Software Reliability and Safety

CSE 8317 — Spring 2015

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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: 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 ∼ 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.

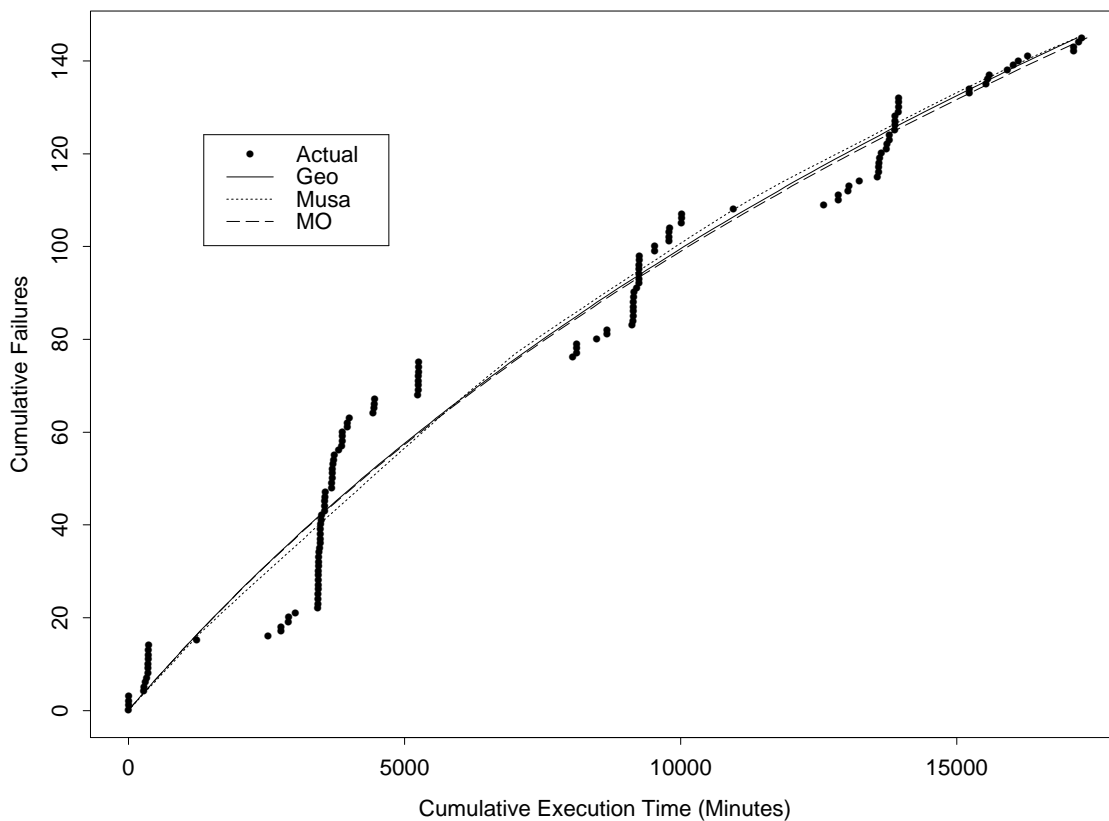184 days, 453 runs, 1293047422 transactions, 835530 execution minutes, 130 failures.
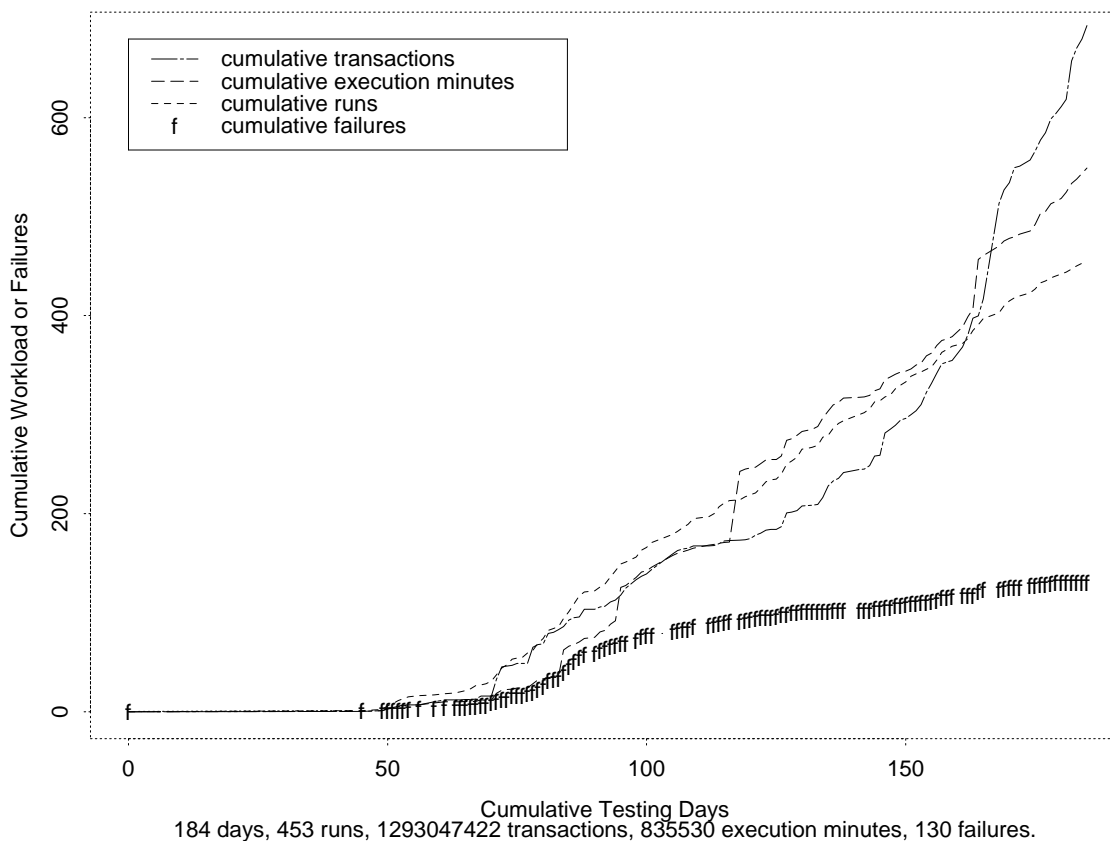
SRGMs: Application Experience

