

Software Reliability and Safety

CS 8317 — Fall 2020

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SRE.2: TBRMs & Integrated SRE

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

Overview

- Reliability: $\text{Prob}(\text{failure-free operations})$
 - ▷ *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.
 - ▷ risk focusing and remedial actions.
 - ▷ details: SRE1_b1sreAIC.pdf (Tian 1998)
and SRE2_j7tbrm.pdf (Tian 1995)

Product Environment

- 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.

Testing Environment

- 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

Needs and Constraints

- 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.

Overall Solution

- Combine SRGMs and IDRMs 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
 - IDRMs (input domain rel. models)
 - identify high risk areas
 - ▷ Automatic partitioning via TBRMs.
 - ▷ Remedial actions for improvement.

Applications: Overview

- 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.

Applications: Testing & Data

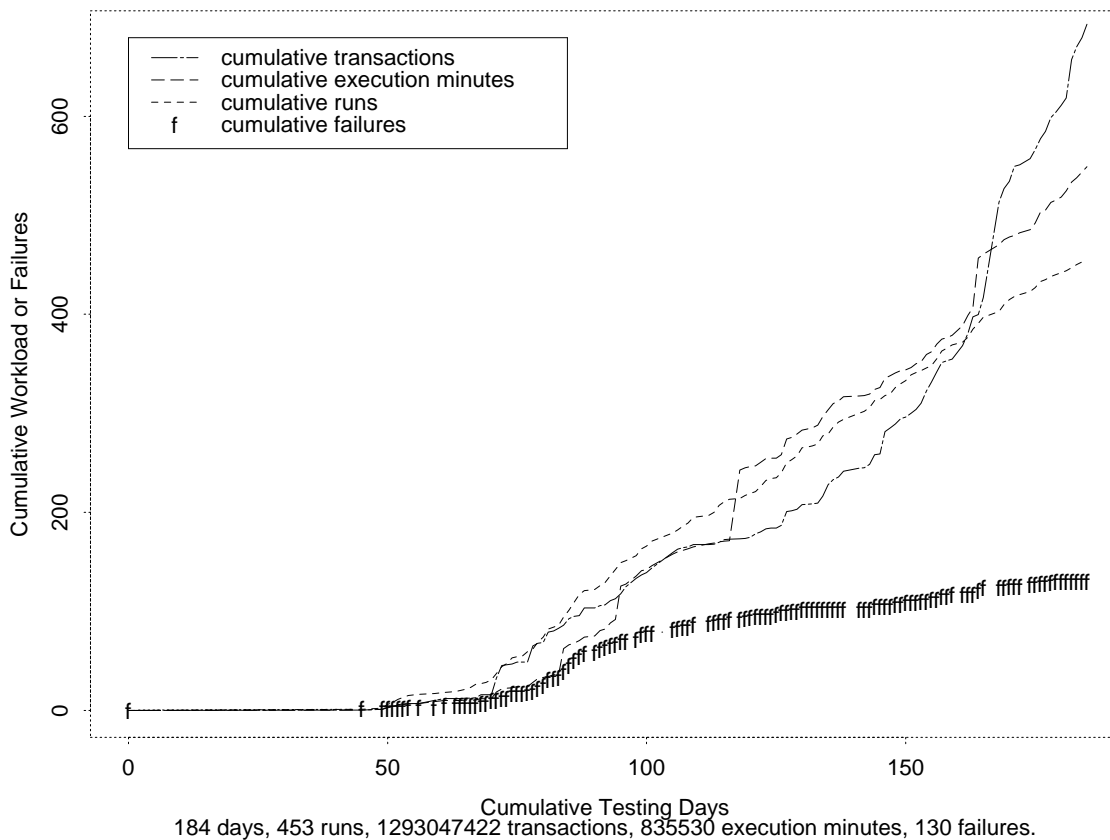
- Data and tracking:
 - ▷ Integration with schedule information.
 - ▷ Normalization effect.
 - ▷ Summary reports and visualization.
 - ▷ Consistency checking automation.

- 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.

