

# Software Reliability and Safety

## CSE 8317 — Fall 2008

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### **SRE.2: TBRMs & Integrated SRE**

- Experience with existing approaches
- TBRMs: Tree-based reliability Models
- Integrated SRE using TBRMs & others

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## Overview

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- Reliability: Prob(failure-free operations)
  - ▷ *time domain*: for a specific period.
    - ⇒ reliability growth models.
  - ▷ *input domain*: for a specific input set.
    - ⇒ repeated sampling models.
  
- A new integrated approach: TBRMs
  - ▷ tree-based reliability models (TBRMs)
  - ▷ both input/time domain information.
  - ▷ data driven/sensitive partitions.
  - ▷ method: tree-based modeling (TBM).
  - ▷ risk focusing and remedial actions.
  - ▷ details: AIC paper (Tian 1998)

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## Product Environment

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- Large (medium-reliable) products:
  - ▷ Commercial: RDBMS, compilers, software tools and computing environments.
  - ▷ Telecommunication products too.
  - ▷ Size: Up to millions of LOC.
  - ▷ Widely distributed/large user population.
  - ▷ No precise operational profile.
  - ▷ Process: roughly waterfall.
  
- Overall testing:
  - ▷ Long testing period (2 ~ 18 months).
  - ▷ Different testing sub-phases.
  - ▷ System testing focuses on reliability.
  - ▷ Test-until-it-breaks commonly used.
  - ▷ Staffing level variations.
  - ▷ Code base stability.

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## Testing Environment

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- Scenario-based testing.
  - ▷ Shifting focus: learning/dependency.
  - ▷ Functionality-based scenario classes:
    - randomized workload
    - progression: complexity & intensity ↑
    - defect fixing and related runs
    - division among testers.
  
- Specific reliability analysis issues:
  - ▷ Scenario-based ~ random testing
    - due to parallelism and interleaving
  - ▷ Defect fixing effect:
    - no long-term dependency
    - short-term dependency ⇒ grouping (later)
  - ▷ Uneven faults ⇒ TBRMs

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## Needs and Constraints

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- Need assessment and analysis:
  - ▷ Track test effort, progress and defect.
  - ▷ Reliability assessment and prediction.
  - ▷ Effective defect detection and removal.
  - ▷ Process and quality improvement.
  
- Environmental constraints:
  - ▷ Minimize cost & schedule risks.
  - ▷ Data availability and affordability.
  - ▷ Process refinement.
  - ▷ Maximize data utilization.
  
- Recommendation:  
new, evolutionary approach, with support.

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## Overall Solution

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- Combine SRGMs and IDRM into TBRMs.
  
- Analysis and control:
  - ▷ SRGMs (s/w rel. growth models).
  - ▷ TBRMs: tree-based reliability models.
  - ▷ Progress monitoring & exit criteria.
  
- Problem identification and correction:
  - ▷ Use of input domain information
    - IDRM (input domain rel. models)
    - identify high risk areas
  - ▷ Automatic partitioning via TBRMs.
  - ▷ Remedial actions for improvement.

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## Applications: Overview

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- Product coverage:
  - ▷ Commercial products from IBM.
  - ▷ Improvement over original process.
  - ▷ Evolutionary approach:
    1. individual techniques.
    2. integration and refinement.
  - ▷ Recent work with Nortel Networks.
  
- Scope of Engagement:
  - ▷ Data definition and collection.
  - ▷ Data visualization and analysis.
  - ▷ Test progress tracking.
  - ▷ Reliability tracking with SRGMs.
  - ▷ Reliability improvement with TBRMs.

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## Applications: Testing & Data

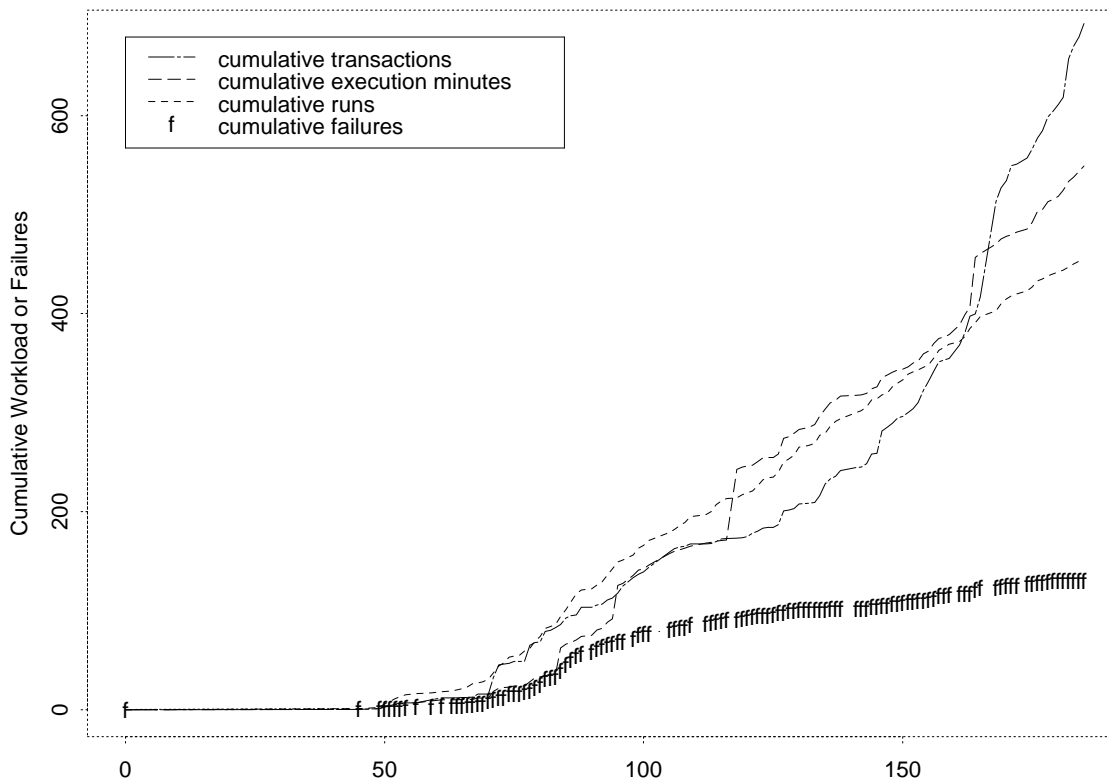
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- Data and tracking:
  - ▷ Integration with schedule information.
  - ▷ Normalization effect.
  - ▷ Summary reports and visualization.
  - ▷ Consistency checking automation.
  
- Customer usage information gathering
  - Operational profile construction.
  
- Coverage and input-domain analysis:
  - ▷ Functionality/function/static/dynamic.
  - ▷ Different levels of coverage for different testing phases.
  - ▷ Focused coverage through TBRM.



