Warranty Prediction During Product Development

Marcos Esterman, Assistant Professor, ISE, RIT
Hee-Rak Kang, Research Assistant, ISE, RIT

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Contributors: Philip Gerst, Paul H. Stiebitz -Rochester Institute of Technology
Kosuke Ishii – Stanford University
Brain Cargille, Steve Kakouros – Hewlett-Packard

Agenda

- Background
- Motivation
- Past Approaches & Issues
- Framework Proposal
- Current work
- Future work

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BACKGROUND

What is warranty?

- Legal contract
- Liability
- Promise between a seller and buyer
- Insurance

Warranty Defined – *Technically*…

- A promise that a seller makes to the buyer concerning the quality of goods or their fitness for a particular purpose.
- Therefore, when describing warranty and warranty events it is vital that the issues of negligence, fault and/or due care are discussed and understood by all parties involved.

Examples of Warranty

- Printers
- Cars
- Computers
- Electronic Devices
- Phones
- Services

Evolution of Warranty

- In early civilizations, the issue of warranty was raised from a variety of products from cattle to slaves. Tablets from Babylonia have been found to have read:
  - *…If a man has bought a male or female slave and the slave has not fulfilled his month, but the bennu disease has fallen upon him, he (the buyer) shall return the slave to the seller and the buyer shall take back the money he paid…*

Money-Back Guarantee - Historically

- Dates back to the Hammurabic Code
  - It offered the buyer compensation for defects discovered in the product after the sale.
  - For various other products and services, it provided an eye-for-an-eye type of compensation, for example, a house builder, "who has not made strong his work" causing the house to collapse thereby killing the owner, is put to death for his negligence.
- Ancient Indian Law dealt with warranty events similar with that of the Babylonians
  - It provided "money back guarantees" to dissatisfied buyers in a specified time period. For example, iron (one day), milking cows (three days), beasts of burden (5 days). In contrast, Islamic law handled warranty events from a religious perspective, placing emphasis on intent.

Caveat Emptor (Let the Buyer Beware)

- From the Industrial Evolution and beyond, protection for the buyer decreased with the growing acceptance of *caveat emptor* or “let the buyer beware”.
  - Buyers were not entitled to receive compensation for any problem associated with product except outright fraud on the part of the seller.
  - Although this may seem unfair to the buyer, in most cases the issue was moot as the buyer and seller were usually from the same local community, and there usually was no need for an express warranty.

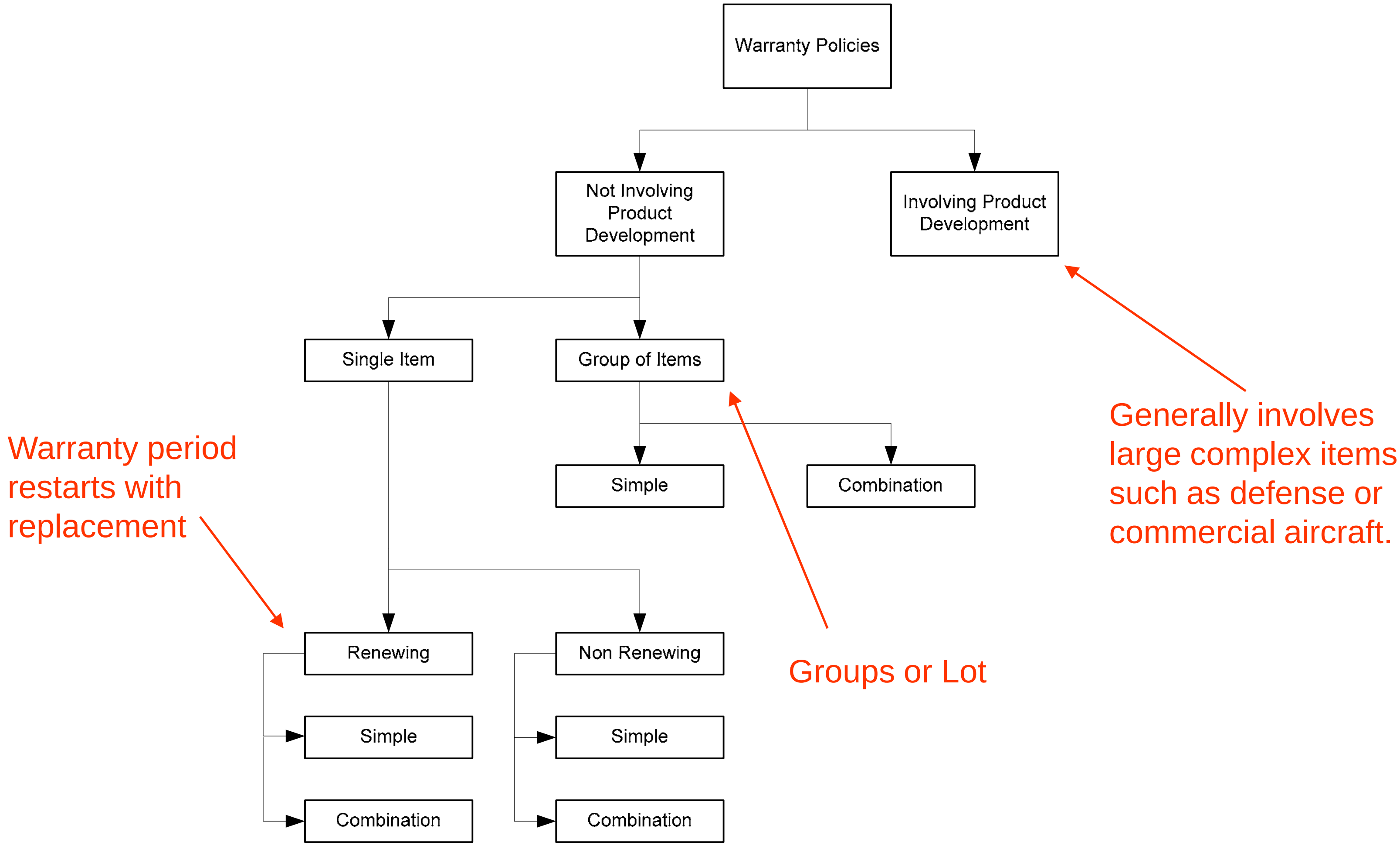
Late Nineteenth Century and Beyond

- It was not until the late nineteenth century that standardized product warranties became common.
- At the start, product warranties were almost always one-sided, providing little to nil protection for the buyer and most likely did not cover failed component parts, transportation charges, ensuing damages, etc.
- In addition, most companies failed to honor warranties, and a trend of dishonest companies caused customers to perceive warranties as an indicator of poor product quality.

Development of Testing Agencies

- Poor product quality led to the development of testing agencies
  - Underwriters Laboratory
  - Good Housekeeping Institute
  - Consumer Reports
- Seals of approval from these independent testing agencies went a long way to gain consumer confidence for a particular product.

Warranty Policies



(Blischke & Murthy, 1992)

What is your experience with product warranty?

