Software Reliability and Safety

CSE 8317 — Spring 2011

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SRE.2: TBRMs & Integrated SRE

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

Overview

- Reliability: Prob(failure-free operations)
  - ▷ *time domain*: for a specific period.
    $\Rightarrow$ reliability growth models.
  - ▷ *input domain*: for a specific input set.
    $\Rightarrow$ 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)

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 ($2 \sim 18$ 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 $\uparrow$
    - – defect fixing and related runs
    - – division among testers.
- Specific reliability analysis issues:
  - ▷ Scenario-based $\sim$ random testing
    - – due to parallelism and interleaving
  - ▷ Defect fixing effect:
    - – no long-term dependency
    - – short-term dependency $\Rightarrow$ grouping (later)
  - ▷ Uneven faults $\Rightarrow$ 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

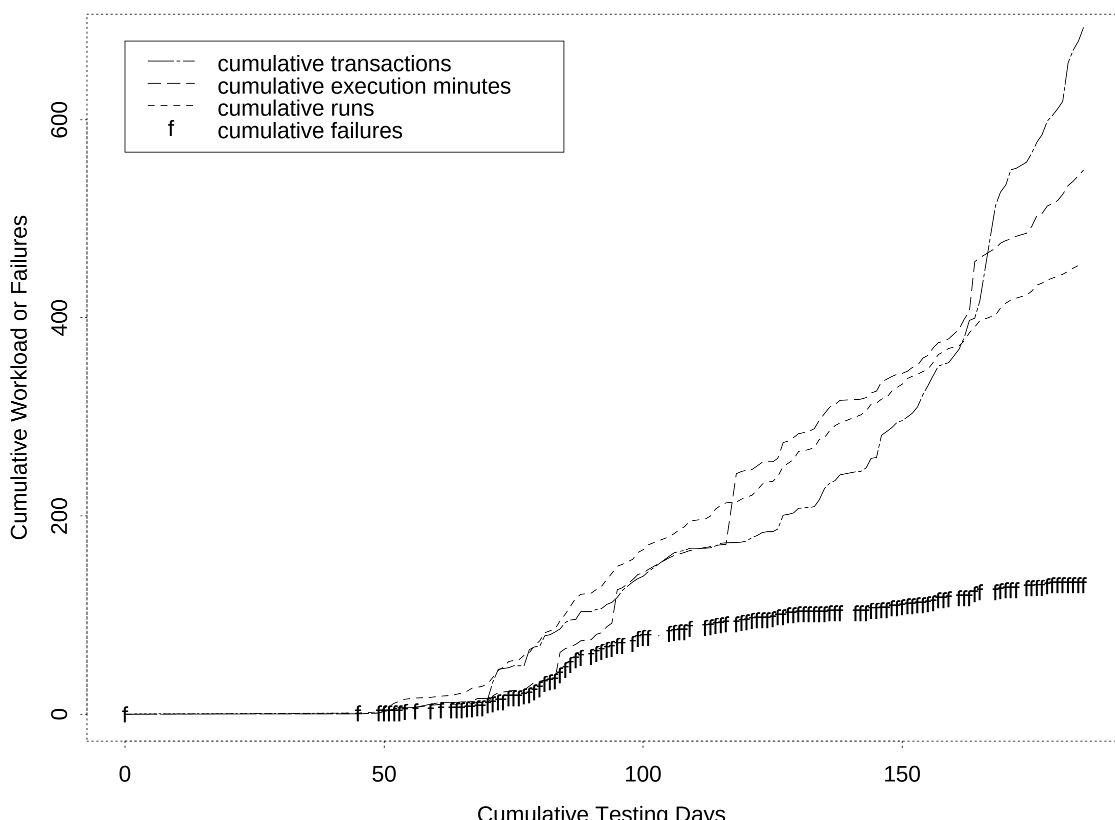
- Data and tracking:
  - ▷ Integration with schedule information.
  - ▷ Normalization effect.
  - ▷ Summary reports and visualization.
  - ▷ Consistency checking automation.

- 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

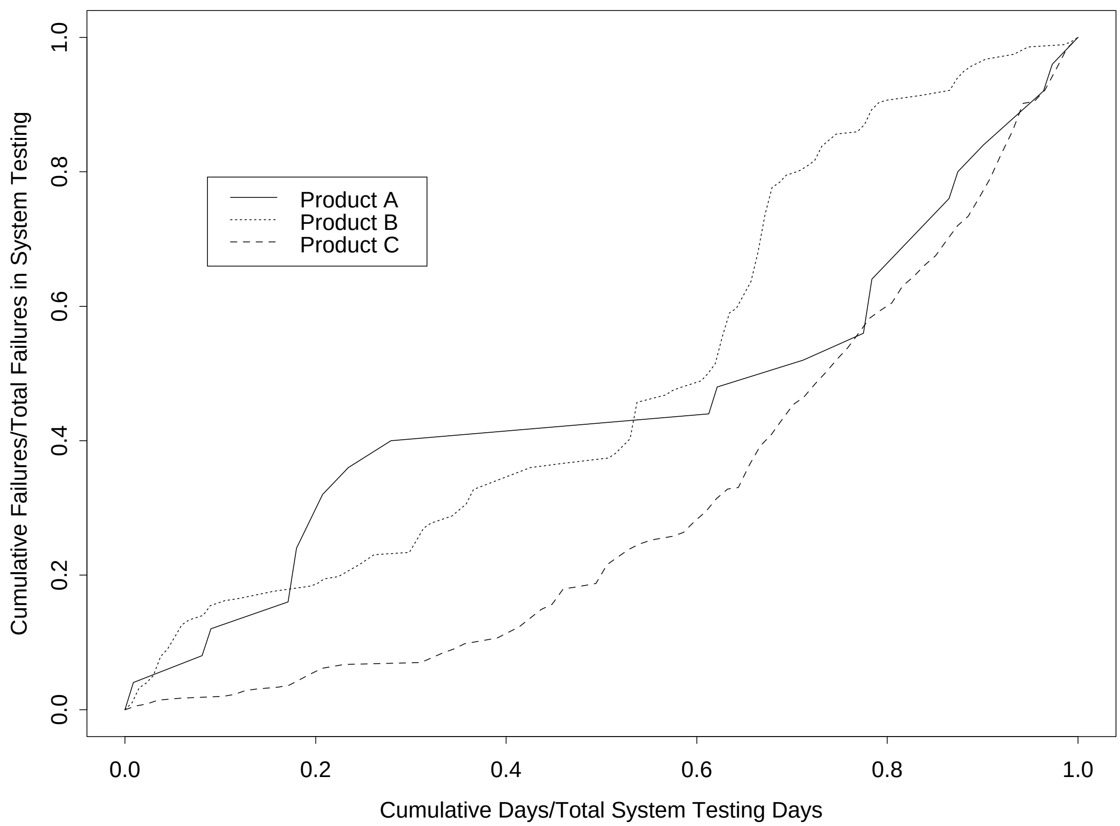
- Time measurements: Fig.2 (Tian 1998)
  - ▷ calendar time.
  - ▷ execution time: Musa models.
  - ▷ logical time: runs, transactions, etc.