## SRGMs: Application Experience

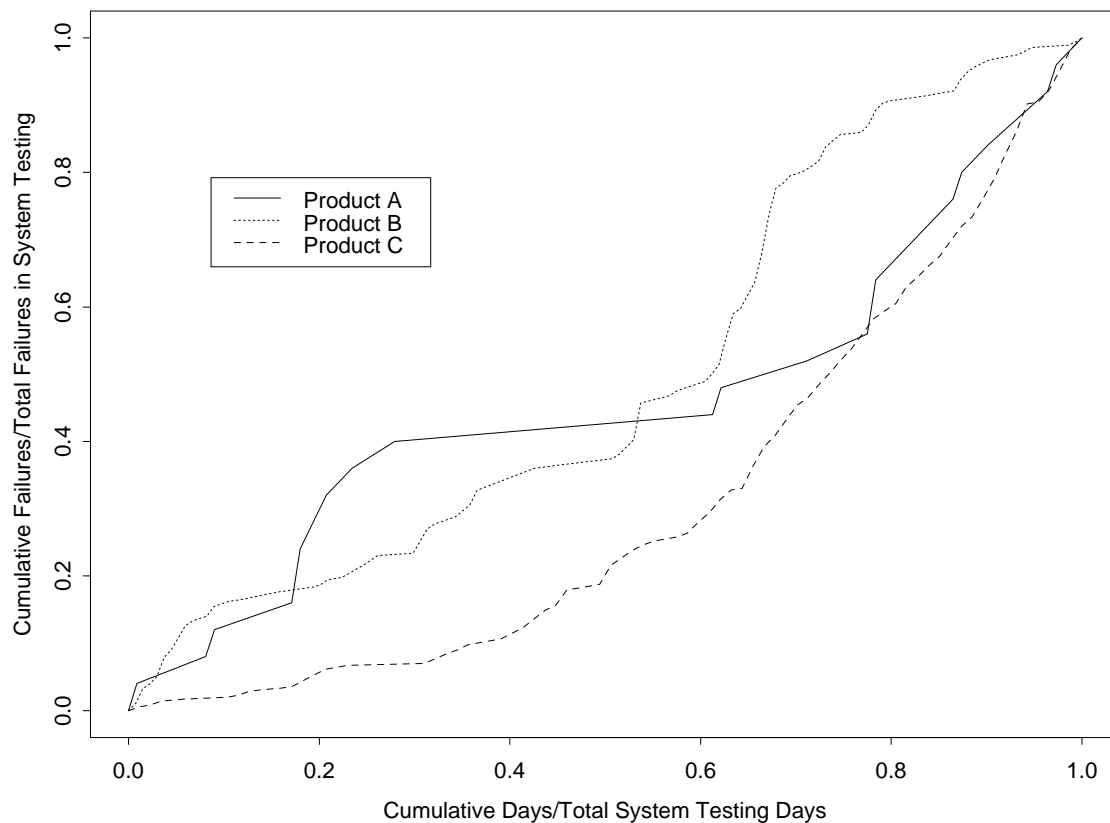
- Time measurements: Fig.2 (Tian 1998)
  - ▷ calendar time.
  - ▷ execution time: Musa models.
  - ▷ logical time: runs, transactions, etc.



184 days, 453 runs, 1293047422 transactions, 835530 execution minutes, 130 failures.

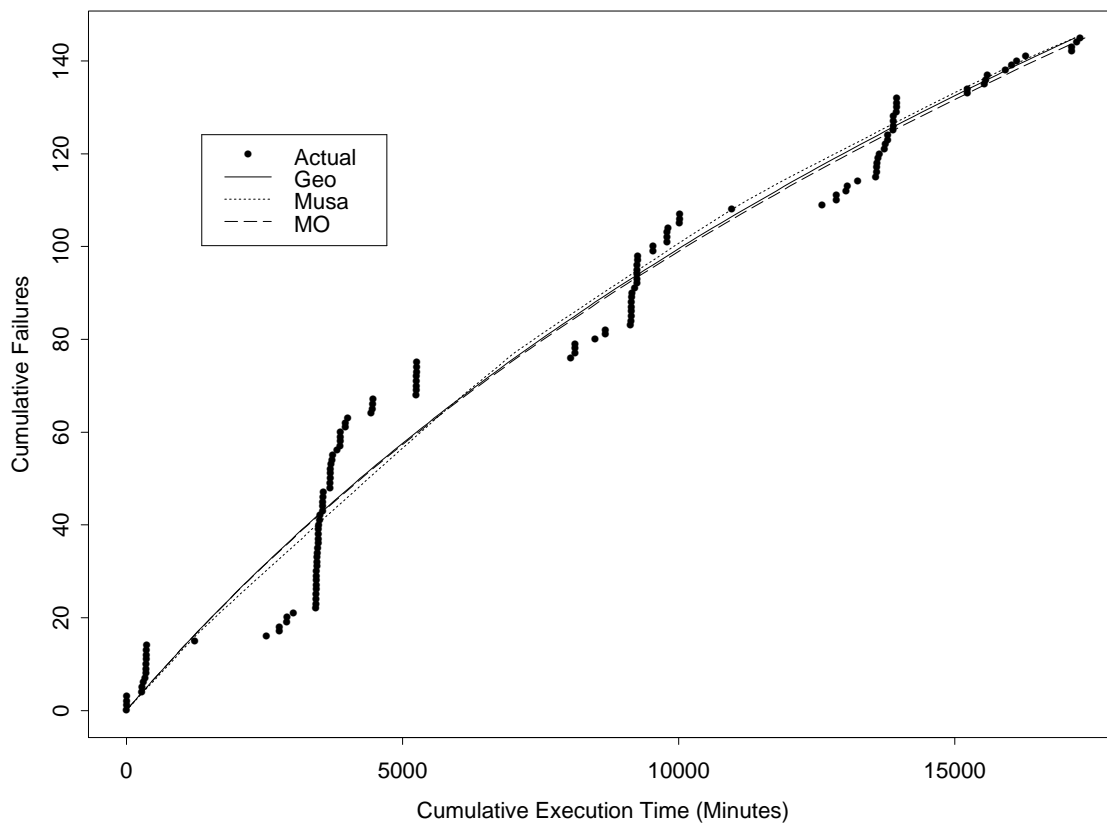
## SRGMs: Application Experience

- Model applicability and effectiveness:
  - ▷ calendar time models useless.
  - ▷ products A, B, and C: Fig.3 (Tian 1998)



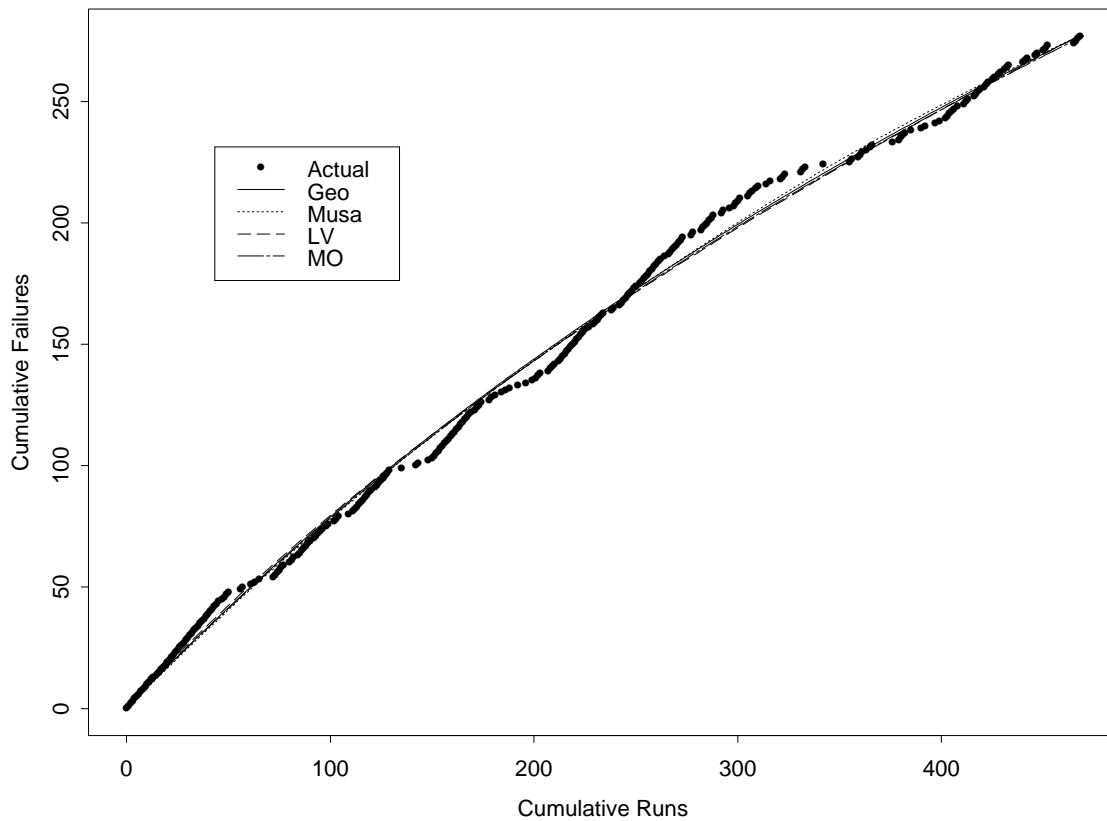
## SRGMs: Application Experience

- Model applicability and effectiveness:
  - ▷ exec. time models costly & sensitive.
  - ▷ product B Fig.6b (Tian 1998)