- Model applicability and effectiveness:

    ▷ calendar time models useless.
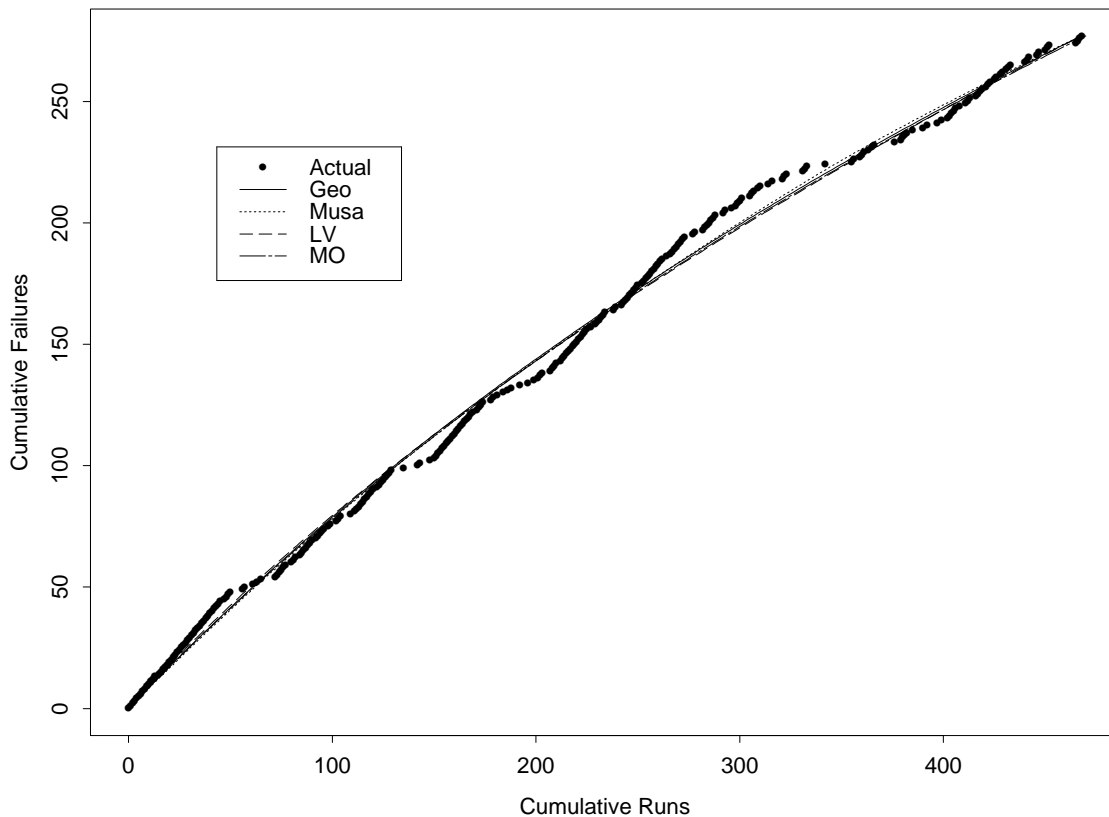   ▷ products A, B, and C: Fig.3 (Tian 1998)
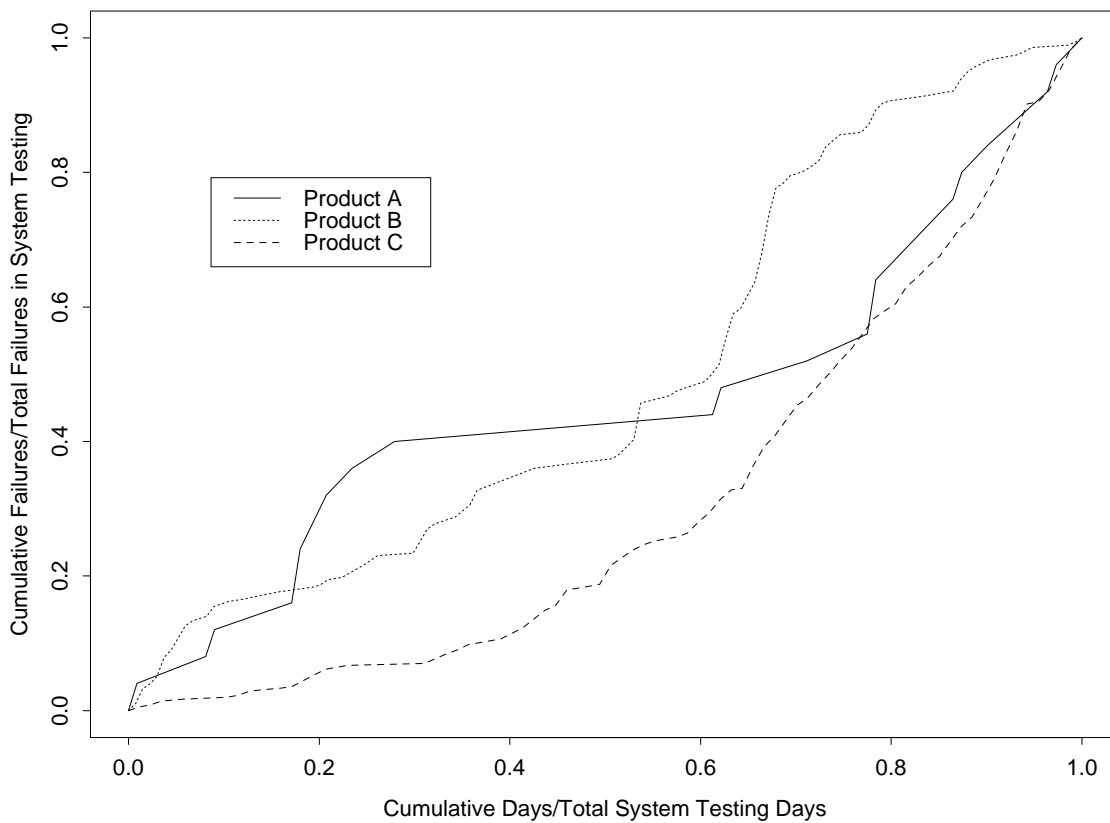
SRGMs: Application Experience