- Does it influence your purchase decisions?
- Does it change how you view a product's quality?
- Give an example of a product warranty that has helped your purchase:
  - Lifetime power train warranty
  - 10 year/100,000 mile warranty

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MOTIVATION, PAST APPROACHES & ISSUES

Challenges in Design for Warranty

- Warranty More than Reliability
  - Misaligned Customer Expectation
  - Sub-optimal Service
  - Poorly Designed Warranty Policies
- Traditional Assessment Methods Insufficient
  - Development engineers were aware of the issues but unable to properly assess the impact
  - Development engineers were aware of the issues and had a sense of the impact, but management acted inappropriately
  - Development engineers did not identify the appropriate warranty scenarios

Problems with Past Approaches

- Reliability Modeling
  - Reliability Characterization Secondary to Improvement
    - Early testing impractical, when practical too late
  - Correlation of development testing to field experience
- Estimate based on Bottoms-Up component failures
- Provides little insight to impact design and service model decisions
- Typically a 1-time analysis
  - Re-use of the analysis to evaluate changes or “what-if” scenarios is difficult
- Interactions between product design, service model and warranty policies not considered

The Opportunity

- Warranty is important to both manufacturer and consumer
  - A warranty is the representation of the characteristics or quality of product
  - A warranty is an expression of the willingness of business to stand behind its products and services. As such it is a badge of business integrity.
- Understanding our warranty costs puts a company in a better position to generate service revenue.

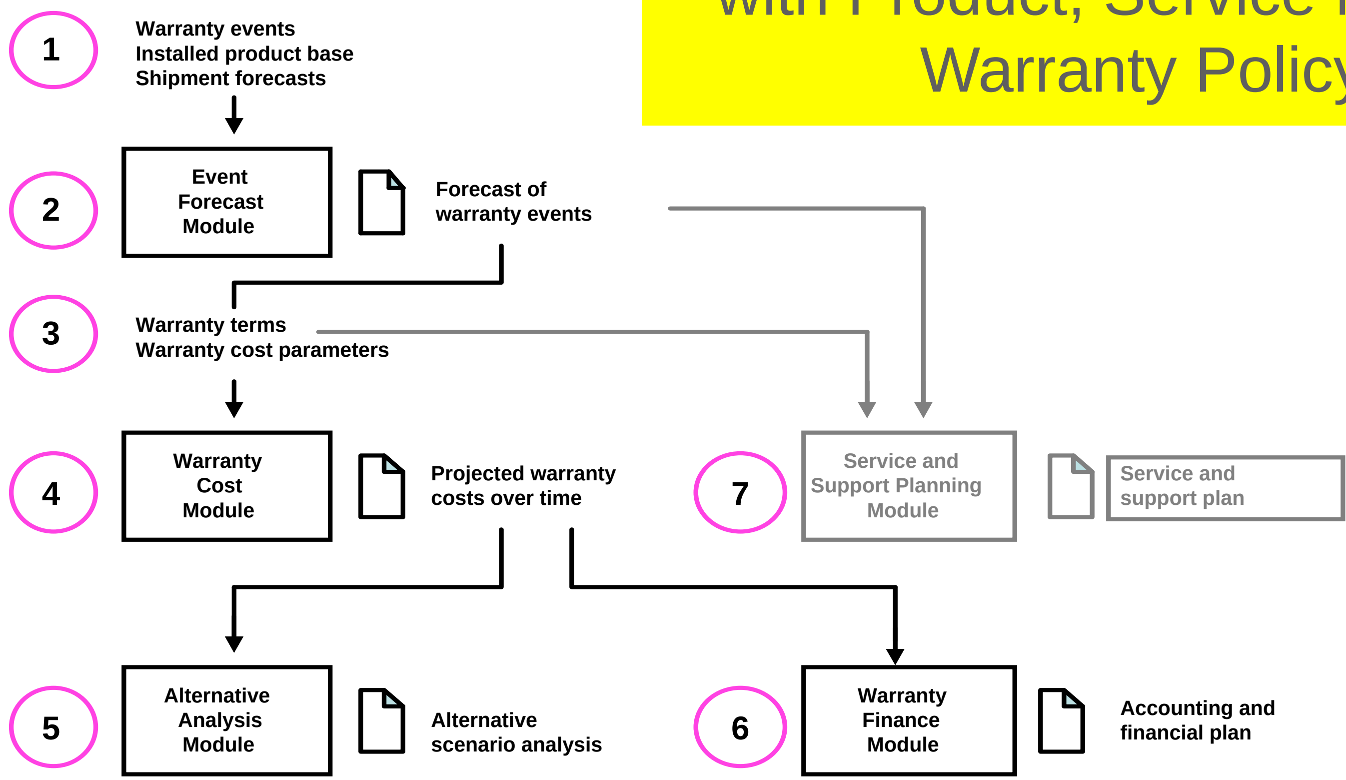
The Need

- Evaluate warranty targets and predict costs associated with
  - Different product architectures
  - Changing reliability performance during PLC
  - Different service delivery models
  - Different warranty policies
- Identify areas of warranty risk; define and implement appropriate actions to manage this risk.

<u>Predict</u> the impact of design & program <u>decisions</u> on warranty events throughout the product life-cycle .

