mean: 8.050 Dev: 1.425
Value: 8.050
0.03% 1.5
1.06% 3.5
12.04% 5.5
45.12% 7.5
41.76% 9.5
Front Seat Roominess
Mean: 7.986 Dev: 1.575
Value: 7.986
0.44% 1.5
1.79% 3.5
13.79% 5.5
40.98% 7.5
43.00% 9.5
Ease of Loading/Unloading Cargo
Mean: 7.826 Dev: 1.602
Value: 7.826
0.65% 1.5
1.81% 3.5
15.97% 5.5
43.74% 7.5
37.84% 9.5
Usefulness of Glove Box
Mean: 7.680 Dev: 1.689
Value: 7.680
1.07% 1.5
1.73% 3.5
19.93% 5.5
41.66% 7.5
35.61% 9.5
Prestige/Reputation of Mfr.
Mean: 7.953 Dev: 1.512
Value: 7.953
0.50% 1.5
0.76% 3.5
14.57% 5.5
43.95% 7.5
40.23% 9.5



Quadrants
Displayed Points: 98
x: 8.39931
y: 0.15396
Mutual Information with Overall New Vehicle Experience
Mutual Information = Importance
Fuel Economy
Rating
Mean Value
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
7.2
7.3
7.4
7.5
7.6
7.7
7.8
7.9
8.0
8.4
Length of Time Vehicle Will Remain Solid/Durable
Front Seat Roominess
Solid Vehicle Construction
Ease of 2nd Row Seat Entry
Freedom From Electrical Problems
Riding Comfort
Safety Features
Technical Innovations
Economical to Own
Ease of Front Seat Entry
Support of Seats
2nd row Seat Comfort
2nd row Seat Roominess
Exterior Trim/Molding
Body Workmanship
Sunroof
Front Seat Comfort
Level of Standard Equipment
Bumpers
Door Handles - Exterior
Maneuverability
Size/Proportions
Quality of Seat Materials
Placement Of Controls/Instruments
Steering Feedback
Fit Of Other Body Panels
Handling
Door Handles - Interior
Price Or Deal Offered
Quality Of Interior Materials
Interior Trim & Finish
Front Visibility - Driver
Fit Of Doors
Seating Stowaway/Conversion
Comfort of Seatbelts
Prestige/Reputation of Mfr.
Road Holding Ability
Taillights Design
Freedom From Wind Noise
Instrument Cluster Gauges
Braking
Headlights Function
Electronic Display of Information
Doors/Trunk/Hatch Shutting
Ground Clearance
Ease of Loading/Unloading Cargo
Appearance Of Paint Job
Or Resale Value
Passenger Seat Adjust
Window Controls
Fuel Economy/Mileage
Freedom From Engine Noise
Speed Control System
Headlights Design
Interior Lighting
HVAC Vents
Operation of HVAC Controls
Fuel Efficiency
Freedom From Road Noise
Driver Armrests
Warranty Coverage
Wiper System Controls
Exterior Color
Passing Capability
Appearance of Tires
Wiper Performance (front/rear)
Cup Holders
Usefulness of Glove Box
Rear Visibility - Driver
Acceleration From Stop
Appearance of Wheels & Rims
Spare Tire
Close
Save

Workflow with BayesiaLab



Proposed Workflow

- Machine-learn a Bayesian network
- Validate network
- Perform clustering
- Induce factors
- Construct PSEM
- Perform Multi-Quadrant Analysis
- Optimize with Target Dynamic Profile

Network Learning

Number of Possible Bayesian Networks

• 2 Nodes:	3
• 3 Nodes:	25
• 4 Nodes:	543
• 5 Nodes:	29,281
• 6 Nodes:	3.8×10^{6}
• 7 Nodes:	1.1×10^{9}
• 8 Nodes:	7.8×10^{11}
• 9 Nodes:	1.2×10^{15}
• 10 Nodes:	4.2×10^{18}
• 11 Nodes:	3.2×10^{22}

⋮

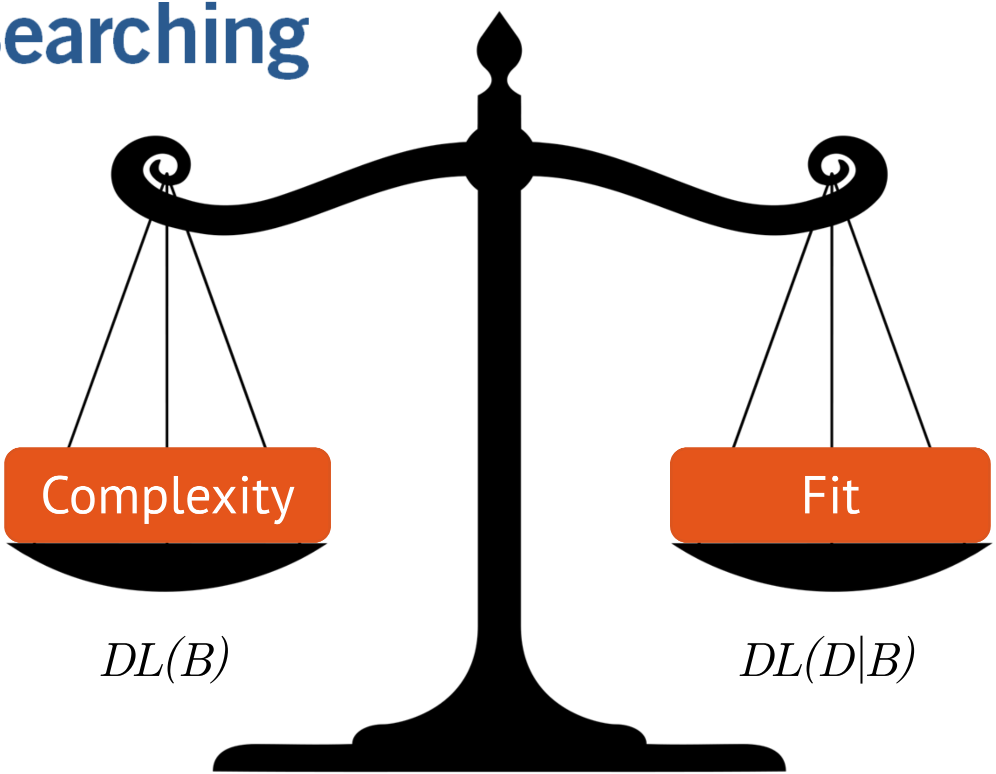
- 100 Nodes: 1.1×10^{1636}

Search Space

Network Learning=Searching

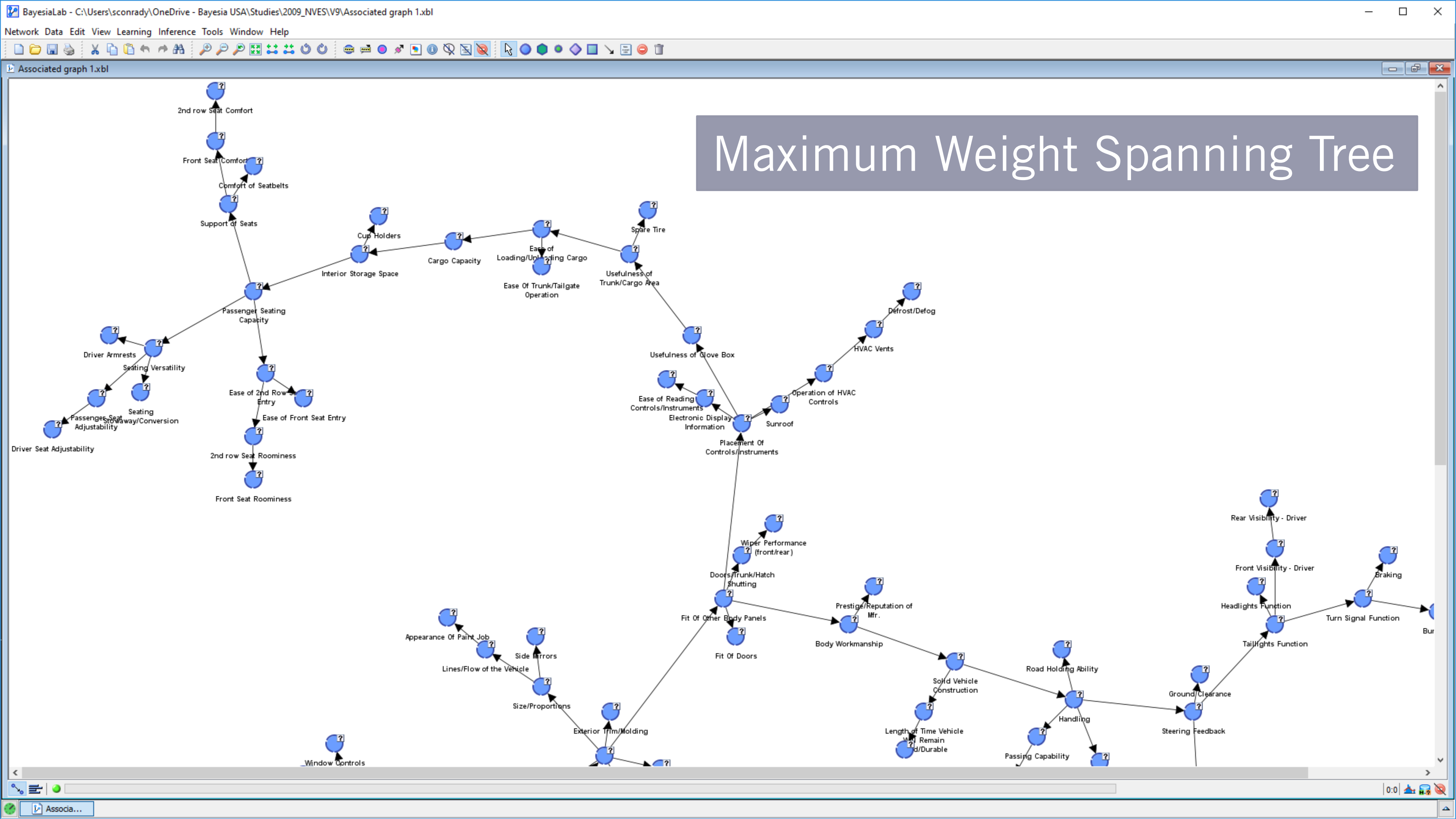
Minimum Description Length

- $DL(B)$ is the number of bits to represent the Bayesian network B (graph and probabilities), and
- $DL(D|B)$ is the number of bits to represent the dataset D given the Bayesian network B (likelihood of the data given the Bayesian network).



$$MDL(B,D)=\alpha\cdot DL(B)+DL(D|B)$$

Structural Coefficient α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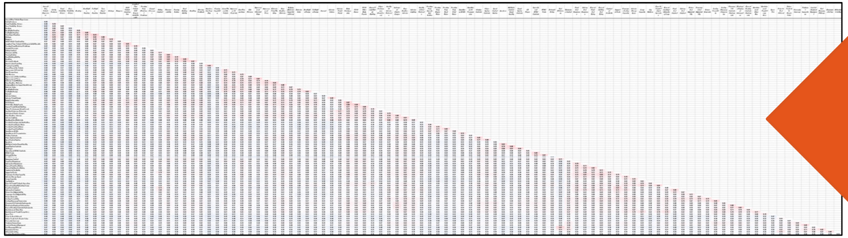
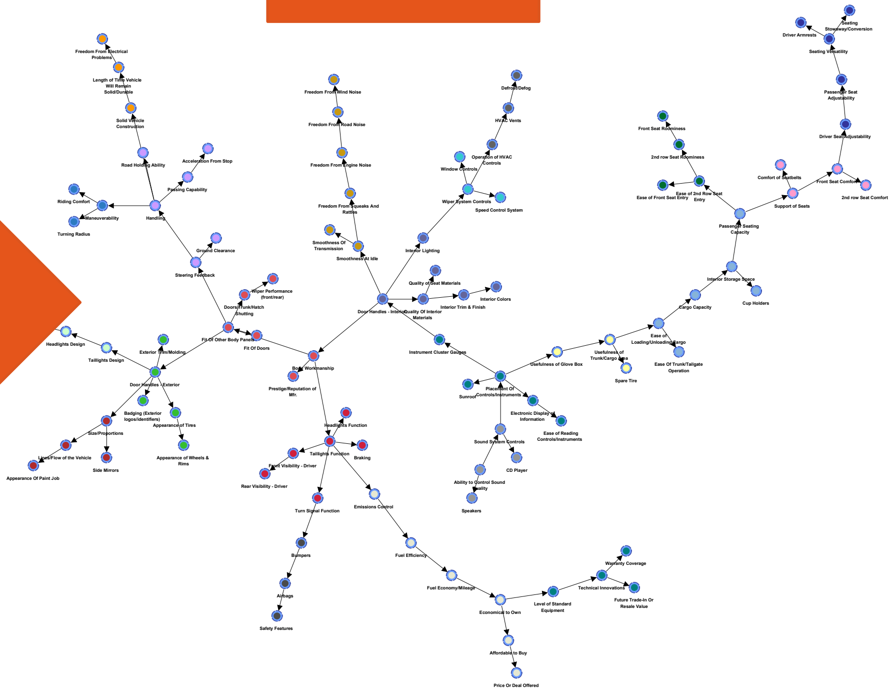
Network Data Edit View Learning Inference Tools Window Help
Associated graph 1.xbl
Maximum Weight Spanning Tree
2nd row Seat Comfort
Front Seat Comfort
Comfort of Seatbelts
Support of Seats
Cup Holders
Cargo Capacity
Ease of Loading/Unloading Cargo
Spare Tire
Usefulness of Trunk/Cargo Area
Interior Storage Space
Ease Of Trunk/Tailgate Operation
Passenger Seating Capacity
Defrost/Defog
HVAC Vents
Usefulness of Glove Box
Driver Armrests
Seating Versatility
Ease of 2nd Row Seat Entry
Ease of Front Seat Entry
Seating Stowaway/Conversion
Passenger Seat Adjustability
Driver Seat Adjustability
2nd row Seat Roominess
Front Seat Roominess
Ease of Reading Controls/Instruments
Electronic Display Information
Operation of HVAC Controls
Sunroof
Placement Of Controls/Instruments
Wiper Performance (front/rear)
Doors/Trunk/Hatch Shutting
Fit Of Other Body Panels
Fit Of Doors
Prestige/Reputation of Mfr.
Body Workmanship
Appearance Of Paint Job
Lines/Flow of the Vehicle
Side Mirrors
Size/Proportions
Exterior Trim/Molding
Window Controls
Solid Vehicle Construction
Length of Time Vehicle Will Remain Solid/Durable
Road Holding Ability
Handling
Passing Capability
Ground Clearance
Steering Feedback
Rear Visibility - Driver
Front Visibility - Driver
Headlights Function
Taillights Function
Turn Signal Function
Braking
Associa...

Knowledge Discovery

Correlation Matrix



Network

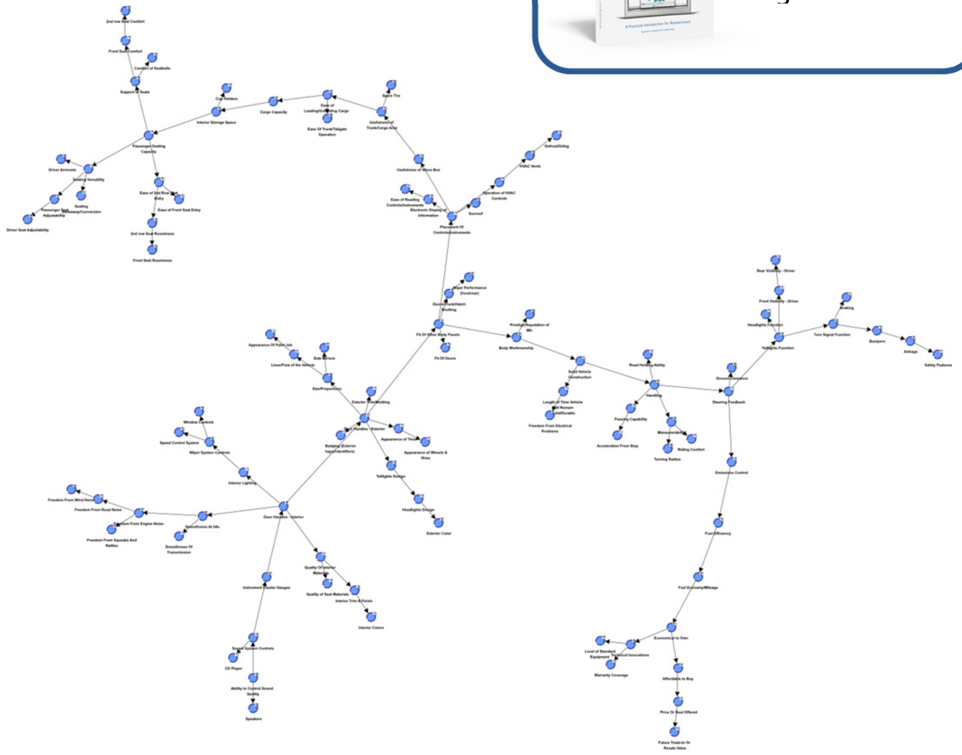


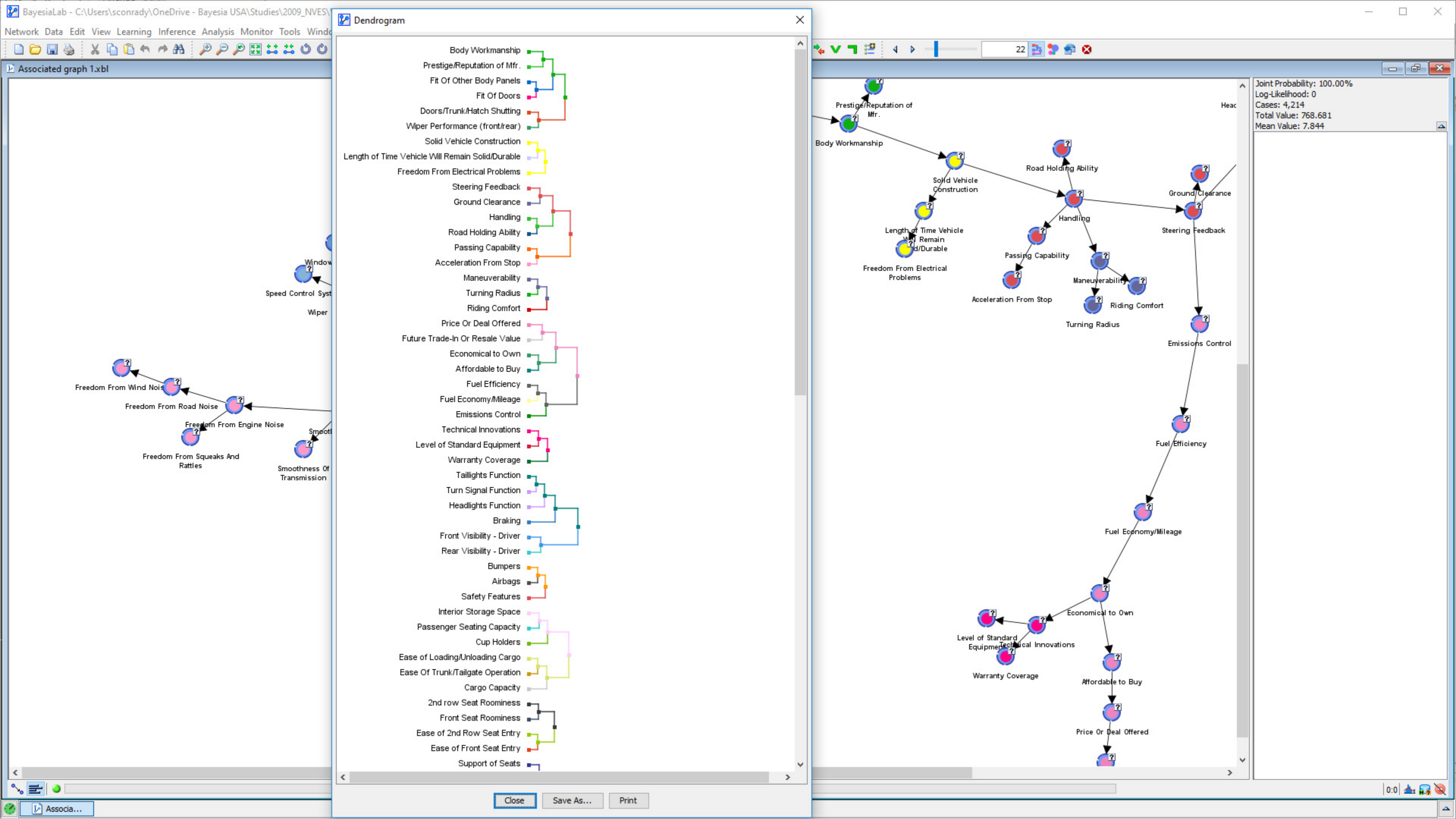
Clustering

See Chapter 8
Page 216

Variable Clustering

- Hierarchical agglomerative process using Arc Force (Kullback-Leibler Divergence).
- Why not a traditional factor analysis?
    - Limited number of factors and difficult interpretability.