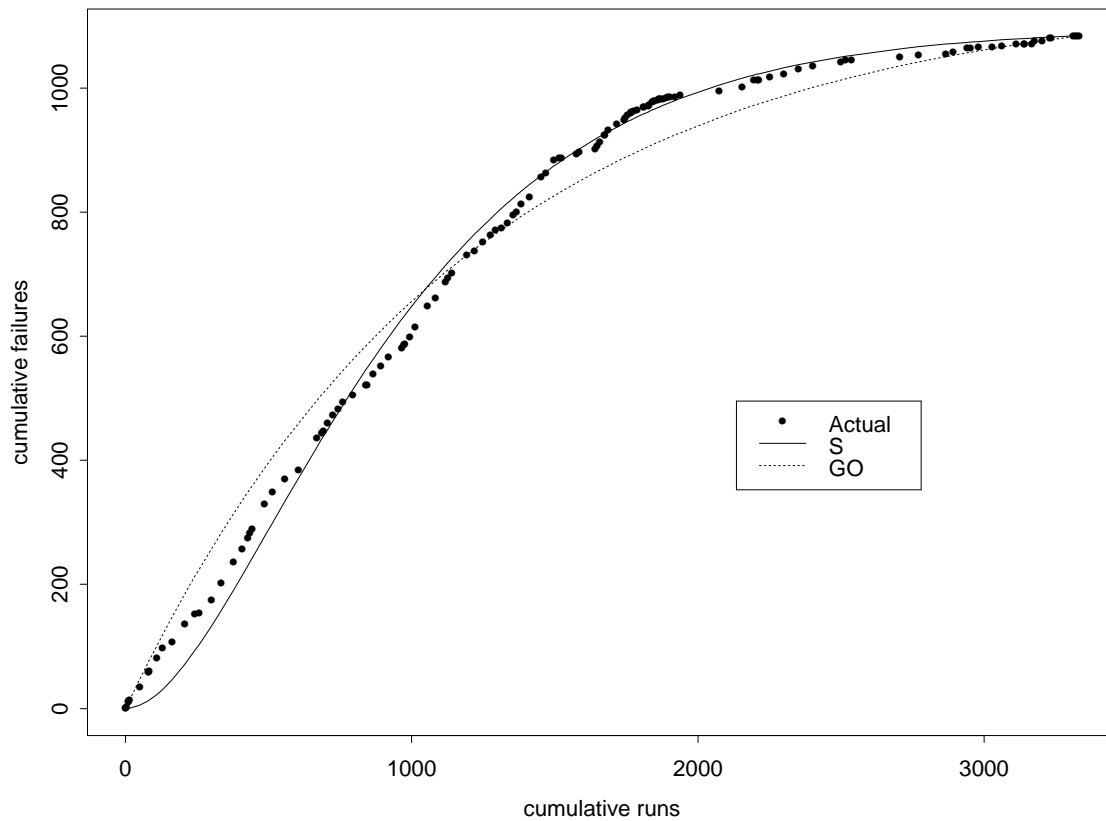
## SRGMs: Application Experience

- Model applicability and effectiveness:
  - ▷ runs suitable for some products.
  - ▷ product B: Fig.6a (Tian 1998)



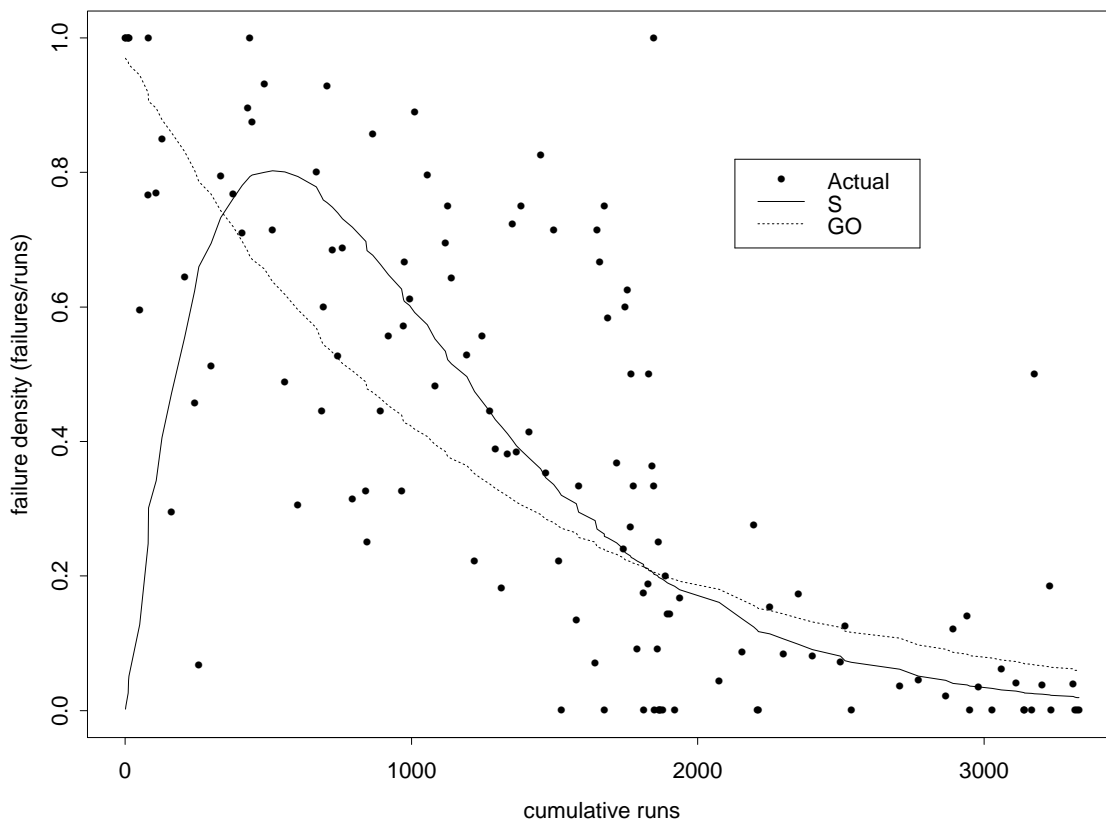
## SRGMs: Application Experience

- Model applicability and effectiveness:
  - ▷ runs suitable for some products.
  - ▷ product D: Fig.8a (Tian 1998)