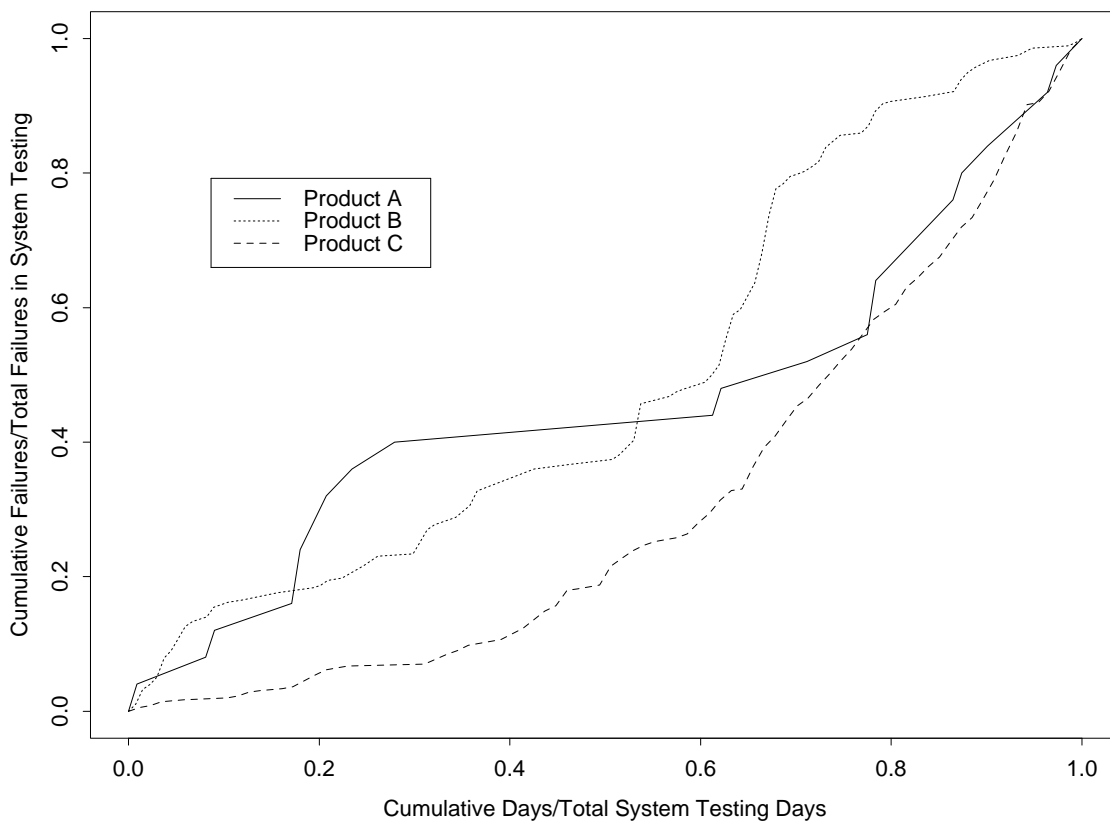
SRGMs: Application Experience

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



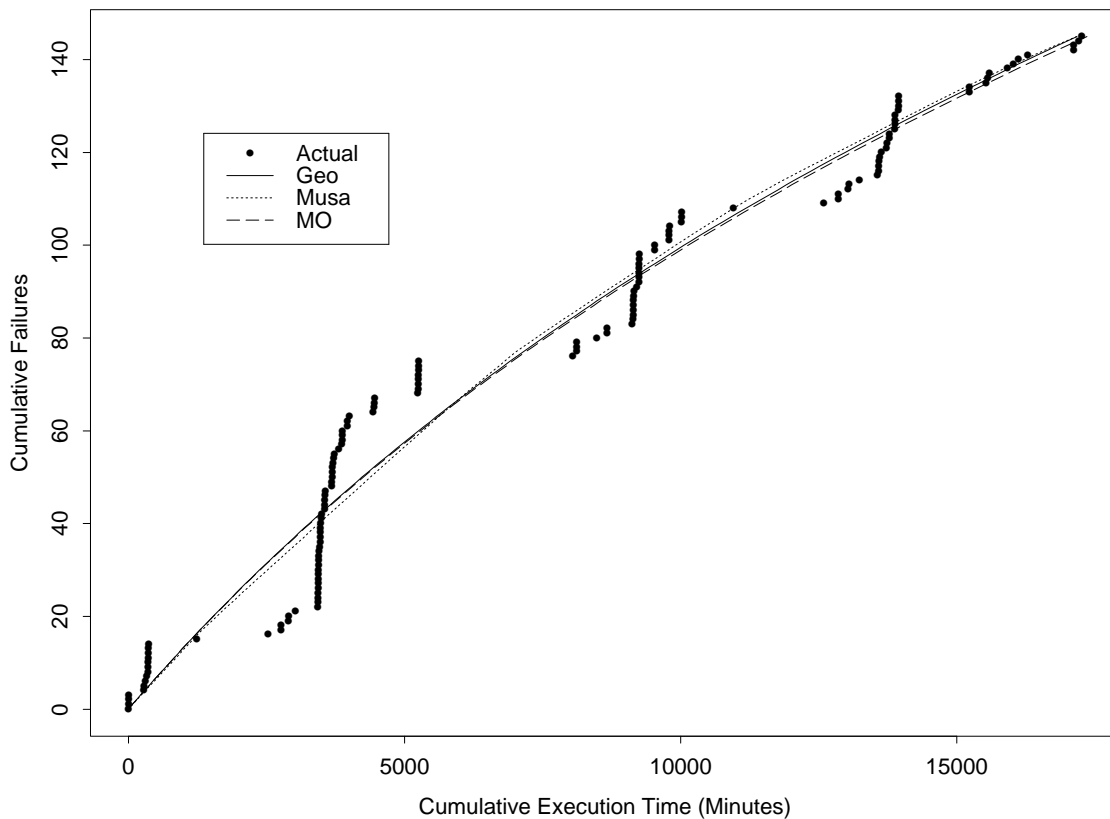
SRGMs: Application Experience

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



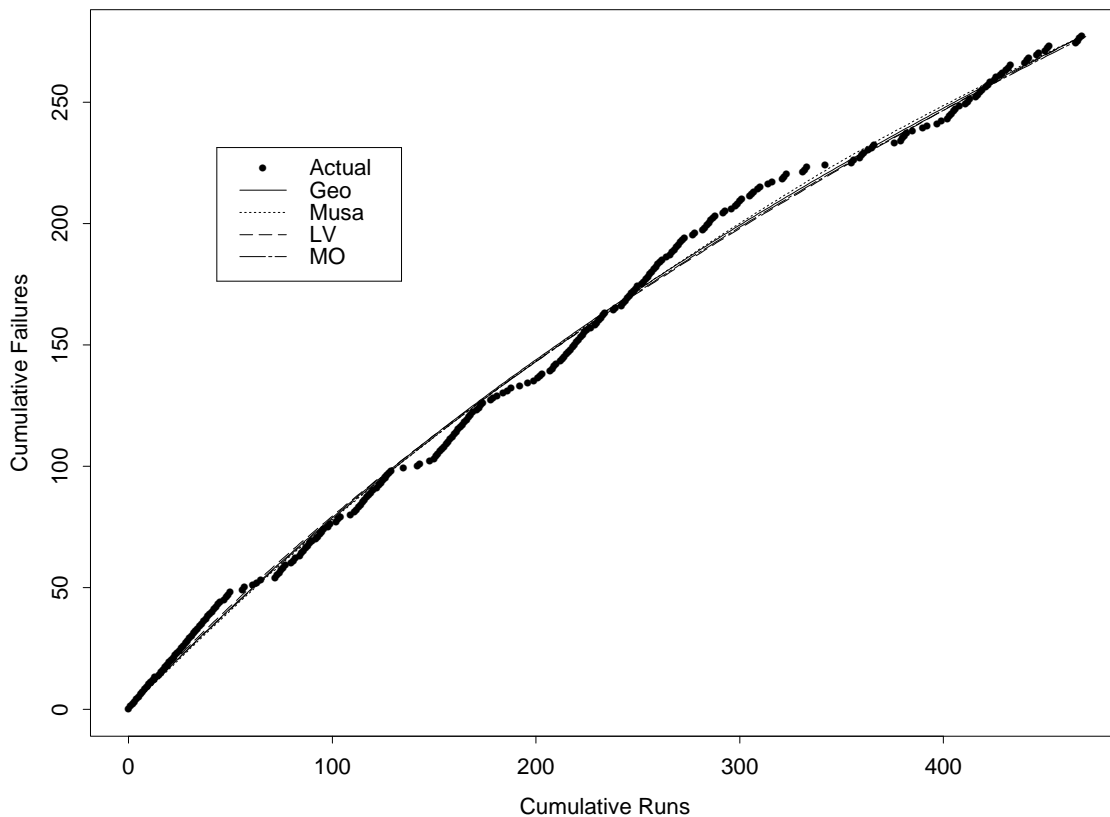
SRGMs: Application Experience

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



