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Cyber Security Risk Assessment Spring 2018

Lecture 11

Quantitative Risk Analysis

Understanding Costs and Probabilities

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Quantitative Risk Analysis

- ***What we really want as a decision?***
  - Risk = Likelihood * Impact
  - Benefit = Original Risk – Risk with Countermeasure
  - Value = Benefit – Cost of Countermeasure
  - Possibly all the above in expressed in the same unit
    - If value >0 do something else do nothing
    - Not always possible
- ***Impact Aspects are easier to quantify***
  - Business Impact
  - Technical Impact
  - Cost of Countermeasures
- ***Uncertainty is harder to manage***
  - Likelihood estimation

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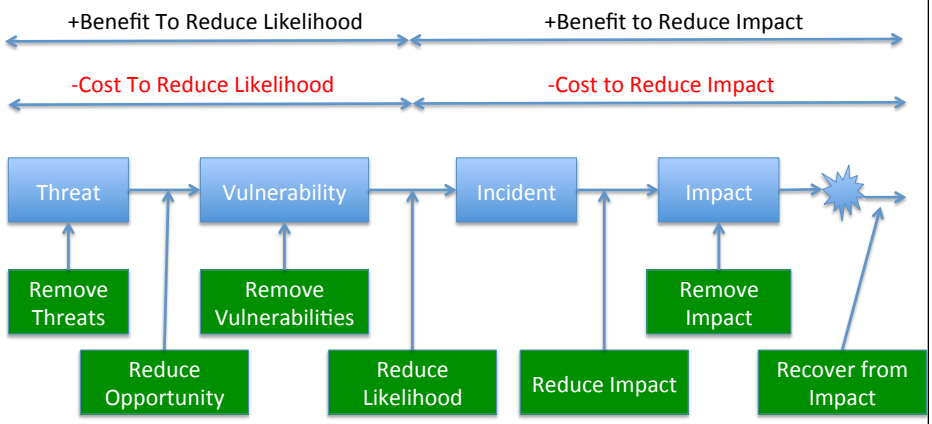
Quantitative Risk Analysis

- ***Reduce Risk = Reduce Likelihood * Reduce Impact***
- ***Increase Costs = Cost to reduce likelihood + cost to reduce impact***



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How we are going to do that?

- ***Step 1 - Understand Technical Metrics***
  - Technical Measurements of Vulnerabilities
  - Business Impact of Vulnerabilities
- ***Step 2 – Understand Financial and Temporal Metrics***
  - Financial Impact
  - Likelihood
- ***Step 3 – Understand Costs***
  - Is reduction in likelihood worth?

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Compliance and Impact

- ***Compliance with laws slightly different than other risks***
- ***Risk of non-compliance***
  - Pay a fine and that's it
    - → impact = fines + legal costs
  - Pay a fine, end on newspaper as "bad company"
    - → impact = fines + legal costs + loss of customers
  - Responsible could end up in jail
    - → depends on mandatory sentencing → cost of "scapegoating"
  - Lose license to operate
    - → impact = +∞
- ***Likelihood (of being caught) is also important***
  - 0*x = 0 for any x

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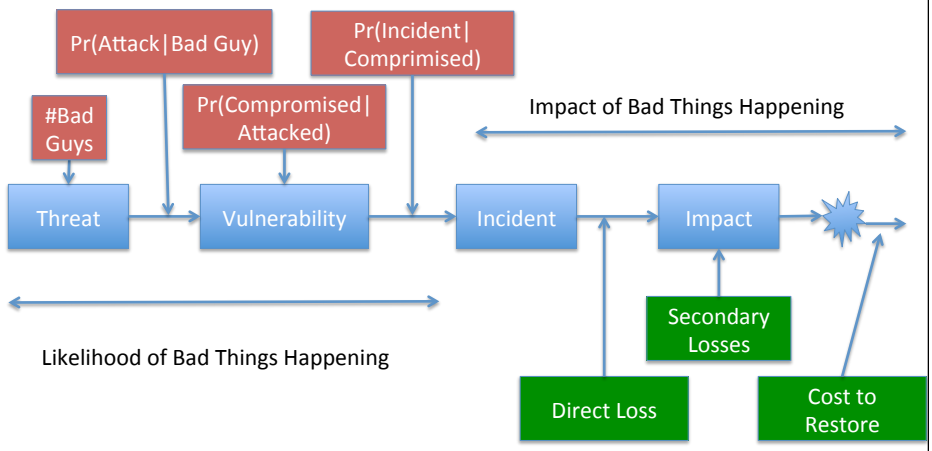
Quantitative Risk Analysis – II