Events Based Warranty Modeling

Model Events & Their Interaction with Product, Service Model & Warranty Policy

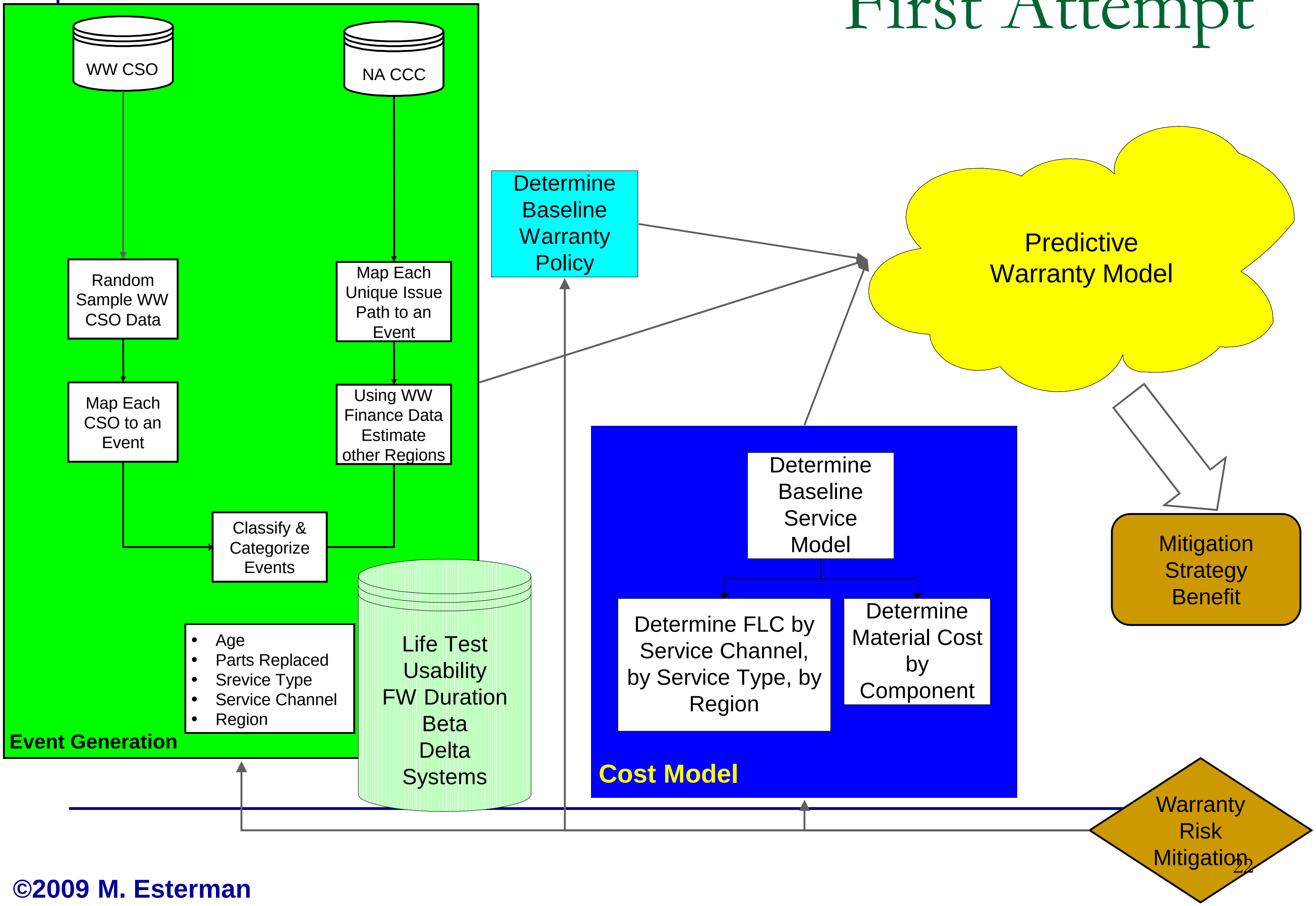


S. Kakouros, B. Cargille,, M. Esterman, *Reinventing Warranty at HP: An Engineering Approach to Warranty*, Quality and Reliability Engineering International Journal, February, 2003, Volume 19, Issue 1, John Wiley & Sons, Ltd., Hoboken, NJ.

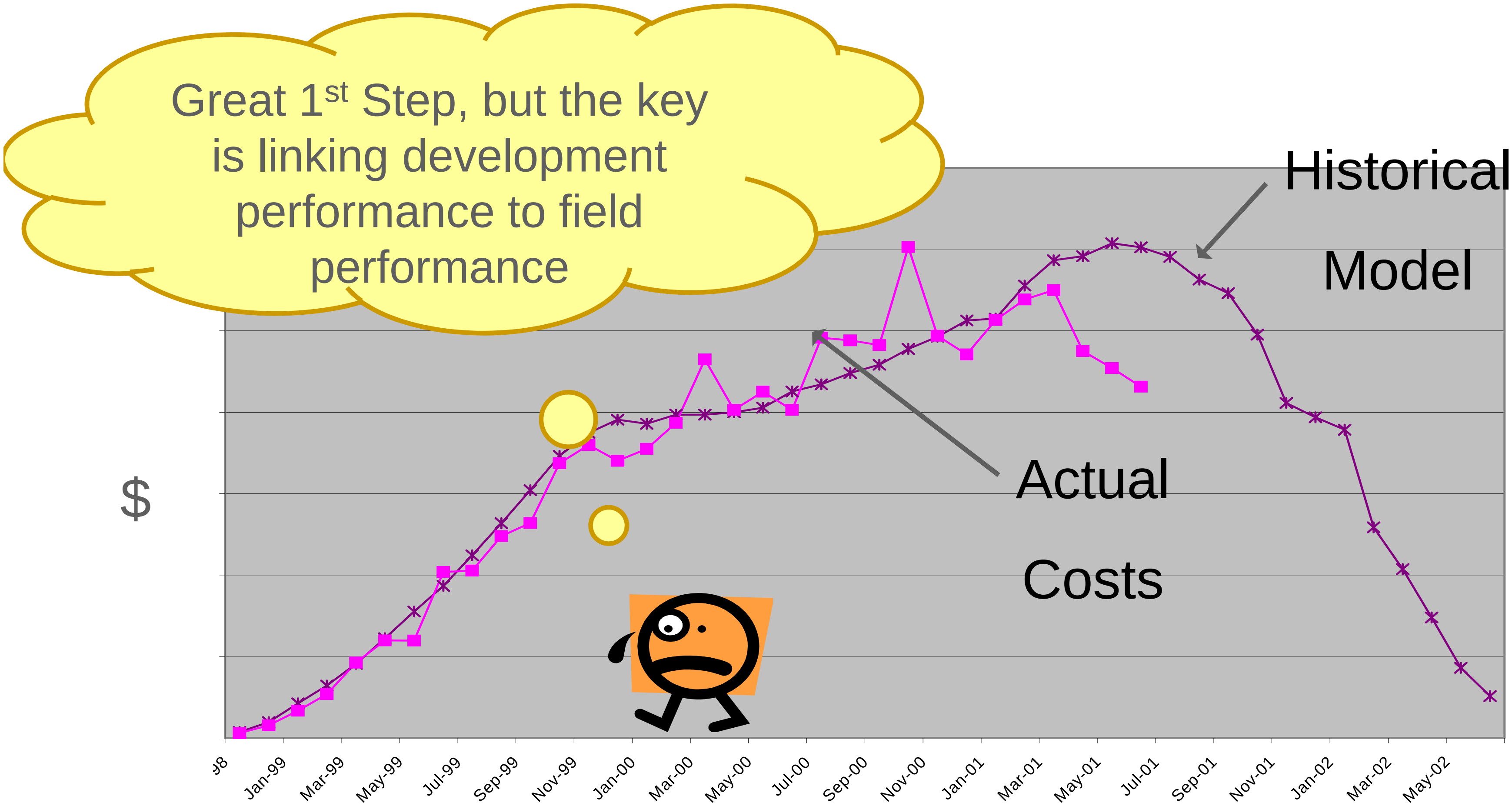
Advantages of Modeling Events

- Customers experience events
- Easier to see system interactions
- Easier to evaluate design change impact on warranty events than on components
- Events more readily transfer between product platforms

First Attempt



Validating the Approach: Historical Model



Issues

- No clear link between development event rates & field event rates
  - Events are a robust representation BUT:
  - Field not proficient collecting event data
  - Current event definitions are not actionable
- Inconsistent failure description language throughout PLC
- By the time historical data stable, N+2 platform already under development
- Event rate prediction models need to better integrate
  - Historical field experience, Product development testing data, Assessment tool information, Engineering judgment