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

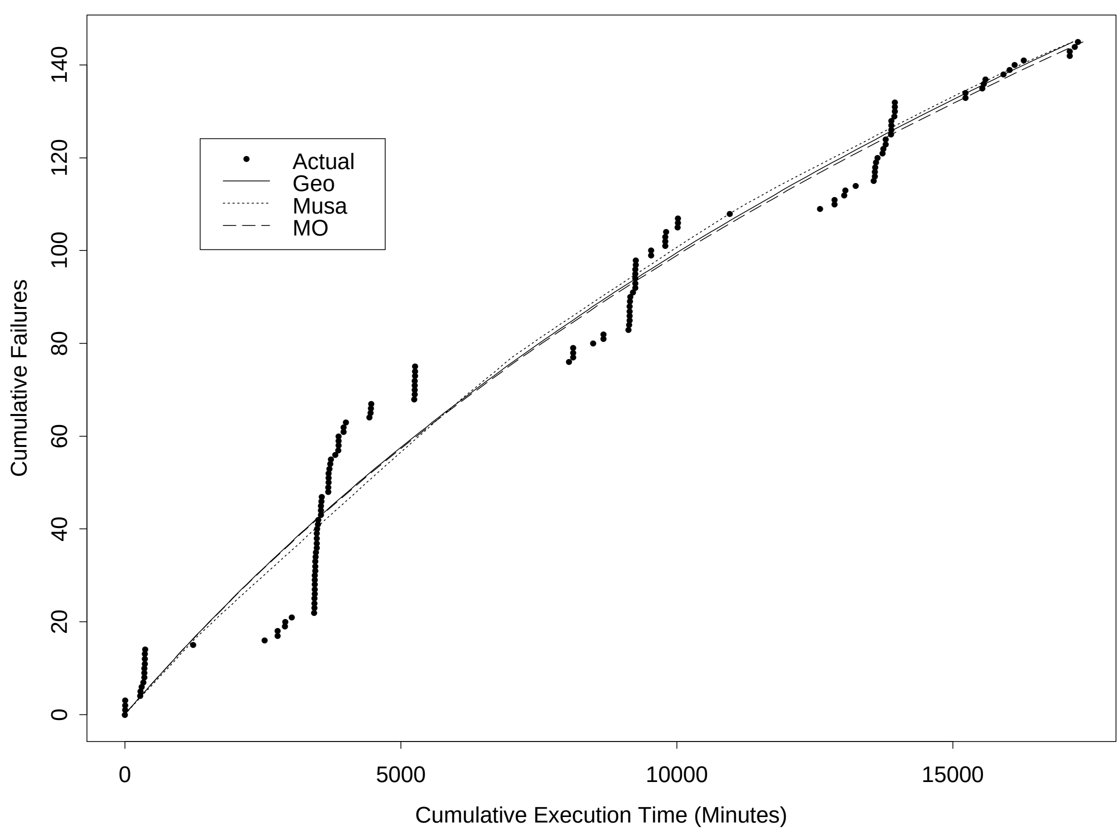
SRGMs: Application Experience

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



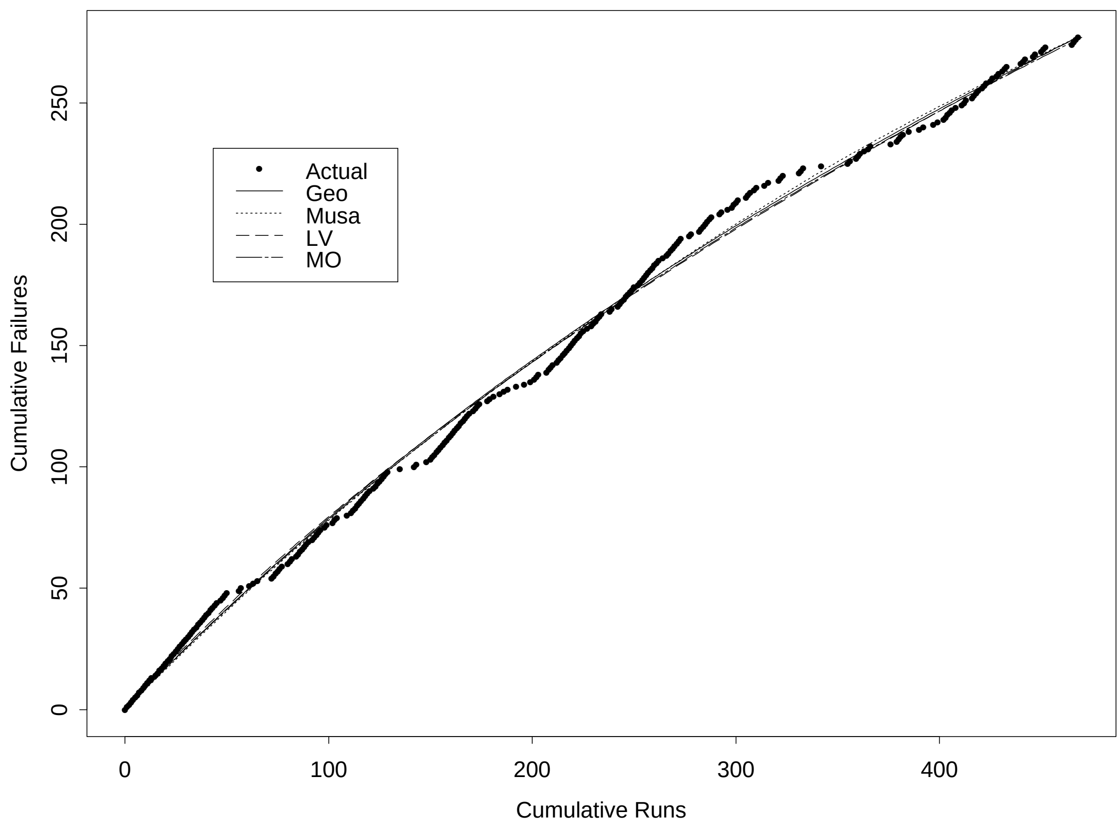
SRGMs: Application Experience

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



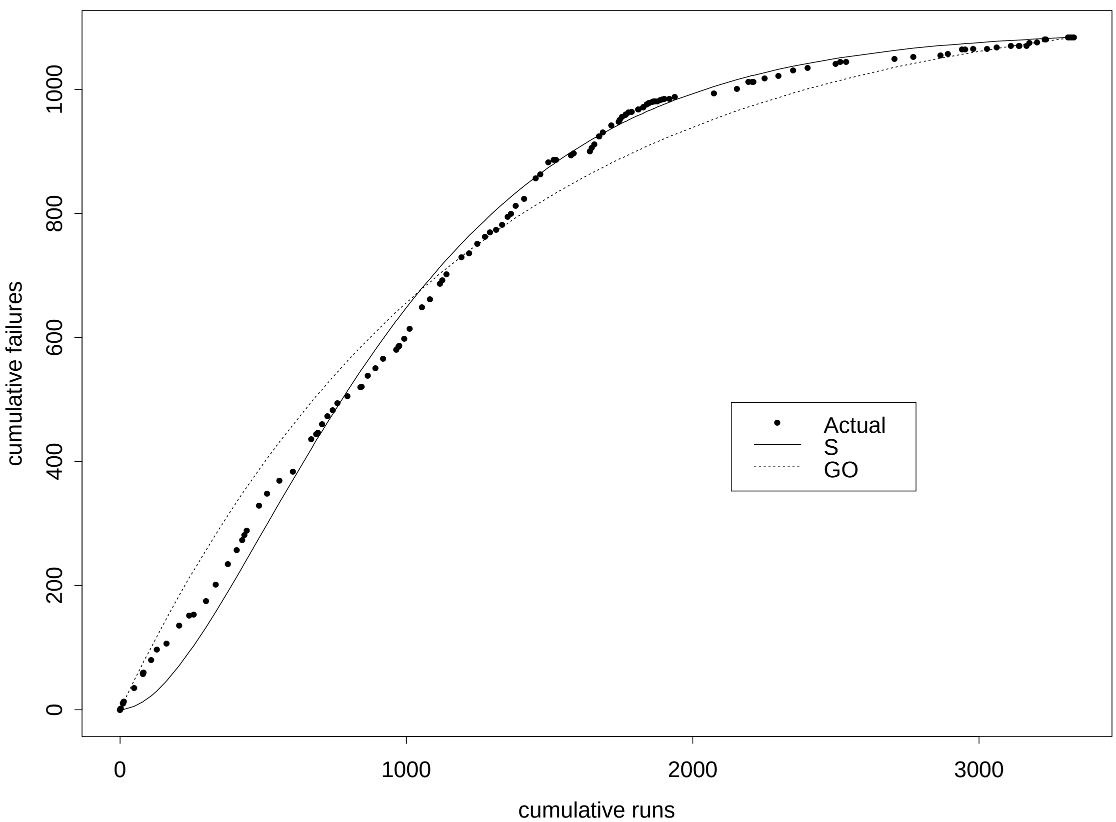