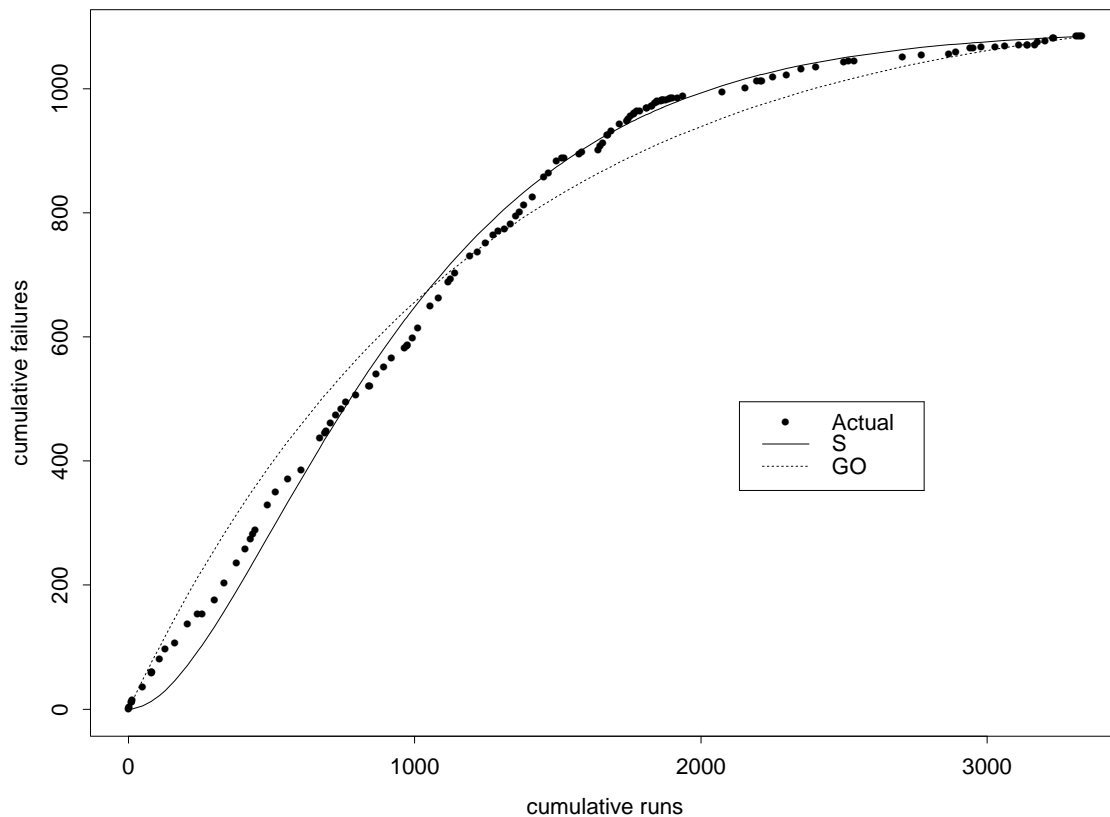
SRGMs: Application Experience

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



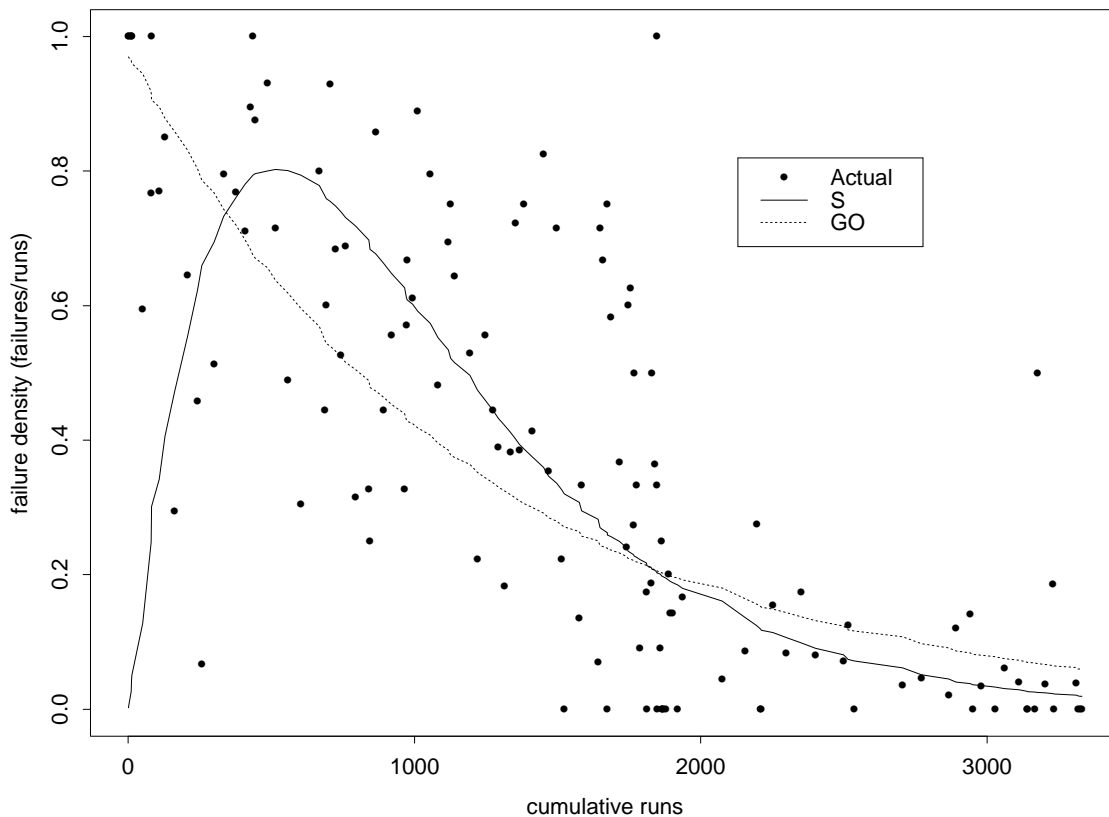
SRGMs: Application Experience

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



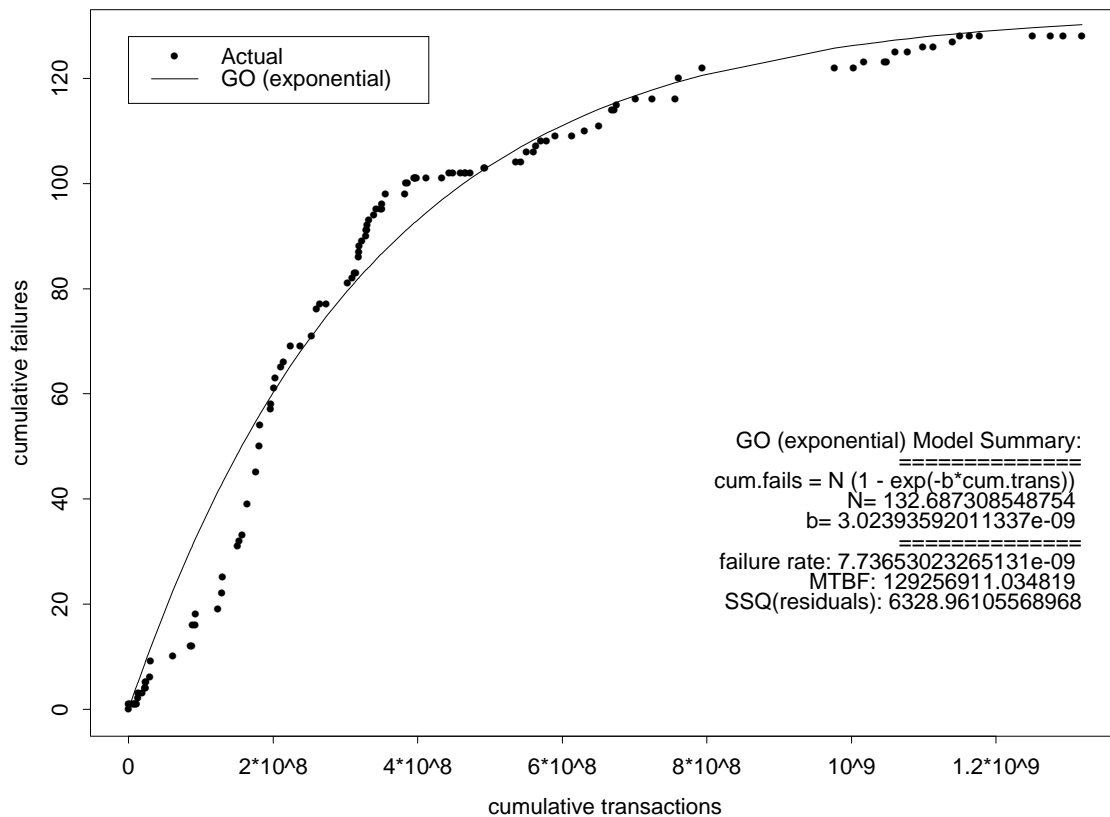
SRGMs: Application Experience

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



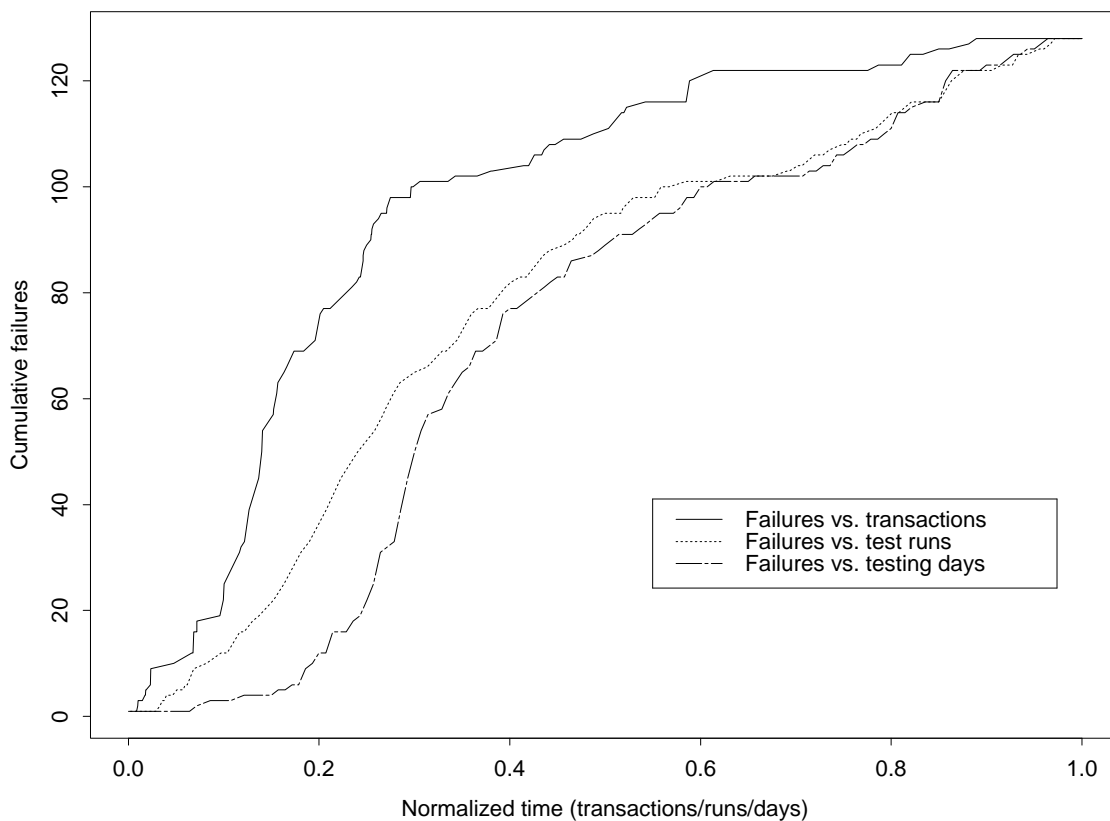