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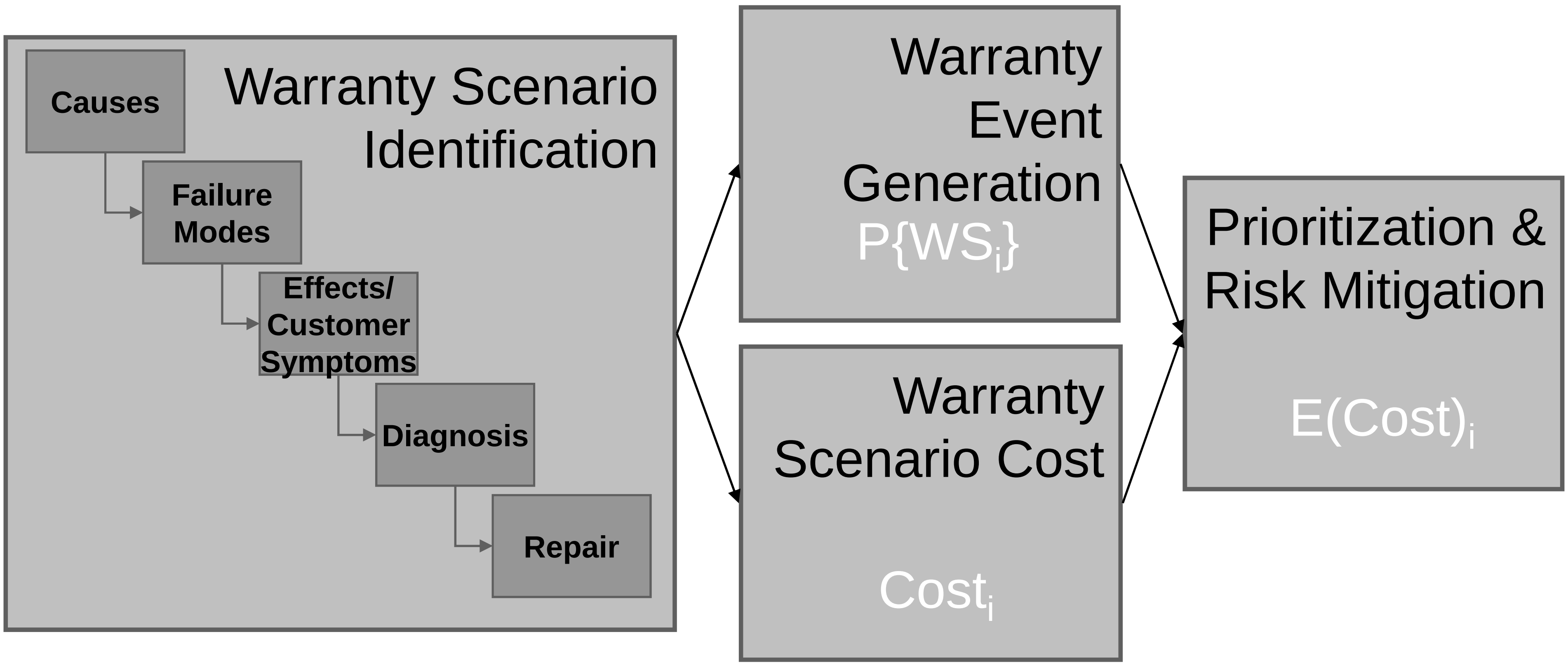
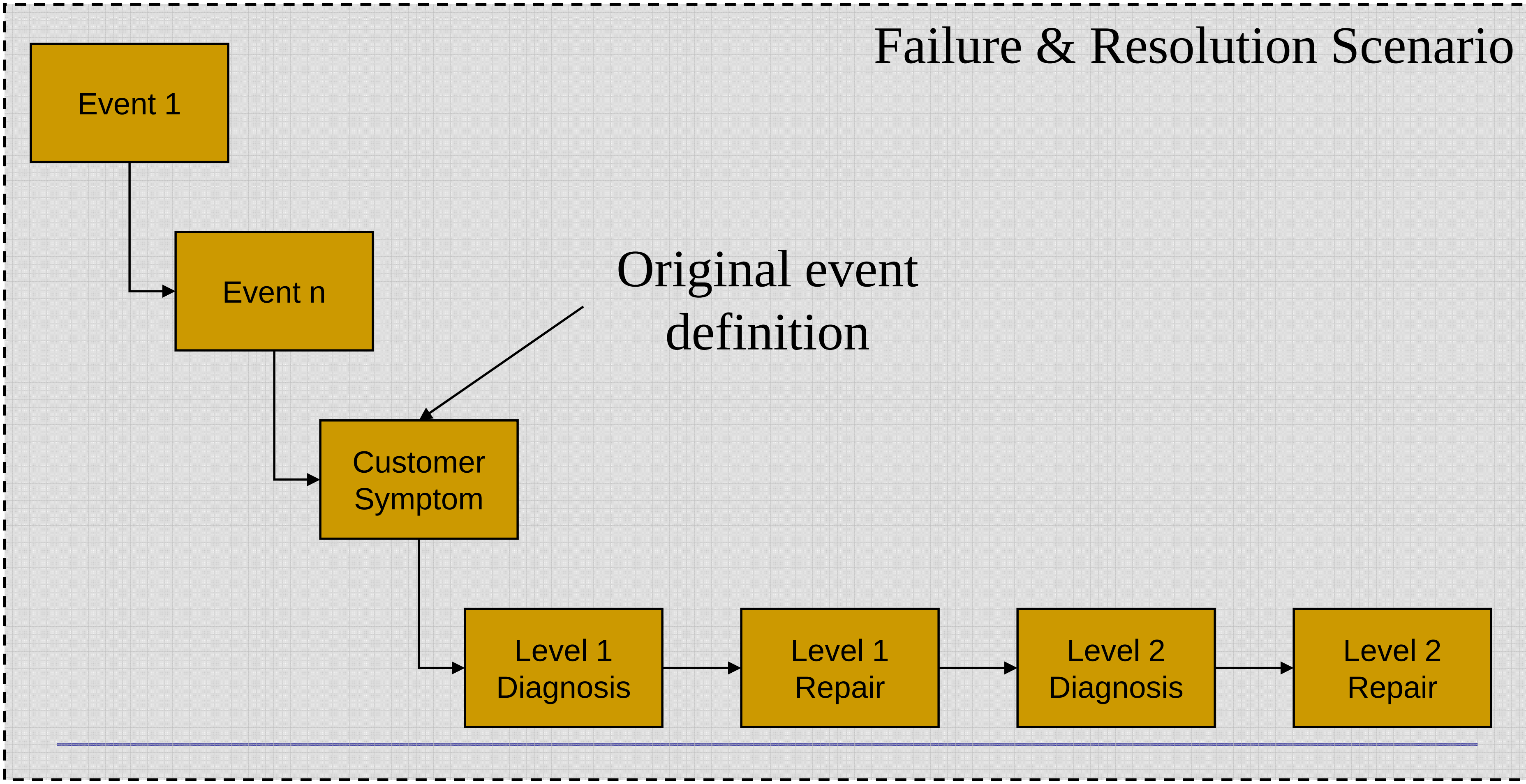
PROPOSED FRAMEWORK