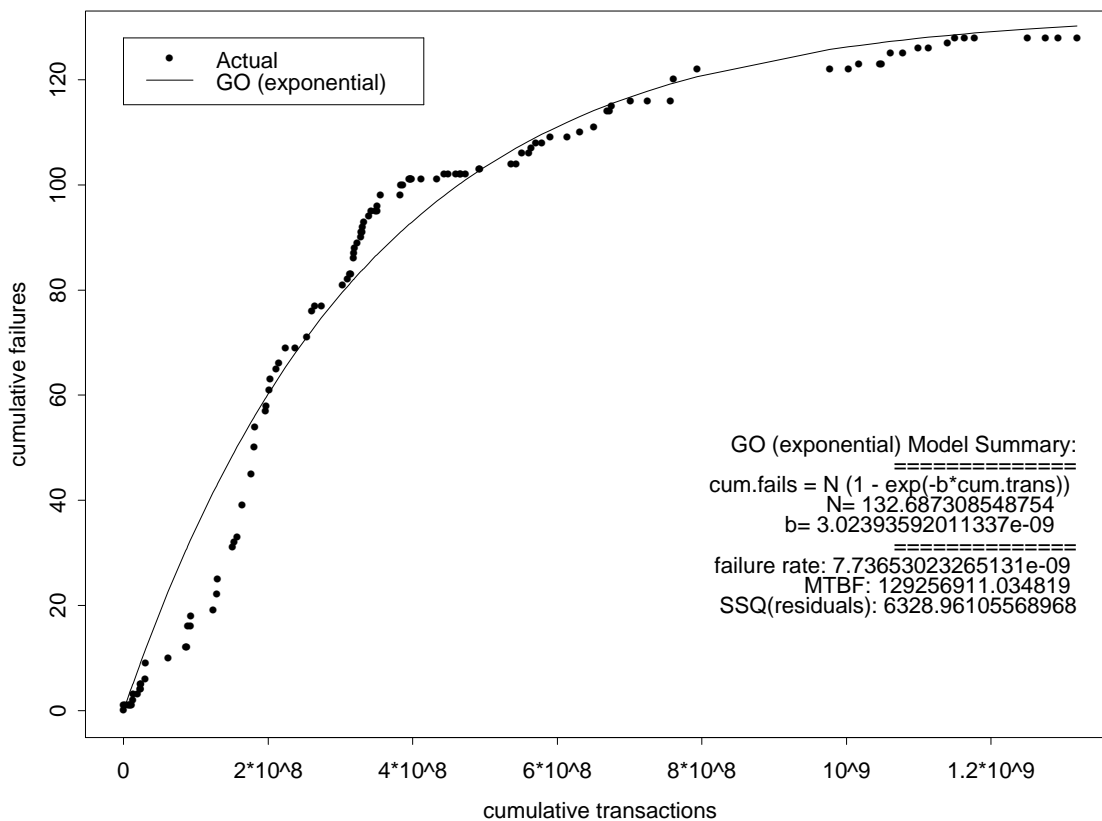
## SRGMs: Application Experience

- Model applicability and effectiveness:
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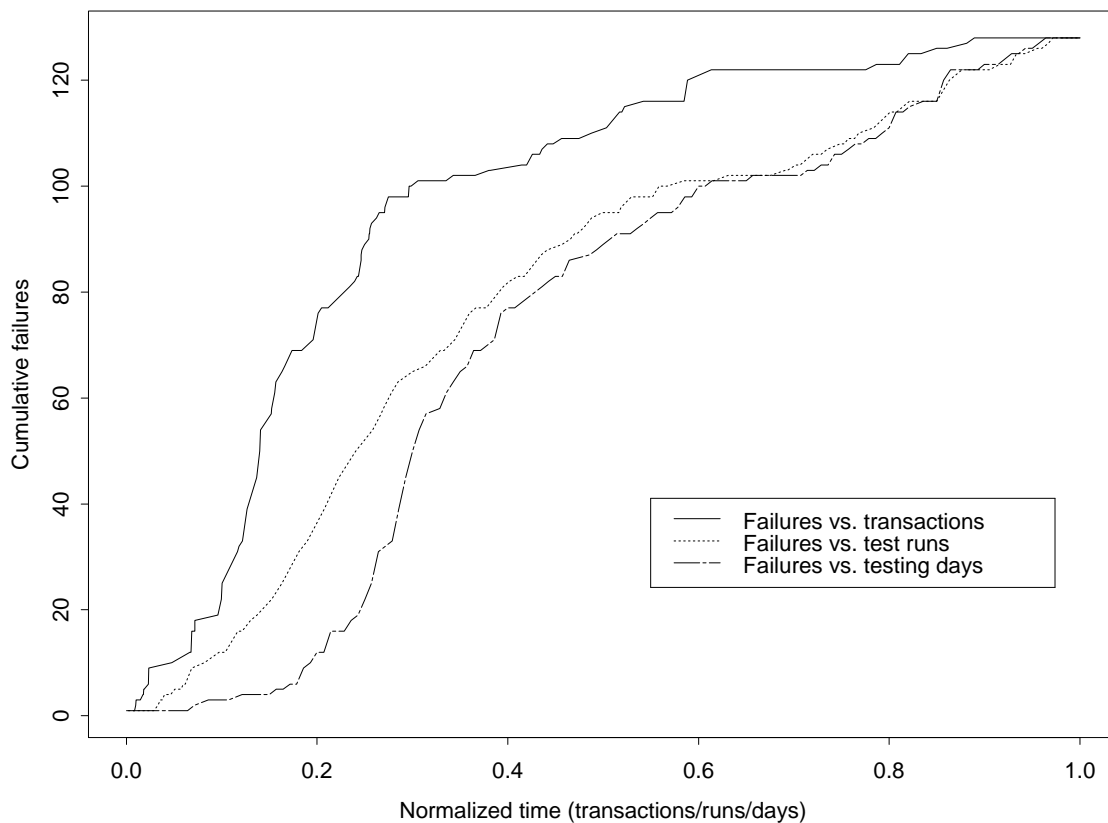
## SRGMs: Application Experience

- Model applicability and effectiveness:
  - ▷ transactions for other products.
  - ▷ product E: Fig.9 (Tian 1998)



## SRGMs: Application Experience

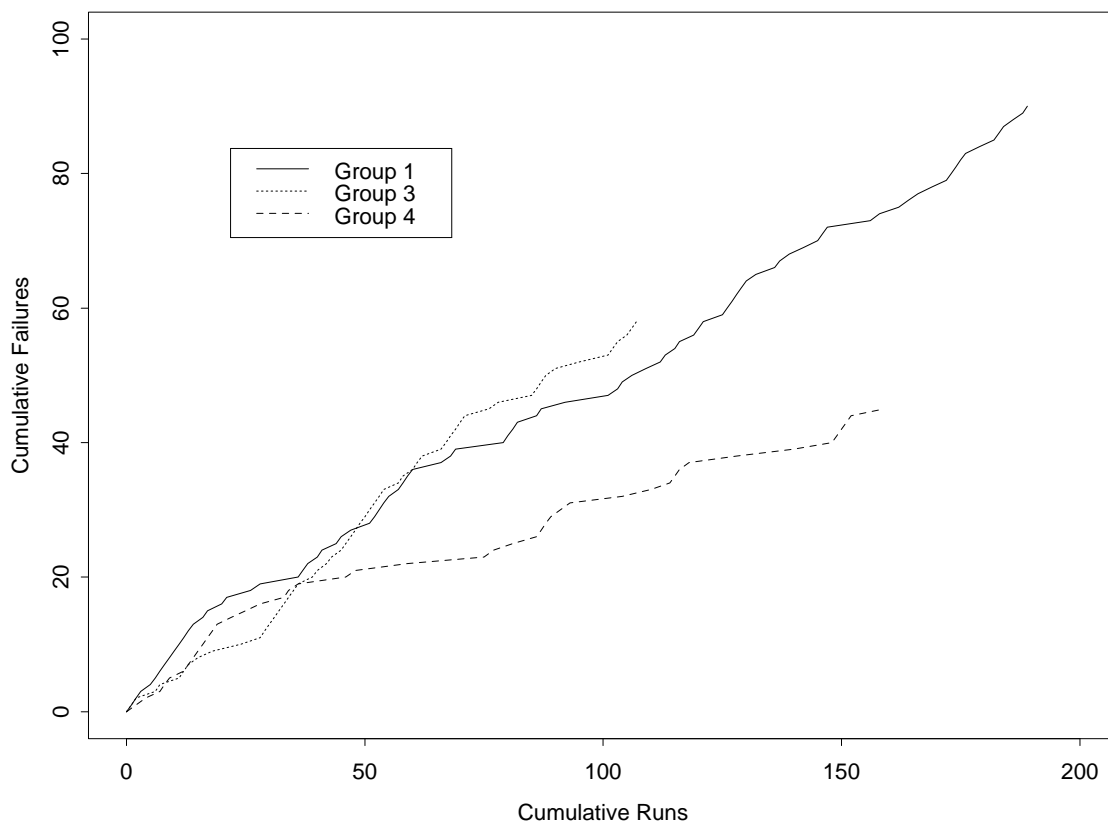
- Model applicability and effectiveness:
  - ▷ time measurement comparison
  - ▷ product E: Fig.5 (Tian 1998)





## SRGMs: Application Experience

- Model applicability and effectiveness:
  - ▷ context sensitive modeling for sub-groups or sub-phases  $\Rightarrow$  TBRMs.
  - ▷ product B: Fig.7 (Tian 1998)



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## SRGM Conclusions

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- Modeling result interpretation:
  - ▷ Accuracy of models:
    - assessment, model goodness-of-fit.
    - prediction: training & testing sets
  - ▷ Product purity at exit.
  - ▷ Bounded estimations: multiple models.
  - ▷ Convergence of modeling results.
  