SRGMs: Application Experience

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



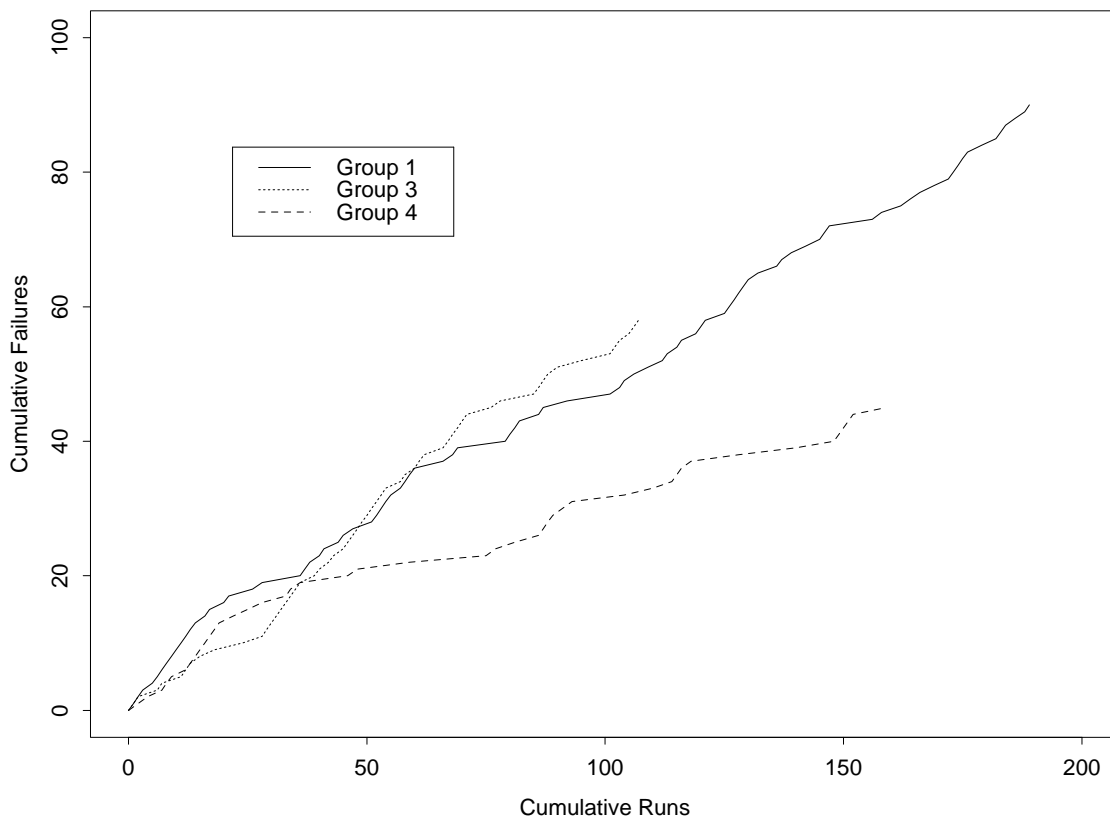
SRGMs: Application Experience

- 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)



SRGM Conclusions

- 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

- 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

- 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.