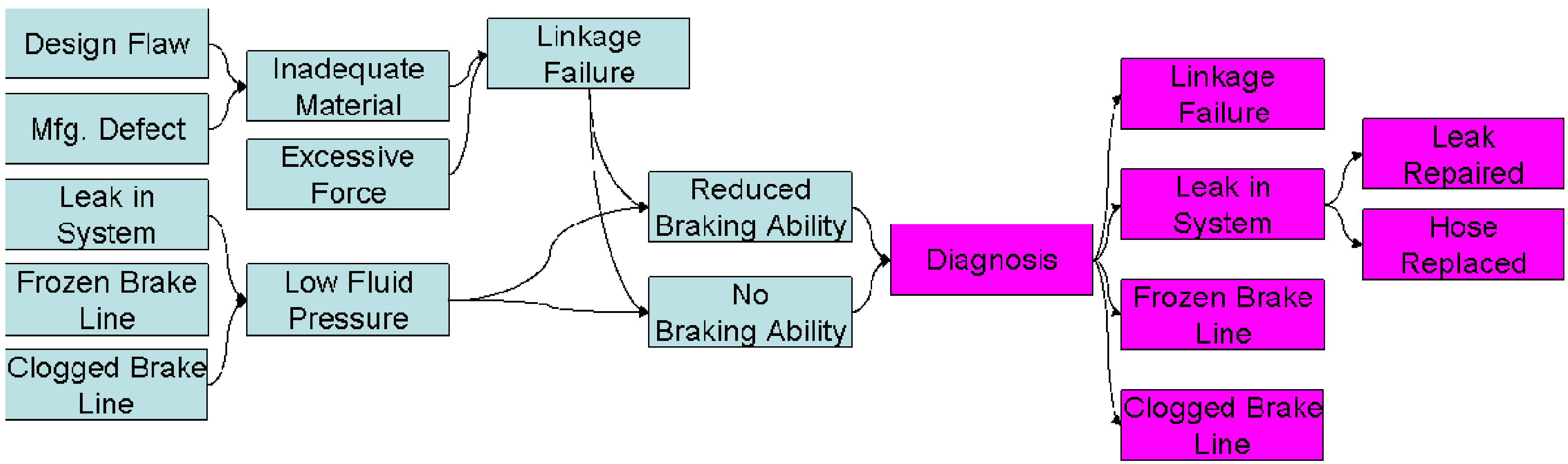
Warranty Prediction Framework



Warranty Scenario Identification

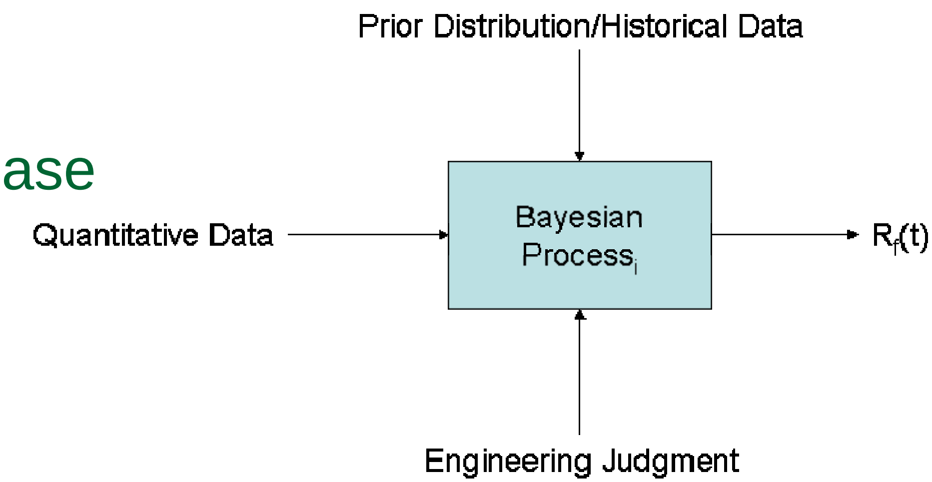


Warranty Scenario Example
(Adapted from Kmenta & Ishii, 2000)



Warranty Event Generation

- Probability assignment difficult
  - Dependent on market segments
    - Representative testing during development difficult
  - Scenario event rate is time dependent
  - Effective use of Historical data is difficult
- Inference Models
  - Expected Reliability at Release
  - Threshold by Market
- Data Mining
  - Tool for Finding Patterns
  - Characteristics
    - Large data sets, Contaminated data sets, Changing population structures and selection bias, Non numeric data



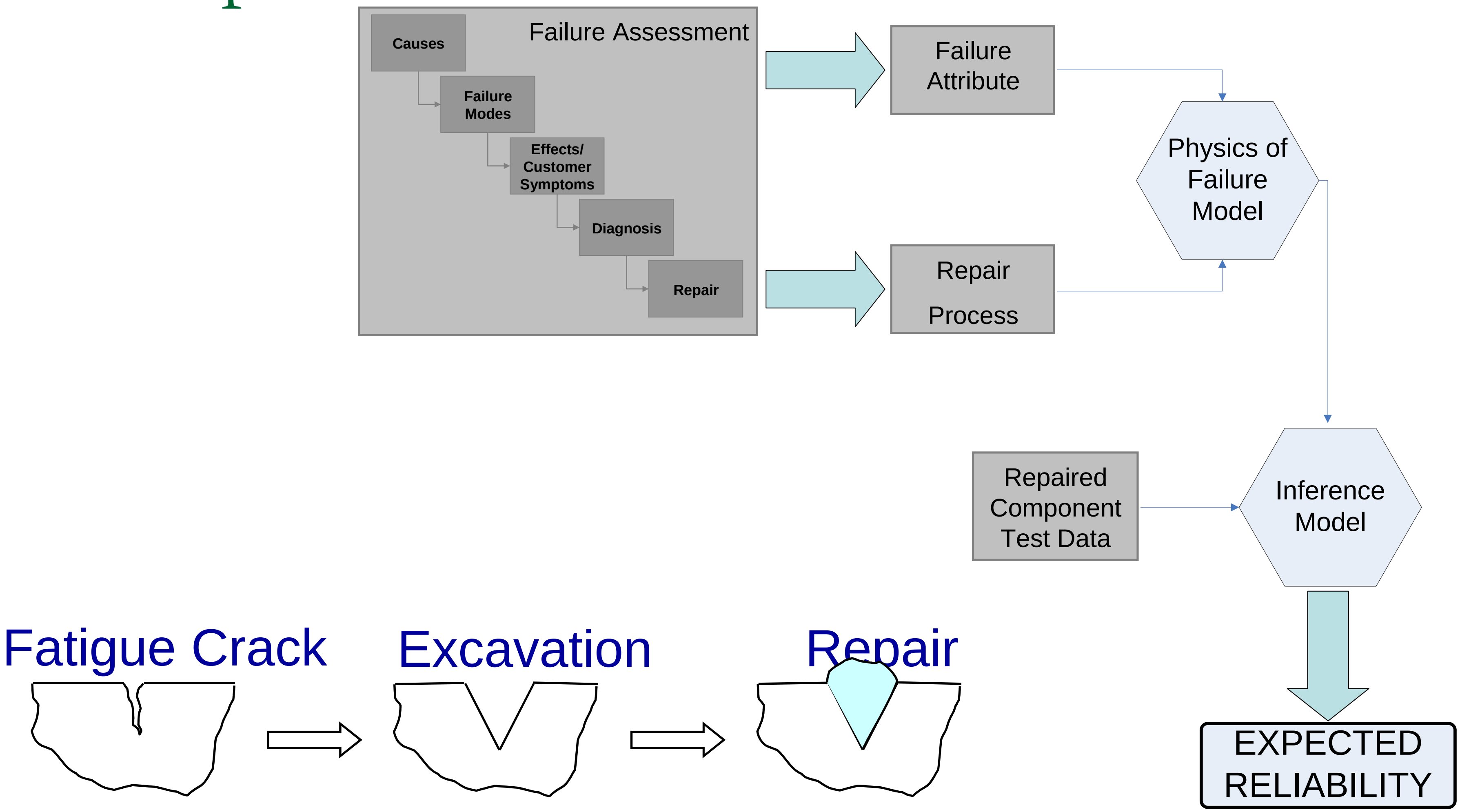
Adapted from Yadav, et. al. (2003)