SRGMs: Application Experience

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



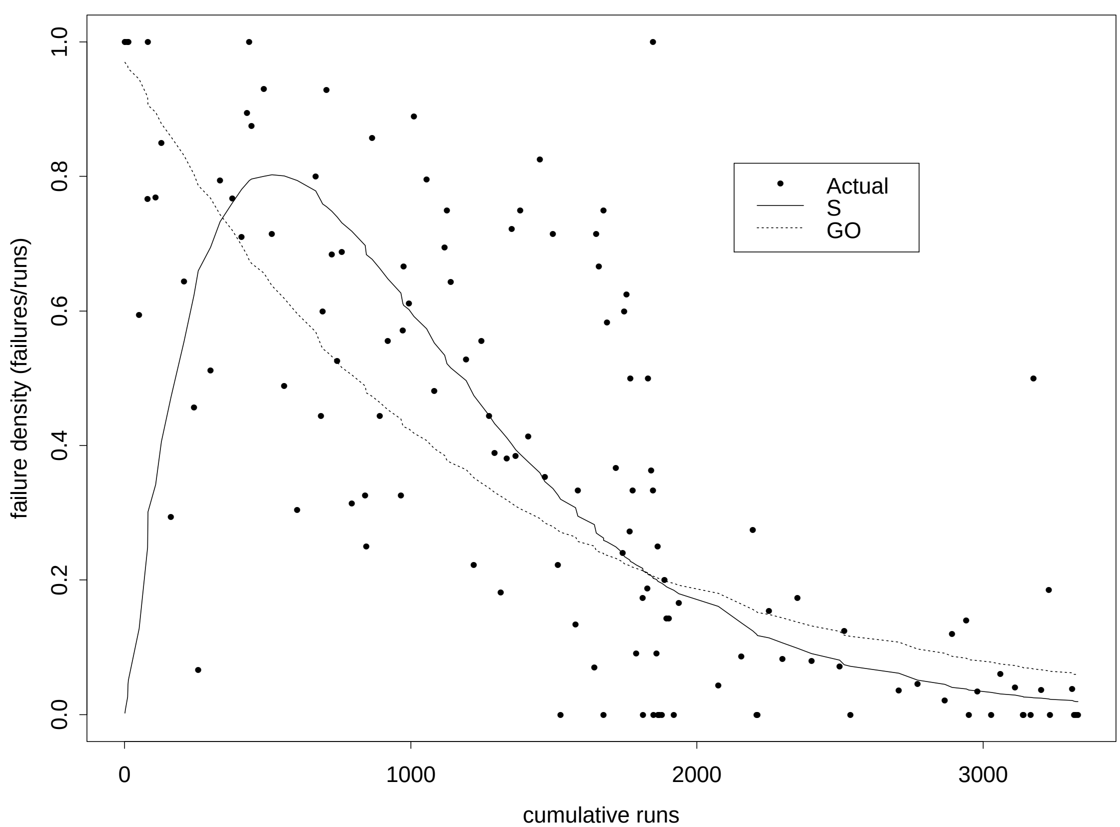
SRGMs: Application Experience

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



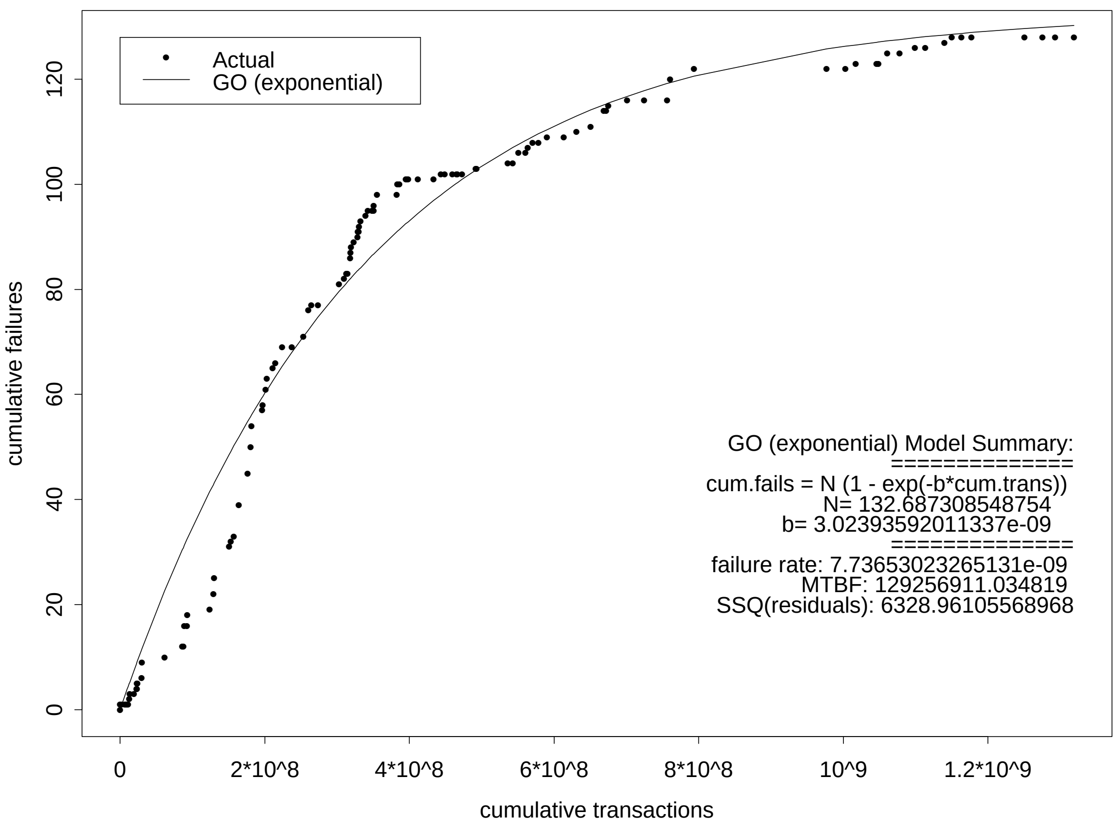
SRGMs: Application Experience

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