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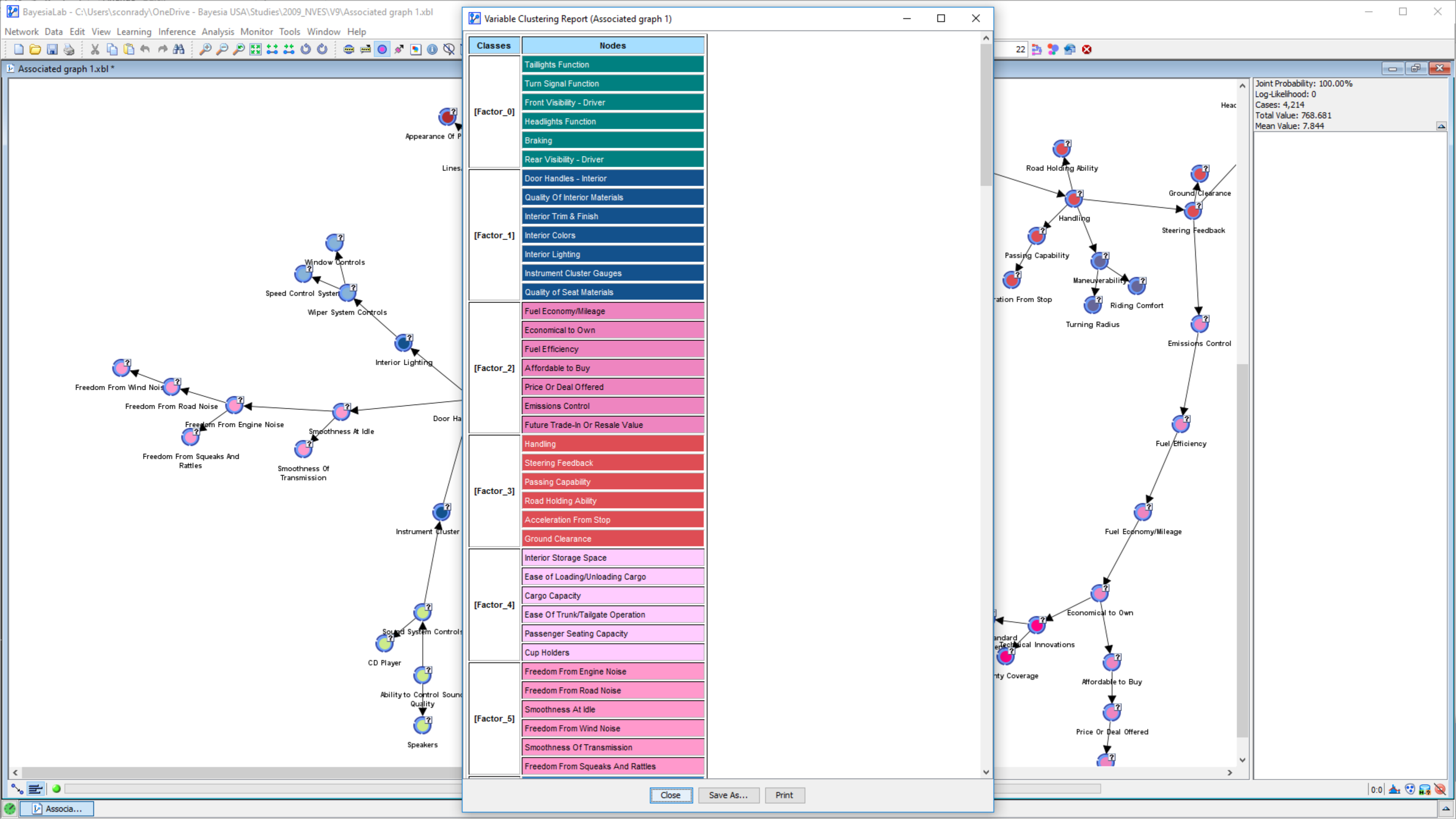
Network Data Edit View Learning Inference Analysis Monitor Tools Windo
Associated graph 1.xbl
Dendrogram
Body Workmanship
Prestige/Reputation of Mfr.
Fit Of Other Body Panels
Fit Of Doors
Doors/Trunk/Hatch Shutting
Wiper Performance (front/rear)
Solid Vehicle Construction
Length of Time Vehicle Will Remain Solid/Durable
Freedom From Electrical Problems
Steering Feedback
Ground Clearance
Handling
Road Holding Ability
Passing Capability
Acceleration From Stop
Maneuverability
Turning Radius
Riding Comfort
Price Or Deal Offered
Future Trade-In Or Resale Value
Economical to Own
Affordable to Buy
Fuel Efficiency
Fuel Economy/Mileage
Emissions Control
Technical Innovations
Level of Standard Equipment
Warranty Coverage
Taillights Function
Turn Signal Function
Headlights Function
Braking
Front Visibility - Driver
Rear Visibility - Driver
Bumpers
Airbags
Safety Features
Interior Storage Space
Passenger Seating Capacity
Cup Holders
Ease of Loading/Unloading Cargo
Ease Of Trunk/Tailgate Operation
Cargo Capacity
2nd row Seat Roominess
Front Seat Roominess
Ease of 2nd Row Seat Entry
Ease of Front Seat Entry
Support of Seats
Close
Save As...
Print
Freedom From Wind Nois
Freedom From Road Noise
Freedom From Engine Noise
Freedom From Squeaks And Rattles
Smoothness Of Transmission
Speed Control Syst
Wiper
Prestige/Reputation of Mfr.
Body Workmanship
Solid Vehicle Construction
Road Holding Ability
Ground Clearance
Handling
Steering Feedback
Passing Capability
Freedom From Electrical Problems
Acceleration From Stop
Riding Comfort
Turning Radius
Emissions Control
Fuel Efficiency
Fuel Economy/Mileage
Economical to Own
Technical Innovations
Warranty Coverage
Affordable to Buy
Price Or Deal Offered
Joint Probability: 100.00%
Log-Likelihood: 0
Cases: 4,214
Total Value: 768.681
Mean Value: 7.844
22
Associa...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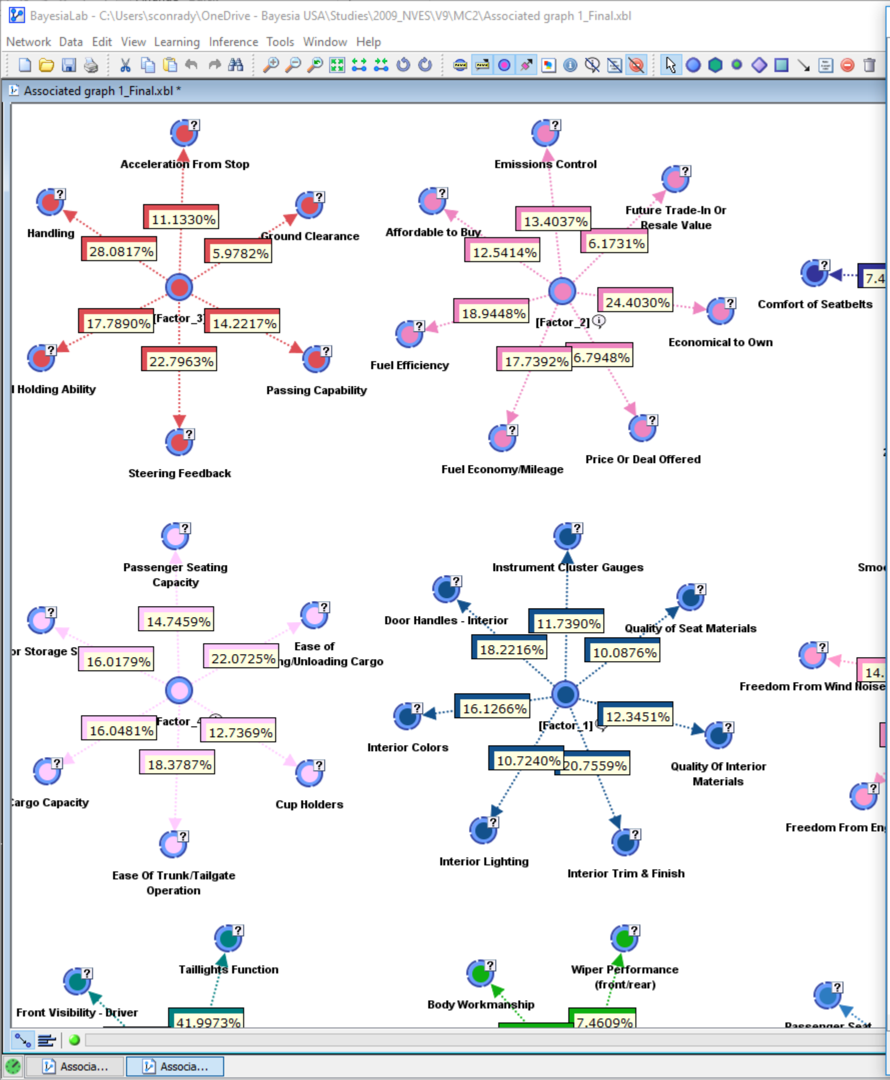
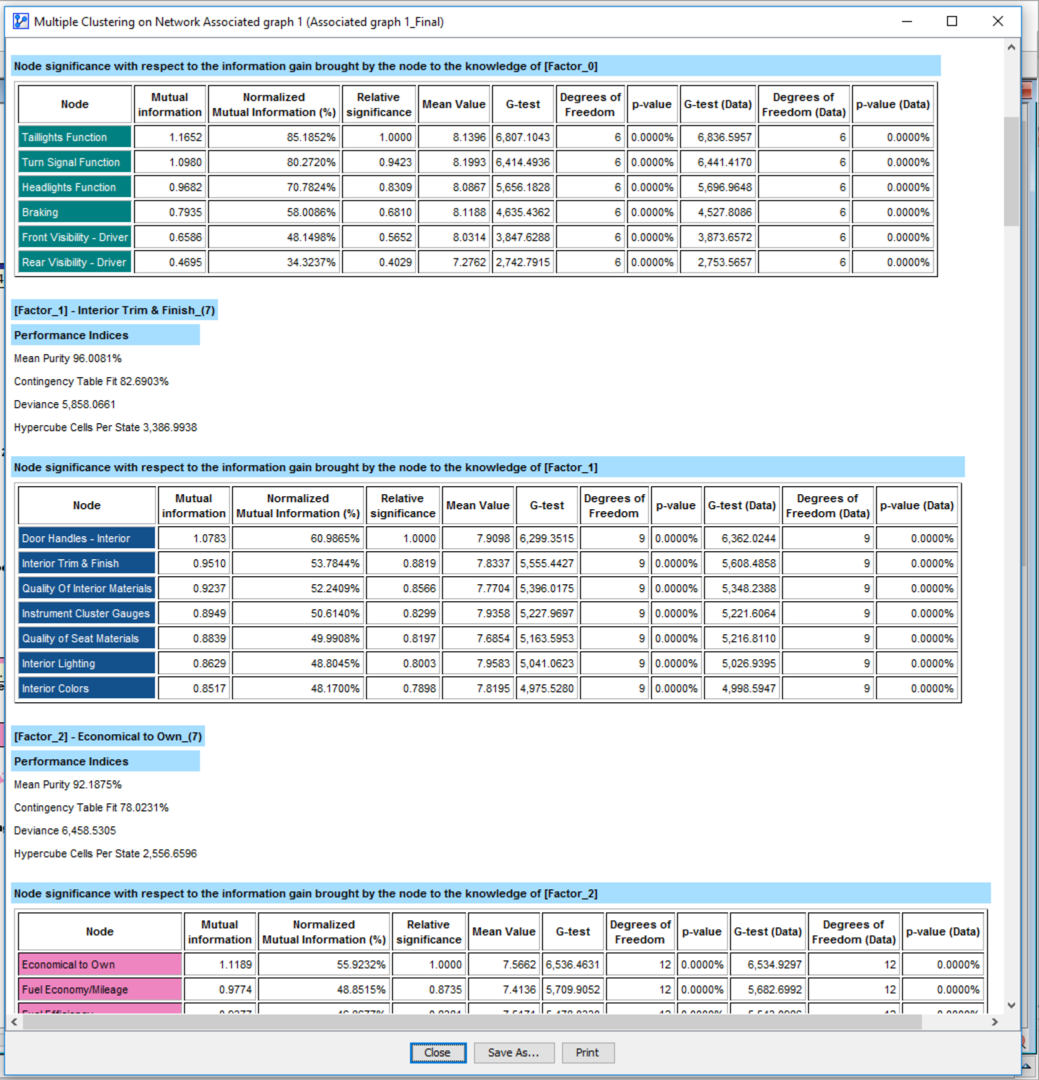
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Associated graph 1.xbl *
Variable Clustering Report (Associated graph 1)
Classes
Nodes
[Factor_0]
Taillights Function
Turn Signal Function
Front Visibility - Driver
Headlights Function
Braking
Rear Visibility - Driver
[Factor_1]
Door Handles - Interior
Quality Of Interior Materials
Interior Trim & Finish
Interior Colors
Interior Lighting
Instrument Cluster Gauges
Quality of Seat Materials
[Factor_2]
Fuel Economy/Mileage
Economical to Own
Fuel Efficiency
Affordable to Buy
Price Or Deal Offered
Emissions Control
Future Trade-In Or Resale Value
[Factor_3]
Handling
Steering Feedback
Passing Capability
Road Holding Ability
Acceleration From Stop
Ground Clearance
[Factor_4]
Interior Storage Space
Ease of Loading/Unloading Cargo
Cargo Capacity
Ease Of Trunk/Tailgate Operation
Passenger Seating Capacity
Cup Holders
[Factor_5]
Freedom From Engine Noise
Freedom From Road Noise
Smoothness At Idle
Freedom From Wind Noise
Smoothness Of Transmission
Freedom From Squeaks And Rattles
Close
Save As...
Print
Joint Probability: 100.00%
Log-Likelihood: 0
Cases: 4,214
Total Value: 768.681
Mean Value: 7.844
Window Controls
Speed Control System
Wiper System Controls
Interior Lighting
Freedom From Wind Noise
Freedom From Road Noise
Freedom From Engine Noise
Smoothness At Idle
Freedom From Squeaks And Rattles
Smoothness Of Transmission
Instrument Cluster
Sound System Controls
CD Player
Ability to Control Sound Quality
Speakers
Road Holding Ability
Ground Clearance
Handling
Steering Feedback
Passing Capability
Maneuverability
Riding Comfort
Turning Radius
Emissions Control
Fuel Efficiency
Fuel Economy/Mileage
Economical to Own
Technical Innovations
Affordable to Buy
Price Or Deal Offered
Associa...





Multiple Clustering on Network Associated graph 1 (Associated graph 1_Final)

Node significance with respect to the information gain brought by the node to the knowledge of [Factor_0]

Node	Mutual information	Normalized Mutual Information (%)	Relative significance	Mean Value	G-test	Degrees of Freedom	p-value	G-test (Data)	Degrees of Freedom (Data)	p-value (Data)
Taillights Function	1.1652	85.1852%	1.0000	8.1396	6,807.1043	6	0.0000%	6,836.5957	6	0.0000%
Turn Signal Function	1.0980	80.2720%	0.9423	8.1993	6,414.4936	6	0.0000%	6,441.4170	6	0.0000%
Headlights Function	0.9682	70.7824%	0.8309	8.0867	5,656.1828	6	0.0000%	5,696.9648	6	0.0000%
Braking	0.7935	58.0086%	0.6810	8.1188	4,635.4362	6	0.0000%	4,527.8086	6	0.0000%
Front Visibility - Driver	0.6586	48.1498%	0.5652	8.0314	3,847.6288	6	0.0000%	3,873.6572	6	0.0000%
Rear Visibility - Driver	0.4695	34.3237%	0.4029	7.2762	2,742.7915	6	0.0000%	2,753.5657	6	0.0000%

[Factor_1] - Interior Trim & Finish_(7)

Performance Indices

Mean Purity 96.0081%

Contingency Table Fit 82.6903%

Deviance 5,858.0661

Hypercube Cells Per State 3,386.9938

Node significance with respect to the information gain brought by the node to the knowledge of [Factor_1]

Node	Mutual information	Normalized Mutual Information (%)	Relative significance	Mean Value	G-test	Degrees of Freedom	p-value	G-test (Data)	Degrees of Freedom (Data)	p-value (Data)
Door Handles - Interior	1.0783	60.9865%	1.0000	7.9098	6,299.3515	9	0.0000%	6,362.0244	9	0.0000%
Interior Trim & Finish	0.9510	53.7844%	0.8819	7.8337	5,555.4427	9	0.0000%	5,608.4858	9	0.0000%
Quality Of Interior Materials	0.9237	52.2409%	0.8566	7.7704	5,396.0175	9	0.0000%	5,348.2388	9	0.0000%
Instrument Cluster Gauges	0.8949	50.6140%	0.8299	7.9358	5,227.9697	9	0.0000%	5,221.6064	9	0.0000%
Quality of Seat Materials	0.8839	49.9908%	0.8197	7.6854	5,163.5953	9	0.0000%	5,216.8110	9	0.0000%
Interior Lighting	0.8629	48.8045%	0.8003	7.9583	5,041.0623	9	0.0000%	5,026.9395	9	0.0000%
Interior Colors	0.8517	48.1700%	0.7898	7.8195	4,975.5280	9	0.0000%	4,998.5947	9	0.0000%

[Factor_2] - Economical to Own_(7)

Performance Indices

Mean Purity 92.1875%

Contingency Table Fit 78.0231%

Deviance 6,458.5305

Hypercube Cells Per State 2,556.6596

Node significance with respect to the information gain brought by the node to the knowledge of [Factor_2]