Related Research

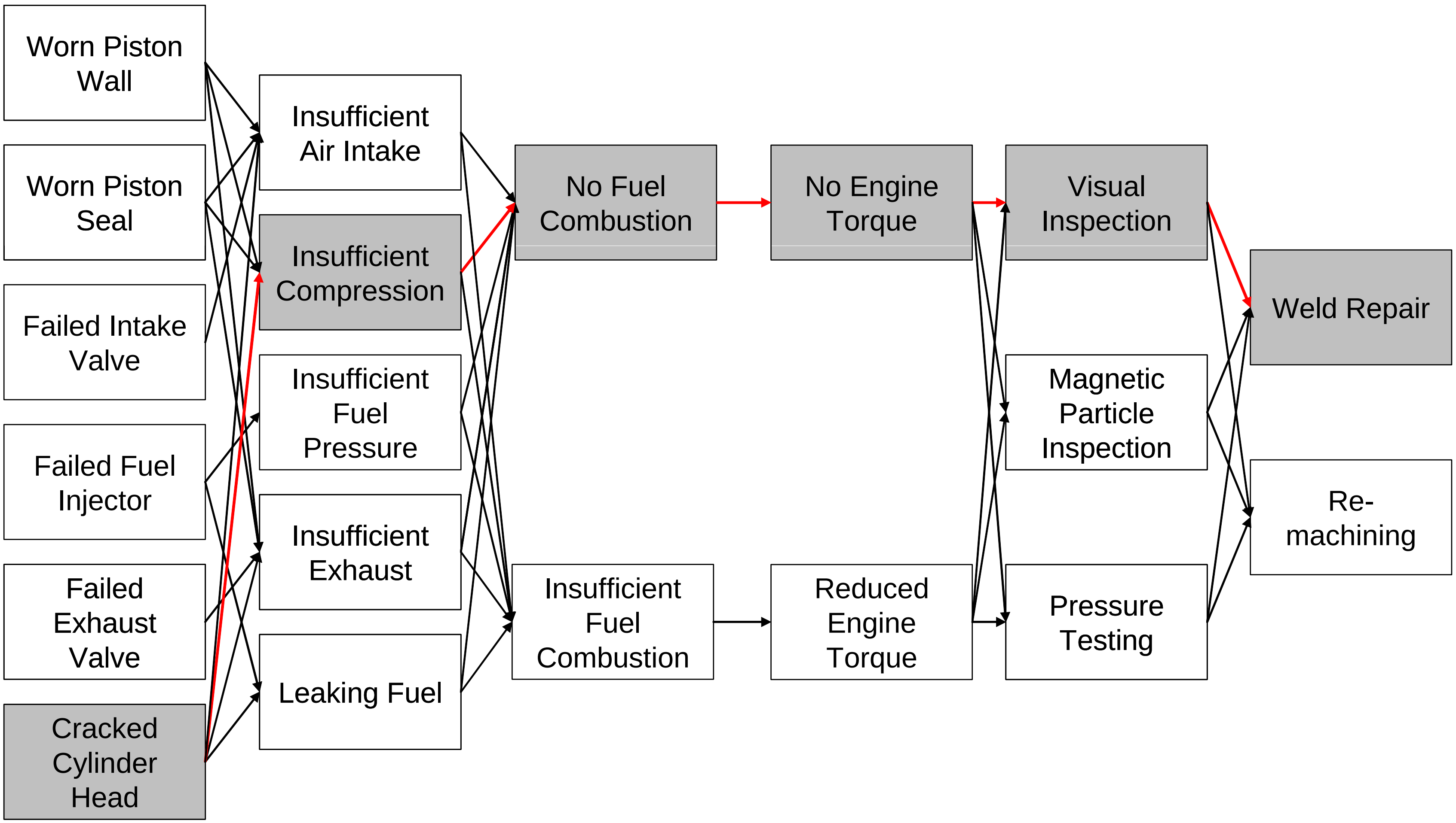
(Esterman, Gerst, DeBartolo, Haselkorn, "Reliability Prediction Of A Remanufactured Product: A Welding Repair Process Case Study", IMECE 2006.)

- Applying approach to remanufacturing
- Cracked engine cylinder heads
  - Remanufacturer recovers engine block
  - Removes material to provide weld rod access
  - Refill the groove with welding material
- What is the expected reliability of repaired part?

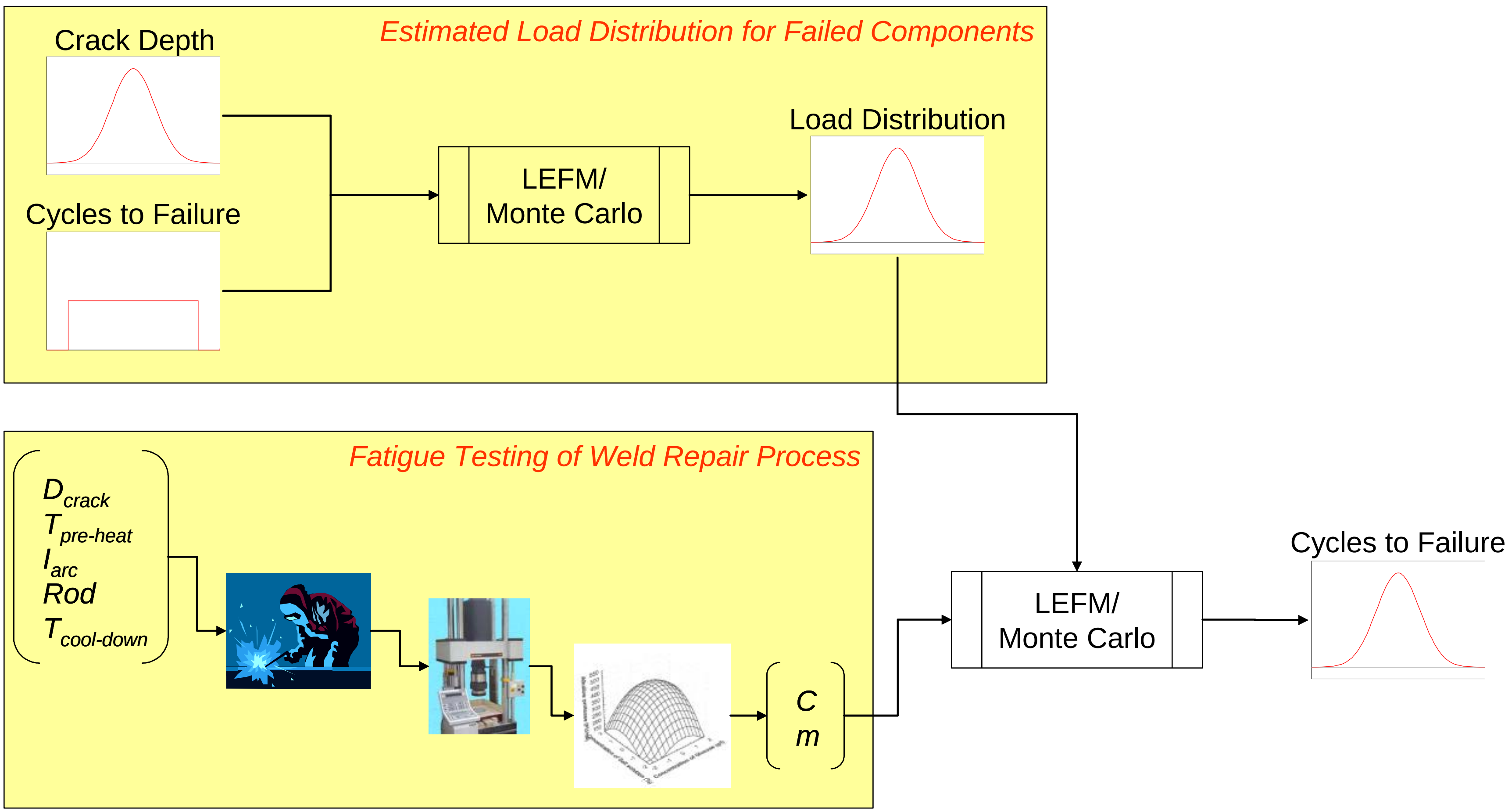
Expected Reliability of Repaired Component



Corrective Action Scenario Identification



Physical Modeling



Benefits of Approach

- Repair process control parameters ultimately related to reliability performance of the component
- Allows remanufacturer to answer questions relative to the reliability performance
  - How does the reliability compare to the OEM engine block?
  - How will the process variability affect the reliability performance?
  - If this process is repeated for other repair scenarios, which process provides the best reliability performance and how does that compare to the cost of each process?

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CURRENT RESEARCH

Current Research Goal

- To develop an event rate prediction model that can effectively integrate historical field experience, product development testing data, product development assessment tool data (e.g. FMEA), and engineering judgment.