- Evolving to usage-based data/model:
  - ▷ Assurance of homogeneity:
    - if 'yes', run-based data/model;
    - if 'no', transaction measurement.
  - ▷ Suitable for input domain analysis.
  - ▷ Also as cross validation for TBRMs.

## Assessing Existing Approaches

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- Time domain reliability analysis:
  - ▷ Customer perspective.
  - ▷ Overall assessment and prediction.
  - ▷ Ability to track reliability change.
  - ▷ Problem: how to improve reliability?
  
- Input domain reliability analysis:
  - ▷ Explicit operational profile.
  - ▷ Better input state definition.
  - ▷ Hard to handle change/evolution.
  - ▷ Problem: realistic reliability assessment and handling numerous data sets/partitions?

## An Integrated Approach

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- Combine strengths of the two.
  
- Using TBRM for individual modeling:
  - ▷ Input state: categorical information.
  - ▷ Each run as a data point.
  - ▷ Time cutoff for partitions too.
  - ▷ Data sensitive partitioning
    - ⇒ Nelson models for subsets.
  
- Integrated reliability analyses:
  - ▷ TBRM: partitioned subset reliability.
  - ▷ Use both input and timing information.
  - ▷ Monitoring changes in trees.
  - ▷ Enhanced exit criteria.
  - ▷ SRGM: overall reliability near exit.
  - ▷ Integrate into the testing process.

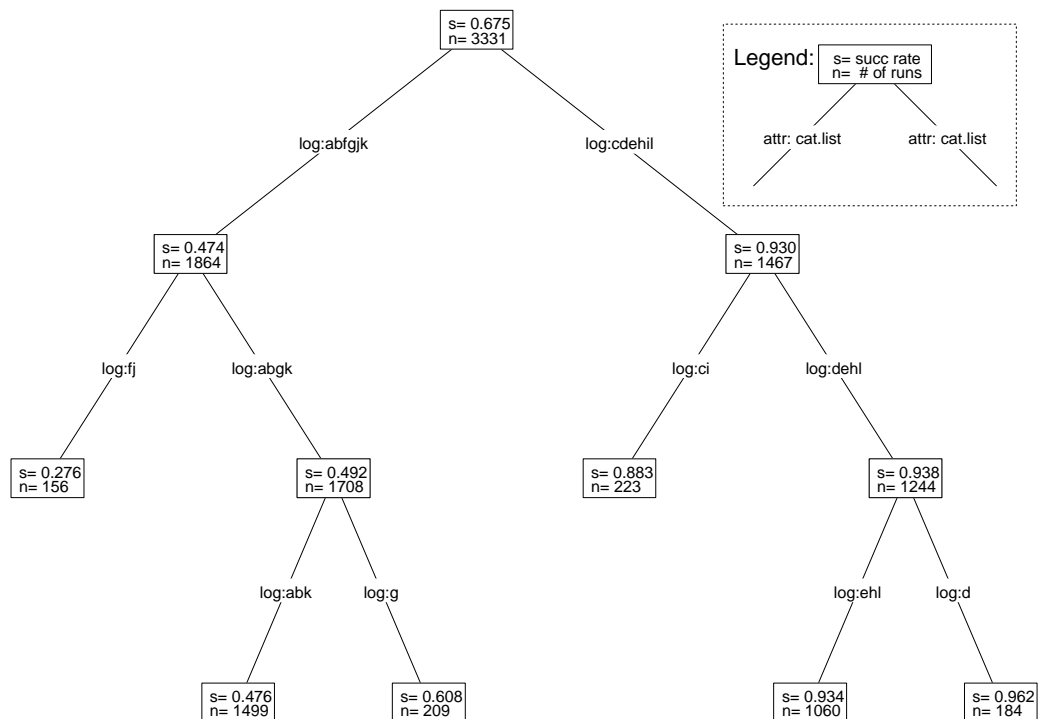
## TBM: Technique for Integration

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- Basic ideas:
  - ▷ TBM: tree-based models.
  - ▷ Tree: nodes=data-set, edges=decision.
  - ▷ Data: 1 response variable  $Y$   
and  $n$  predictor variables  $X_1, \dots, X_n$ .
  - ▷ Construction: recursive partitioning.  
(controlled growth vs growing&pruning)
  
- Usage and applications:
  - ▷ Basic usage:  $Y = Tree(X_1, \dots, X_n)$
  - ▷ Applicability: mixed-types of data.
  - ▷ Past applications: social sciences
  - ▷ In SE: risk identification by Selby & Porter,  
Tian & Troster, etc.
  
- Details: Tian/SQE book Ch.21.

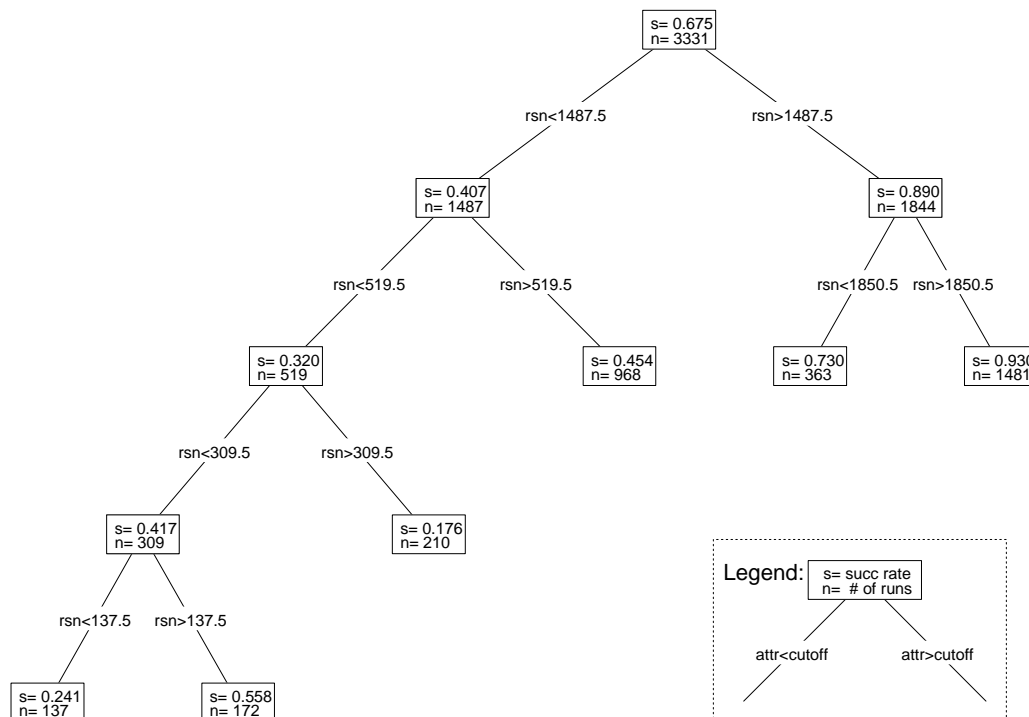
## TBRM Simple Example

- 1 categorical predictor and 1 response:
  - ▷ Binary grouping for partitioning
  - ▷ Example: Fig 10 (Tian 1998)