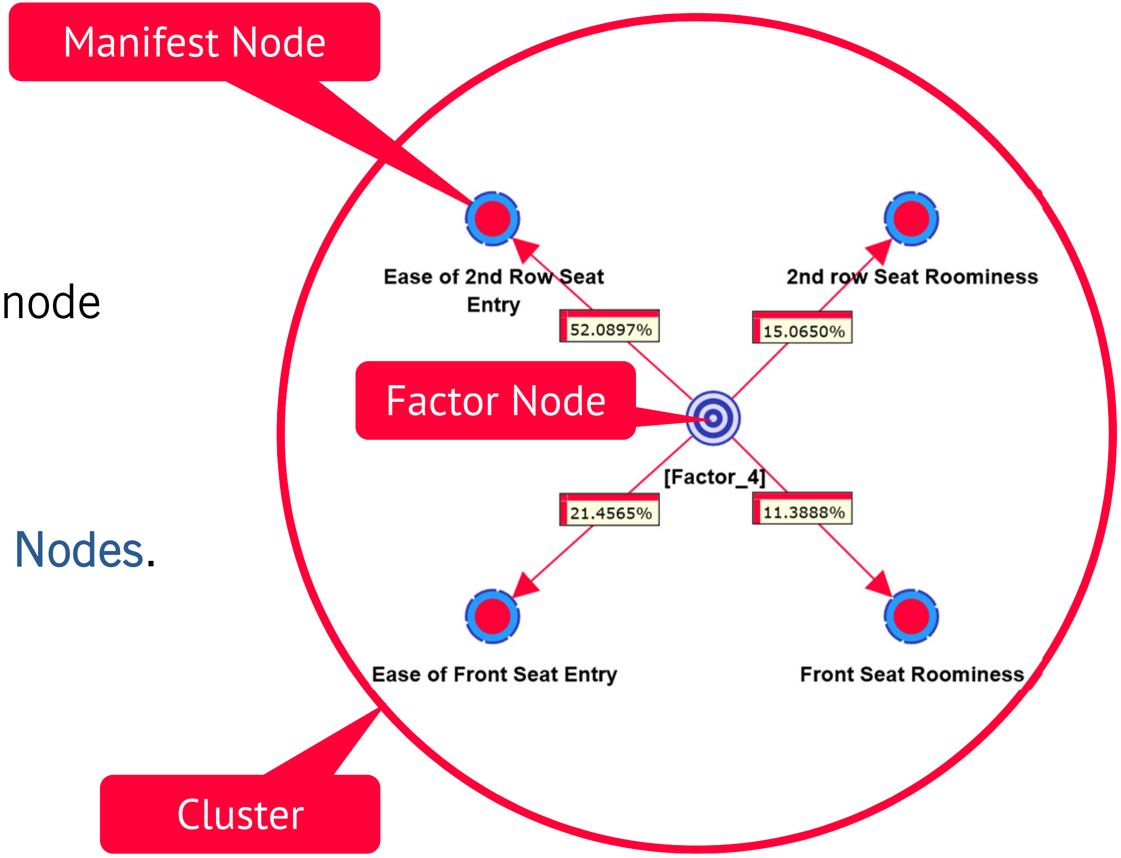
Node	Mutual information	Normalized Mutual Information (%)	Relative significance	Mean Value	G-test	Degrees of Freedom	p-value	G-test (Data)	Degrees of Freedom (Data)	p-value (Data)
Economical to Own	1.1189	55.9232%	1.0000	7.5662	6,536.4631	12	0.0000%	6,534.9297	12	0.0000%
Fuel Economy/Mileage	0.9774	48.8515%	0.8735	7.4136	5,709.9052	12	0.0000%	5,682.6992	12	0.0000%

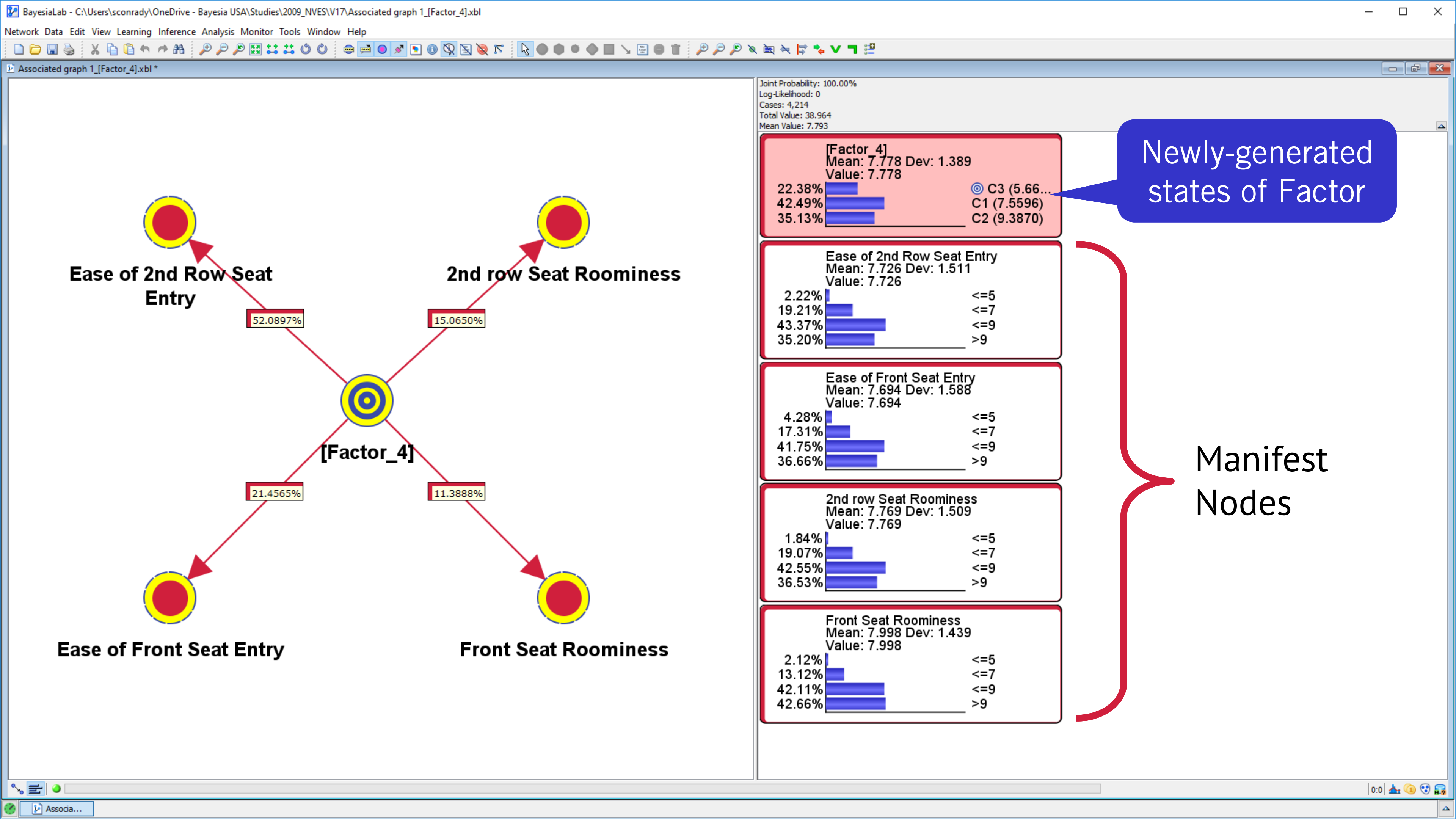
Close Save As... Print

Factors

Nomenclature

- Manifest node = observed node
- Factor = latent variable
- In BayesiaLab, a cluster is implemented as a Class of Nodes.

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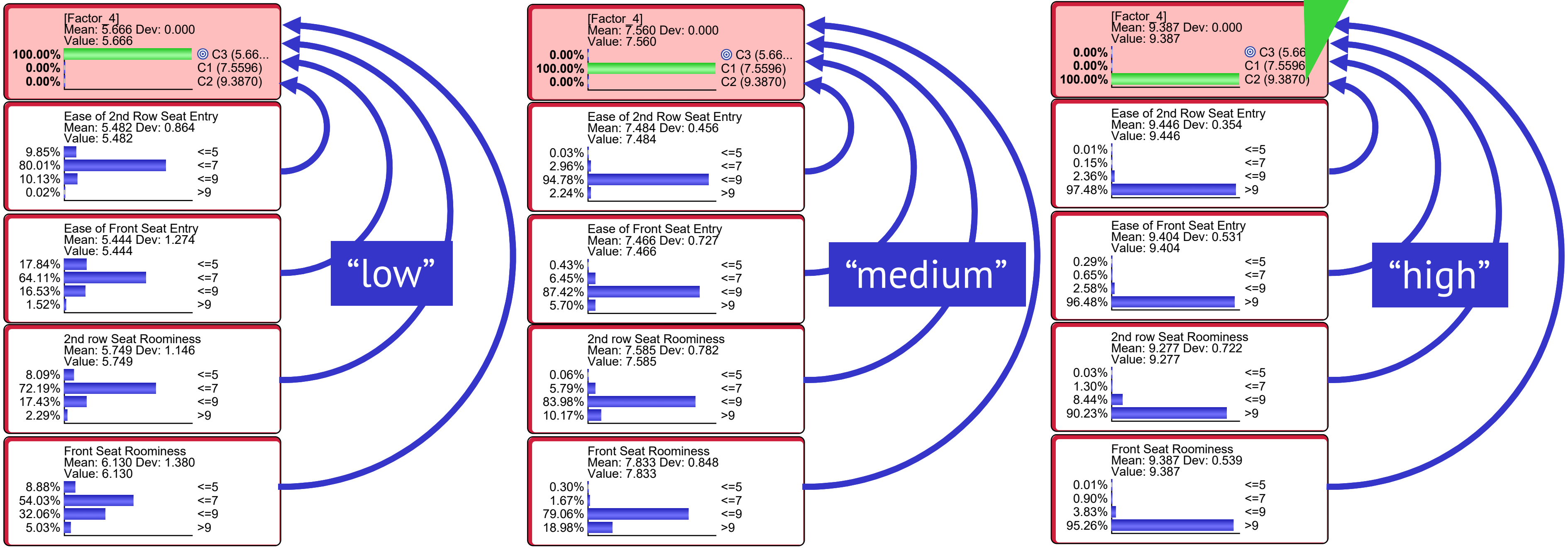
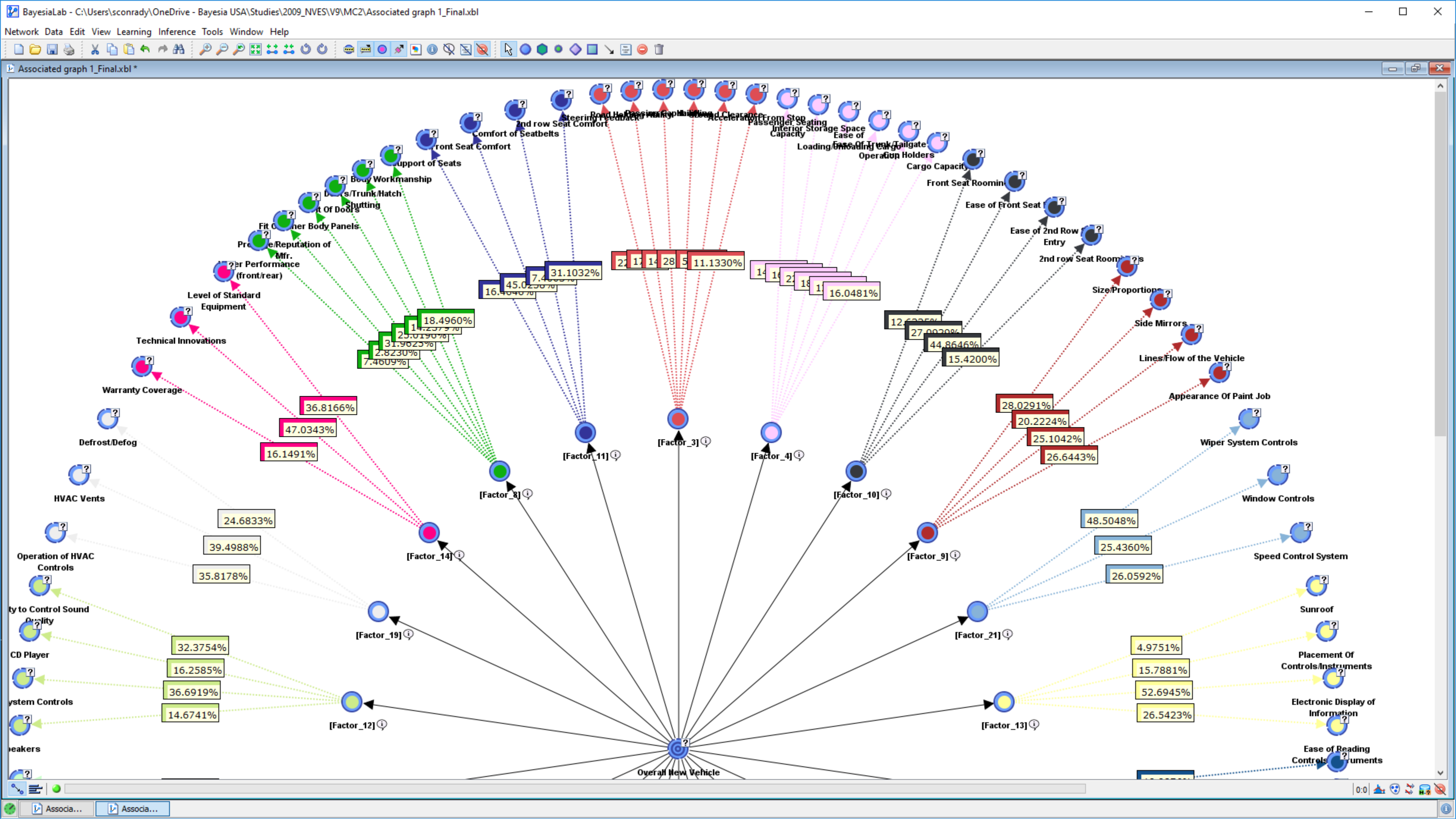
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Associated graph 1_[Factor_4].xbl *
Ease of 2nd Row Seat Entry
2nd row Seat Roominess
52.0897%
15.0650%
[Factor_4]
21.4565%
11.3888%
Ease of Front Seat Entry
Front Seat Roominess
Joint Probability: 100.00%
Log-Likelihood: 0
Cases: 4,214
Total Value: 38.964
Mean Value: 7.793
[Factor_4]
Mean: 7.778 Dev: 1.389
Value: 7.778
22.38% C3 (5.66...
42.49% C1 (7.5596)
35.13% C2 (9.3870)
Ease of 2nd Row Seat Entry
Mean: 7.726 Dev: 1.511
Value: 7.726
2.22% <=5
19.21% <=7
43.37% <=9
35.20% >9
Ease of Front Seat Entry
Mean: 7.694 Dev: 1.588
Value: 7.694
4.28% <=5
17.31% <=7
41.75% <=9
36.66% >9
2nd row Seat Roominess
Mean: 7.769 Dev: 1.509
Value: 7.769
1.84% <=5
19.07% <=7
42.55% <=9
36.53% >9
Front Seat Roominess
Mean: 7.998 Dev: 1.439
Value: 7.998
2.12% <=5
13.12% <=7
42.11% <=9
42.66% >9
Newly-generated states of Factor
Manifest Nodes
Associa...

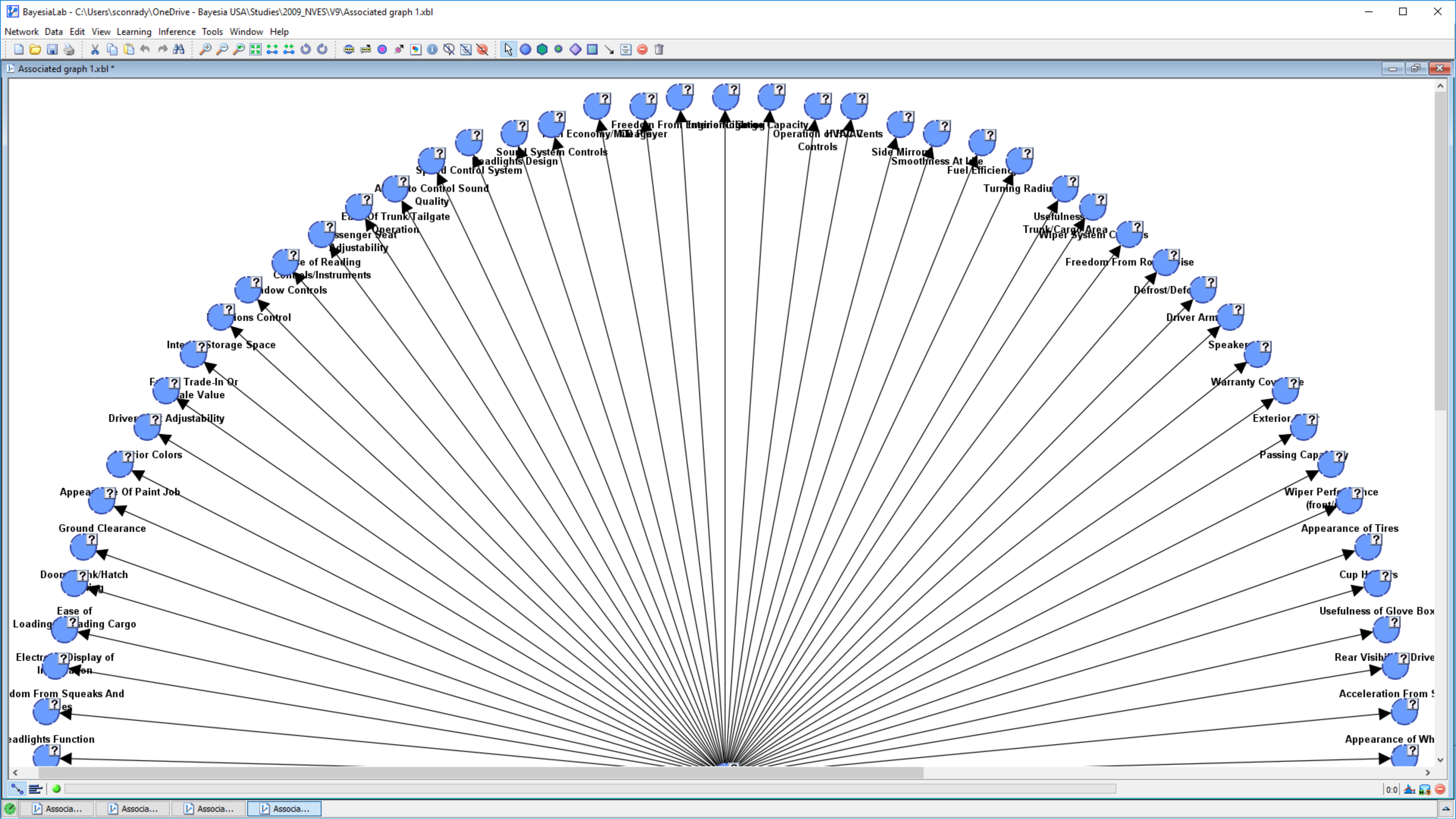
Factors

Numerical values of the factor states are the weighted averages of the values of the manifest states