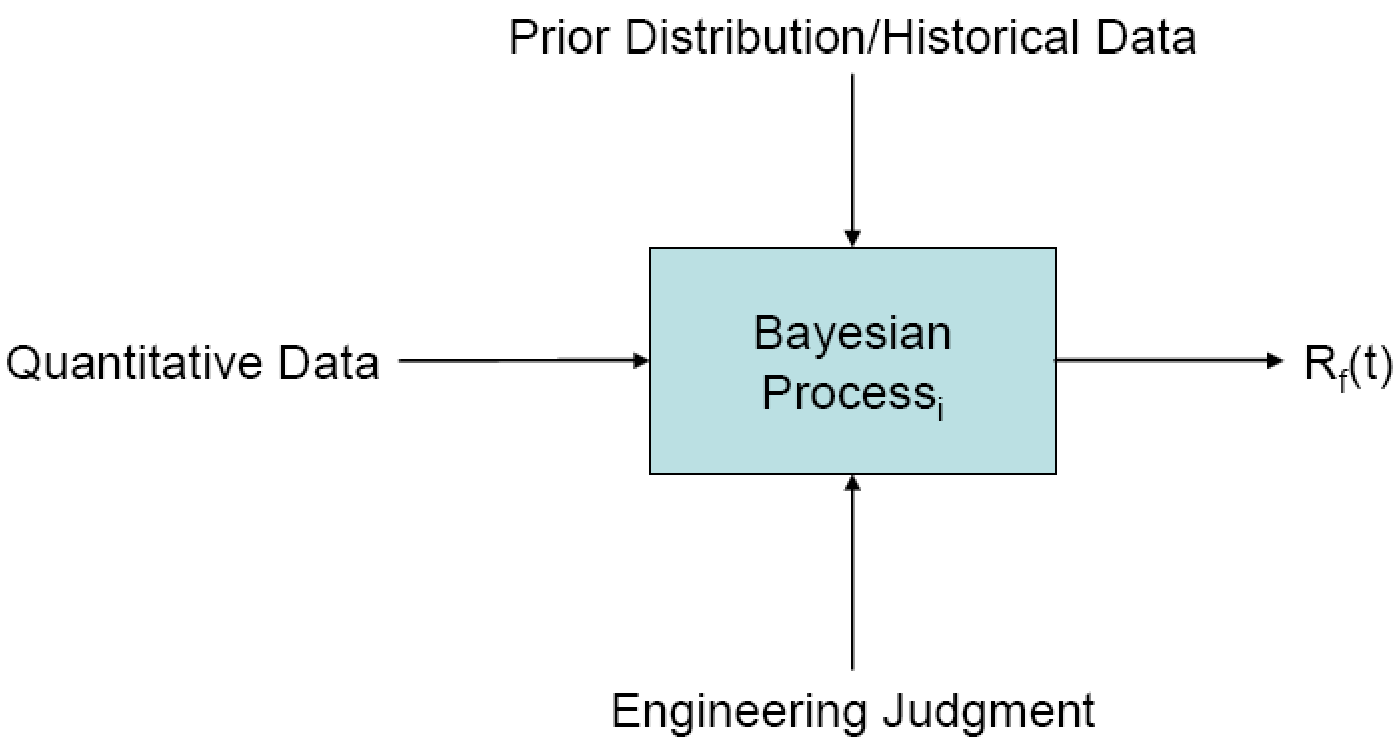
Approach

- Identification of Failure Events
- Reliability Modeling and Prediction
- Prototyping and Validation Testing

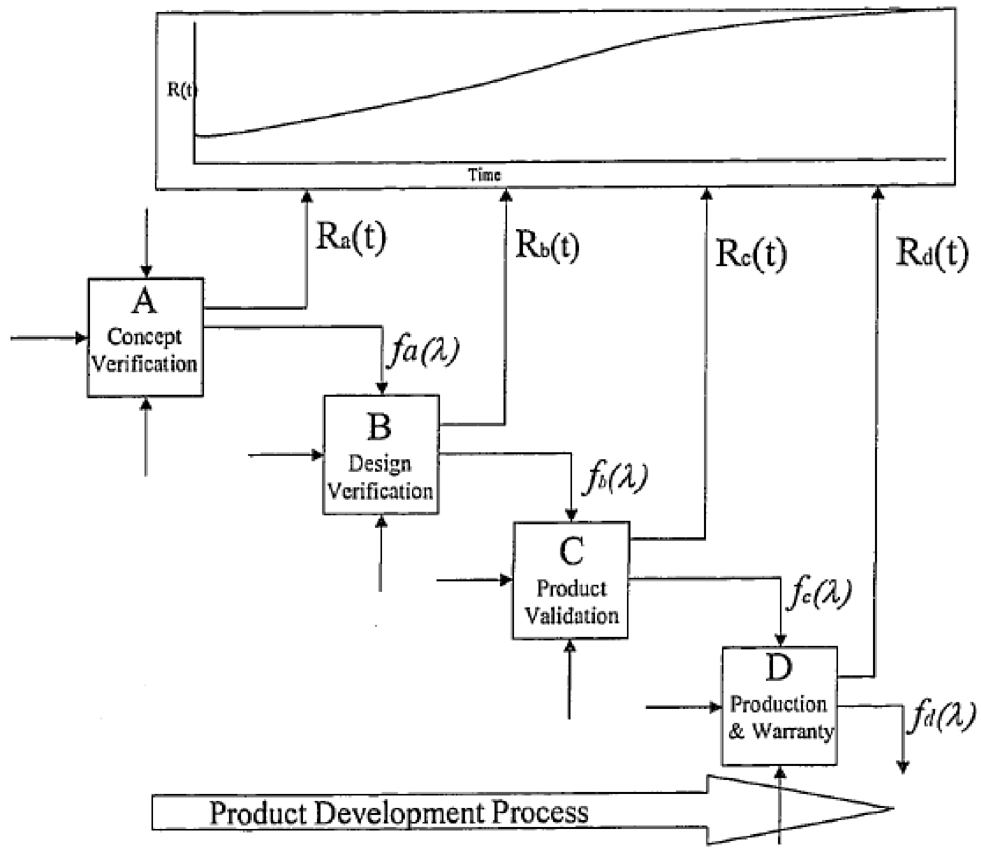
Data Sources

- Historical Field Data
- Product Development Test Data
- Failure Assessment Tool
- Engineering Judgement

Event Rate Prediction Model



Integrating information – Test Stage



(Yadav & Prakash, 2002)

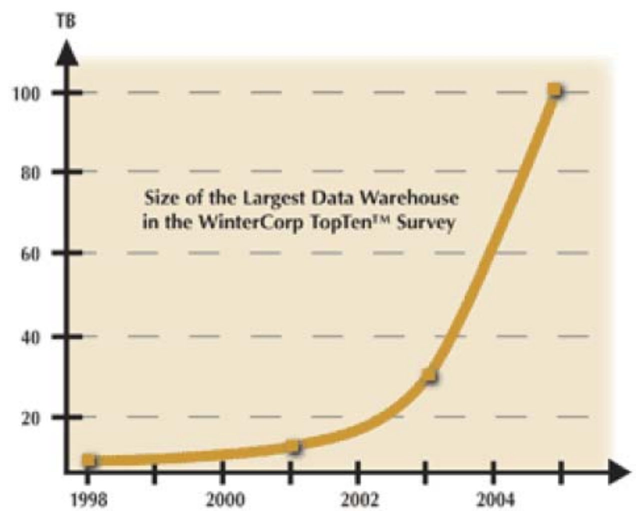
What tools can we use?

- Bayesian Probability
- Data Mining

- By characterizing and understanding the changes we make, we can develop better reliability models.

Data Mining

- What is Data Mining?
  - Knowledge Discovery – Finding and Understanding patterns in data.
- Why do we need data mining?