- ***Risk = Likelihood * Impact (negative)***



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Third - Compute Costs

- ***Review different types of countermeasure***
  - In-place countermeasures
    - For example already in place to meet other goals (e.g. compliance)
  - Already Planned countermeasures
  - Approved countermeasures
  - Overlapping countermeasures
- ***Consider also <u>alternative ways of executing</u> the same CBFs***

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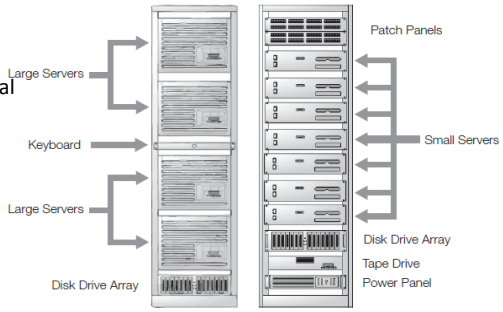
Calculating Costs

- ***Initial purchase***
  - Small servers vs big server
- ***Facility***
  - Do we need to change the physical location
- ***Installation & Operation***
  - Things never work by themselves
    - Air Carrier → very powerful but requires 1K people to operate
    - Nuclear submarine → can do a lot less but 25 people can operate it
  - This may be a recurring costs!
- ***Training***
  - Can anybody use it?



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Sample Costs

Type	What	€€€
Service	switch L3 (500)	20K
Service	Metropolitan Area Network	210K
Service	Internet Connection GARR Giga	30K
Service	Radio Bridges	10K
Service	Load Balancers	10K
Service	Fixed and Mobile Phones	90K
Service	Datacenter Server	20K
Service	Storage	20K
Service	AVM	70K

Type	What	€€€
Purchase	beamers for Ingegneria	40K
Purchase	Switch for Economics	40K
Purchase	Switch for Datacenter	40K
Purchase	Storage for Cloud Platform	10K
Purchase	Server DR for VDI clients	40K
Licenses	Cineca (Esse3, Ugov, ...)	80K
Licenses	Oracle	60K
Licenses	ERP (SAP, InfoTN)	120K
Licenses	Adobe (Adobe Connect,	20K
Licences	Antivirus	20K
Licences	VmWare+VDI Licenses	120K

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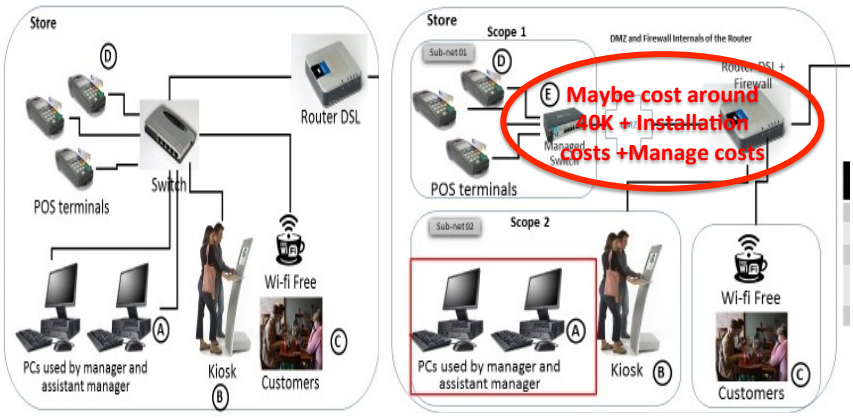
Remember Joe?