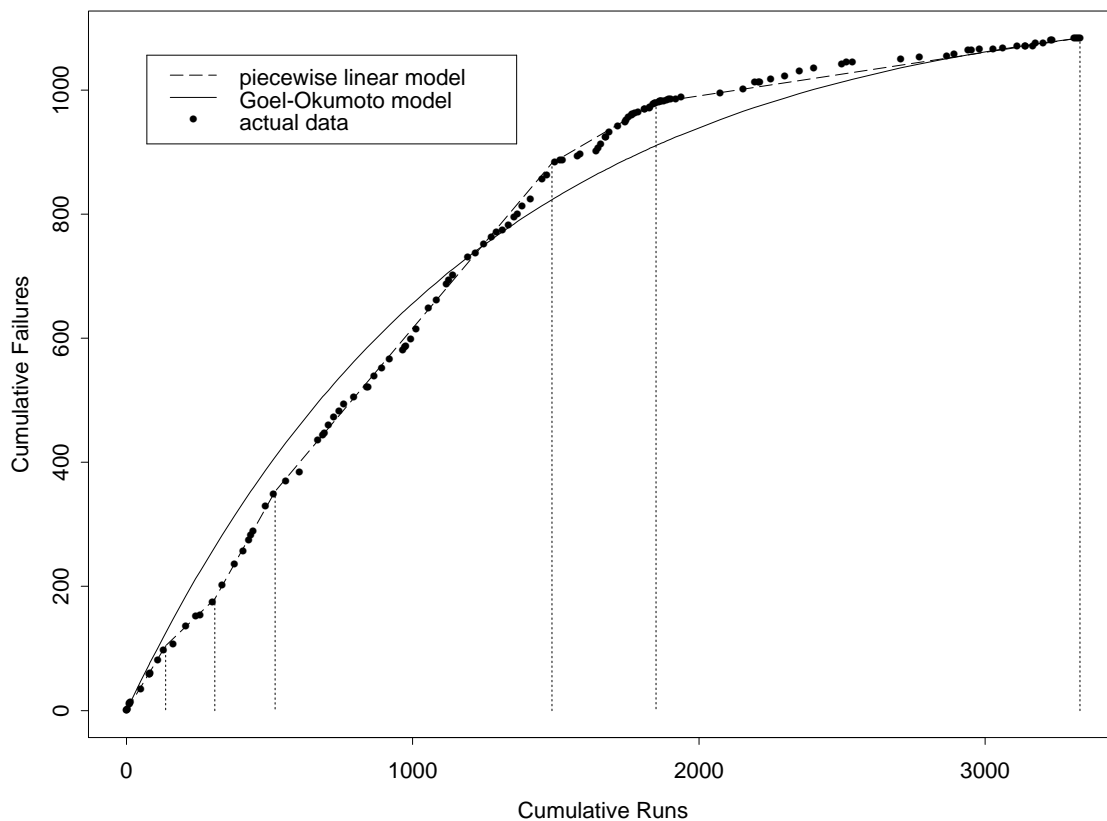
## TBRM Simple Example

- 1 numerical predictor and 1 response:
  - ▷ Binary operator ( $\geq$ ) for partitioning
  - ▷ Example: Fig 15 (Tian 1998)



## TBRM Simple Example

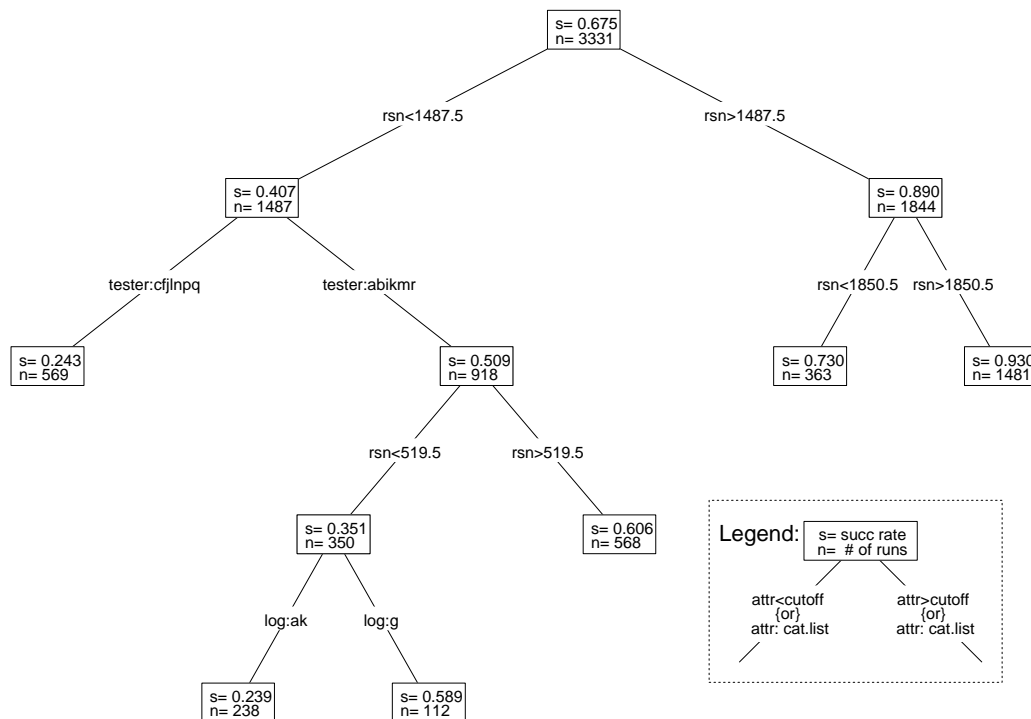
- 1 categorical predictor and 1 response:
  - ▷ Interpretation as piecewise linear model
  - ▷ Example continued: Fig 14 (Tian 1998)





# TBRM Example

- n mixed predictors and 1 response:
  - ▷ full TBRM
  - ▷ Example: Fig 11 (Tian 1998)



## TBRM in Integrated Analysis

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- Tree-based reliability models (TBRMs) using all information:
  - ▷ Input domain partitioning information.
  - ▷ Testing results.
  - ▷ Timing information.
  - ▷ Each run as a data point.
  
- Model construction:
  - ▷ Response: Result indicator.
    - 1 for success, 0 for failure.
    - ⇒ Nelson model for subsets.
    - Mapping to failure rate or MTBF.
  - ▷ Predictor: Timing and input states.
    - Data sensitive partitioning.
    - Key factors affecting reliability.
    - Homogeneity of product reliability.

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## Using Integrated Analysis

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- Interpretation of trees:
  - ▷ Predicted response: success rate.  
(Nelson reliability estimate.)
  - ▷ Time predictor: reliability change.
  - ▷ State predictor: risk identification.
  
- Monitoring reliability change:
  - ▷ Change in predicted response.
  - ▷ Through tree structural change.
  
- Risk identification and remedies:
  - ▷ Identify high risk input state.
  - ▷ Additional analysis.
  - ▷ Enhanced test cases.
  - ▷ Remedies for components.

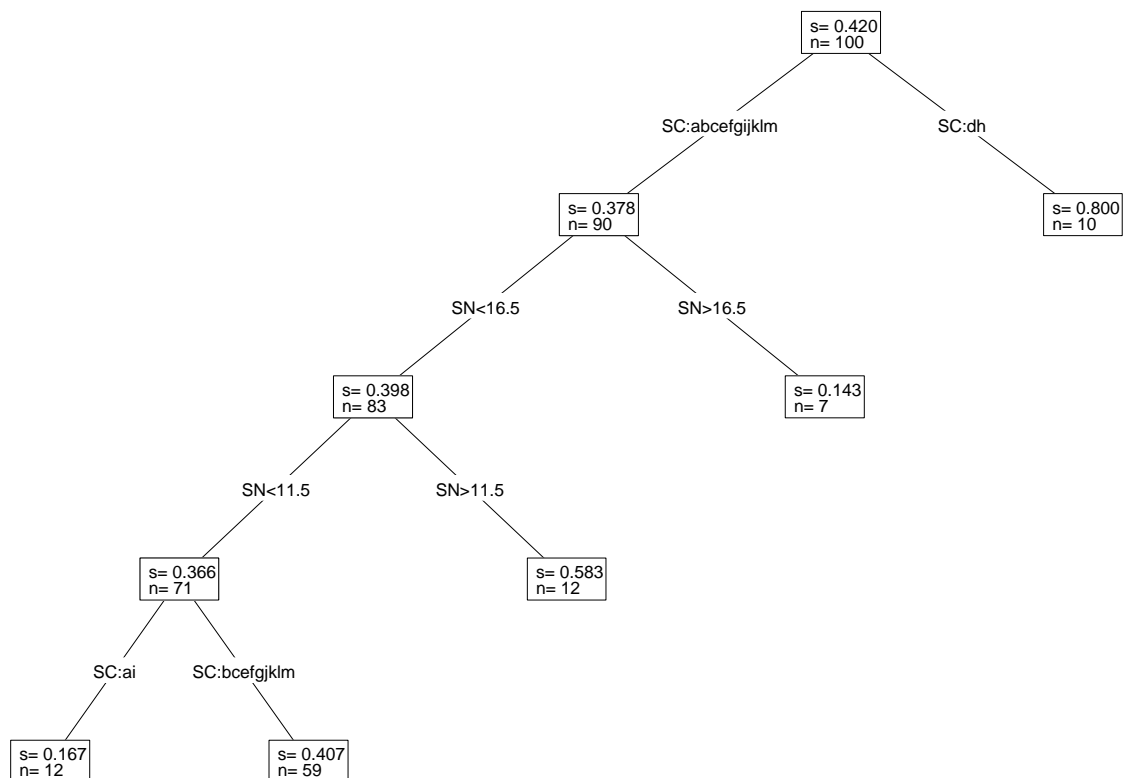
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## TBRMs in Integrated Analysis