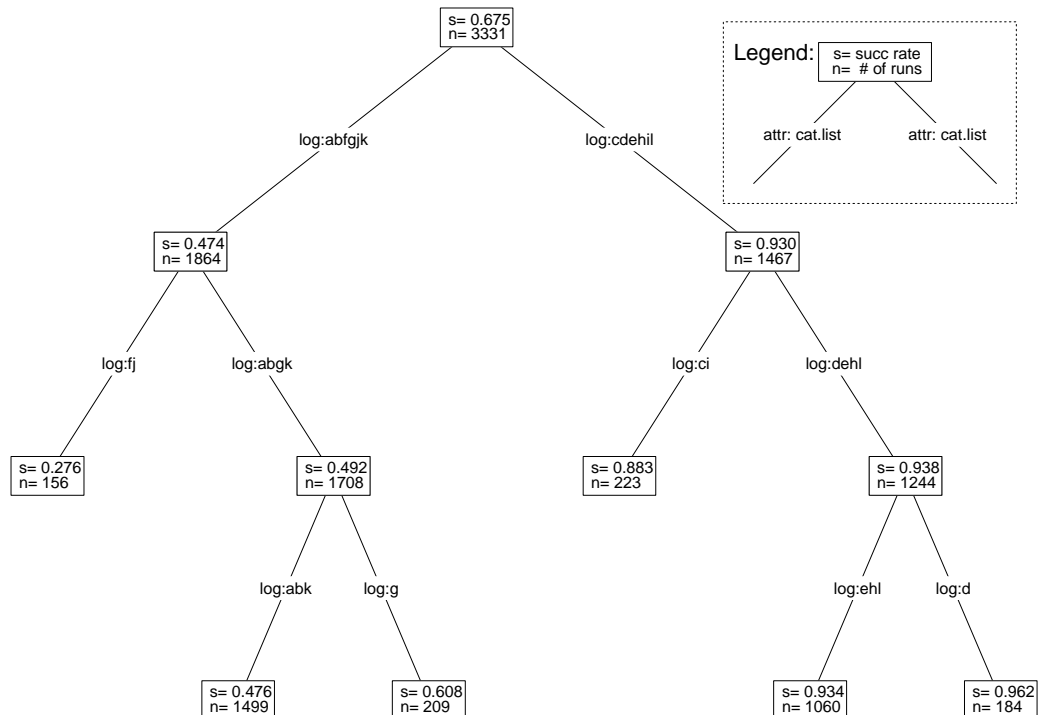
- Integrated reliability analyses:
 - ▷ TBRM: partitioned subset reliability.
 - ▷ Use both input and timing information.
 - ▷ Monitoring changes in trees.
 - ▷ Enhanced exit criteria.
 - ▷ SRGM: overall reliability near exit.
 - ▷ Integrate into the testing process.

TBM: Technique for Integration

- 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.