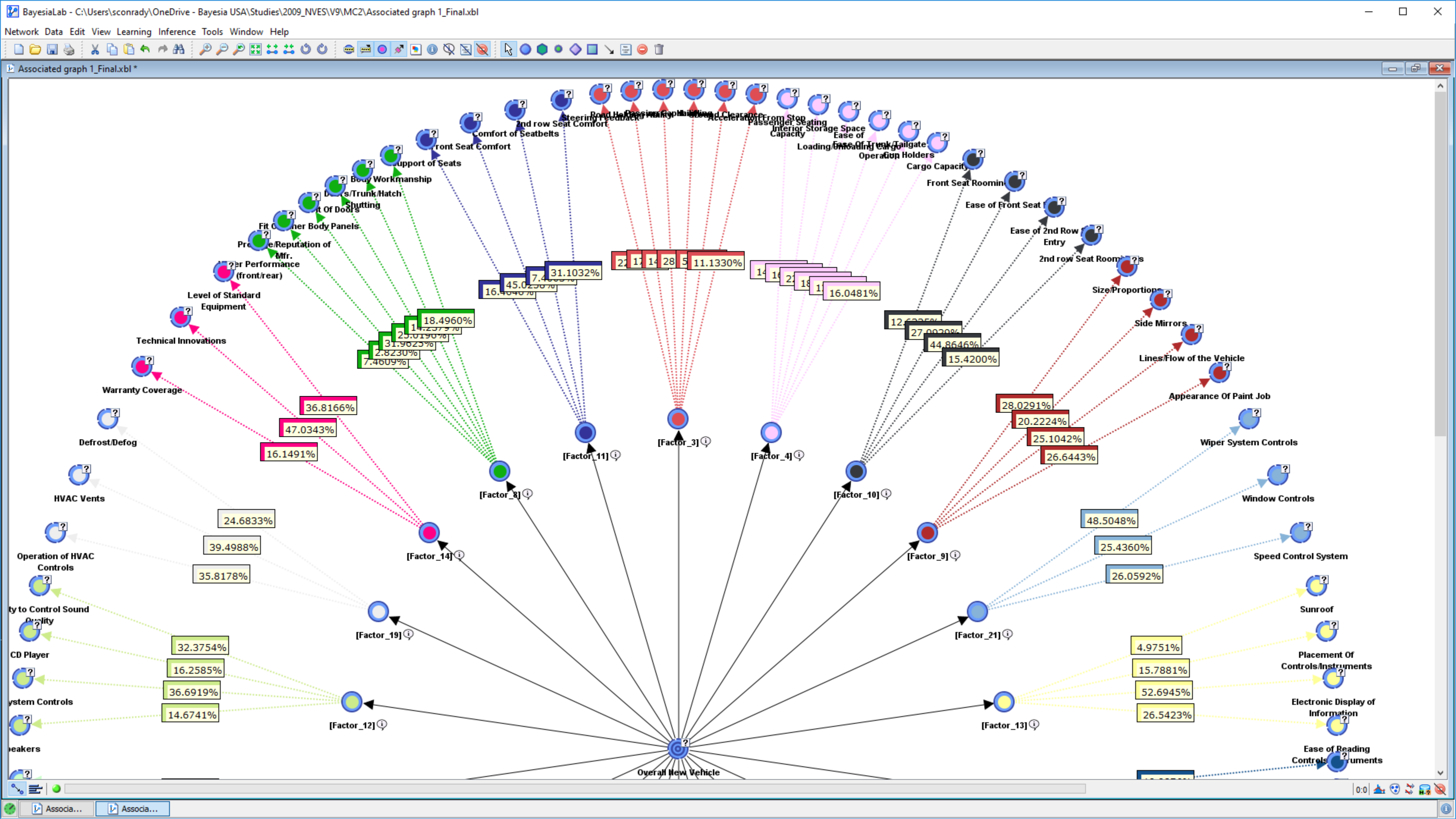
Factor States Summarize the States of the Manifest Nodes




BayesiaLab - C:\Users\sconrady\OneDrive - Bayesia USA\Studies\2009_NVES\V9\MC2\Associated graph 1_Final.xbl
Network Data Edit View Learning Inference Tools Window Help
Associated graph 1_Final.xbl *
Comfort of Seatbelts
2nd row Seat Comfort
Passenger Seating Capacity
Interior Storage Space
Cup Holders
Cargo Capacity
Support of Seats
Body Workmanship
Level of Standard Equipment
Technical Innovations
Warranty Coverage
Defrost/Defog
HVAC Vents
Operation of HVAC Controls
CD Player
Size/Proportions
Side Mirrors
Lines/Flow of the Vehicle
Appearance Of Paint Job
Wiper System Controls
Window Controls
Speed Control System
Sunroof
Placement Of Controls/Instruments
Electronic Display of Information
Ease of Reading Controls/Instruments
Overall New Vehicle
[Factor_11]
[Factor_3]
[Factor_4]
[Factor_8]
[Factor_10]
[Factor_14]
[Factor_9]
[Factor_19]
[Factor_21]
[Factor_12]
[Factor_13]
31.1032%
11.1330%
16.0481%
18.4960%
15.4200%
44.8646%
36.8166%
47.0343%
16.1491%
28.0291%
20.2224%
25.1042%
26.6443%
24.6833%
39.4988%
35.8178%
48.5048%
25.4360%
26.0592%
32.3754%
16.2585%
36.6919%
14.6741%
4.9751%
15.7881%
52.6945%
26.5423%
Associa...
Associa...



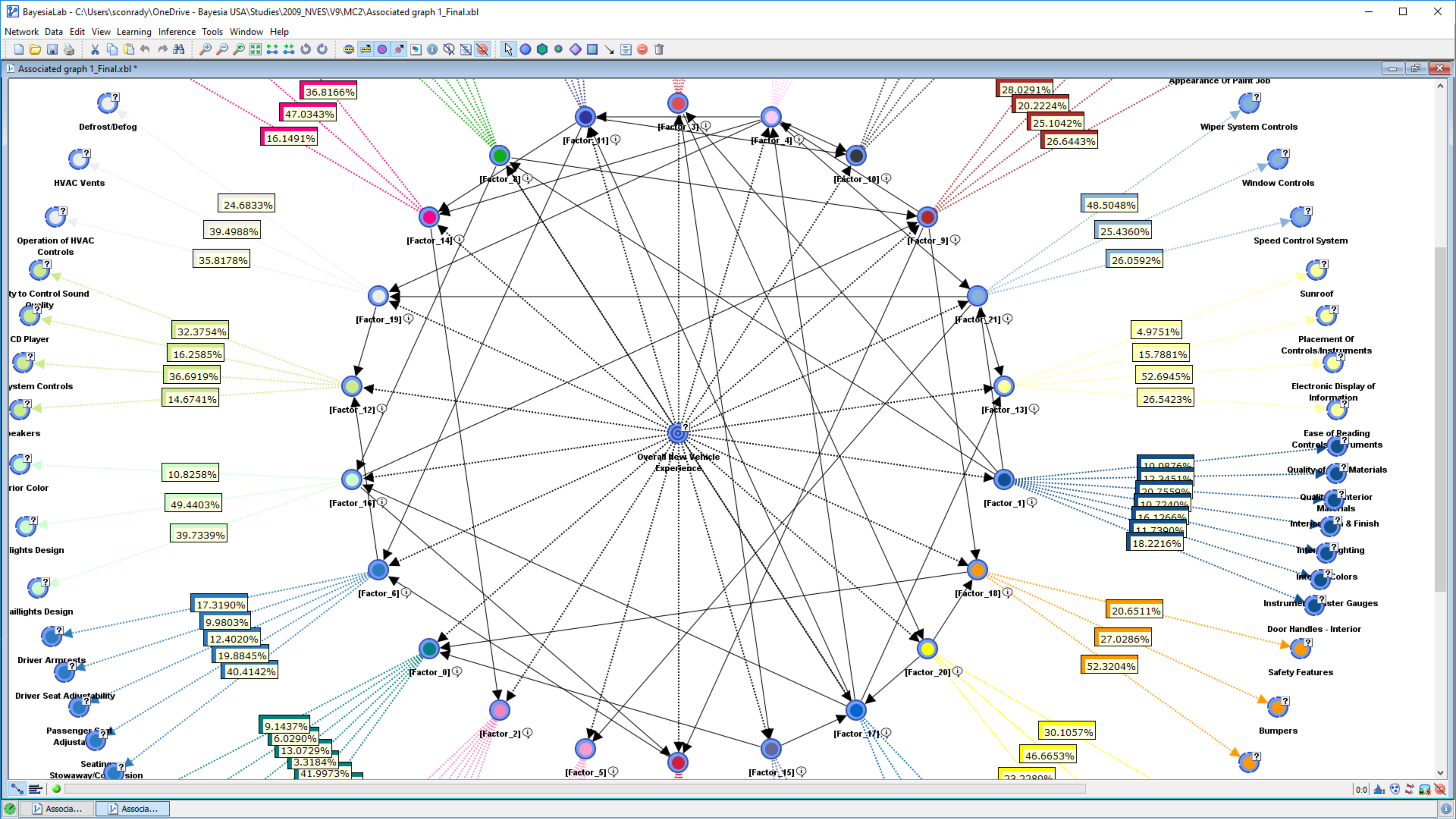
BayesiaLab - C:\Users\sconrady\OneDrive - Bayesia USA\Studies\2009_NVES\V9\Associated graph 1.xbl
Network Data Edit View Learning Inference Tools Window Help
Associated graph 1.xbl *
Sound System Controls
Turning Radiu
Ground Clearance
Appearance of Tires
Usefulness of Glove Box
Passenger Seat Adjustability
Ease of Reading Controls/Instruments
Usefulness Trunk/Cargo Area
Acceleration From
Warranty Cov
Speaker
Interior Colors
Appearance Of Paint Job
Associa...

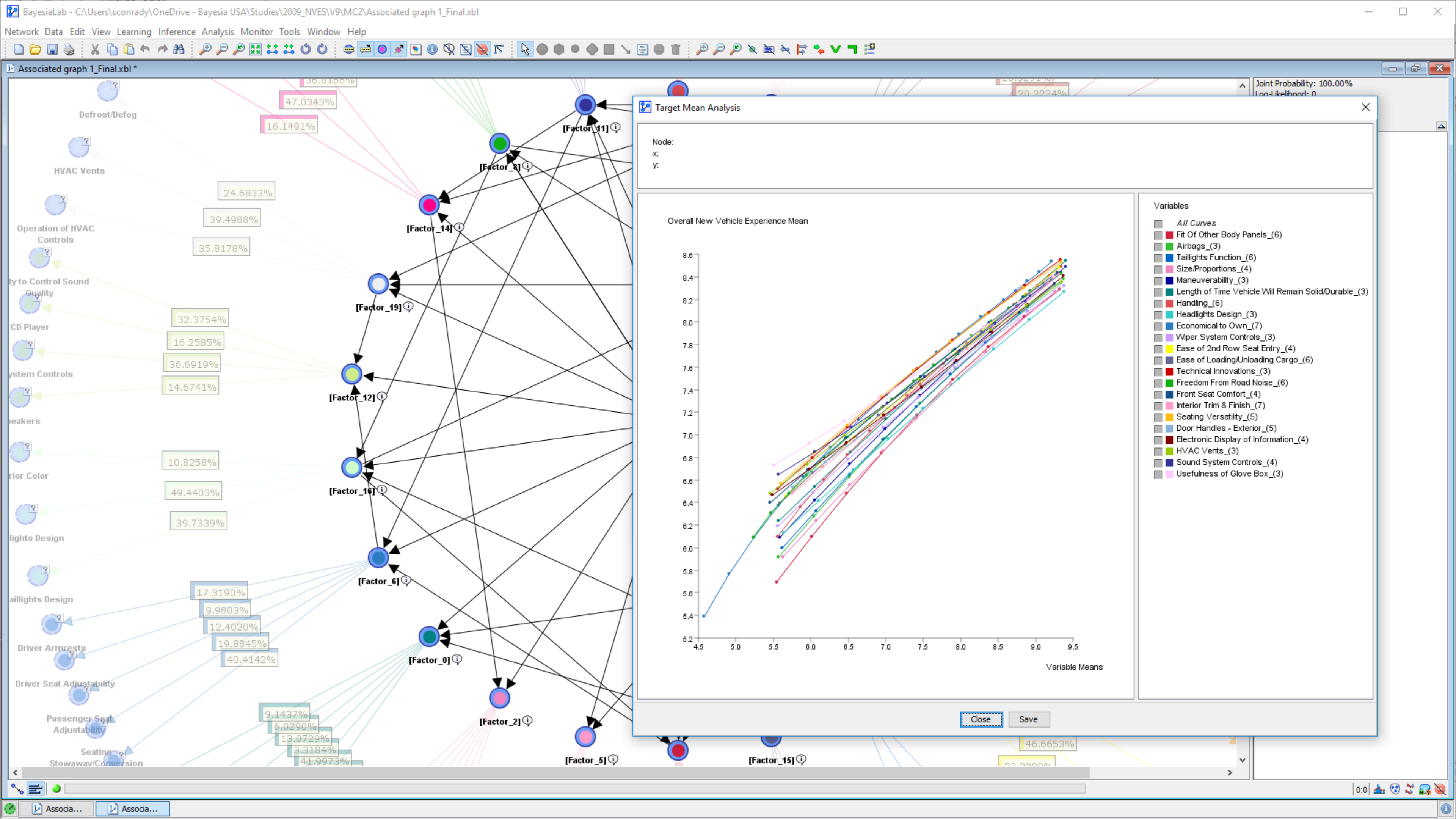


BayesiaLab - C:\Users\sconrady\OneDrive - Bayesia USA\Studies\2009_NVES\V9\MC2\Associated graph 1_Final.xbl
Network Data Edit View Learning Inference Tools Window Help
Associated graph 1_Final.xbl *
Front Seat Comfort
Comfort of Seatbelts
2nd row Seat Comfort
Support of Seats
Body Workmanship
Shutting
Fit Of Doors
Level of Standard Equipment
Technical Innovations
Warranty Coverage
Defrost/Defog
HVAC Vents
Operation of HVAC Controls
CD Player
Interior Storage Space
Loading/Unloading Cargo
Cup Holders
Cargo Capacity
Ease of Front Seat
Ease of 2nd Row Entry
Size/Proportions
Side Mirrors
Lines/Flow of the Vehicle
Appearance Of Paint Job
Wiper System Controls
Window Controls
Speed Control System
Sunroof
Placement Of Controls/Instruments
Electronic Display of Information
Ease of Reading
31.1032%
11.1330%
16.0481%
18.4960%
7.4609%
36.8166%
47.0343%
16.1491%
24.6833%
39.4988%
35.8178%
32.3754%
16.2585%
36.6919%
14.6741%
44.8646%
15.4200%
28.0291%
20.2224%
25.1042%
26.6443%
48.5048%
25.4360%
26.0592%
4.9751%
15.7881%
52.6945%
26.5423%
[Factor_11]
[Factor_3]
[Factor_4]
[Factor_8]
[Factor_10]
[Factor_14]
[Factor_9]
[Factor_19]
[Factor_21]
[Factor_12]
[Factor_13]
Overall New Vehicle

Completing the PSEM

- There is no reason to assume that the newly-generated factors are orthogonal.
- We use Taboo Learning to discover the relationships between the Factors

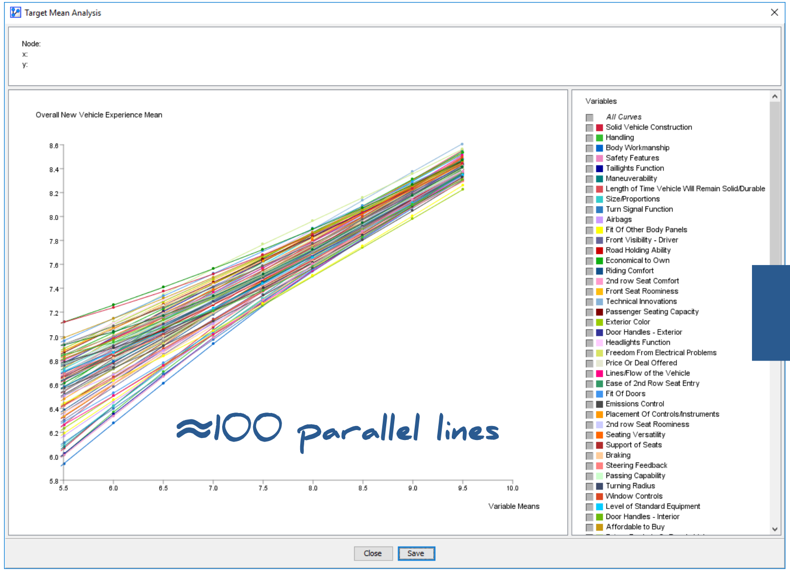

BayesiaLab - C:\Users\sconrady\OneDrive - Bayesia USA\Studies\2009_NVES\V9\MC2\Associated graph 1_Final.xbl
Network Data Edit View Learning Inference Tools Window Help
Associated graph 1_Final.xbl *
Overall New Vehicle Experience
[Factor_0]
[Factor_1]
[Factor_2]
[Factor_3]
[Factor_4]
[Factor_5]
[Factor_6]
[Factor_8]
[Factor_9]
[Factor_10]
[Factor_11]
[Factor_12]
[Factor_13]
[Factor_14]
[Factor_15]
[Factor_16]
[Factor_17]
[Factor_18]
[Factor_19]
[Factor_20]
[Factor_21]
Defrost/Defog
HVAC Vents
Operation of HVAC Controls
CD Player
Driver Armrests
Driver Seat Adjustability
Wiper System Controls
Window Controls
Speed Control System
Sunroof
Placement Of Controls/Instruments
Electronic Display of Information
Door Handles - Interior
Safety Features
Bumpers
36.8166%
47.0343%
16.1491%
24.6833%
39.4988%
35.8178%
32.3754%
16.2585%
36.6919%
14.6741%
10.8258%
49.4403%
39.7339%
17.3190%
9.9803%
12.4020%
19.8845%
40.4142%
9.1437%
6.0290%
13.0729%
3.3184%
41.9973%
28.0291%
20.2224%
25.1042%
26.6443%
48.5048%
25.4360%
26.0592%
4.9751%
15.7881%
52.6945%
26.5423%
18.2216%
20.6511%
27.0286%
52.3204%
30.1057%
46.6653%
Associa...
Associa...