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Staff Costs

- ***Italian Industry Assoc. ICT Salary (24-30 yrs old)***
  - Web Developer/ IT/Network Admin. – 21-26K€
  - Programmer/Analyst – 29-41K€
  - Sys Engineer/Architect – 31-44K€
  - Sw Project Leader/IS Manager – 47-78K€
  - CIO – 98K€/year
- ***Working hours vs Salary***
  - 1.640hrs/year (EU average working hours)
  - Tax/Industrial Cost wedge (% of salary vs costs. In EU 40%-70%)
  - 24/7 coverage need at least 8.760hrs/year
- ***Maintain and patch server etc.***
  - Around 2hrs weekly (bare minimum)
    - pure sys-admin, no changes of data, regression testing, etc.
  - Major patches may be 1-2 days or more

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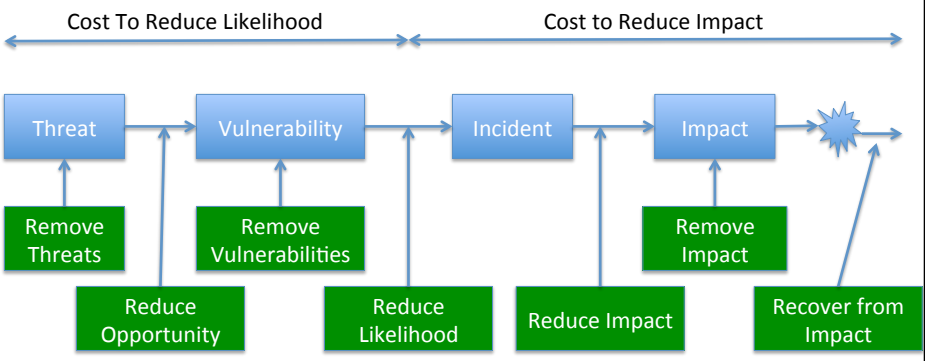
Quantitative Risk Analysis - III

- ***Fix an interval of observation (say N years)***

Benefit = + Likelihood*Impact – NewLikelihood*NewImpact

Value = + Benefit - Cost for NewLikelihood - Cost for NewImpact



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Two Types of Uncertainty

- ***Epistemic***
  - The world is deterministic but we don't know it
    - What is the value of an already tossed coin hidden in my hand?
- ***Stochastic***
  - The world is not deterministic
    - What will be the value of tossing coin?
- ***In security both aspects are present***
  - Some attacks depends on the random layout of the memory → may not work all the time
  - Some attacks took place but we don't know it yet
- ***Mostly we use a Bayesian Interpretation***
  - Probability is a subjective degree of belief that we update given some information

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What to believe?

- ***Linda is***
  - 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student she was deepy concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations.
- ***Which is more likely?***
  - Linda is a bank teller
  - Linda is a feminist bank teller

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Where is the fallacy?

- ***What description implies***
  - Pr(L feminist) = High
  - Pr(L feminist bank teller | L is bank teller) = High
- ***What the question was about***
  - Pr(L is feminist bank teller) vs Pr(L is bank teller)
- ***Conditional vs Absolute Probability***
  - Pr(L is feminist bank teller) = Pr(L feminist bank teller | L is bank teller) * Pr(L is bank teller)
  - Pr(L is feminist bank teller) < Pr(L is bank teller)

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How to protect?

- ***Bomber pilots can***
  - carry either a flak jacket or a parachute because of weight limitations. The probability of being strafed by enemy guns is ¾ (requiring flak jacket to survive) the probability of plane being shot down is ¼ (requiring parachute to survive)
- ***What is best?***
  - Flak jacket at all times
  - Parachute at all times
  - Flak jackets 3 times out of 4 and parachute 4th time
  - Flak jackets 1st time and parachute 3 out of 4 times

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The fallacy

- ***Fallacy is chances don't repeat themselves***
  - The law of large numbers is actually working on large numbers…
  - UNLESS you really know this is a process that has memory (but then probability should be described differently)
- ***Pilot taking flak jacket first three times***
  - Clearly has not been shot down before the fourth one
  - So he has seen the series "strafed;strafed;strafed" → next time it is going to be "shotDown"
  - By taking the parachute the fourth time he has ¾ chance to die, ¼ of survival
    - Strafing and shooting down are independent on the previous event