- 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.
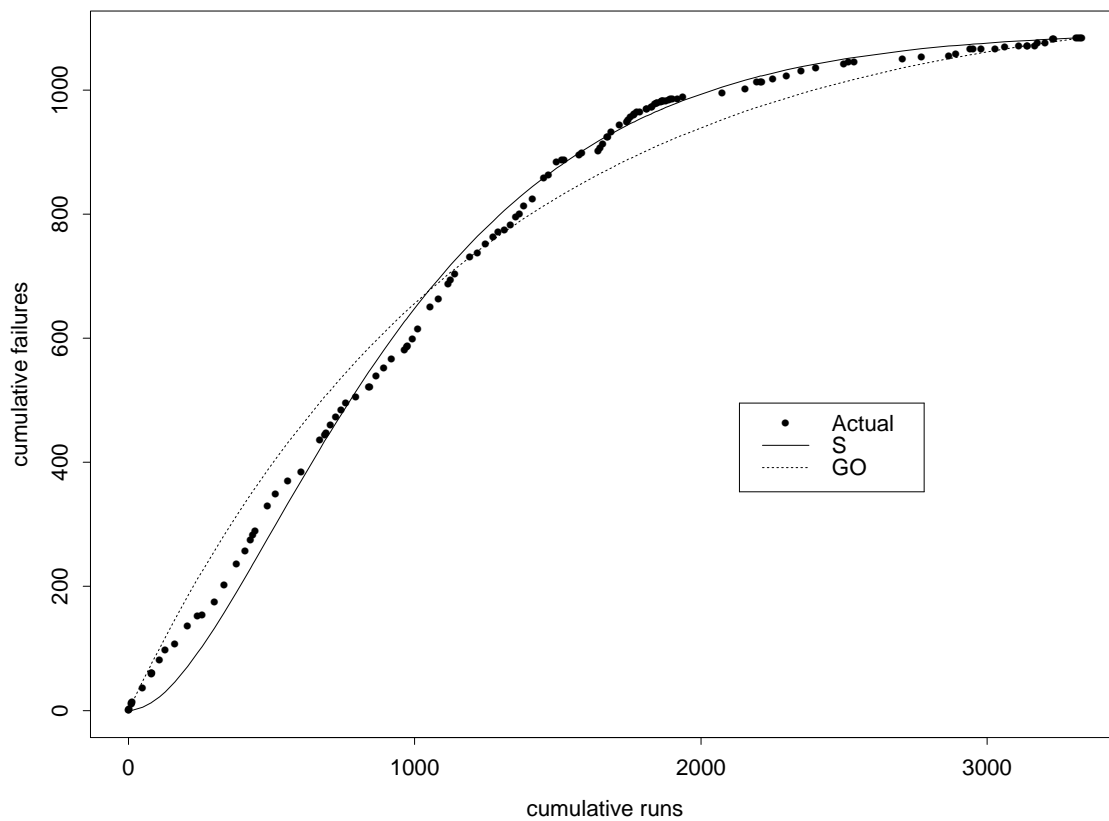 ▷ product B: Fig.6a (Tian 1998)

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.
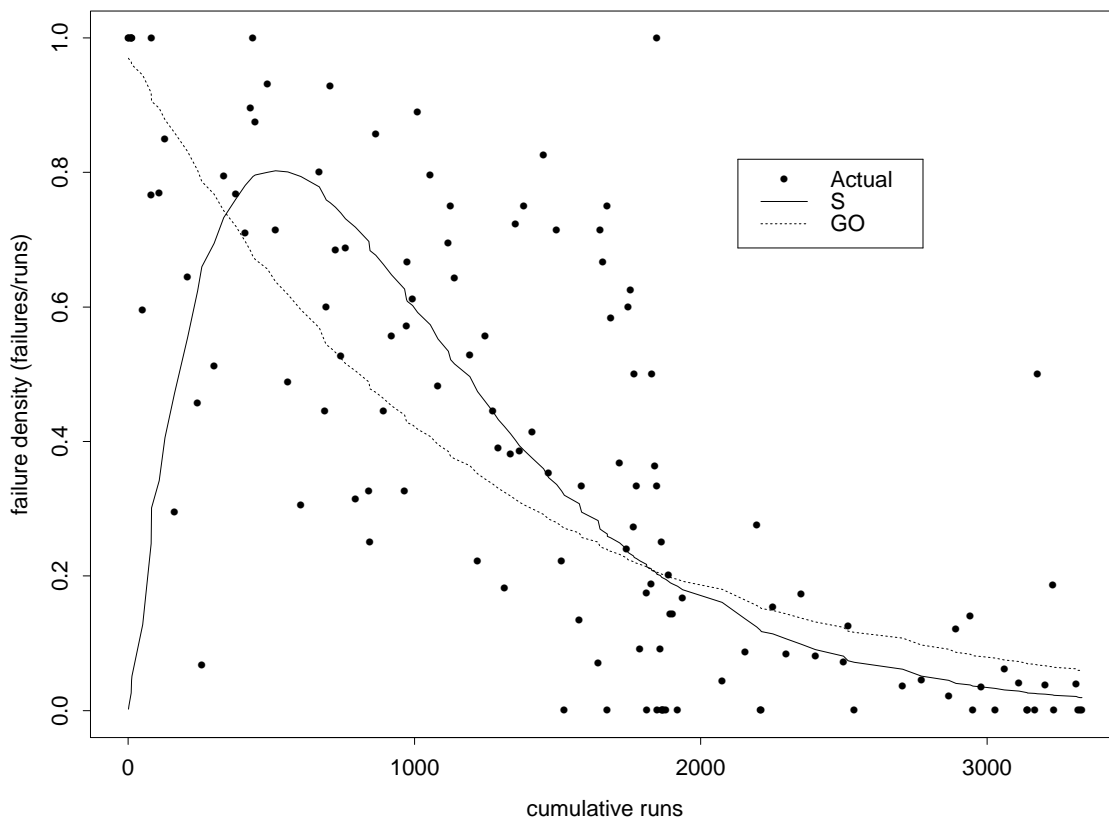   ▷ product D: Fig.8b (Tian 1998)