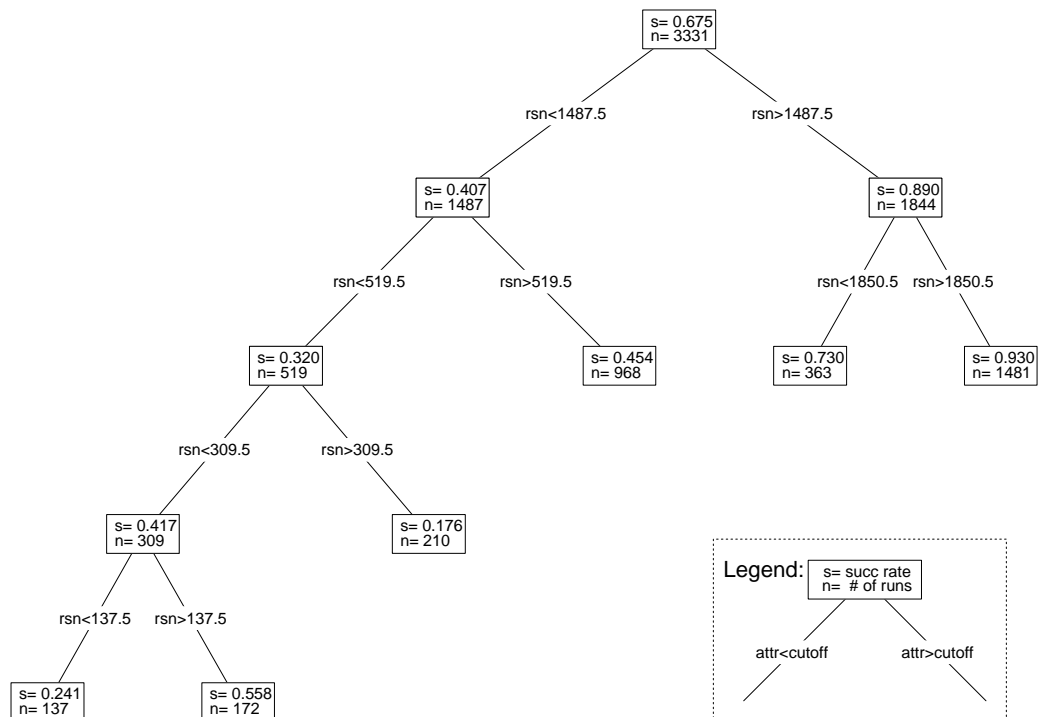
TBRM Simple Example

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



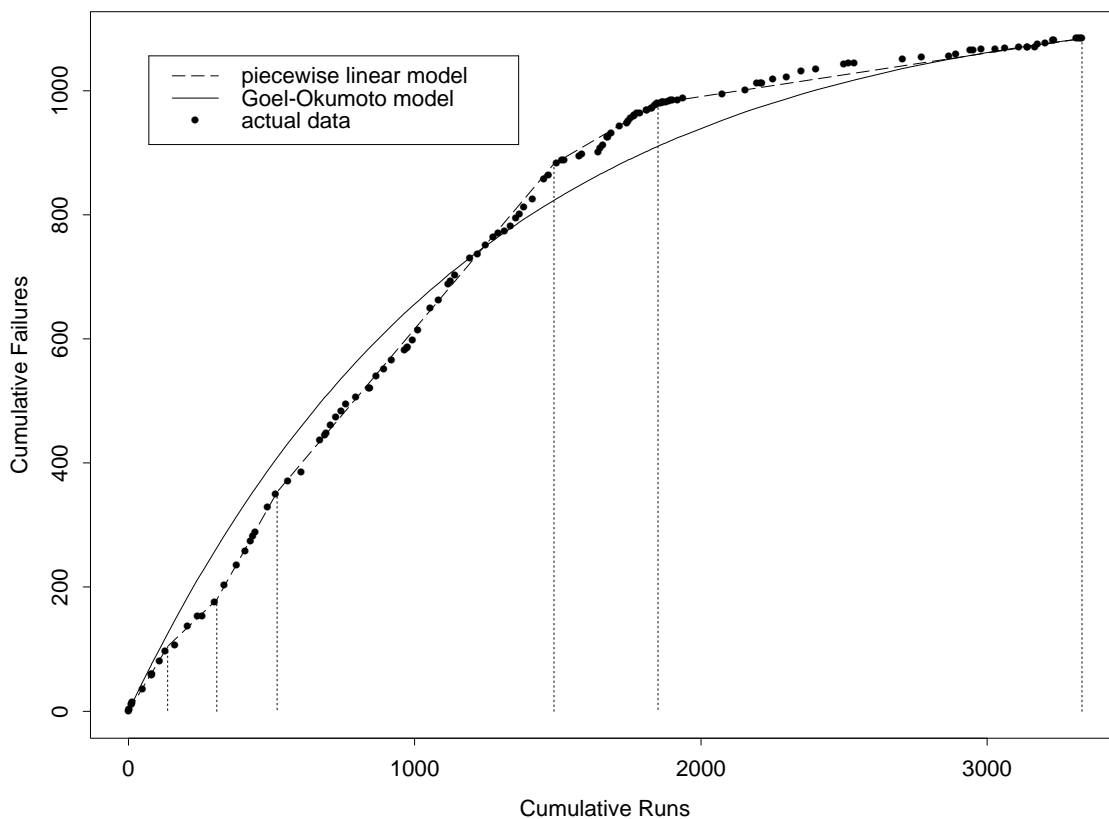
TBRM Simple Example

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



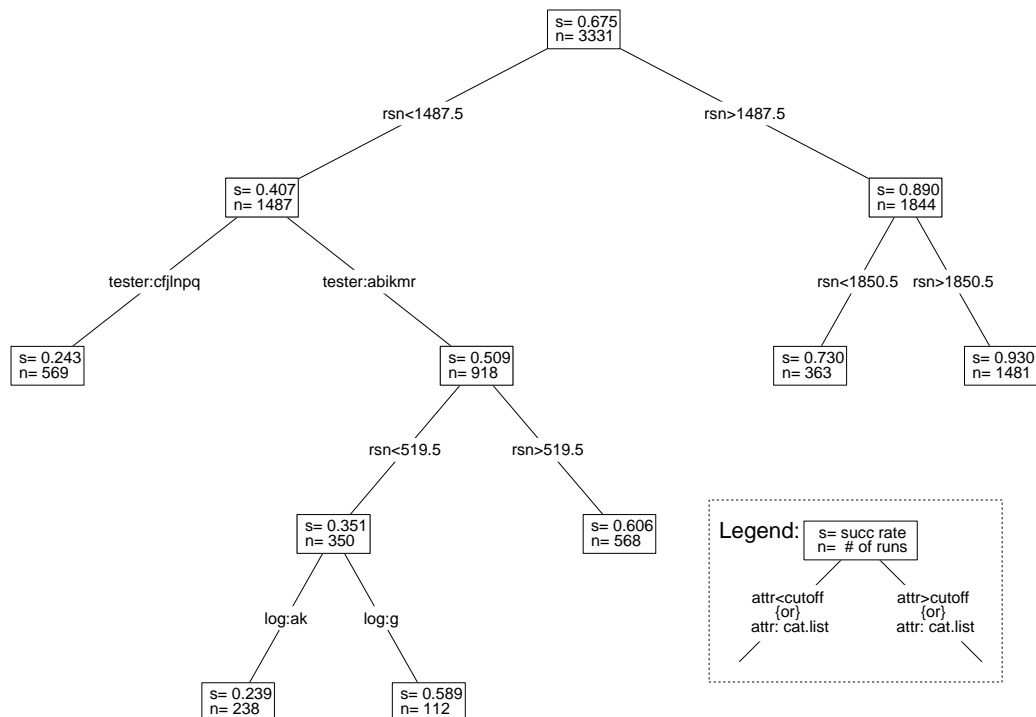
TBRM Simple Example

- 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

- 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.

Using Integrated Analysis

- 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.