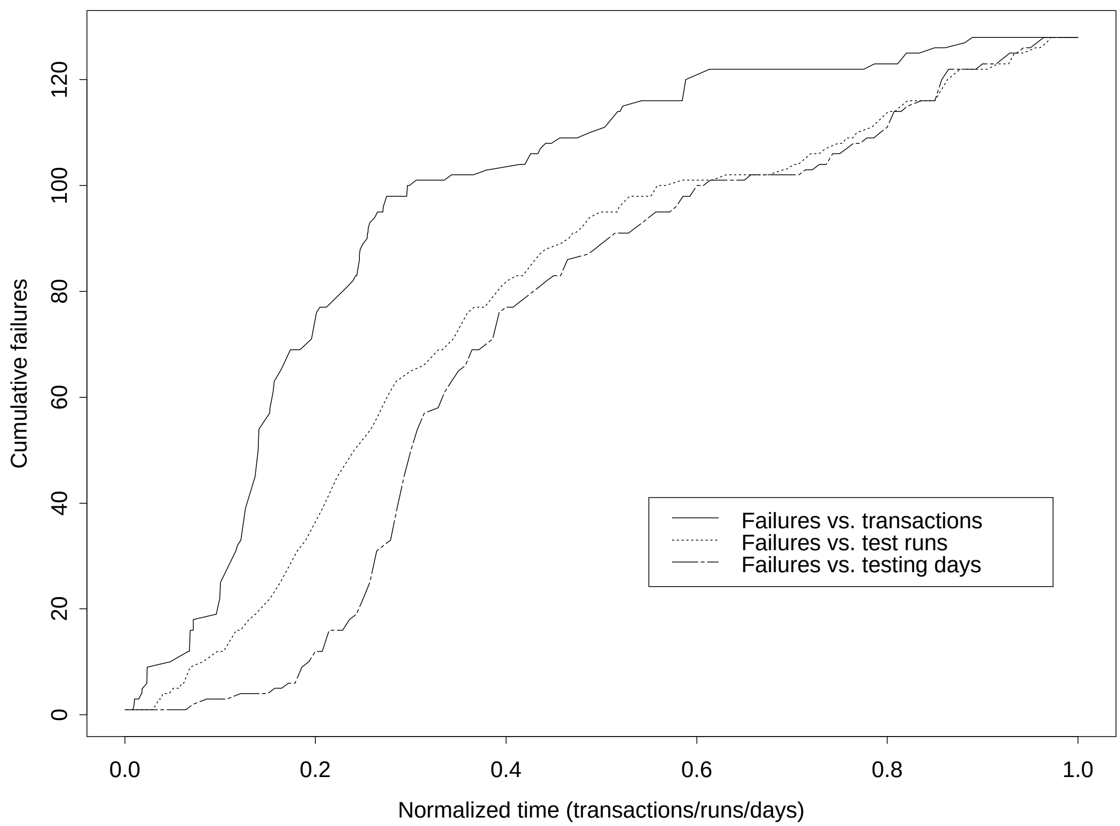
SRGMs: Application Experience

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



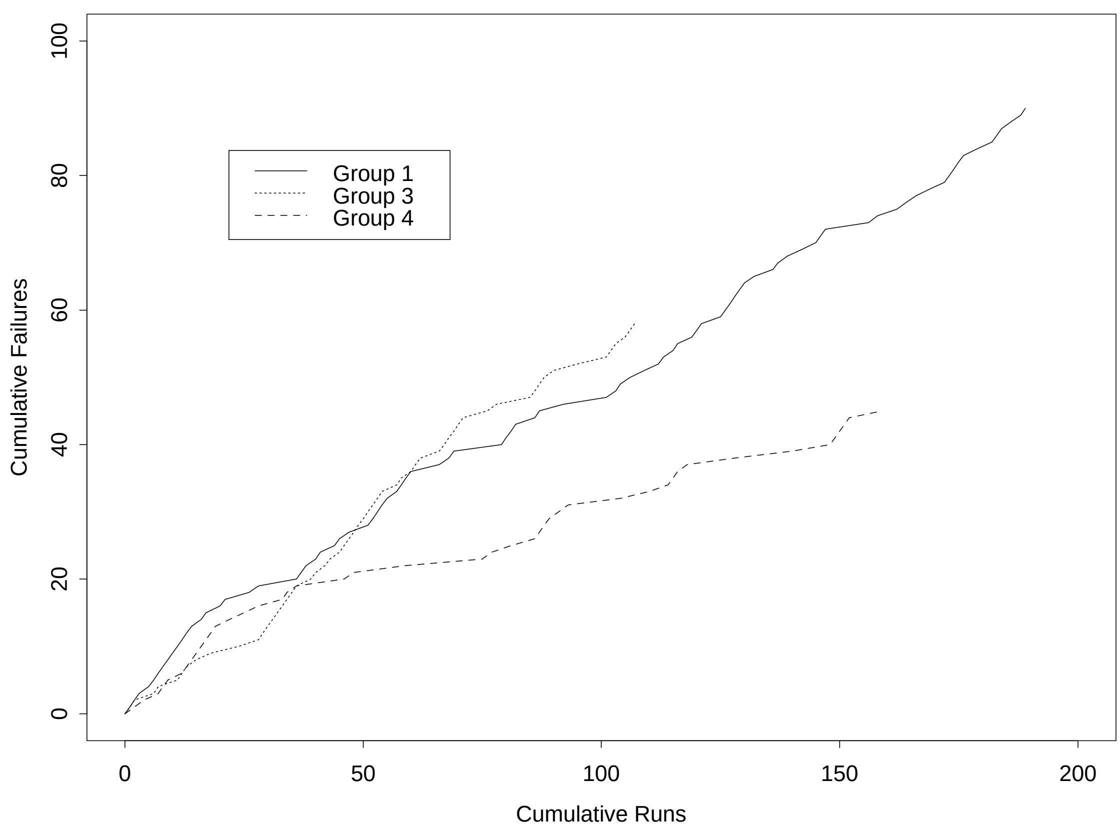
SRGMs: Application Experience

- 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 ⇒ 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.