SRGMs: Application Experience

- Model applicability and effectiveness:

  ▷ transactions for other products.
  ▷ product E: Fig.9 (Tian 1998)
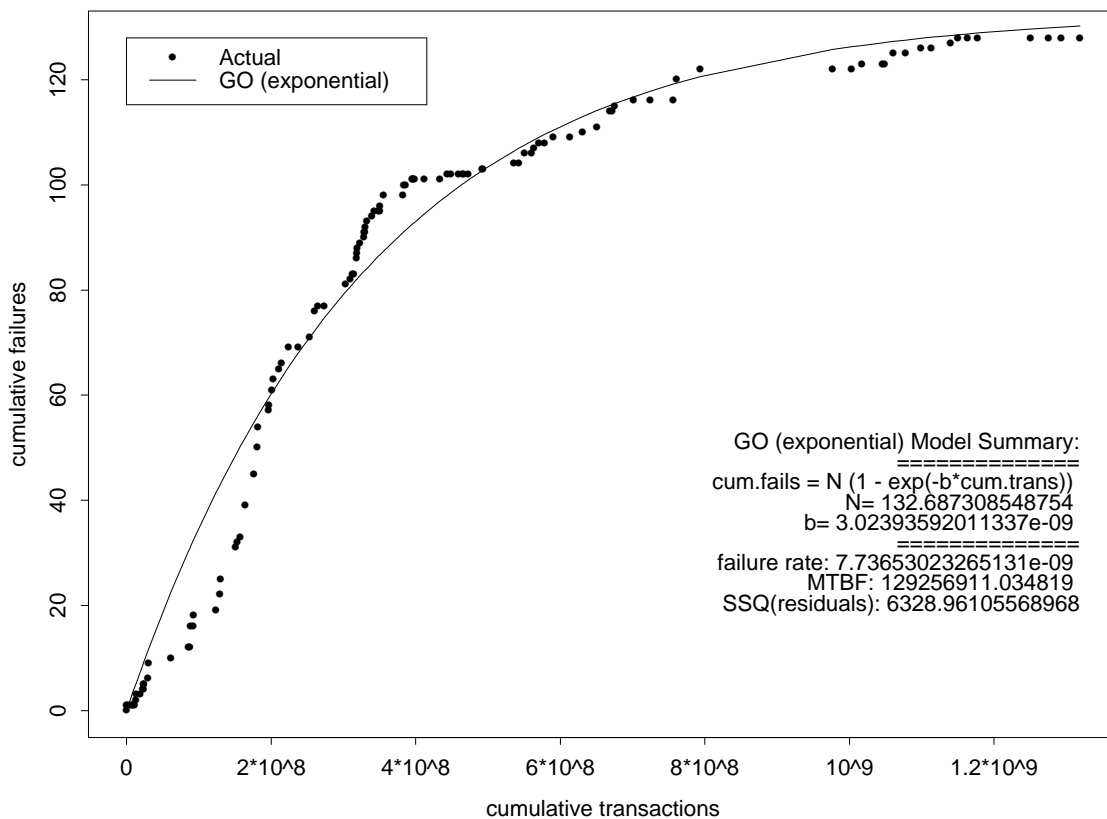
SRGMs: Application Experience