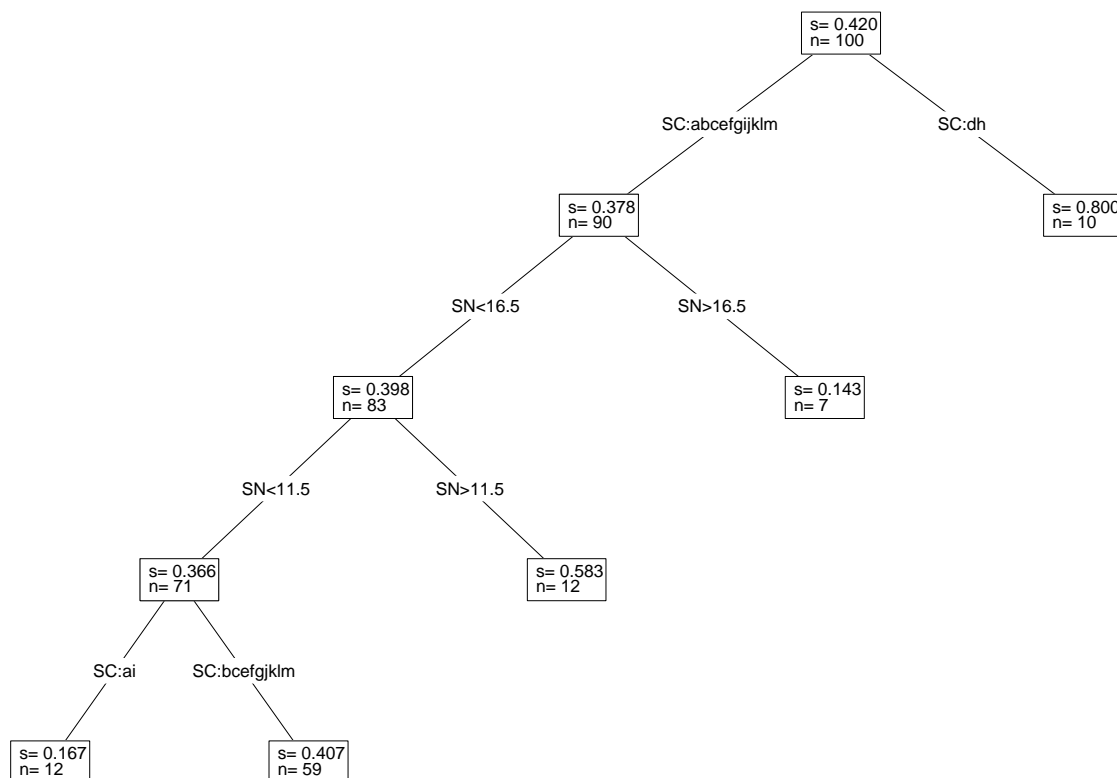
TBRMs in Integrated Analysis

- 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.

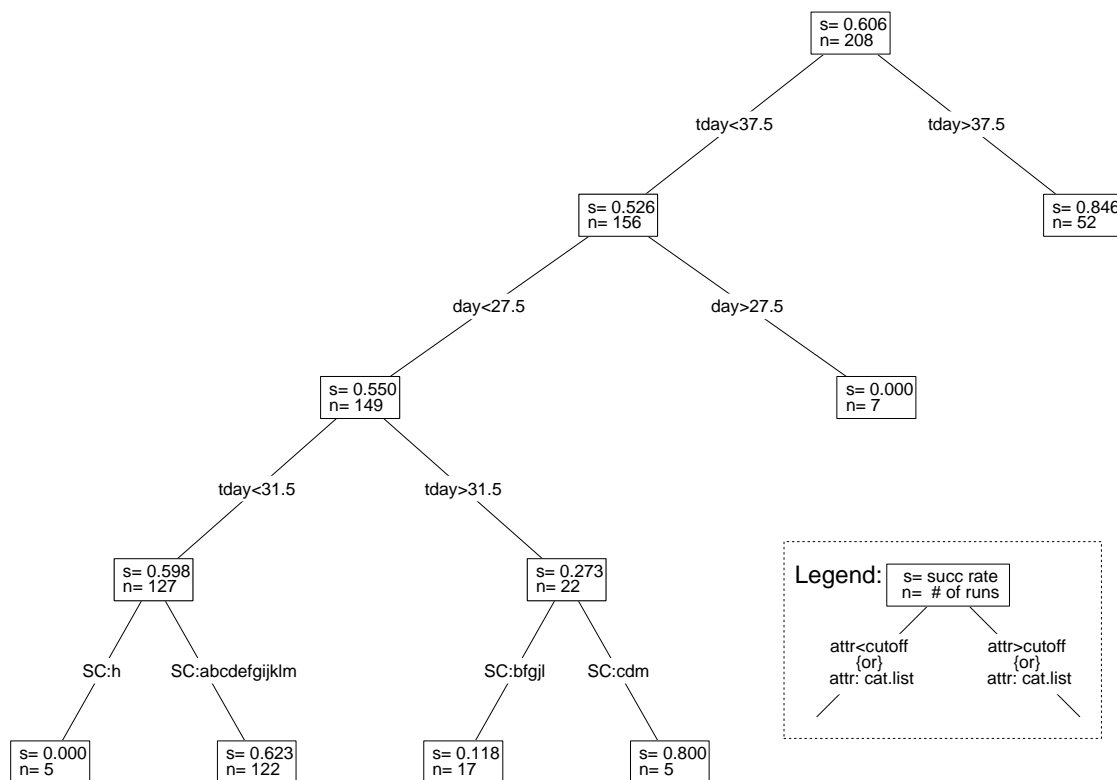
- Results interpretation:
 - ▷ Progression of trees & tree types.
 - ▷ Usage as exit criteria.

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

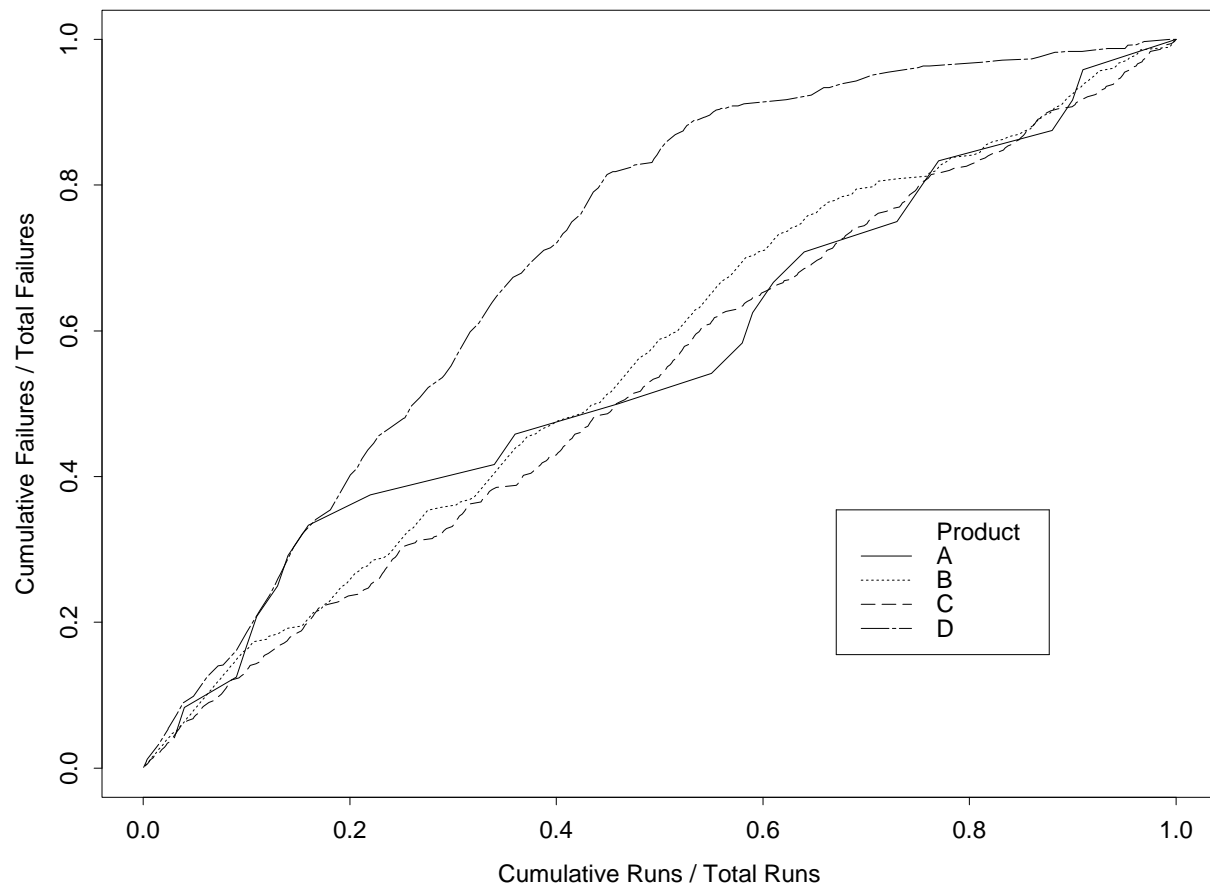
- Consistency with macro models:
 - ⇒ Effects on cost, schedule, quality.