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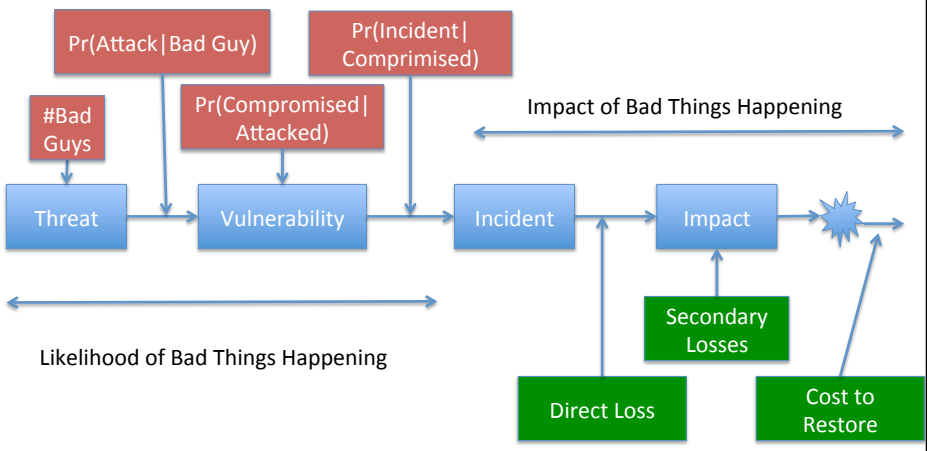
Quantitative Risk Analysis - I

- ***Risk = Likelihood * Impact (negative)***



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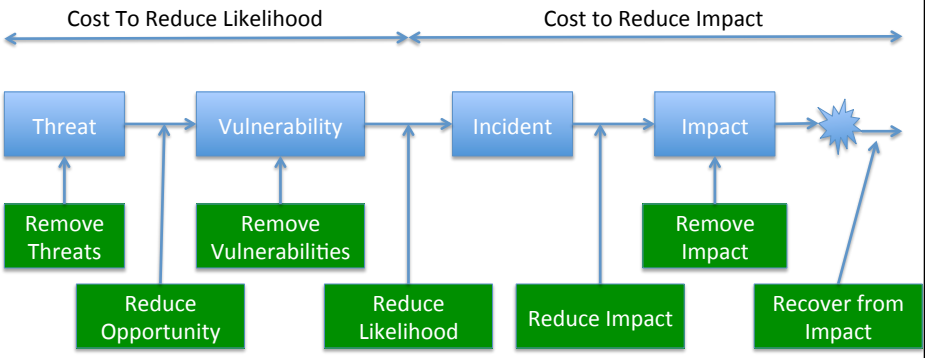
Quantitative Risk Analysis - II

- ***Fix an interval of observation (say N years)***

Benefit = + Likelihood*Impact – NewLikelihood*NewImpact

Value = + Benefit - Cost for NewLikelihood - Cost for NewImpact



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What we need to estimate

- ***#Threats***
  - Intentions to attack by cyber-terrorist, financially motivated criminals, hackivists, disgruntled employees, etc.
- ***Pr(Attack|Threat)***
  - If a given threat is active how many attacks are we going to get?
- ***Pr(Compromise|Attack)***
  - Once we are attacked would this generate an actual compromise of the machine (so the exploit would actually work)
- ***Pr(Incident|Compromise)***
  - Once we have been exploited, has this exploit been transformed into an incident that has a specific cost?
- ***May not be possible to estimate everything individually***
  - E.g. some probability might be difficult to disentangle from actual data

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Example Verizon DBiR

- ***Verizon Reports***
  - #Number of Incidents x Victim Type
  - #Number of Data Breaches x Victim Type
  - #Typology of attacks
- ***Example in 2015***
  - Retail 370 incidents, 182 breaches
  - Professional services 916 incidents, 53 breaches
  - Cyberspies 247 incidents, web app attack 5334
- ***What can be calculated?***

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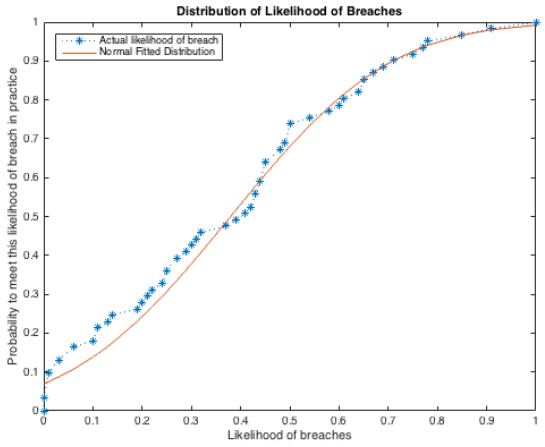
What we have