- Model applicability and effectiveness:

  ▷ time measurement comparison
  ▷ product E: Fig.5 (Tian 1998)
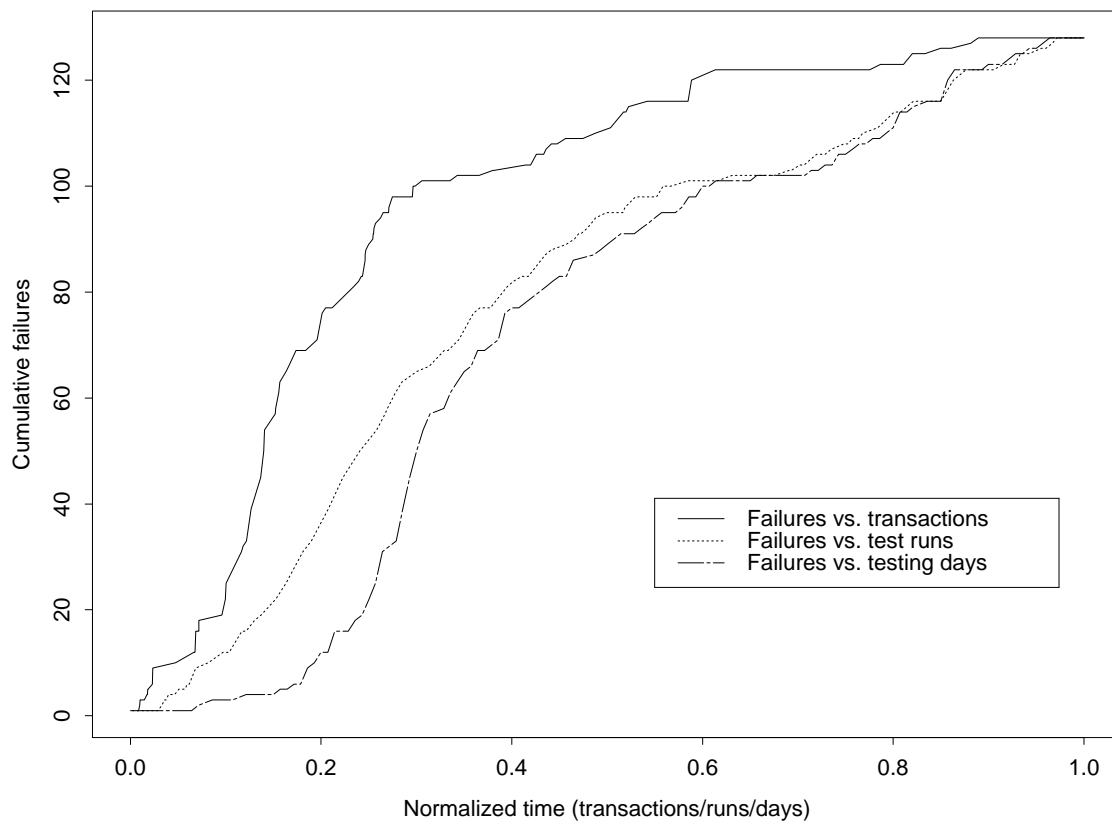
SRGMs: Application Experience

- Model applicability and effectiveness:

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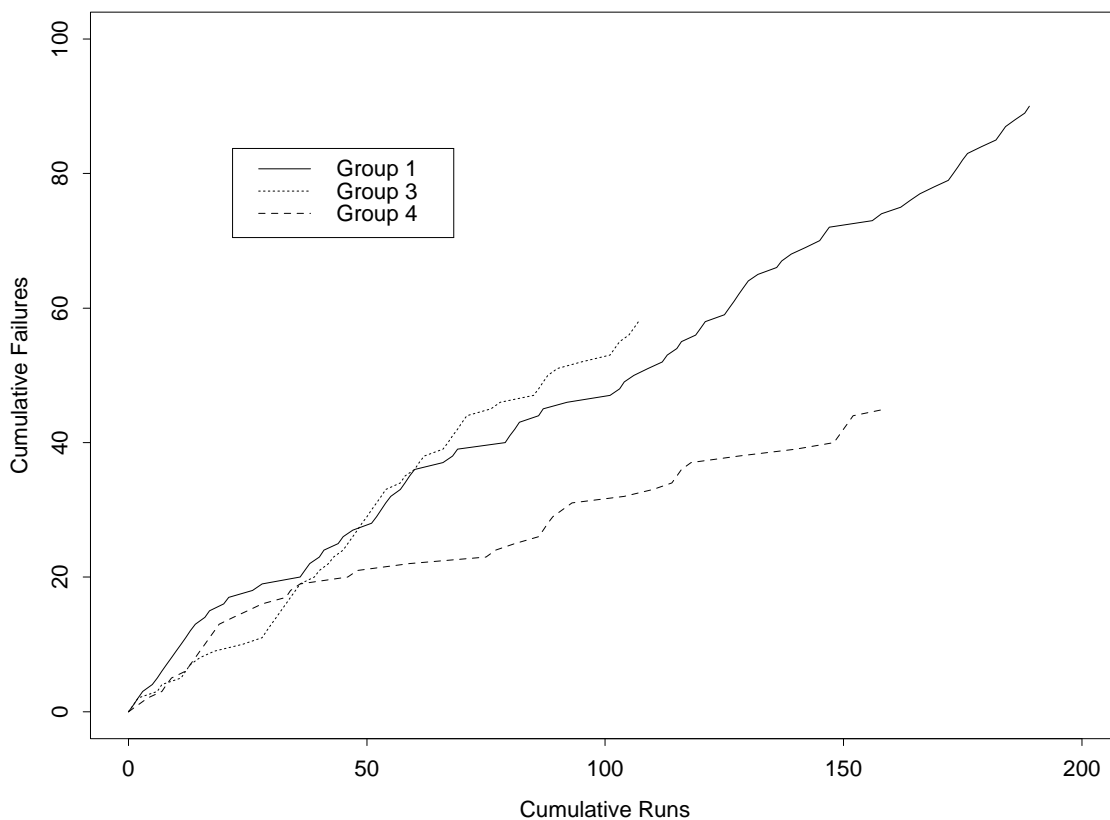
SRGM Conclusions

- 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 $X_1, \ldots, X_n$.

  ▷ 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)

```
                              s= 0.675
                              n= 3331
                   log:abfgjk          log:cdehil        Legend:  s= succ rate
                                                                  n=  # of runs
          s= 0.474                        s= 0.930
          n= 1864                         n= 1467       attr: cat.list      attr: cat.list
      log:fj      log:abgk          log:ci     log:dehl
  s= 0.276      s= 0.492          s= 0.883      s= 0.938
  n= 156        n= 1708           n= 223        n= 1244
           log:abk   log:g                  log:ehl   log:d
       s= 0.476    s= 0.608              s= 0.934    s= 0.962
       n= 1499     n= 209                n= 1060     n= 184
```
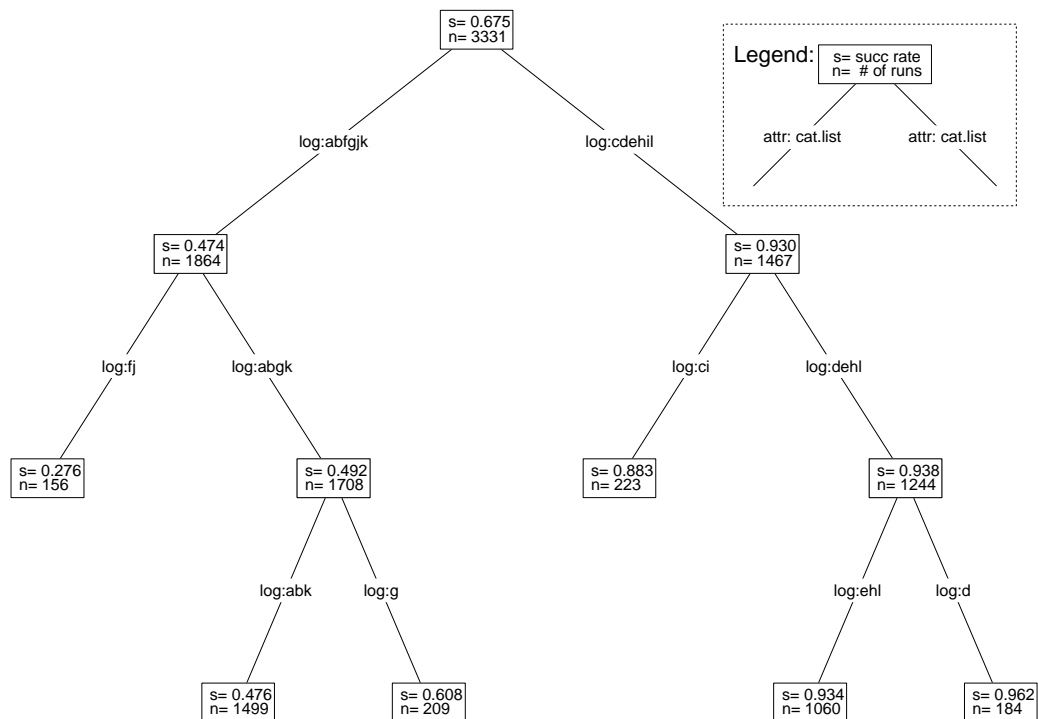
TBRM Simple Example