BayesiaLab - C:\Users\sconrady\OneDrive - Bayesia USA\Studies\2009_NVES\V9\MC2\Associated graph 1_Final.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Associated graph 1_Final.xbl *
Joint Probability: 100.00%
Defrost/Defog
HVAC Vents
Operation of HVAC Controls
CD Player
Driver Armrests
Driver Seat Adjustability
Passenger Seat Adjustability
[Factor_11]
[Factor_8]
[Factor_14]
[Factor_19]
[Factor_12]
[Factor_16]
[Factor_6]
[Factor_0]
[Factor_2]
[Factor_5]
[Factor_15]
Target Mean Analysis
Node:
x:
y:
Overall New Vehicle Experience Mean
Variable Means
Variables
All Curves
Fit Of Other Body Panels_(6)
Airbags_(3)
Taillights Function_(6)
Size/Proportions_(4)
Maneuverability_(3)
Length of Time Vehicle Will Remain Solid/Durable_(3)
Handling_(6)
Headlights Design_(3)
Economical to Own_(7)
Wiper System Controls_(3)
Ease of 2nd Row Seat Entry_(4)
Ease of Loading/Unloading Cargo_(6)
Technical Innovations_(3)
Freedom From Road Noise_(6)
Front Seat Comfort_(4)
Interior Trim & Finish_(7)
Seating Versatility_(5)
Door Handles - Exterior_(5)
Electronic Display of Information_(4)
HVAC Vents_(3)
Sound System Controls_(4)
Usefulness of Glove Box_(3)
Close
Save

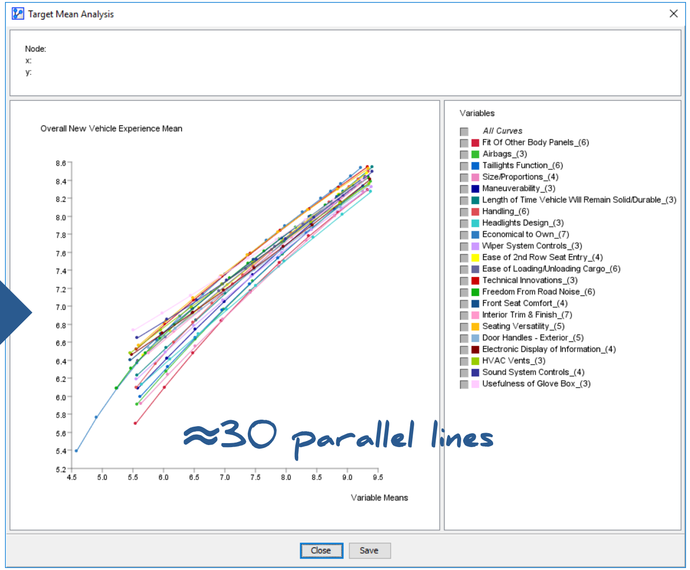
Key Drivers Analysis

Key Drivers Analysis

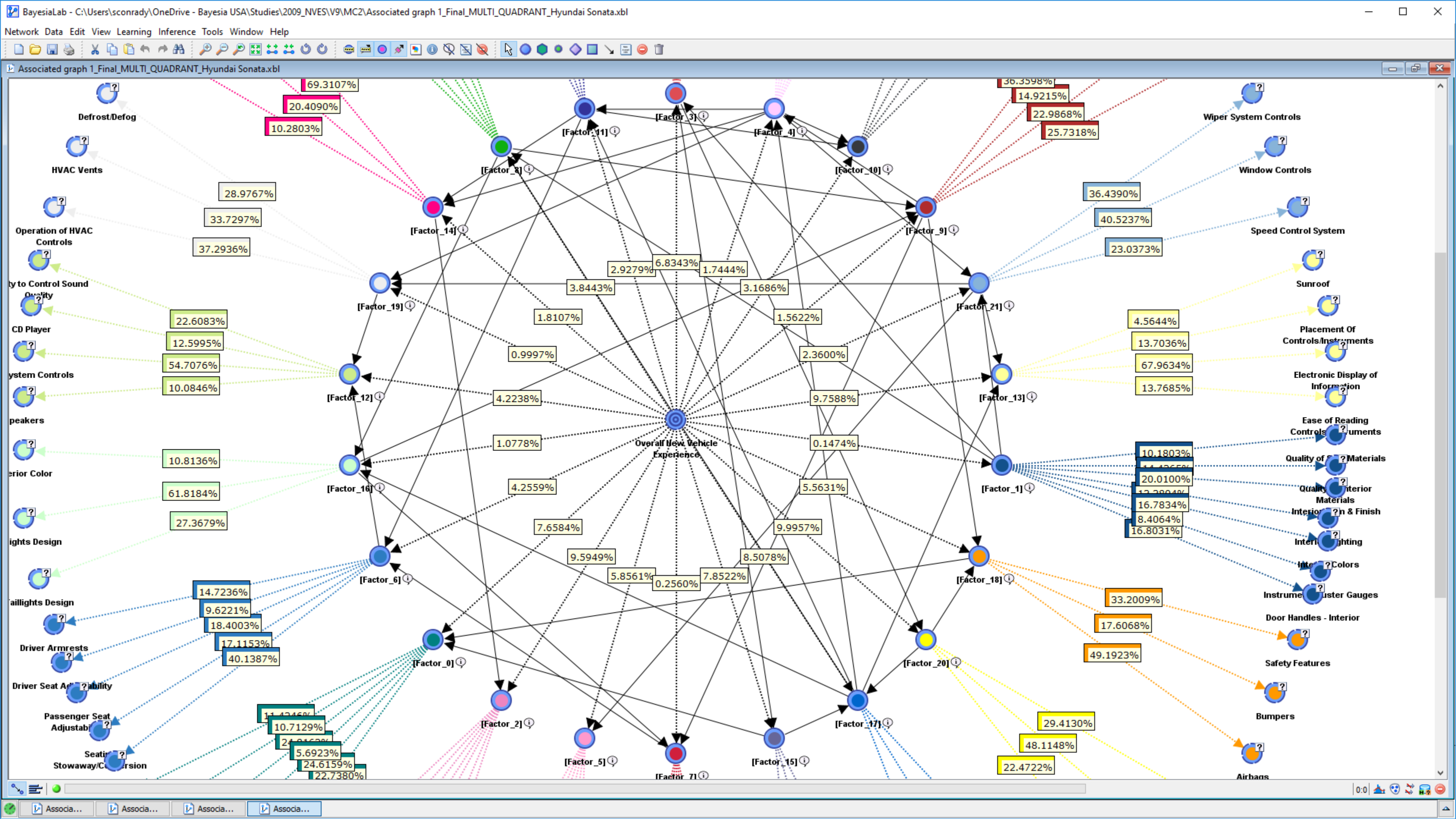
What did we gain?



Overall New Vehicle Experience vs. Manifest Ratings

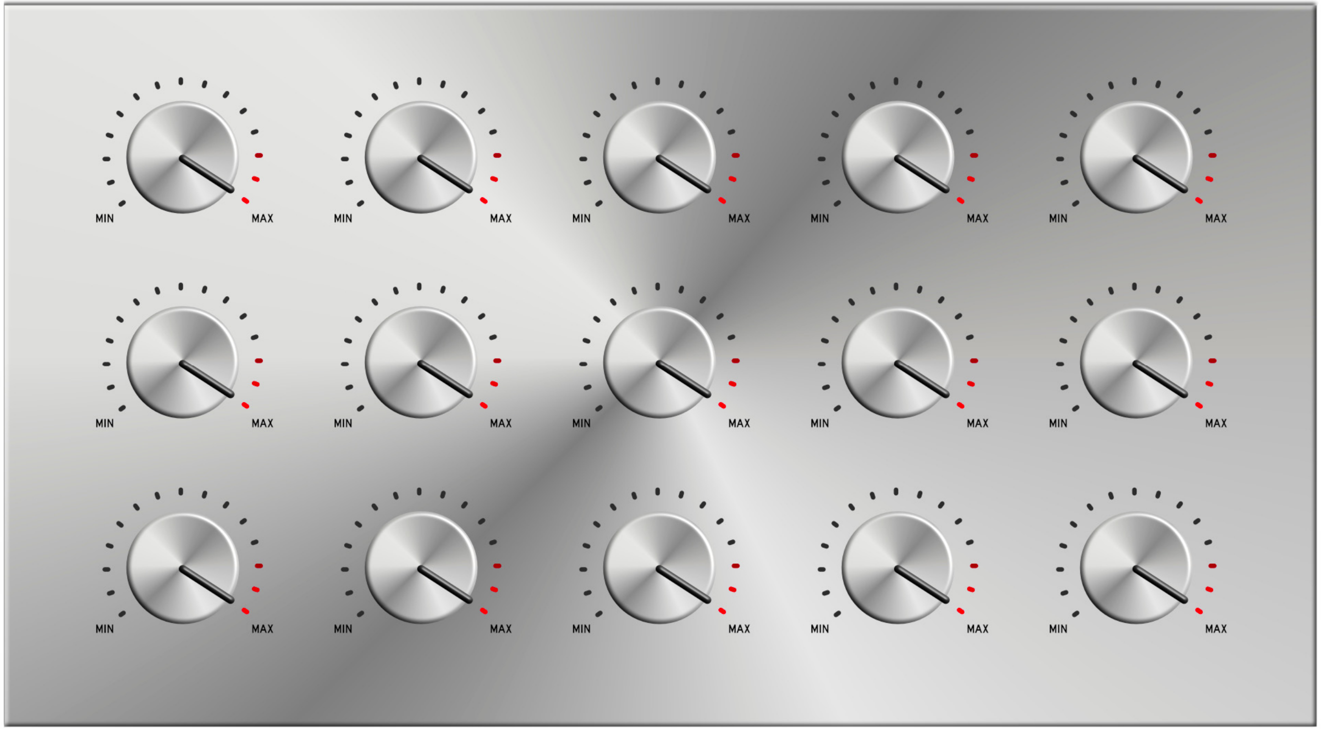


Overall New Vehicle Experience vs. Factor Ratings



BayesiaLab - C:\Users\sconrady\OneDrive - Bayesia USA\Studies\2009_NVES\V9\MC2\Associated graph 1_Final_MULTI_QUADRANT_Hyundai Sonata.xbl
Network Data Edit View Learning Inference Tools Window Help
Associated graph 1_Final_MULTI_QUADRANT_Hyundai Sonata.xbl
Overall New Vehicle Experience
[Factor_0]
[Factor_1]
[Factor_2]
[Factor_3]
[Factor_4]
[Factor_5]
[Factor_6]
[Factor_8]
[Factor_9]
[Factor_10]
[Factor_11]
[Factor_12]
[Factor_13]
[Factor_14]
[Factor_15]
[Factor_16]
[Factor_17]
[Factor_18]
[Factor_19]
[Factor_20]
[Factor_21]
Defrost/Defog
HVAC Vents
Operation of HVAC Controls
CD Player
Wiper System Controls
Window Controls
Speed Control System
Sunroof
Placement Of Controls/Instruments
Electronic Display of Information
Driver Armrests
Passenger Seat Adjustability
Safety Features
Bumpers
Airbags
Door Handles - Interior
69.3107%
20.4090%
10.2803%
28.9767%
33.7297%
37.2936%
22.6083%
12.5995%
54.7076%
10.0846%
10.8136%
61.8184%
27.3679%
14.7236%
9.6221%
18.4003%
17.1153%
40.1387%
10.7129%
5.6923%
24.6159%
22.7380%
36.3598%
14.9215%
22.9868%
25.7318%
36.4390%
40.5237%
23.0373%
4.5644%
13.7036%
67.9634%
13.7685%
10.1803%
20.0100%
16.7834%
8.4064%
16.8031%
33.2009%
17.6068%
49.1923%
29.4130%
48.1148%
22.4722%
6.8343%
2.9279%
1.7444%
3.8443%
3.1686%
1.8107%
1.5622%
0.9997%
2.3600%
4.2238%
9.7588%
1.0778%
0.1474%
4.2559%
5.5631%
7.6584%
9.9957%
9.5949%
8.5078%
5.8561%
0.2560%
7.8522%
Associa...

Optimization



We have no constraints, so why not set all "drivers" to their maximum levels?

Optimization

Optimization Constraint #1

- “Gain” × Joint Probability ÷ Cost

Optimization Constraint # 2

- Automatic calculation of “gap to best level” via Multi-Quadrant Analysis
- Expert-defined constraints

Simulation of Values

- Minimum Cross-Entropy

Optimization Objective

- Establish Priorities

Optimization

Optimization Constraint #1

- "Gain" × Joint Probability ÷ Cost

Optimization Constraint # 2

- Expert-defined constraints
- Automatic calculation of "gap to best level" via Multi-Quadrant Analysis