- ***#Threats → don't know***
- ***Pr(Attacks|Threats) * Threats → "incidents" in Verizon terminology***
- ***Exploited Vulnerabilities → don't know (here)***
  - From the PDF report, they only tell us the gross total
  - the information of exploited attack is actually there in the DB, so you may get it from there
- ***Pr(Incidents|Compromise) * Pr(Compromise|Attack) * Pr(Attack|Threats) * Threats → "data losses"***
- ***Can reconstruct***
  - Pr(Incidents|Threats) = "Verizon data losses"/"Verizon's incidents"

How to construct the Cumulative Distribution

- ***Basic Data -→ set of companies***
  - $\#Incidents_C$ for a certain class C of companies
  - $\#Breaches_C$ for the same class C of companies
- ***Likelihood of successful breach***
  - $Likelihood_C = \#Breaches_C/\#Incidents_C$
  - Now sort by increasing Likelihood
- ***Calculate cumulative frequencies***
  - $\#TotIncidents_0 = \#Incidents_0$ for the lowest $Likelihood_0$
  - $\#TotIncidents_{C+1} = \#TotIncidents_C + \#Incidents_{C+1}$

Global Data of Breach Likelihood



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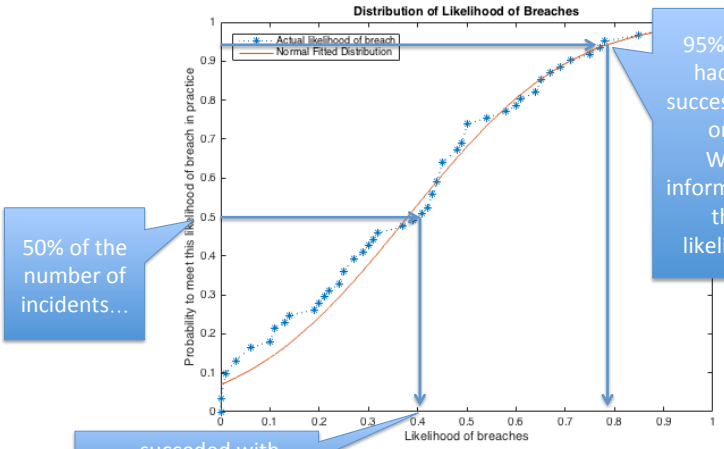
How do we read it?



50% of the number of incidents…

95% of the incidents had a probaility of successful impact lower or equal to 0.8. We can use this information to estimate the worst case likelihood of impact.

… succeded with Probability 0.4 or less

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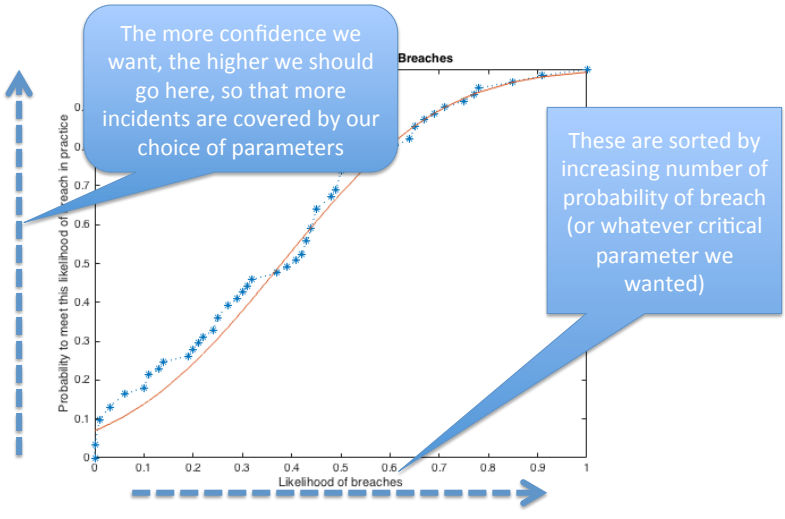
Global Data of Breach Likelihood



The more confidence we want, the higher we should go here, so that more incidents are covered by our choice of parameters