Data Mining (Continued)

- Major Data Mining Tasks
  - Classification
  - Clustering
  - Associations

Example Data Set

Features

Class

Outlook	Temp	Humidity	Windy	Play
Sunny	Hot	High	False	No
Sunny	Hot	High	True	No
Overcast	Hot	High	False	Yes
Rainy	Mild	High	False	Yes
Rainy	Cool	Normal	False	Yes
Rainy	Cool	Normal	True	No
Overcast	Cool	Normal	True	Yes
Sunny	Mild	High	False	No
Sunny	Cool	Normal	False	Yes
Rainy	Mild	Normal	False	Yes
Sunny	Mild	Normal	True	Yes
Overcast	Mild	High	True	Yes
Overcast	Hot	Normal	False	Yes
Rainy	Mild	High	True	No

Weather Data Probabilities

Outlook			Temperature			Humidity			Windy			Play	
	Yes	*No*		*Yes*	*No*		*Yes*	*No*		*Yes*	*No*	*Yes*	*No*
Sunny	2	3	Hot	2	2	High	3	4	False	6	2	9	5
Overcast	4	0	Mild	4	2	Normal	6	1	True	3	3		
Rainy	3	2	Cool	3	1								
Sunny	2/9	3/5	Hot	2/9	2/5	High	3/9	4/5	False	6/9	2/5	9/14	5/14
Overcast	4/9	0/5	Mild	4/9	2/5	Normal	6/9	1/5	True	3/9	3/5		
Rainy	3/9	2/5	Cool	3/9	1/5								

Likelihood for a new day

Outlook	Temp.	Humidity	Windy	Play
Sunny	Cool	High	True	?

Likelihood of the two classes

For "yes" = $2/9 \times 3/9 \times 3/9 \times 3/9 \times 9/14 = 0.0053$

For "no" = $3/5 \times 1/5 \times 4/5 \times 3/5 \times 5/14 = 0.0206$

Conversion into a probability by normalization:

P("yes") = 0.0053 / (0.0053 + 0.0206) = 0.205

P("no") = 0.0206 / (0.0053 + 0.0206) = 0.795

Bayes Rule

Probability of event *H* given evidence *E* :

$$\Pr[H \mid E] = \frac{\Pr[E \mid H]\Pr[H]}{\Pr[E]}$$

A priori probability of *H* : $\Pr[H]$

- Probability of event *before* evidence is seen

A posteriori probability of *H* : $\Pr[H \mid E]$

- Probability of event *after* evidence is seen

Bayes Rule – Example Data

Outlook	Temp.	Humidity	Windy	Play
Sunny	Cool	High	True	?

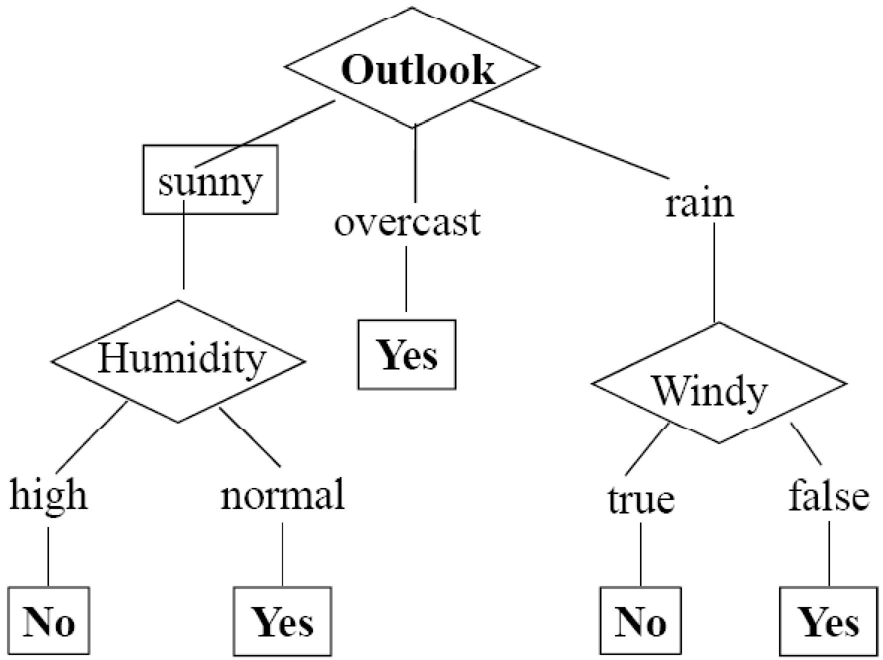
← ***Evidence E***

$$\Pr[yes \mid E] = \Pr[Outlook = Sunny \mid yes] \times \Pr[Temperature = Cool \mid yes] \times \Pr[Humidity = High \mid yes] \times \Pr[Windy = True \mid yes] \times \frac{\Pr[yes]}{\Pr[E]}$$

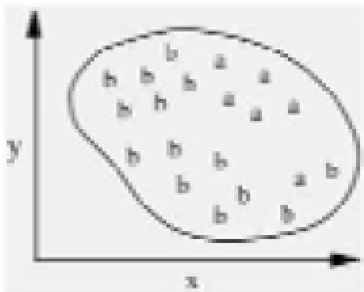
Probability of class "yes"

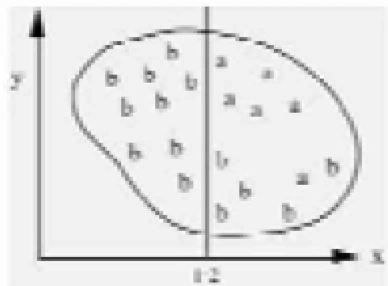
$$= \frac{\frac{2}{9} \times \frac{3}{9} \times \frac{3}{9} \times \frac{3}{9} \times \frac{9}{14}}{\Pr[E]}$$

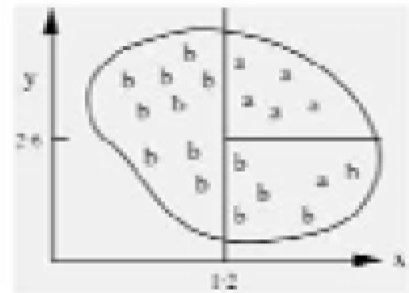
Decision Trees



Covering Algorithms








```
If true
then class = a
```

```
If x > 1.2
then class = a
```

```
If x > 1.2 and y > 2.6
then class = a
```

- Possible rule set for class “b”:

```
If x ≤ 1.2 then class = b
If x > 1.2 and y ≤ 2.6 then class = b
```

What are some of the issues?

- Noisy data
- Unreliable data
- Not an exact math (more heuristic)

Why use Bayesian methods?

- Bayesian methods provide a formal means of including subjective information as part of the analysis methods.

Immediate Research Agenda

- Integrate Bayesian methods and data mining techniques to develop the event generation engine
- Demonstrating the feasibility of the approach
- Develop relationship with industrial partner to use actual data to uncover additional issues

Scope and Research Methodology

- Problem Identification
  - Identify factors & attributes that affect warranty events
  - Understand the warranty events for toner related failures
- If industry data is not available
  - Develop Data – FMEA, BN-FMEA, Fault Tree Analysis, Reliability Block Diagrams, etc.
- If industry data is available
  - Apply data mining algorithms to Historical Data
- Develop data conditioning requirements
- Summarize findings and Opportunities

Conclusion – Key Points Review

- Bayesian methods update with new data
- Integrating multiple data sources will allow us to better estimate warranty costs during product design
- Understanding our customer expectations will help us remain competitive.

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THE ROAD AHEAD

Long-Term Future Work

- Develop Mathematical Framework for Inference Model
- Representation of consumer and environmental effects
- Partner with Industry
  - Validation of Approach
  - Cost Model Development
- Extensions to Include Cost of Quality