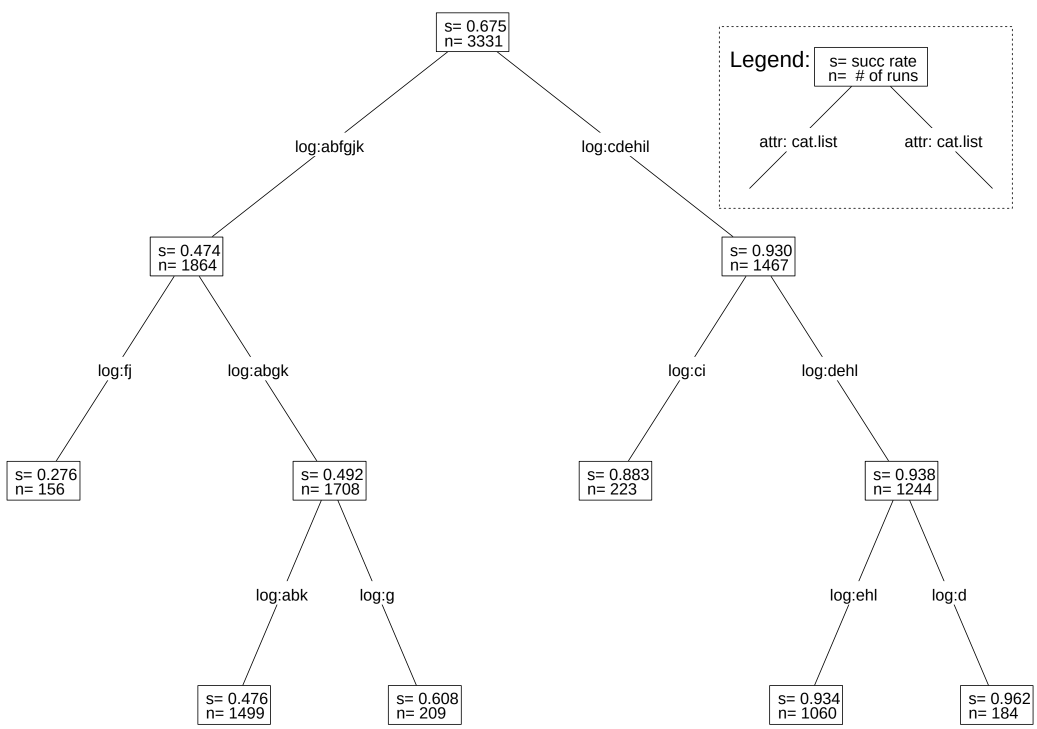
- Integrated reliability analyses:
  - ▷ TBRM: partitioned subset reliability.
  - ▷ Use both input and timing information.
  - ▷ Monitoring changes in trees.
  - ▷ Enhanced exit criteria.
  - ▷ SRGM: overall reliability near exit.
  - ▷ Integrate into the testing process.

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 $X_1, \ldots, X_n$.
  - ▷ Construction: recursive partitioning. (controlled growth vs growing&pruning)
- Usage and applications:
  - ▷ Basic usage: $Y = Tree(X_1, \ldots, X_n)$
  - ▷ 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.