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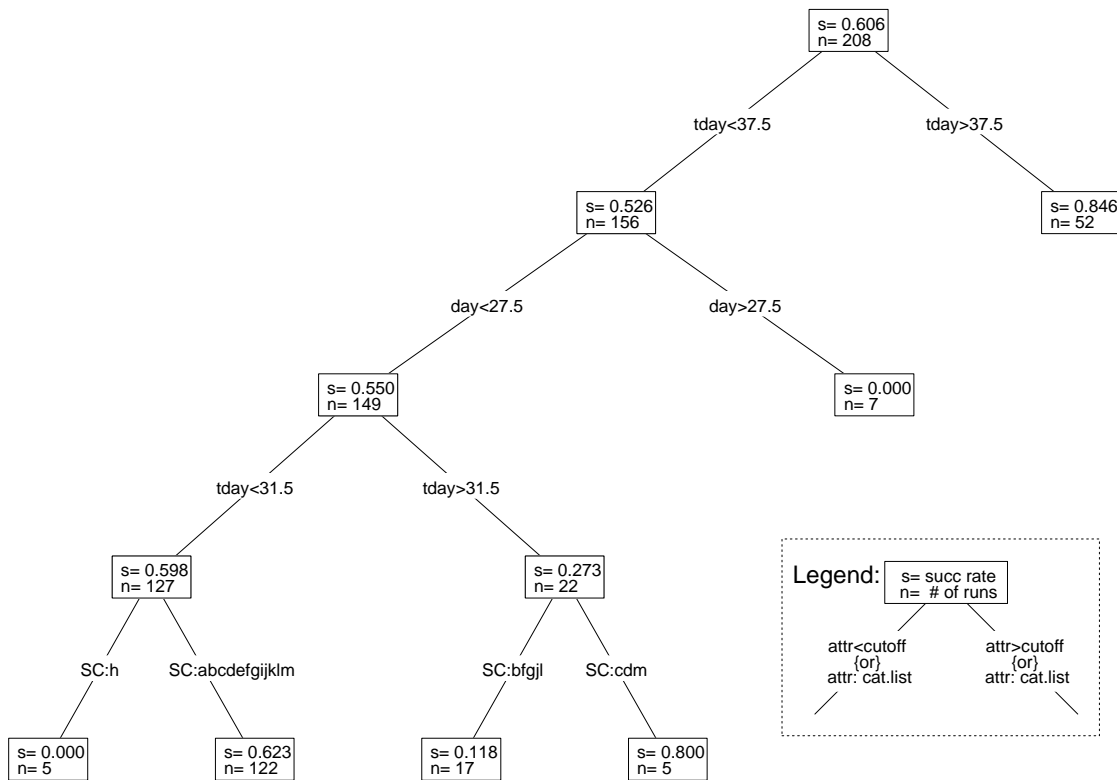
- Treatment of product bundles:
  - ▷ TBRM for individual products.
  - ▷ Dynamic change w.r.t. process needs.
  - ▷ SRGM (& TBRM) for bundle near exit.
  
- Risk identification:
  - ▷ High risk input sub-domains.
  - ▷ Additional analysis for the identified.
  - ▷ Guide for remedial actions.
  
- Results interpretation:
  - ▷ Progression of trees & tree types.
  - ▷ Usage as exit criteria.

## TBRMs at Different Times



- Fig 12a (Tian 1998): an early TBRM.
  - ▷ high-risk areas identified by input
  - ▷ early actions to improve reliability

# TBRMs at Different Times



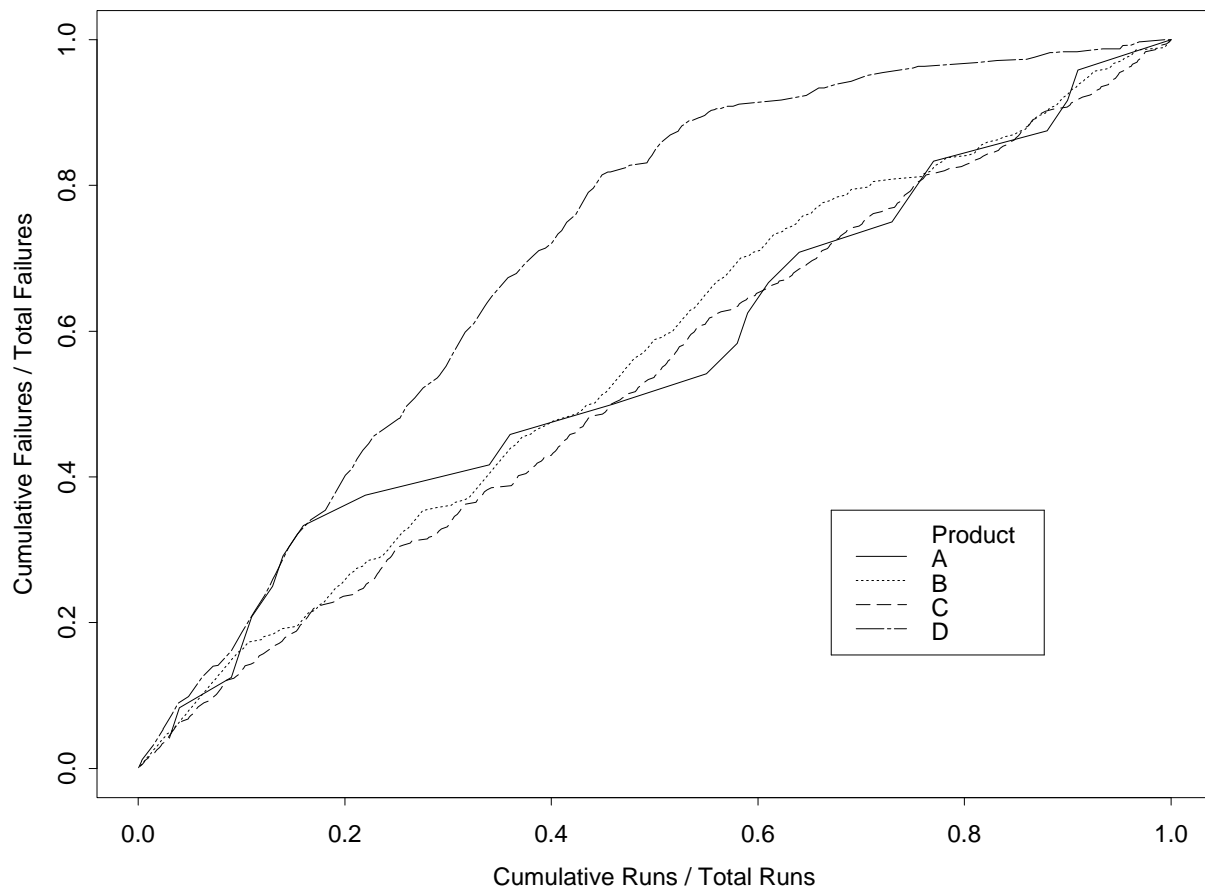
- Fig 12b (Tian 1998): a late TBRM.
  - ▷ high-risk areas  $\approx$  early runs
  - ▷ uniformly reliable  $\Rightarrow$  ready for release

## Cross Validation

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- Consistency with macro models:
  - ⇒ Effects on cost, schedule, quality.
  
- Validate with reliability growth models:
  - ▷ Trend of reliability growth.
  - ▷ Stability of failure arrivals.
  - ▷ Estimated reliability.
  - ▷ Product purity level at exit.
  
- Process changes & improvements:
  - ▷ Failure detection and fault removal.
  - ▷ Long term effect on development.
  
- Ultimate test: in-field problems.