These are sorted by increasing number of probability of breach (or whatever critical parameter we wanted)

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Data on Three Industries

- ***Average Number of Attacks***
  - Personal Services (Finance, health) = 435.2
  - Physical Production (Agriculture etc) = 8.5
  - Industries (Utilities, Wholesale, etc.) = 112.1
- ***Average Probability of Success***
  - Personal Services (Finance, health) = 0.41
  - Physical Production (Agriculture etc) = 0.62
  - Industries (Utilities, Wholesale, etc.) =0.39

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Scale down to the company

- ***What are we missing?***
  - We don't know how many industries are in the sample by Verizon.
  - We must investigate that into the database
    - 200 Attacks over 100 Companies means 2 attacks against <u>your</u> company per year.
    - 200 Attacks over 1000 Companies means 0.2 attacks against your company = 2 attacks every 10 years.
  - We could assume #Incidents/#Firms =1
- ***Compute the final Likelihood***
  - Avg(Prob of Breaches|Incidents) * #Incidents/#Firms
- ***Multiply by impact → (average) risk***

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Refining the analysis

- ***Exploited Vulnerabilities***
  - If we have access to the data we can use this information to estimate the effect of countermeasures
- ***Pr(Compromise|Attack) → Pr(Compromise|Attack & CVSS=x)***
  - How many vulnerabilities with a given CVSS score have been attacked
  - How many of them has been the cause of a data breach?
  - If we remove the vulnerabilities with highest probability → reduce likelihood
- ***Approximate calculation also possible***
  - Assume that vuln with CVSS=10 yields a compromise with Pr=1
  - Conservative but may be an overkill

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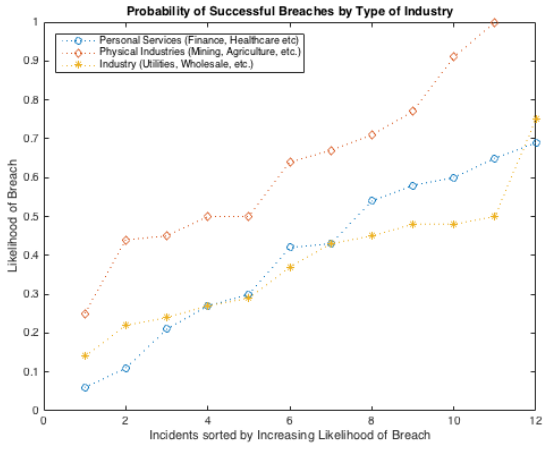
Also distribution and type matter



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What About Extreme Risks?

- ***So far we calculated averages of success***
  - Personal Services (Finance, health) = 0.41
  - Physical Production (Agriculture etc) = 0.62
  - Industries (Utilities, Wholesale, etc.) =0.39
- ***Which is the probability of success for breaches if we consider 90% of incidents ordered by success?***
  - Personal Services (Finance, health) = 0.58
  - Physical Production (Agriculture etc) = **0.95**
    - In other words 10% of incidents will have a probability of success of 0.95 or more
  - Industries (Utilities, Wholesale, etc.) = 0.66

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The Problem

- ***With Normal/Poisson distributions***
  - as we we go away from the average → there are very few dangerous cases
  - So we can reasonably use the average, at most moderate with the standard deviation
- ***Our data is not normal***
  - we have very fat tails of the distribution → dangerous cases may not be so few
  - Extreme risks may be less rare than we thought
- ***We need to estimate "worst cases"***

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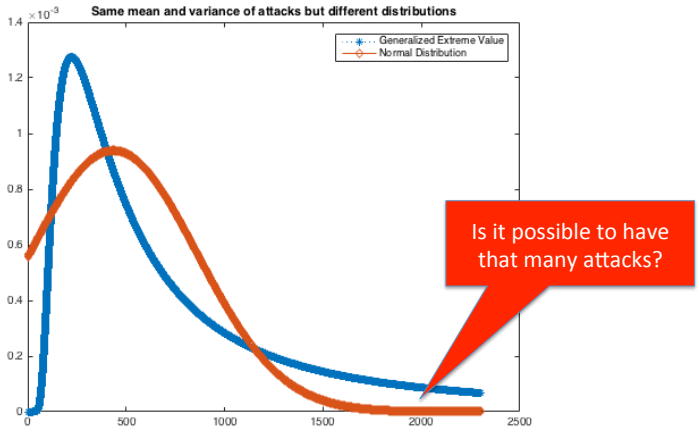
Two distributions with same μ and σ