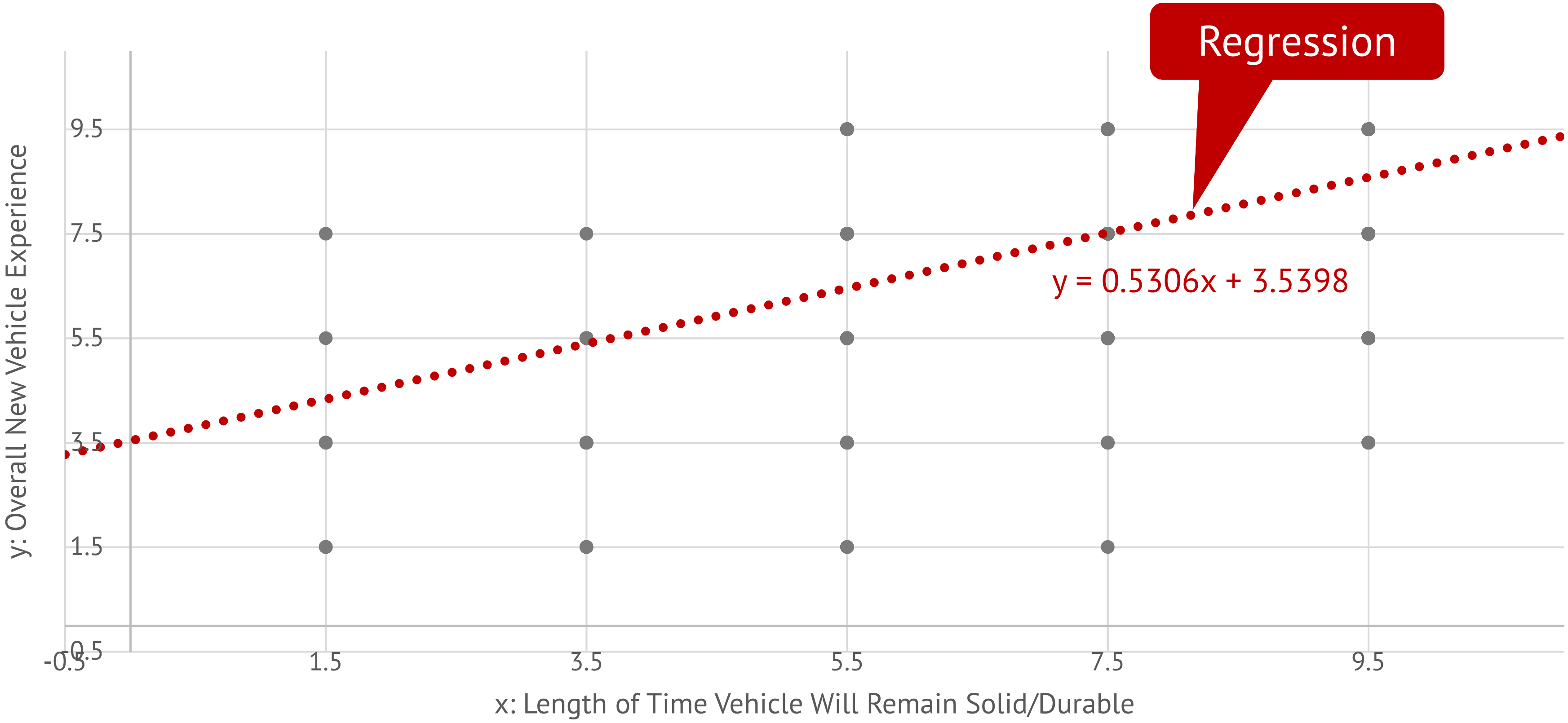
Simulation of Values

- Minimum Cross-Entropy

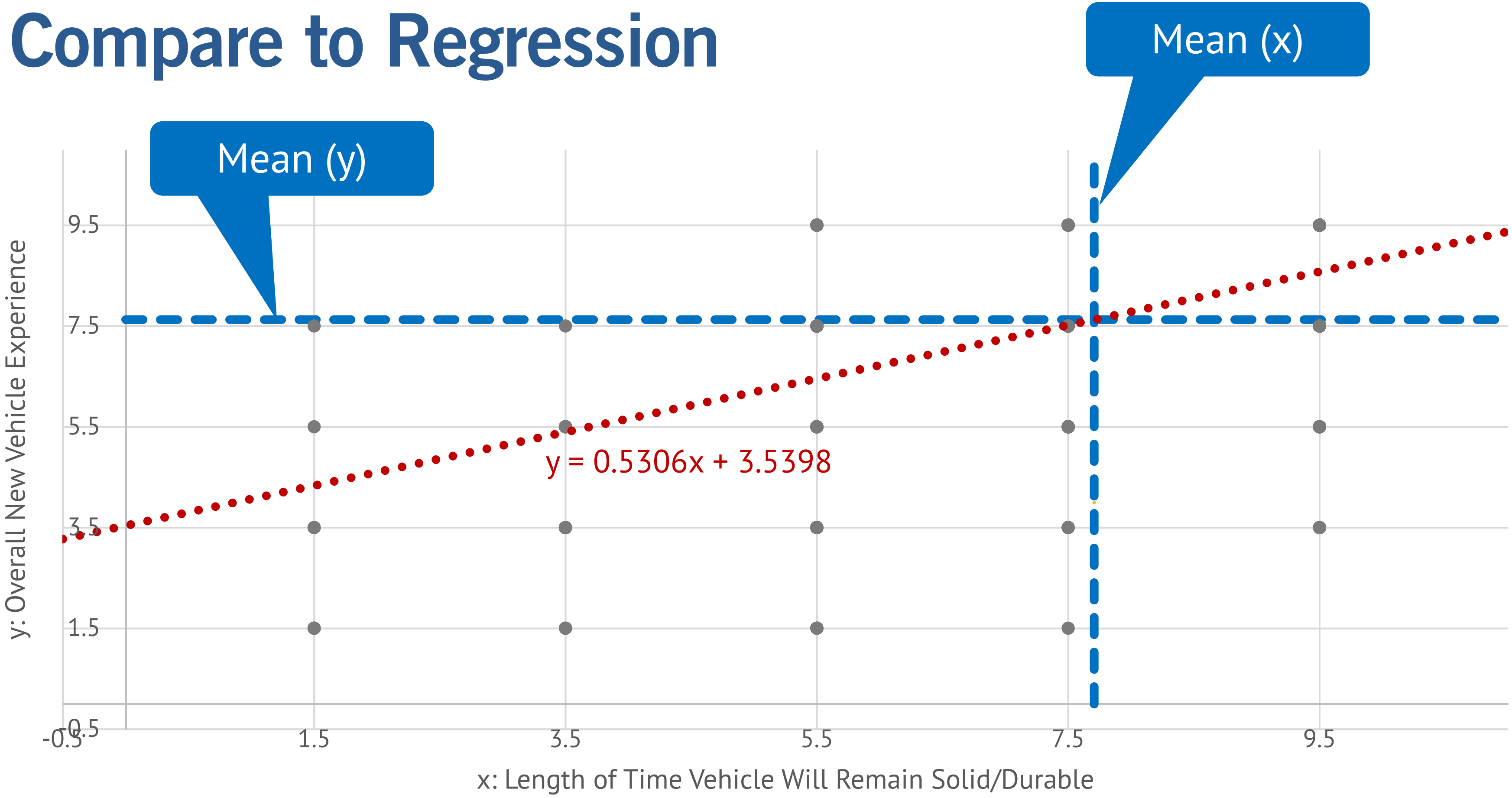
Optimization Objective

- Establish Priorities

Compare to Regression

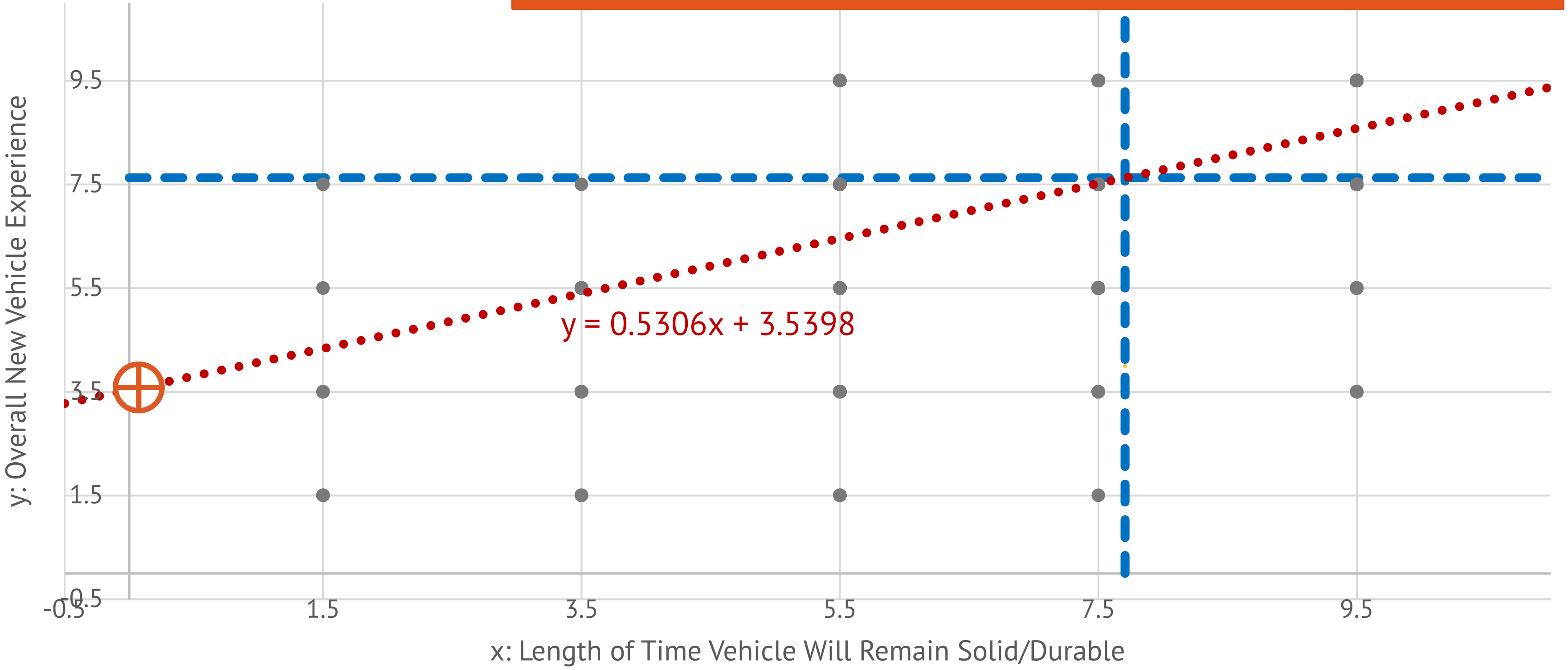


Compare to Regression

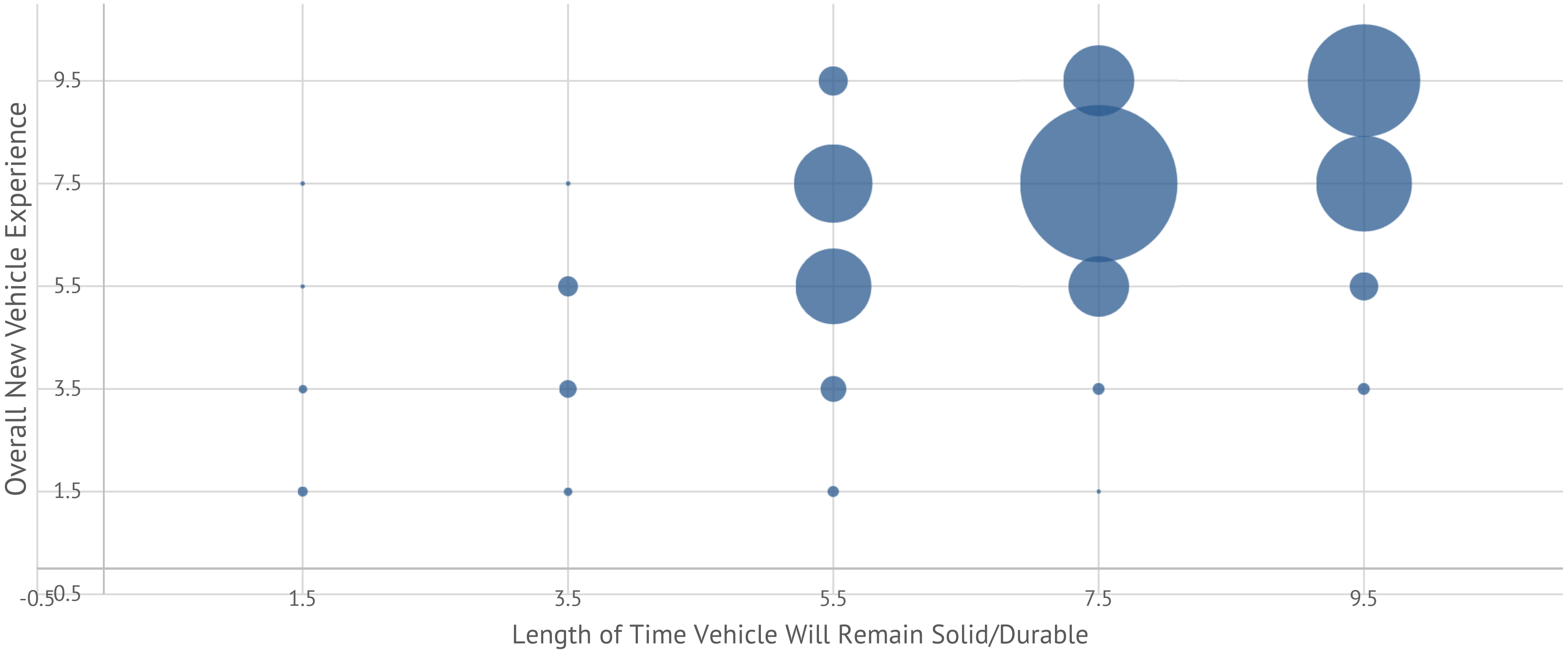


Compare to Regression

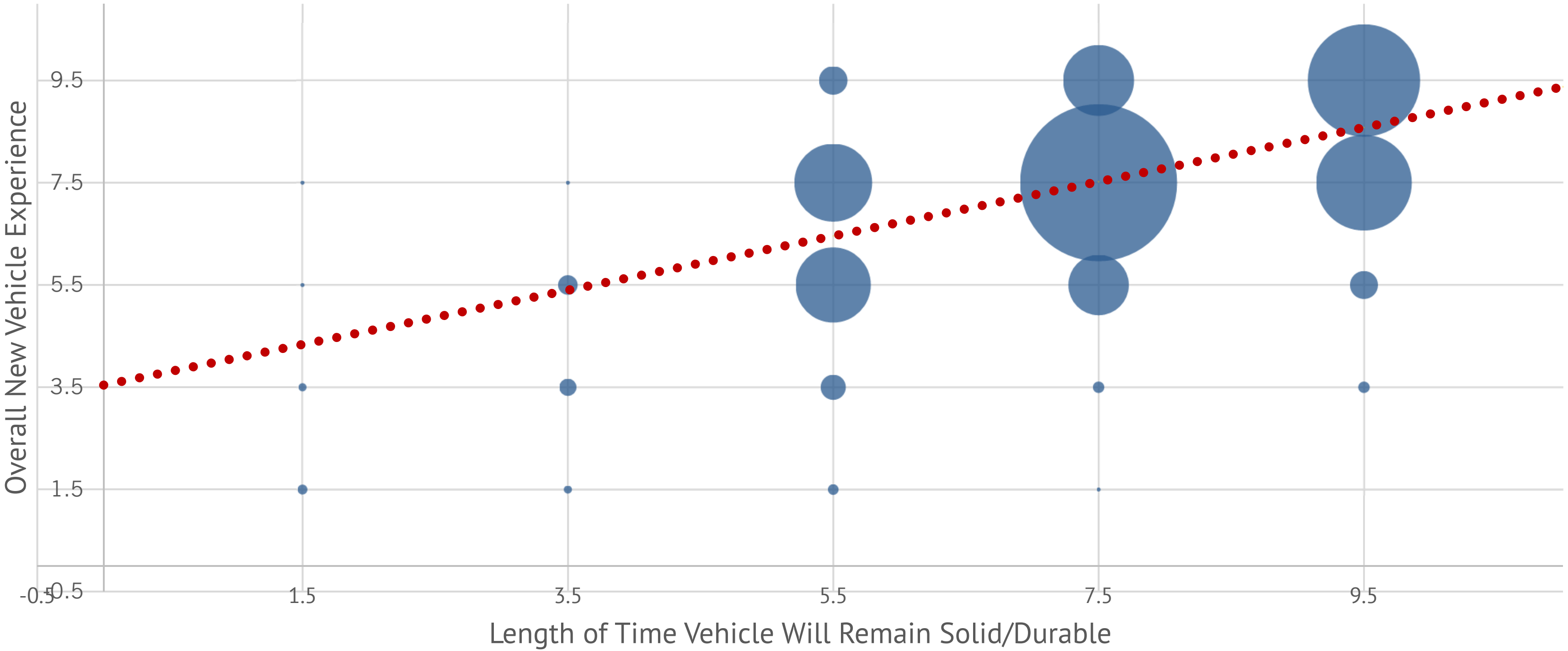
Simulation by conditioning on hypothetical values of x



Joint Distribution



Joint Distribution



Joint Distribution

Marginal Distribution

Overall New Vehicle Experience						
	9.5	0	8	47	547	755
	7.5	1	8	219	1475	301
	5.5	7	38	338	363	49
	3.5	4	18	23	1	0
	1.5	6	4	1	1	0
100%		**1.5**	**3.5**	**5.5**	**7.5**	**9.5**
		Length of Time Vehicle Will Remain Solid/Durable				

Joint Distribution

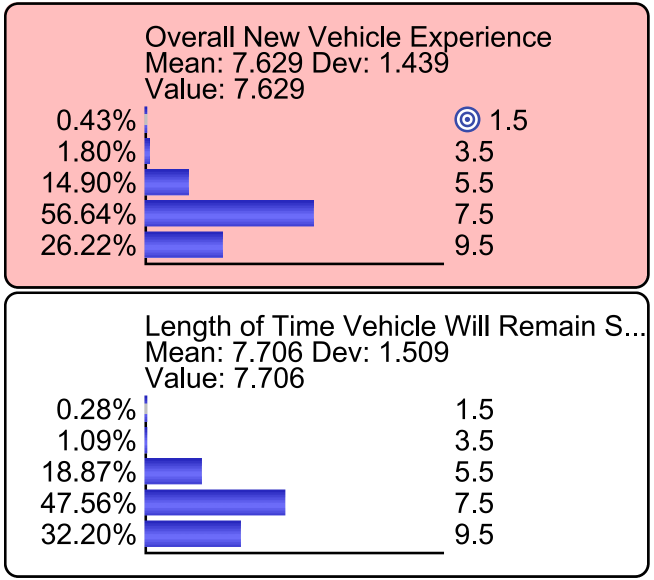
Is this realistic?

Distribution of y conditional on x=9.5 → Mean(y)=8.78

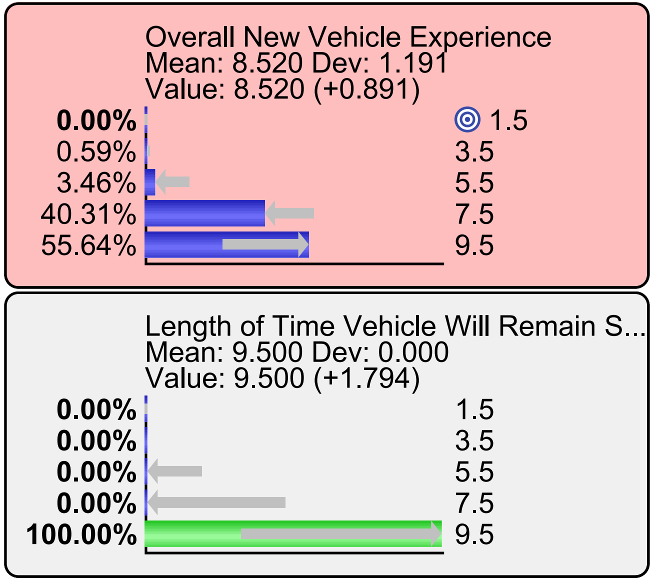
Overall New Vehicle Experience						
	9.5	0	0	0	0	755
	7.5	0	0	0	0	301
	5.5	0	0	0	0	49
	3.5	0	0	0	0	0
	1.5	0	0	0	0	0
26%		**1.5**	**3.5**	**5.5**	**7.5**	**9.5**
		Length of Time Vehicle Will Remain Solid/Durable				

Joint Distribution

Simulation of Values



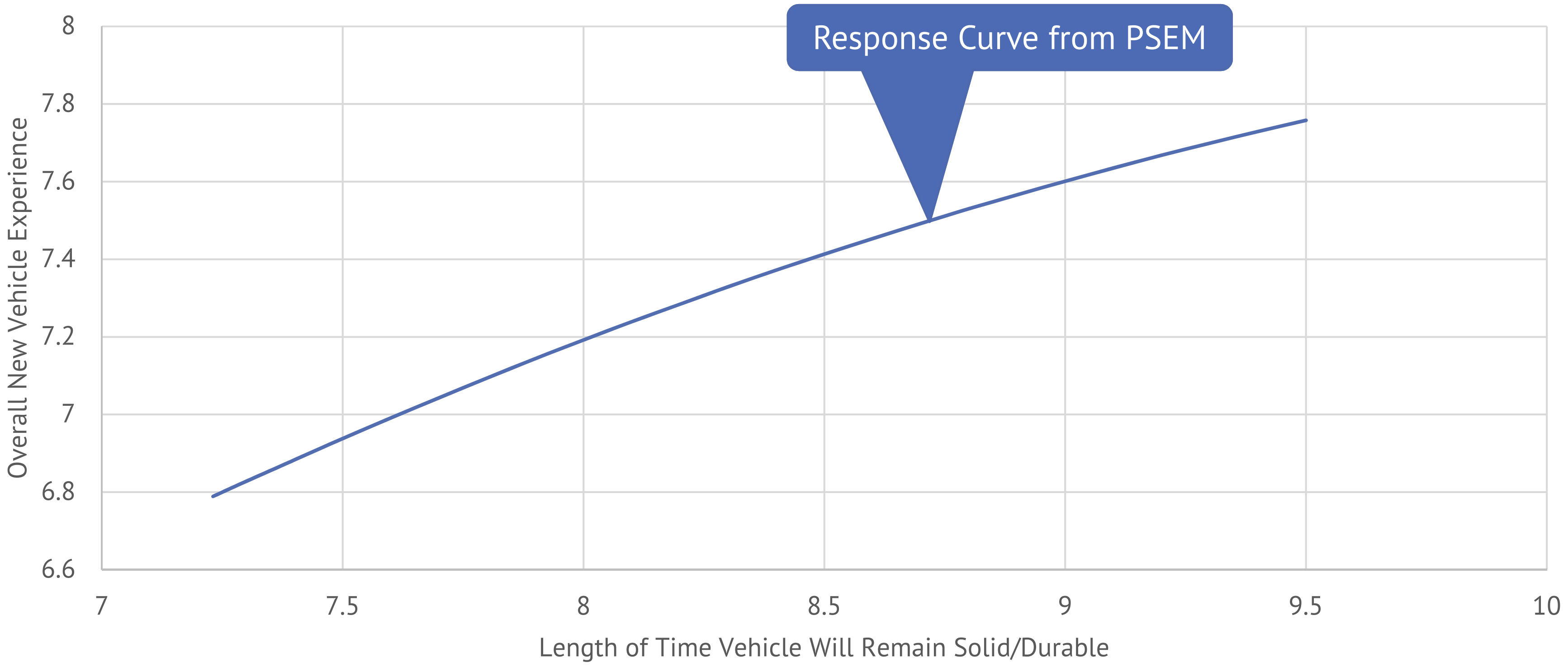
Joint Probability: 100%



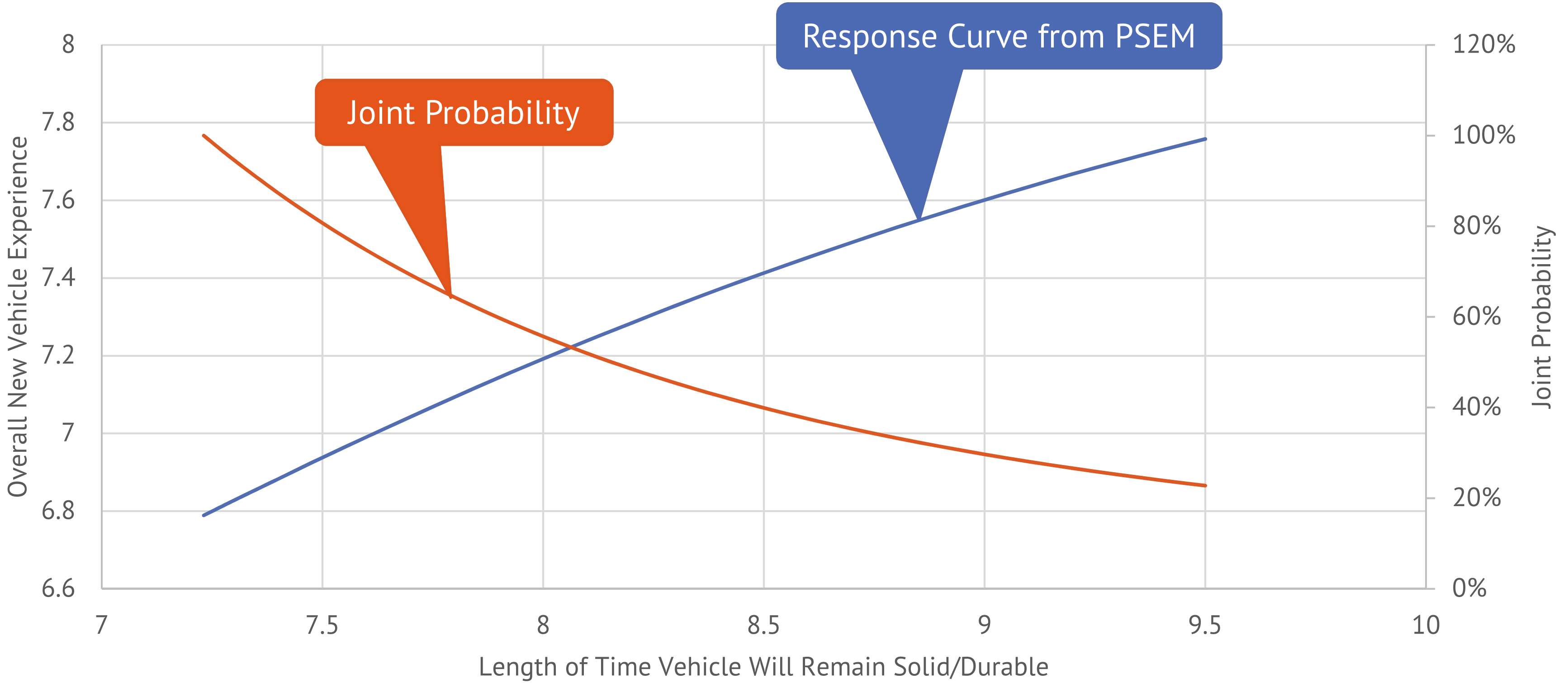
Joint Probability: 26%

Why not go to the max?