- 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

- Table 22.3 (p.384):
quantitative comparison with ρ

| Purification Level ρ | 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 |

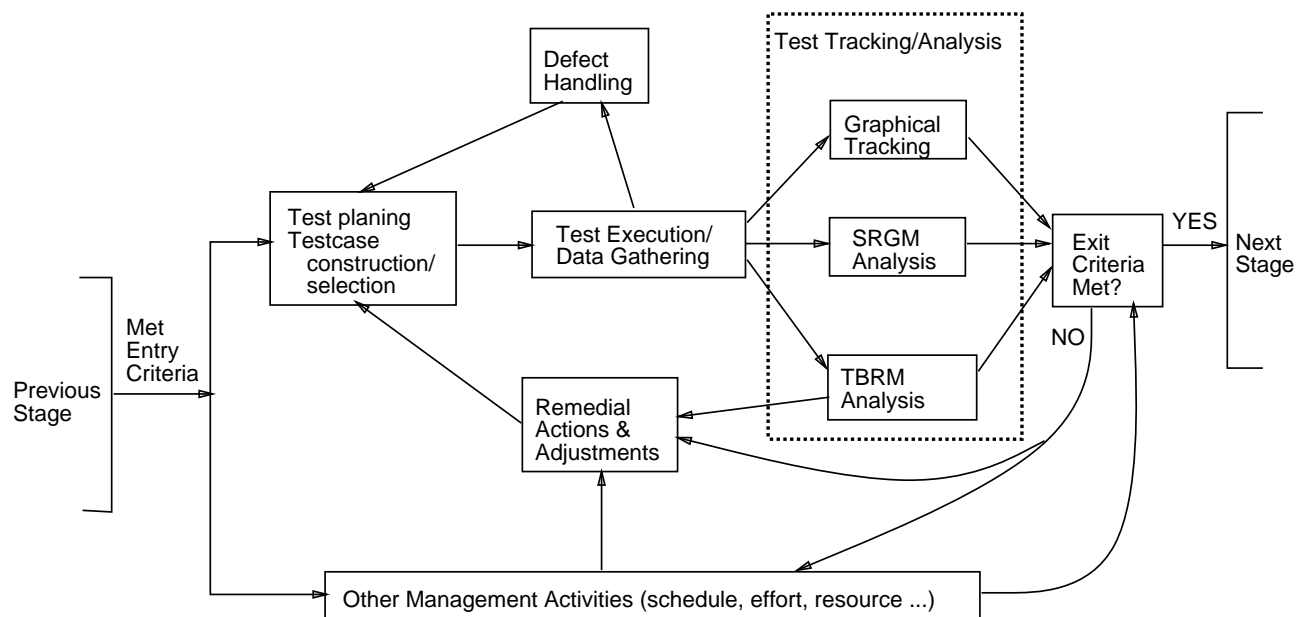
Where:
$$\rho = \frac{\lambda_0 - \lambda_T}{\lambda_0} = 1 - \frac{\lambda_T}{\lambda_0}$$

λ_0 : failure rate at start of testing

λ_T : failure rate at end of testing

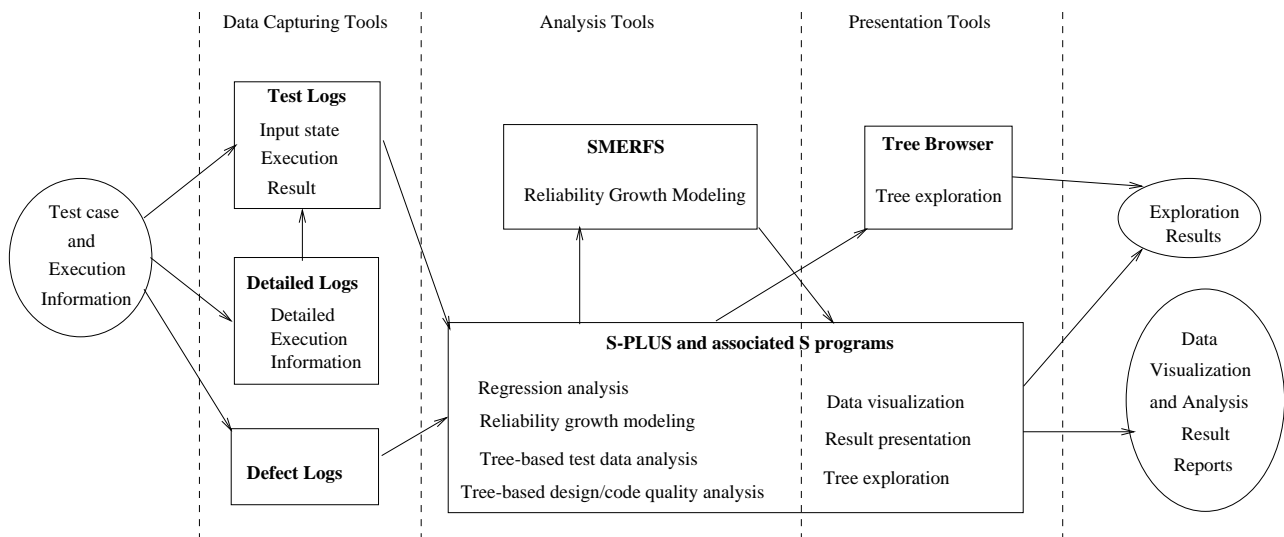
Integrated Approach: Implementation

- 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

- 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

Implementation Support

- 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

Application Summary

- 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

- 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.