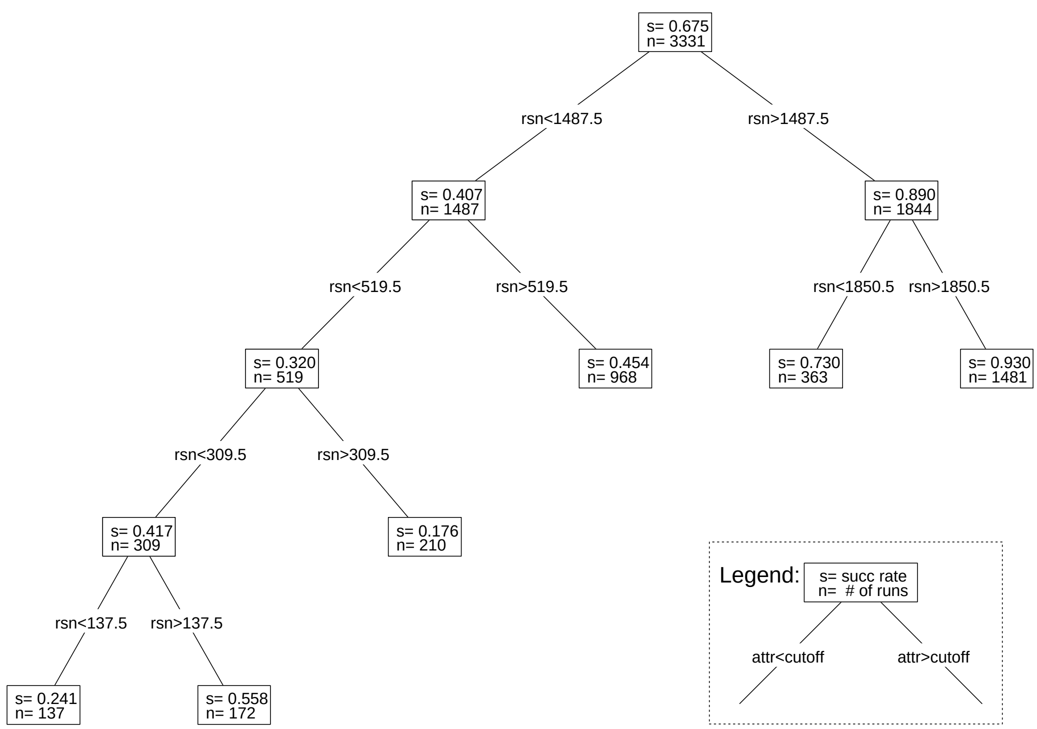
TBRM Simple Example

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



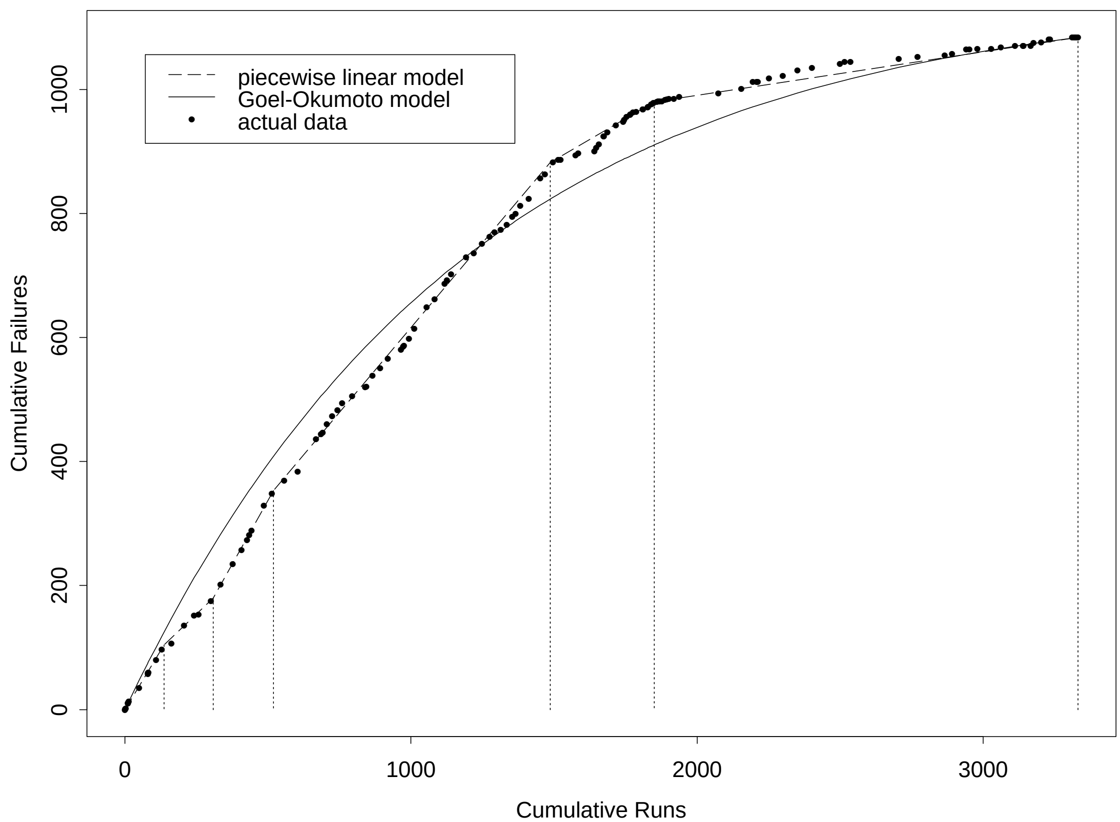
TBRM Simple Example

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



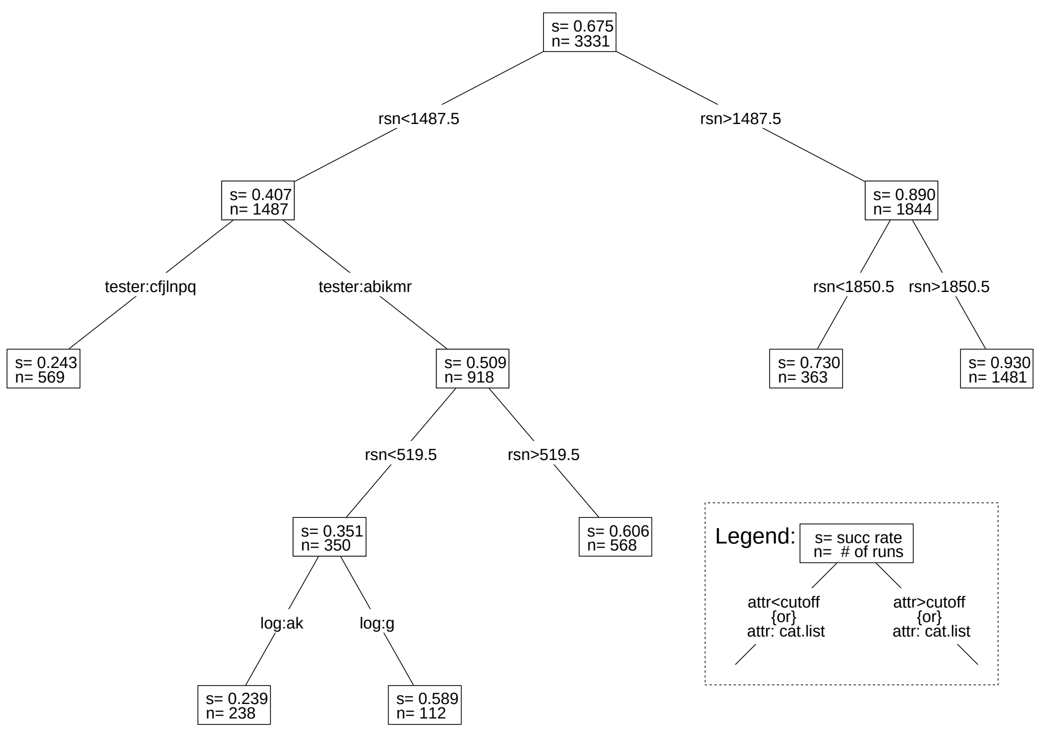
TBRM Simple Example

- 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.

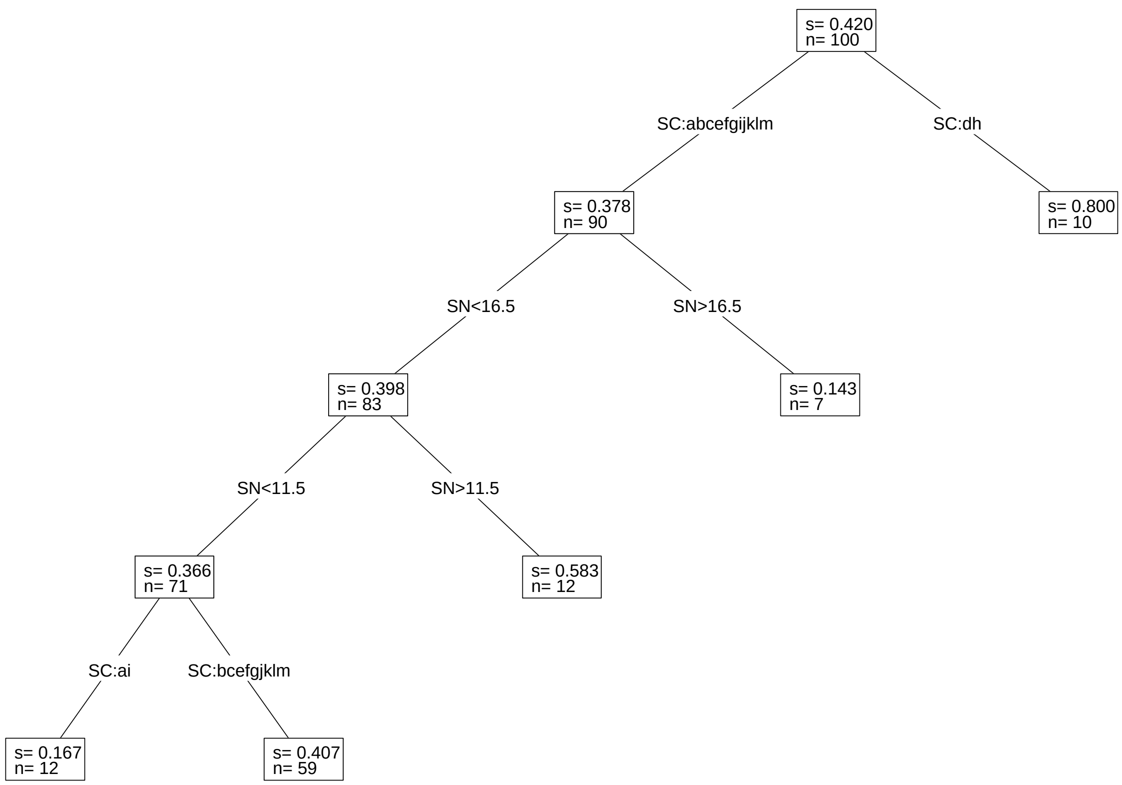
- Monitoring reliability change:
  - ▷ Change in predicted response.
  - ▷ Through tree structural change.