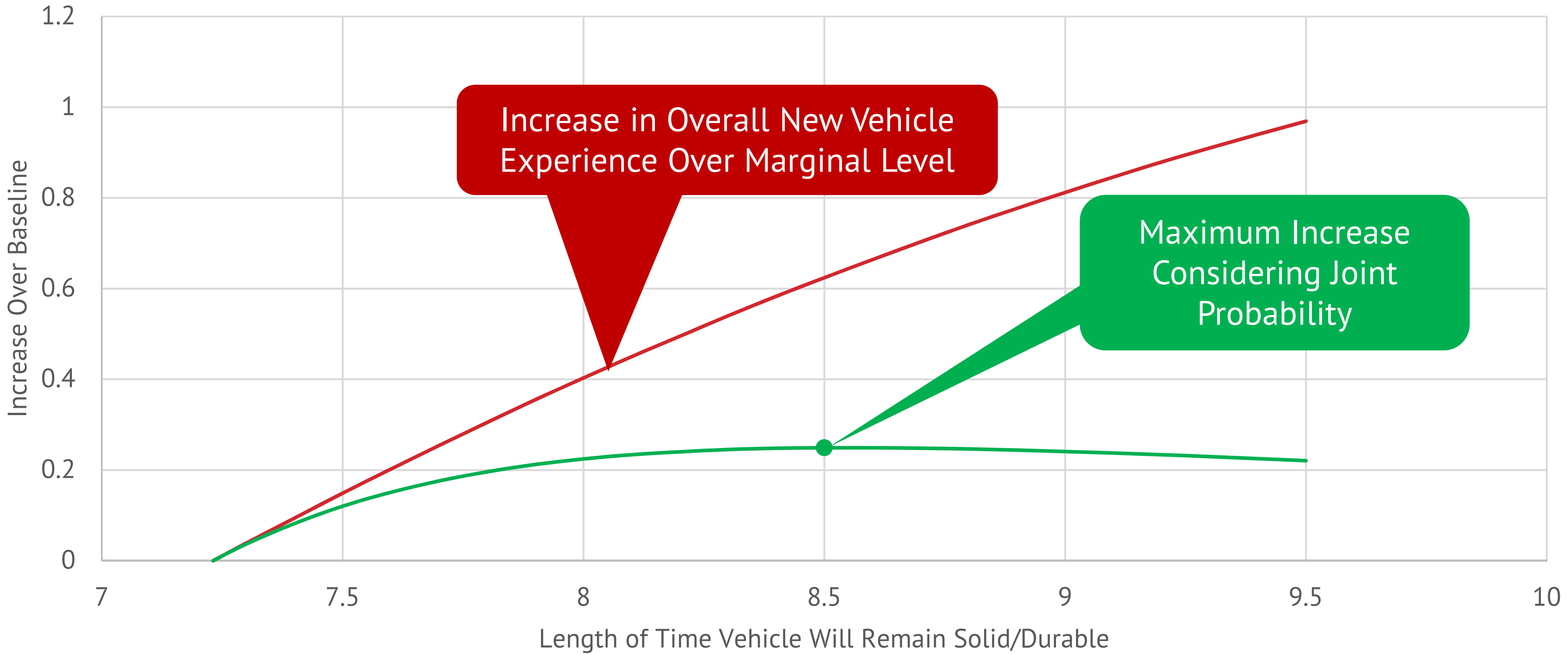
Optimization Constraint #1



Optimization Constraint #1



Optimization Constraint #1



Optimization

Optimization Constraint #1

- "Gain" × Joint Probability ÷ Cost

Optimization Constraint # 2

- Expert-defined constraints
- Automatic calculation of "gap to best level" via Multi-Quadrant Analysis

Simulation of Values

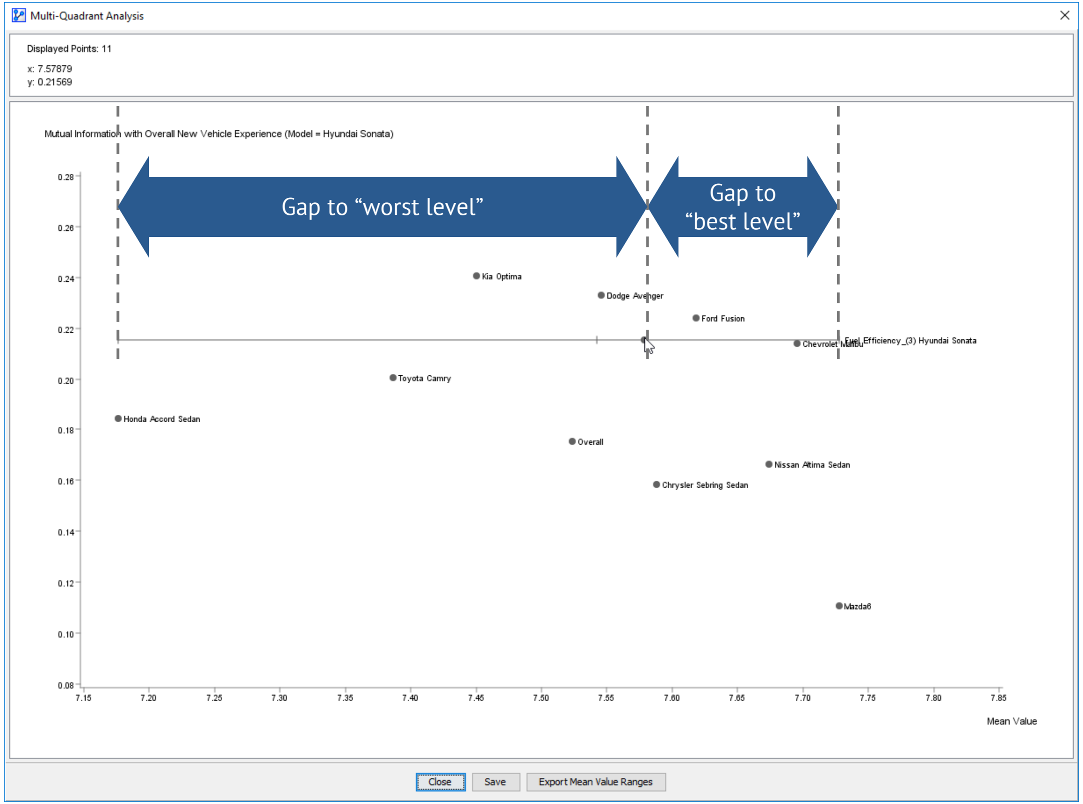
- Minimum Cross-Entropy

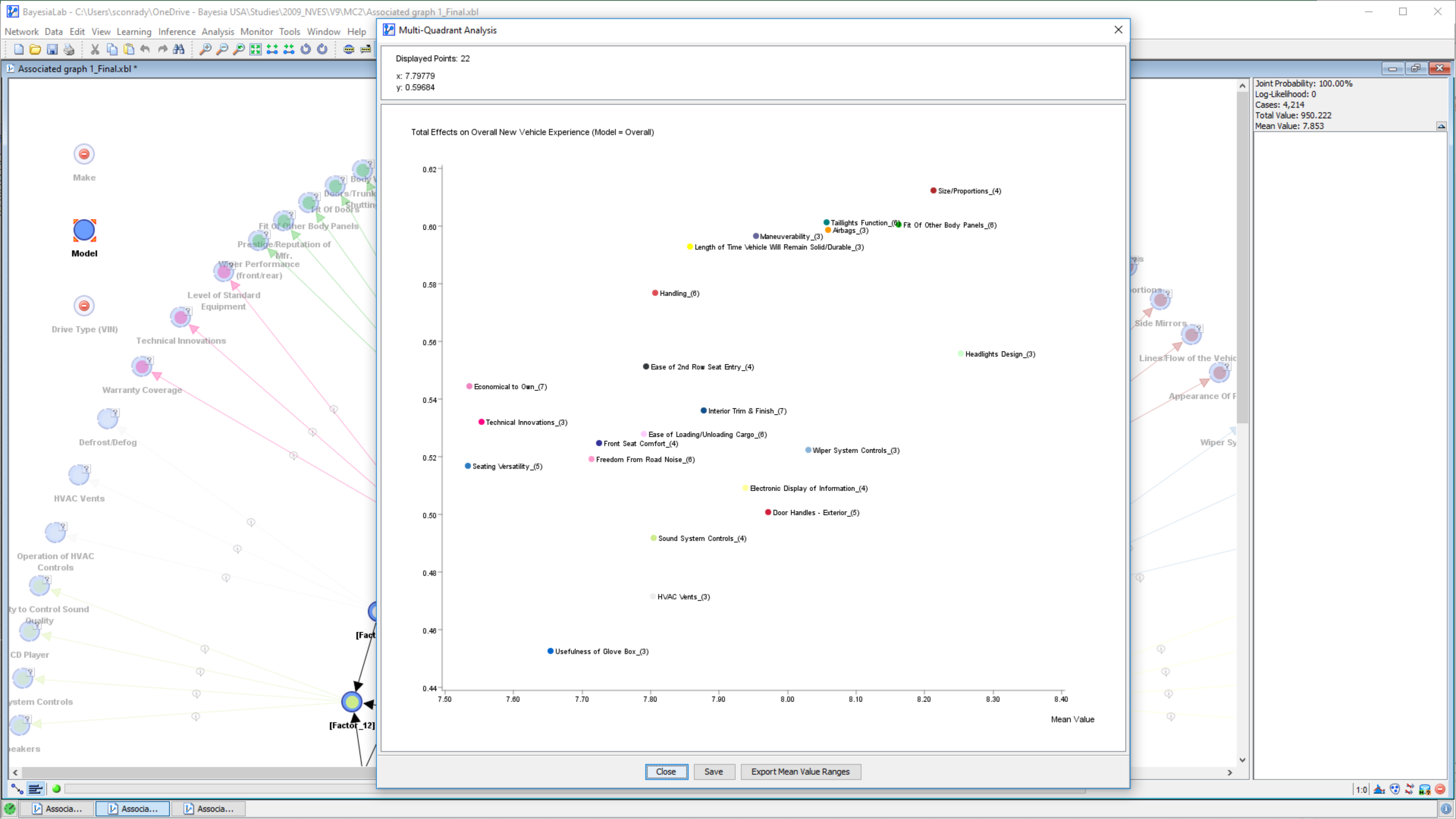
Optimization Objective

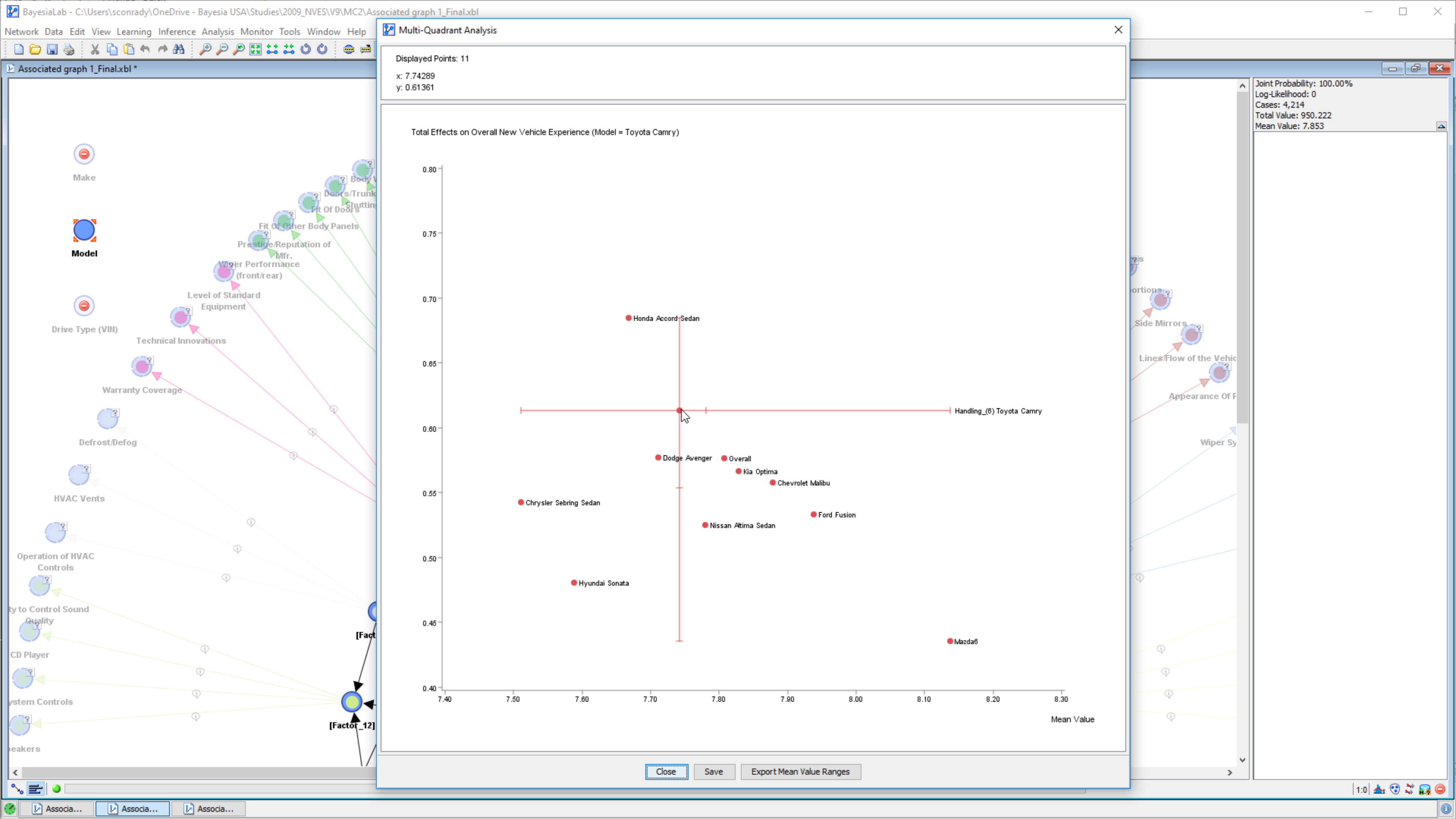
- Establish Priorities

Constraint #2

Multi-Quadrant Analysis as Source of Constraints




BayesiaLab - C:\Users\sconrady\OneDrive - Bayesia USA\Studies\2009_NVES\V9\MC2\Associated graph 1_Final.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Associated graph 1_Final.xbl *
Multi-Quadrant Analysis
Displayed Points: 22
x: 7.79779
y: 0.59684
Total Effects on Overall New Vehicle Experience (Model = Overall)
Size/Proportions_(4)
Taillights Function_(6)
Fit Of Other Body Panels_(6)
Airbags_(3)
Maneuverability_(3)
Length of Time Vehicle Will Remain Solid/Durable_(3)
Handling_(6)
Headlights Design_(3)
Ease of 2nd Row Seat Entry_(4)
Economical to Own_(7)
Interior Trim & Finish_(7)
Technical Innovations_(3)
Ease of Loading/Unloading Cargo_(6)
Front Seat Comfort_(4)
Wiper System Controls_(3)
Freedom From Road Noise_(6)
Seating Versatility_(5)
Electronic Display of Information_(4)
Door Handles - Exterior_(5)
Sound System Controls_(4)
HVAC Vents_(3)
Usefulness of Glove Box_(3)
0.62
0.60
0.58
0.56
0.54
0.52
0.50
0.48
0.46
0.44
7.50 7.60 7.70 7.80 7.90 8.00 8.10 8.20 8.30 8.40
Mean Value
Close
Save
Export Mean Value Ranges
Joint Probability: 100.00%
Log-Likelihood: 0
Cases: 4,214
Total Value: 950.222
Mean Value: 7.853
Make
Model
Drive Type (VIN)
Technical Innovations
Warranty Coverage
Defrost/Defog
HVAC Vents
Operation of HVAC Controls
Level of Standard Equipment
Prestige/Reputation of Mfr.
Fit Of Other Body Panels
Side Mirrors
[Factor_12]


BayesiaLab - C:\Users\sconrady\OneDrive - Bayesia USA\Studies\2009_NVES\V9\MC2\Associated graph 1_Final.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Associated graph 1_Final.xbl *
Multi-Quadrant Analysis
Displayed Points: 11
x: 7.74289
y: 0.61361
Total Effects on Overall New Vehicle Experience (Model = Toyota Camry)
Honda Accord Sedan
Handling_(6) Toyota Camry
Dodge Avenger
Overall
Kia Optima
Chevrolet Malibu
Chrysler Sebring Sedan
Ford Fusion
Nissan Altima Sedan
Hyundai Sonata
Mazda6
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
7.40
7.50
7.60
7.70
7.80
7.90
8.00
8.10
8.20
8.30
Mean Value
Close
Save
Export Mean Value Ranges
Joint Probability: 100.00%
Log-Likelihood: 0
Cases: 4,214
Total Value: 950.222
Mean Value: 7.853
Make
Model
Drive Type (VIN)
Technical Innovations
Warranty Coverage
Defrost/Defog
HVAC Vents
Operation of HVAC Controls
CD Player
Level of Standard Equipment
Fit Of Other Body Panels
Fit Of Doors
Side Mirrors
[Factor_12]

Optimization

Optimization Constraint #1

- "Gain" × Joint Probability ÷ Cost

Optimization Constraint # 2

- Expert-defined constraints
- Automatic calculation of "gap to best level" via Multi-Quadrant Analysis

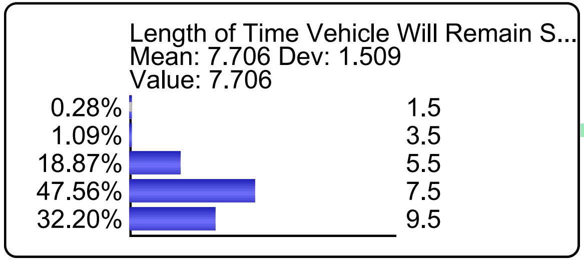
Simulation of Values

- Minimum Cross-Entropy

Optimization Objective

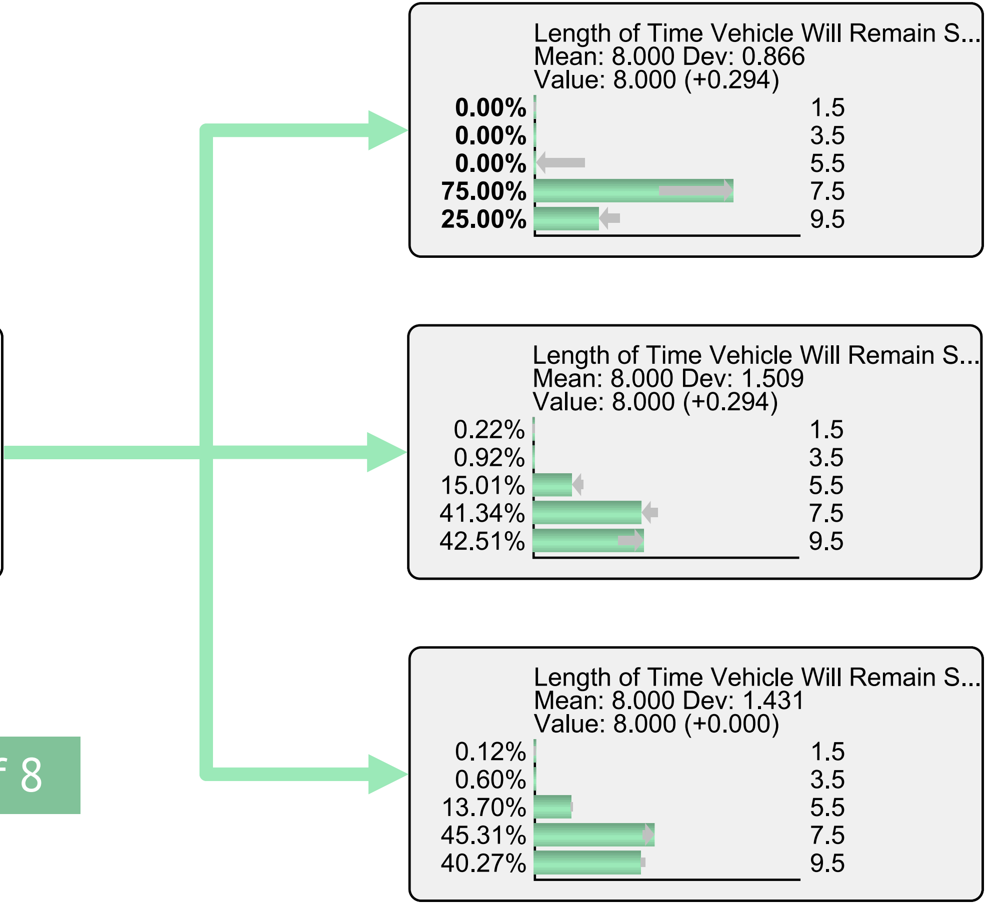
- Establish Priorities

Simulation



Marginal Distribution
Mean: 7.706

Now simulate a mean value of 8



Binary

Value Shift

MinXEnt
☑

Optimization

Optimization Constraint #1

- “Gain” × Joint Probability ÷ Cost

Optimization Constraint # 2

- Expert-defined constraints
- Automatic calculation of “gap to best level” via Multi-Quadrant Analysis

Simulation of Values

- Minimum Cross-Entropy

Optimization Objective

- Establish Priorities

Optimization

e.g. Marketing Mix Optimization

Optimization

- Genetic
- Dynamic Profile
  - Priority 1
  - Priority 2
  - Priority 3

e.g. Key Drivers Optimization

Optimization

Genetic Optimization

[Factor_15]	[Factor_1]	[Factor_2]	[Factor_5]	[Factor_7]	[Factor_25]	[Factor_27]	[Factor_3]	[Factor_10]	[Factor_23]
7.98	7.6428	7.9837	7.9843	7.6736	7.7203	7.5317	7.6944	7.3772	7.902
7.8751	7.6428	8.4286	7.9096	8.1286	7.5816	8.1922	8.2986	7.2026	8.4386
(-0.1049)	(0.0000)	(0.4450)	(-0.0747)	(0.4549)	(-0.1387)	(0.6605)	(0.6042)	(-0.1746)	(0.5366)

[Factor_21]	[Factor_6]	[Factor_12]	[Factor_20]	[Factor_24]	[Factor_14]	[Factor_22]	[Factor_26]	[Factor_17]
7.6704	7.9897	7.7471	7.9541	7.7341	7.8653	7.6782	7.2518	7.5818
8.1330	8.3600	8.3615	8.2713	7.7502	8.2785	8.1439	7.9747	7.9716
(0.4627)	(0.3703)	(0.6144)	(0.3172)	(0.0161)	(0.4132)	(0.4657)	(0.7229)	(0.3898)

[Factor_18]	[Factor_13]	[Factor_0]	[Factor_4]	[Factor_8]	[Factor_11]	[Factor_9]	[Factor_16]	[Factor_19]
7.8011	7.6539	7.3971	7.6046	7.7374	7.7305	7.6038	7.8068	7.5773
8.2469	8.0311	7.3551	7.7844	7.4880	8.1497	7.5302	7.8068	7.6538
(0.4458)	(0.3771)	(-0.0420)	(0.1798)	(-0.2494)	(0.4191)	(-0.0735)	(0.0000)	(0.0765)

Is this "actionable"?