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Estimating Extreme Risks

- ***The problem of slide 24***
  - We have the data but it only arrive to some incidents, then it flattens out we really want to have 99.9% of the incidents
  - Solution: we fit the data (the blue dots) we have with a mathematical distribution (the red curve) and extrapolate the point we are interest (use the point on the red curve to do what we did in slide 25).
- ***Simplified version of Basel-II approach***
  - Used by banks to estimate rare but anyhow big risks
    - Banks do a double convolution: estimate likelihood and estimate losses → we take impact as given
- ***Approach***
  - Collect data of value of the variable of interests (attack, percentage of success, vulnerabilities, etc.)
  - Fit data into a distribution (try both slim and heavy tails)
  - Calculate at the alpha-percentile of the distribution
    - Typically the 95%-percentile
  - This is the number we use for the calculation of the final risk

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Poisson Distribution

- ***Key Idea***
  - Probabily that n incidents will happen in a give time interval → decreases linearly with the size
  - $Pr(k) = Pr(k-1) * \lambda/k$
- ***Typically very thin tail***
  - Large number of incidents are very very rare
- ***Cumulative Distribution***
  - $Pr(X < x) = e^{-\lambda} \Sigma^{x}_{i=0} \lambda^{x} / x!$
- ***Parameter estimation from data***
  - $\lambda = 1/n \, \Sigma^{n}_{j=0} x_j$

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Pareto Distribution

- ***Key Idea***
  - Power Law for distribution of income
  - The people with a (large) pot of money *m* are progressively fewer and fewer i.e. they are only a/m^b
  - Used to model large losses (m) in property and liability insurance → the larger the b the more likely we have people with large losses
    - Typical values of b for earthquakes (1), fire industry (1.5), general liability (1.8), occupational injuries (2), motor liability (2.5)
- ***Cumulative Distribution***
  - $Pr(X<x) = 1 - (a/x)^b$
- ***Parameters estimation from data***
  - $a = \min(x_j)$
    - if we have 0% probability of attacks we may assume it is slightly larger than 0
  - $b = n \, [\Sigma^{n}_{j=1} \log(x_j/a)]^{-1}$

Generalized Extreme Value Distribution

- ***Key Idea***
  - Try to captures the possible maxima (or minima) of a batch of random values
  - If the tail goes esponentially to zero → collapse to normal/Poisson distribution
  - If the tail goes polynomially to zero → Student's t distribution or Frechet's distribution
  - If the tail is bounded → Beta distribution
- ***E.g. Cumulative Distribution (Frechet)***
  - $Pr(X < x) = e^{-b/(x-a)^C}$

Estremal Values for Likelihood

- ***Data***
  - Use the "Incidents" in Verizon DBiR terminolgy
- ***Goal***
  - We want to now the worst possible number of attacks, at 95% percentile for different type of small firms
    - Banks have to calculate at the 99.9% (but we don't have enough data here)
- ***Process***
  - Compare Distributions
    - Actual (the empirical distribution), Poisson, Generalised Extreme Value, Pareto Tails
  - Find best distribution
    - We do this "visually", should be done with statistical tests → advanced courses
  - Return the inverse value of the 95% percentile

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Extremal Number of Attacks

95%	Administr.	Consumers	Industry	Personal	Production
Empirical	26	179	18	50	4
Normal (fit)	24	164*	13	50	3
Poisson	15	80	9	34	3*
GEV	30*	374*	16*	50*	1343
ParetoTails	24	169	17	49	4

Starred nodes correspond to the distributions that seem to fit best (from the plots)

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Further reading

- ***Chapters 10, 11 on Textbook***
- ***Chapters 1-3, Claudio Franzetti, "Operational Risk Modelling and Management", CRC Press***
- *Ross Anderson's book*
- *L. Allodi, F. Massacci.* Comparing vulnerability severity and exploits using case-control studies. ACM Trans. on Information and System Security, 17(1):1 (2014).