- Risk identification and remedies:
  - ▷ Identify high risk input state.
  - ▷ Additional analysis.
  - ▷ Enhanced test cases.
  - ▷ Remedies for components.

TBRMs in Integrated Analysis

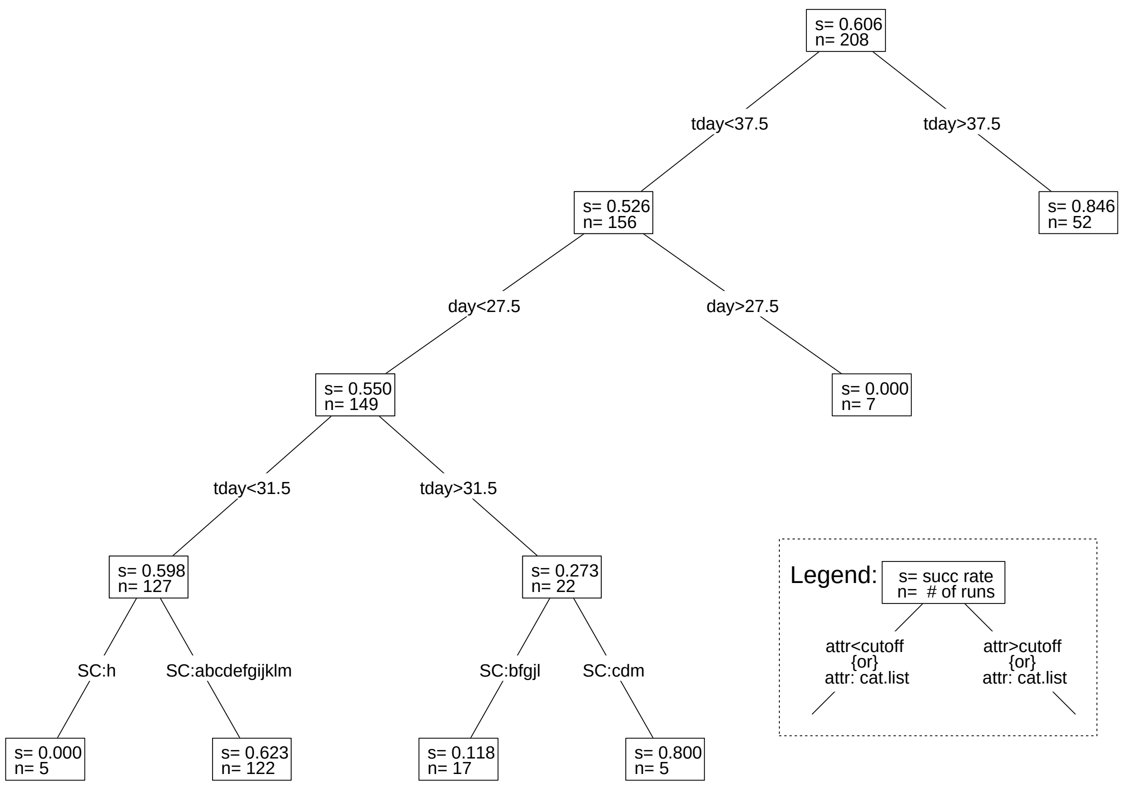
- Treatment of product bundles:
  - ▷ TBRM for individual products.
  - ▷ Dynamic change w.r.t. process needs.
  - ▷ SRGM (& TBRM) for bundle near exit.
- Risk identification:
  - ▷ High risk input sub-domains.
  - ▷ Additional analysis for the identified.
  - ▷ Guide for remedial actions.
- Results 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 ≈ early runs
  - ▷ uniformly reliable ⇒ ready for release

Cross Validation

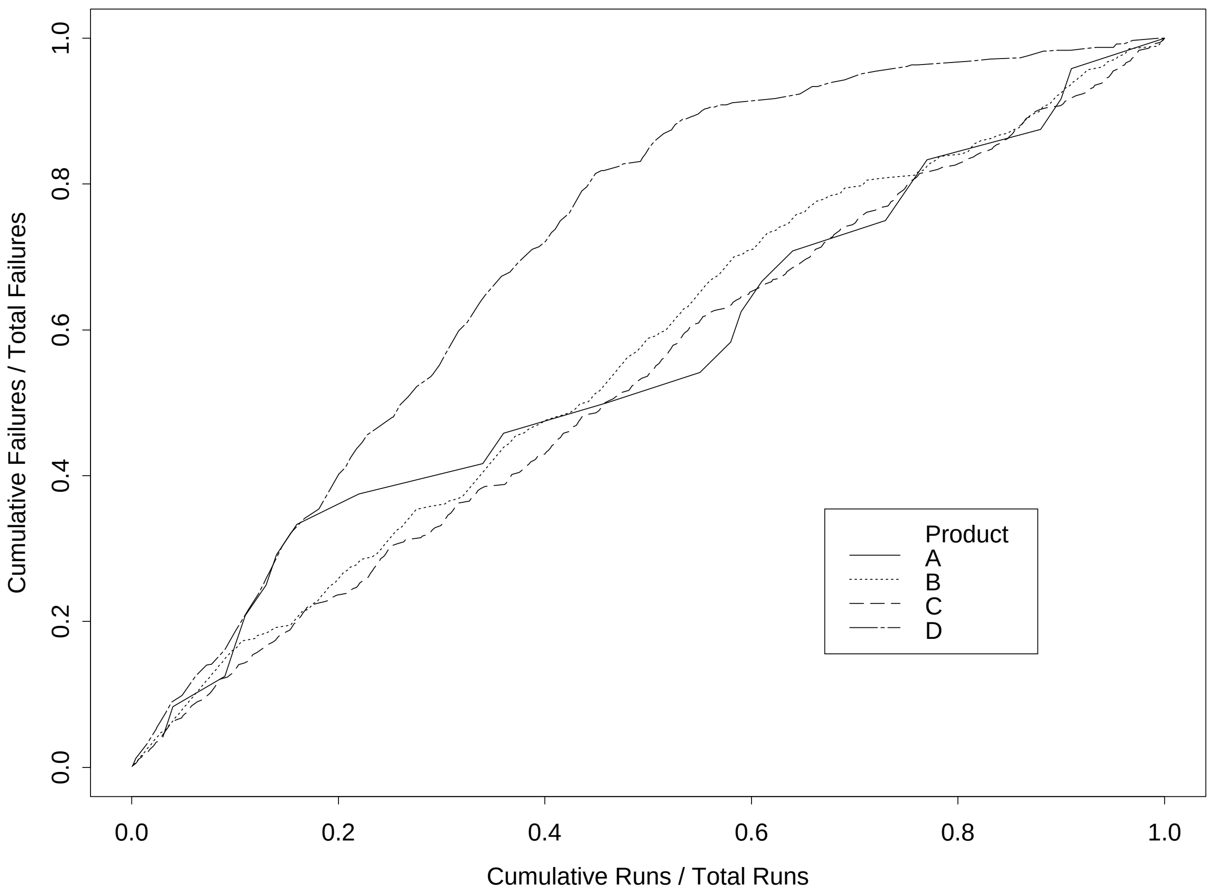
- Consistency with macro models:
  $\Rightarrow$ Effects on cost, schedule, quality.