Optimization

e.g. Marketing
Mix Optimization

Optimization

Genetic

Dynamic
Profile

Priority 1

Priority 2

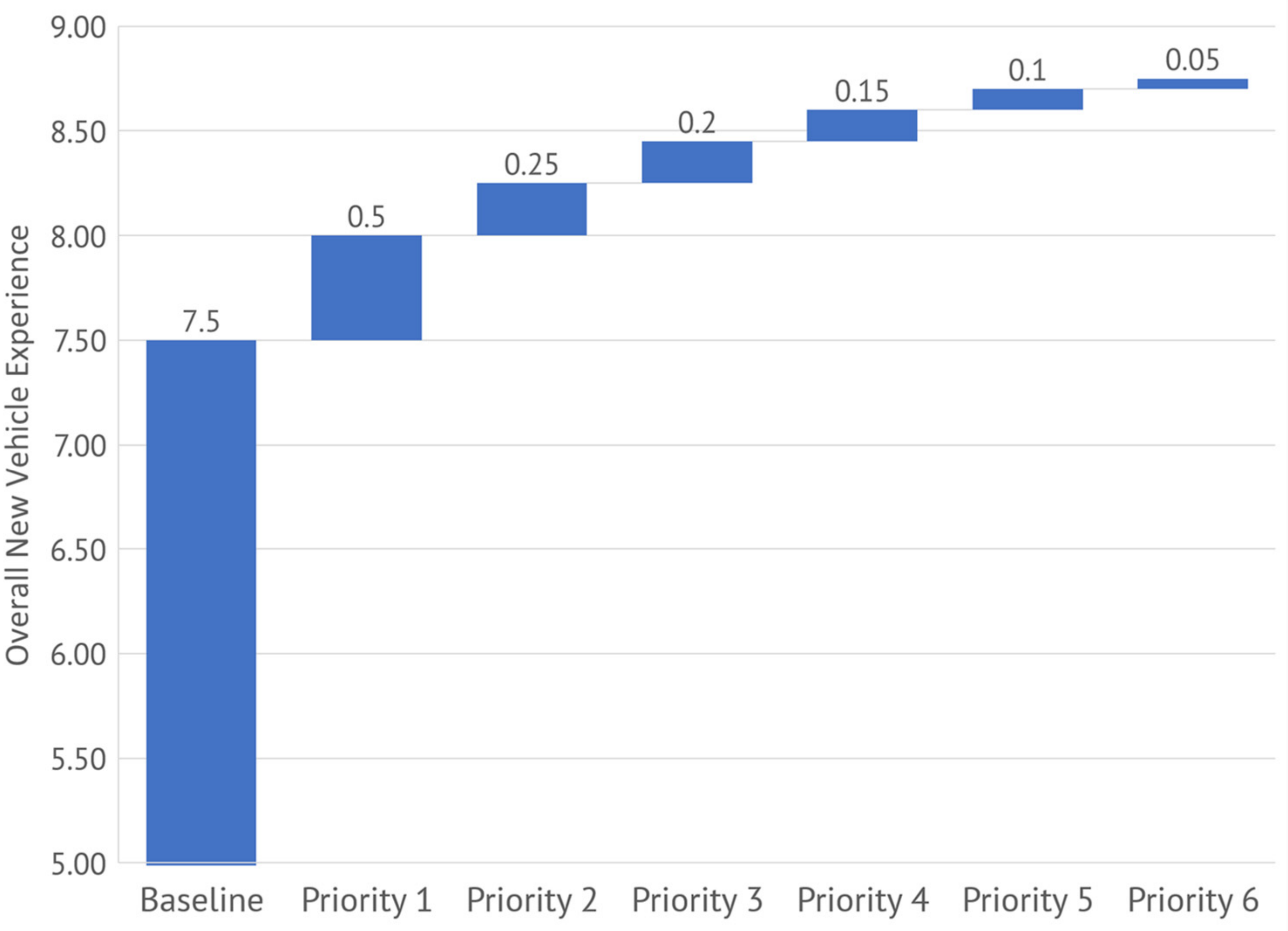
Priority 3

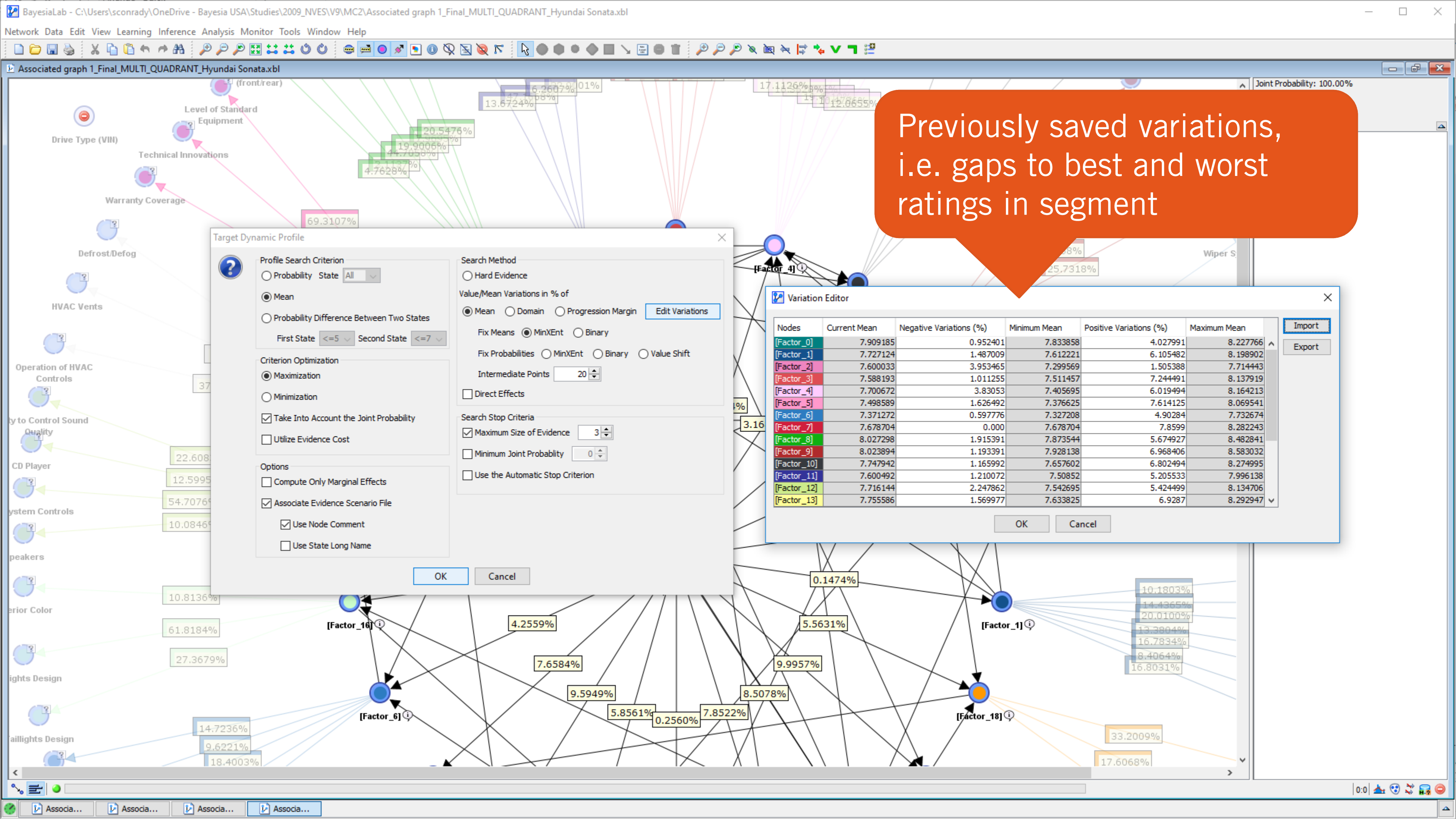
e.g. Key Drivers Optimization


CC
3
2
1

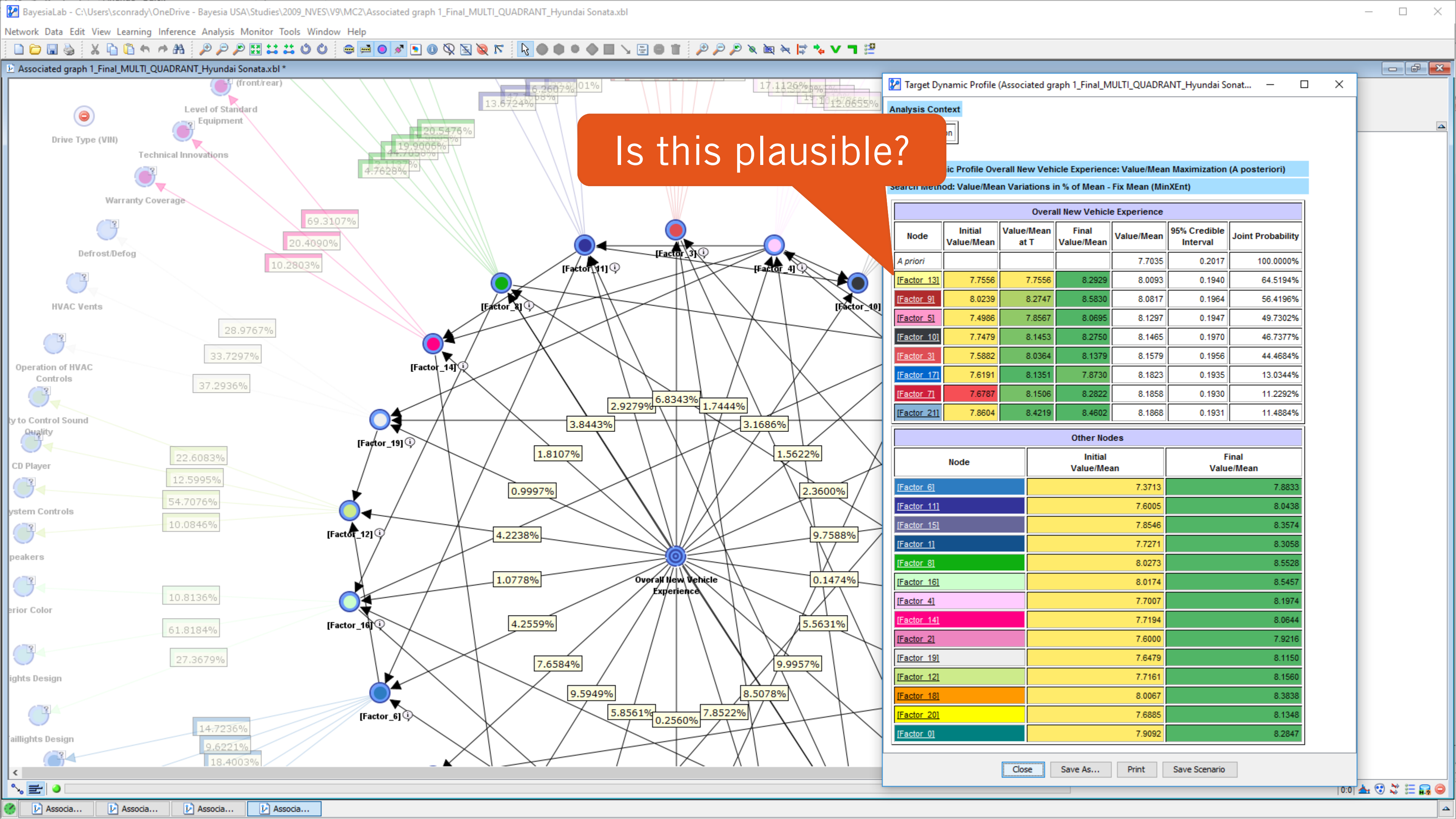
Optimization

Target Dynamic Profile





Nodes	Current Mean	Negative Variations (%)	Minimum Mean	Positive Variations (%)	Maximum Mean
[Factor_0]	7.909185	0.952401	7.833858	4.027991	8.227766
[Factor_1]	7.727124	1.487009	7.612221	6.105482	8.198902
[Factor_2]	7.600033	3.953465	7.299569	1.505388	7.714443
[Factor_3]	7.588193	1.011255	7.511457	7.244491	8.137919
[Factor_4]	7.700672	3.83053	7.405695	6.019494	8.164213
[Factor_5]	7.498589	1.626492	7.376625	7.614125	8.069541
[Factor_6]	7.371272	0.597776	7.327208	4.90284	7.732674
[Factor_7]	7.678704	0.000	7.678704	7.8599	8.282243
[Factor_8]	8.027298	1.915391	7.873544	5.674927	8.482841
[Factor_9]	8.023894	1.193391	7.928138	6.968406	8.583032
[Factor_10]	7.747942	1.165992	7.657602	6.802494	8.274995
[Factor_11]	7.600492	1.210072	7.50852	5.205533	7.996138
[Factor_12]	7.716144	2.247862	7.542695	5.424499	8.134706
[Factor_13]	7.755586	1.569977	7.633825	6.9287	8.292947



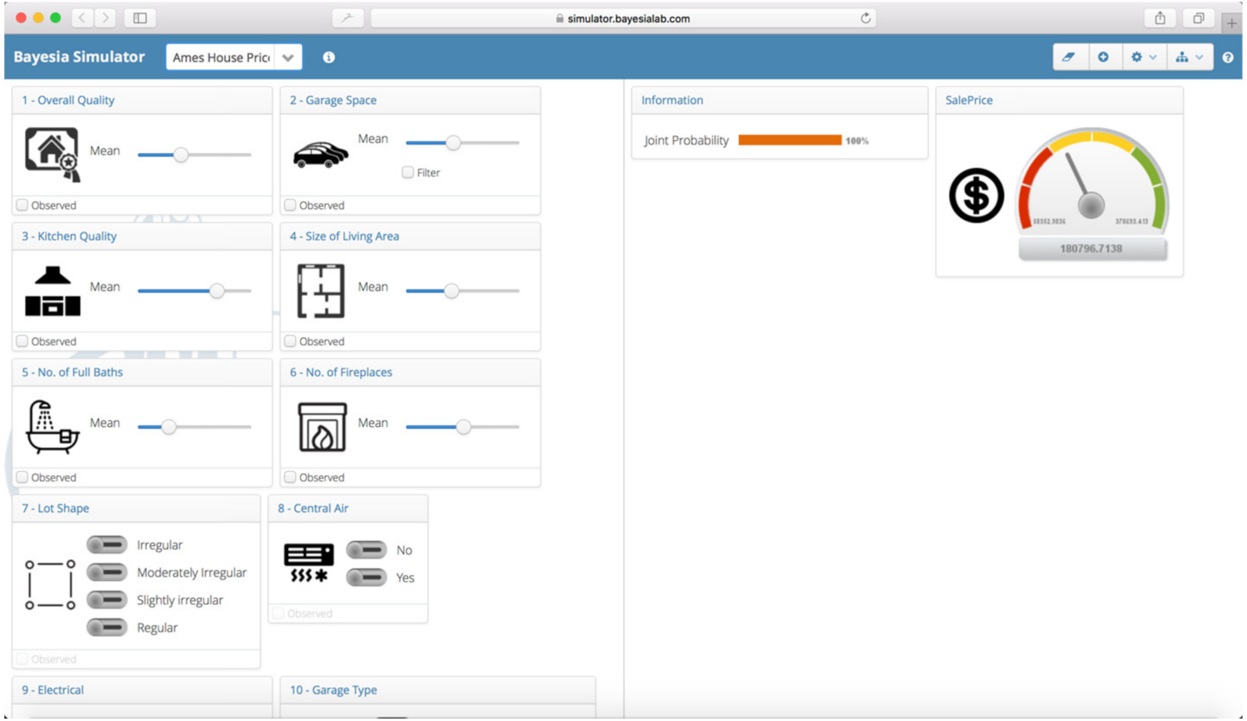
Overall New Vehicle Experience						
Node	Initial Value/Mean	Value/Mean at T	Final Value/Mean	Value/Mean	95% Credible Interval	Joint Probability
A priori				7.7035	0.2017	100.0000%
[Factor_13]	7.7556	7.7556	8.2929	8.0093	0.1940	64.5194%
[Factor_9]	8.0239	8.2747	8.5830	8.0817	0.1964	56.4196%
[Factor_5]	7.4986	7.8567	8.0695	8.1297	0.1947	49.7302%
[Factor_10]	7.7479	8.1453	8.2750	8.1465	0.1970	46.7377%
[Factor_3]	7.5882	8.0364	8.1379	8.1579	0.1956	44.4684%
[Factor_17]	7.6191	8.1351	7.8730	8.1823	0.1935	13.0344%
[Factor_7]	7.6787	8.1506	8.2822	8.1858	0.1930	11.2292%
[Factor_21]	7.8604	8.4219	8.4602	8.1868	0.1931	11.4884%

Other Nodes		
Node	Initial Value/Mean	Final Value/Mean
[Factor_6]	7.3713	7.8833
[Factor_11]	7.6005	8.0438
[Factor_15]	7.8546	8.3574
[Factor_1]	7.7271	8.3058
[Factor_8]	8.0273	8.5528
[Factor_16]	8.0174	8.5457
[Factor_4]	7.7007	8.1974
[Factor_14]	7.7194	8.0644
[Factor_2]	7.6000	7.9216
[Factor_19]	7.6479	8.1150
[Factor_12]	7.7161	8.1560
[Factor_18]	8.0067	8.3838
[Factor_20]	7.6885	8.1348
[Factor_0]	7.9092	8.2847

2009 Hyundai Sonata

Definitely!

BayesiaLab WebSimulator



Just for reference, since you will ask…

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Final Questions?

Thank You!

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