## TBRM Result Comparison



- Fig 22.6 (p.384): TBRMs used in D
  - ▷ better reliability growth in D
  - ▷ compare to A, B, and C (no TBRMs)



## TBRM Result Comparison

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- Table 22.3 (p.384):  
quantitative comparison with  $\rho$

Purification Level $\rho$	Product			
	A	B	C	D
maximum	0.715	0.527	0.542	0.990
median	0.653	0.525	0.447	0.940
minimum	0.578	0.520	0.351	0.939

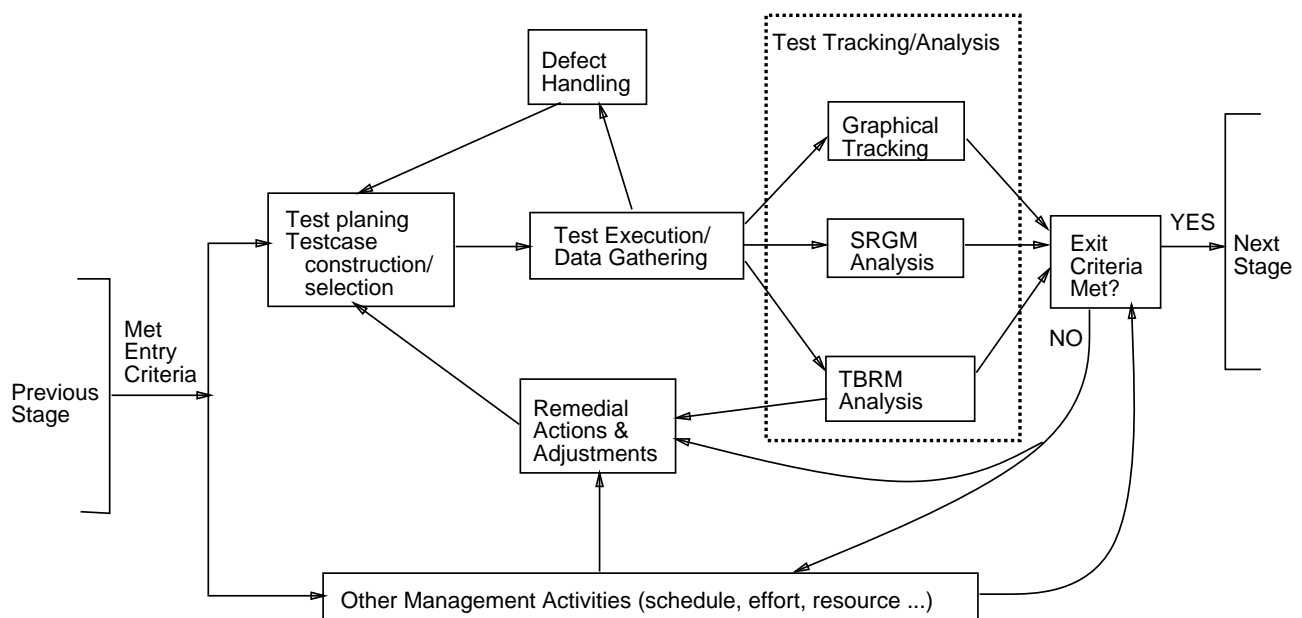
Where: 
$$\rho = \frac{\lambda_0 - \lambda_T}{\lambda_0} = 1 - \frac{\lambda_T}{\lambda_0}$$

$\lambda_0$ : failure rate at start of testing

$\lambda_T$ : failure rate at end of testing

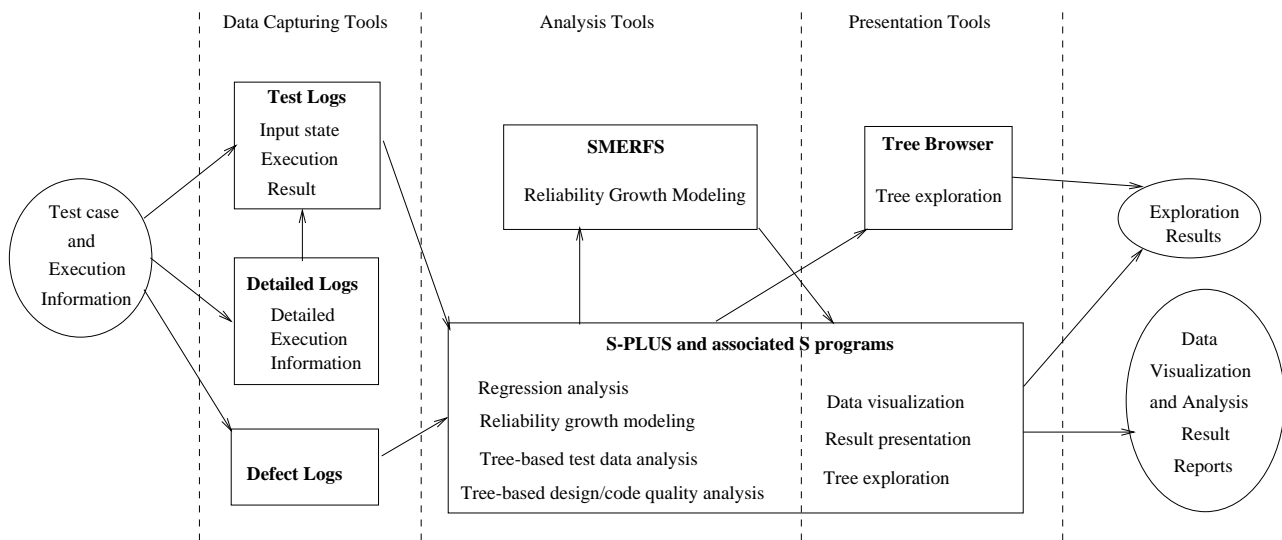
## Integrated Approach: Implementation

- Modified testing process: Fig 18 (Tian 1998)
  - ▷ Additional link for data analysis.
  - ▷ Process change and remedial actions.



## Integrated Approach: Implementation

- Tool support: Fig 20 (Tian 1998)
  - ▷ different types of tools
  - ▷ I/O and interconnection



## Integrated Approach: Implementation

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- Activities and Responsibilities:
  - ▷ Evolutionary, stepwise refinement.
  - ▷ Collaboration: project & quality orgs.
  - ▷ Experience factory prototype (Basili).
  
- Implementation:
  - ▷ Passive tracking and active guidance.
  - ▷ Periodic and event-triggered.
  - ▷ S/W tool support

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## Implementation Support

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- Types of tool support:
  - ▷ Data capturing
    - mostly existing logging tools
    - modified to capture new data
  - ▷ Analysis and modeling
    - SMERFS modeling tool
    - S-PLUS and related programs
  - ▷ Presentation/visualization and feedback
    - S-PLUS and Tree-Browser
  
- Implementation of tool support:
  - ▷ Existing (IBM+others) tools: cost ↓
  - ▷ New tools and utility programs
  - ▷ Tool integration
    - loosely coupled suite of tools
    - connectors/utility programs
    - common depository: S-PLUS

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## Application Summary

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- Tracking and input-domain analysis:
  - ▷ Effectiveness of visualization.
  - ▷ Problems with input-domain assessment.
  
- Time-domain analysis refinement:
  - ▷ Data normalization by runs/trans best.
  - ▷ Context sensitive modeling promising.
  
- Integrated approach using TBRM:
  - ▷ Guidance as well as assessment.
  - ▷ Risk focusing  $\Rightarrow$  reliability improvement.
  - ▷ Progression of trees.
  - ▷ Usage as exit criteria.
  - ▷ Cross validation.

## Future Directions

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- Implementation and deployment:
  - ▷ Data: automated data capturing.
  - ▷ OP: evolutionary approach.
  - ▷ Integration: analysis and improvement.
  - ▷ Use in different industrial environments.
  
- Exploration and improvement:
  - ▷ Customize time/transaction measurement.
  - ▷ Early indicators/predictive modeling.
  - ▷ Customer environment/OP refinement.
  - ▷ Integrate to life-cycle quality models.
  - ▷ Management and cost modeling.
  - ▷ Refinement of modeling techniques.
  
- Continued research at SMU and collaboration with our industrial partners.