- 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

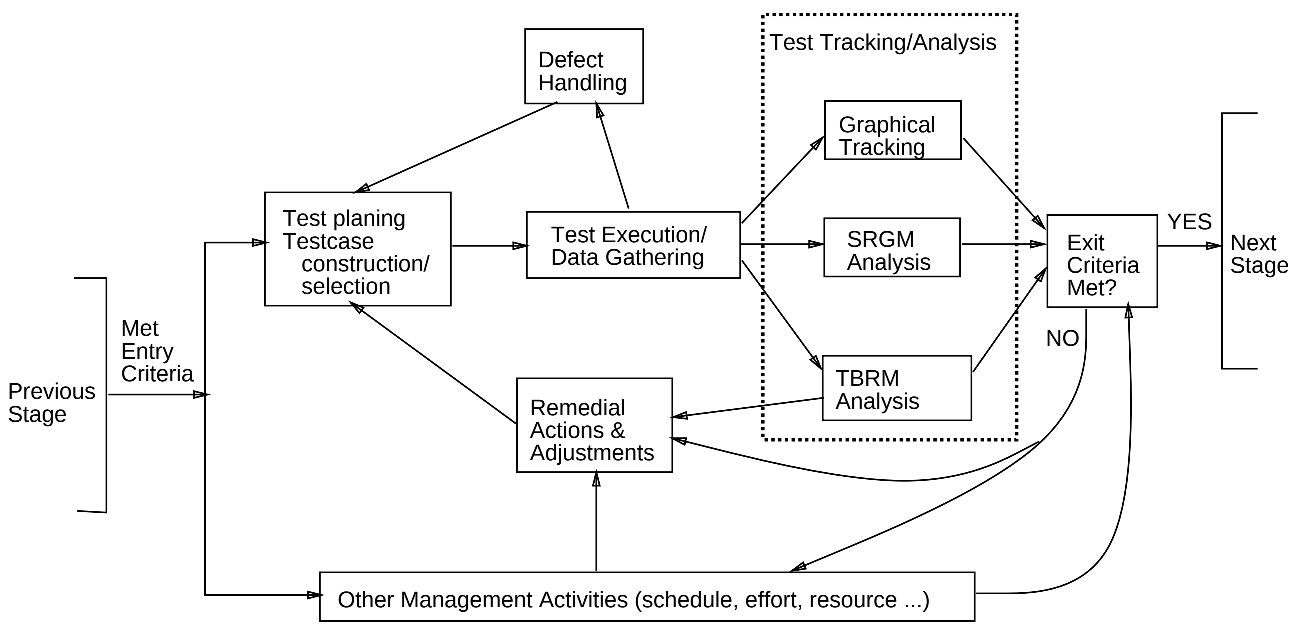
Purification Level ρ	Product			
	A	B	C	D
maximum	0.715	0.527	0.542	0.990
median	0.653	0.525	0.447	0.940
minimum	0.578	0.520	0.351	0.939

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

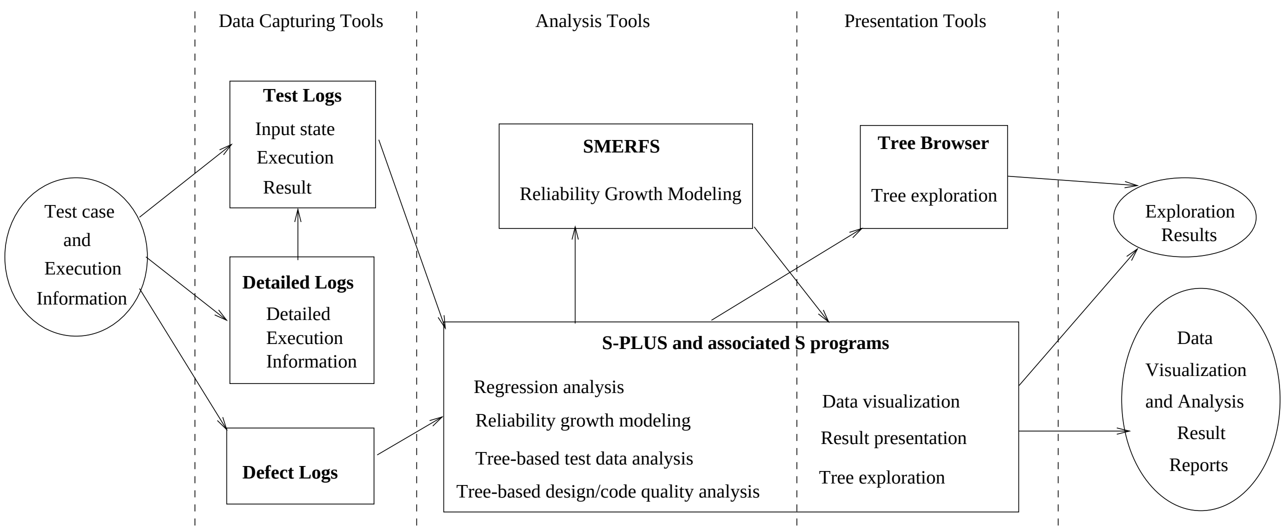
Integrated Approach: Implementation

- 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 $\downarrow$
  - ▷ 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.