- ## 1 numerical predictor and 1 response:

  ▷ Binary operator ($\geq$) for partitioning

  ▷ Example: Fig 15 (Tian 1998)

```
                              s= 0.675
                              n= 3331
                 rsn<1487.5              rsn>1487.5
              s= 0.407                        s= 0.890
              n= 1487                         n= 1844
        rsn<519.5    rsn>519.5         rsn<1850.5  rsn>1850.5
      s= 0.320          s= 0.454      s= 0.730        s= 0.930
      n= 519           n= 968         n= 363         n= 1481
   rsn<309.5  rsn>309.5
  s= 0.417      s= 0.176
  n= 309       n= 210
rsn<137.5  rsn>137.5
s= 0.241    s= 0.558
n= 137      n= 172
```

Legend: s= succ rate / n= # of runs
attr<cutoff attr>cutoff
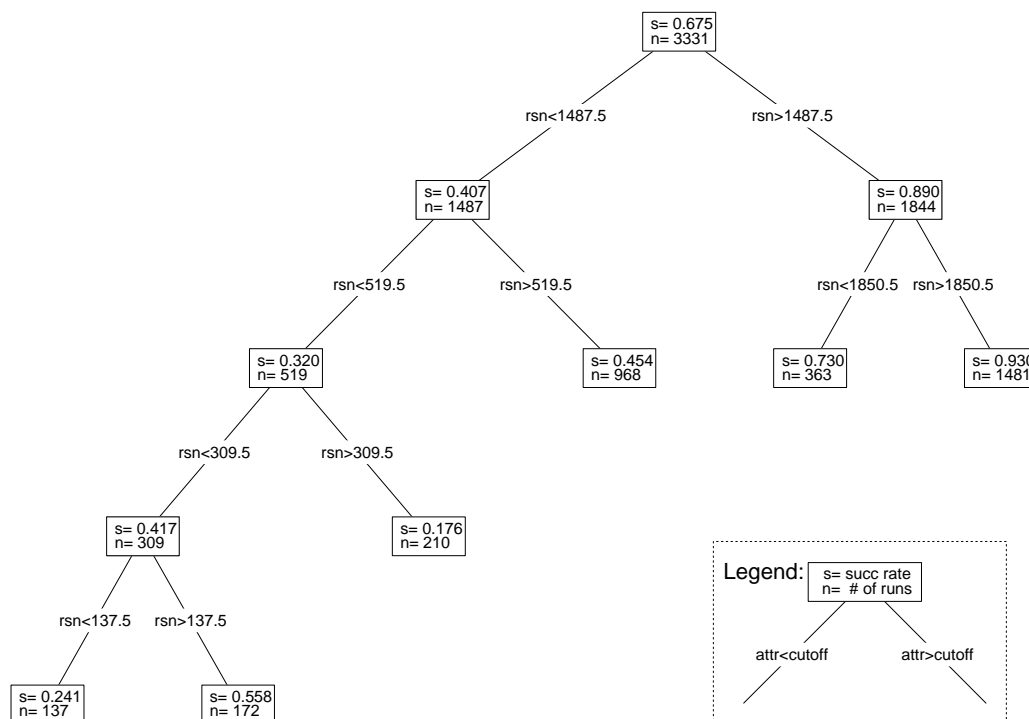
TBRM Simple Example

- 1 categorical predictor and 1 response:

    ▷ Interpretation as piecewise linear model
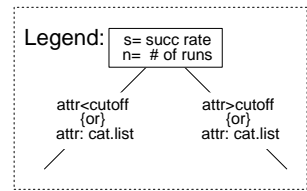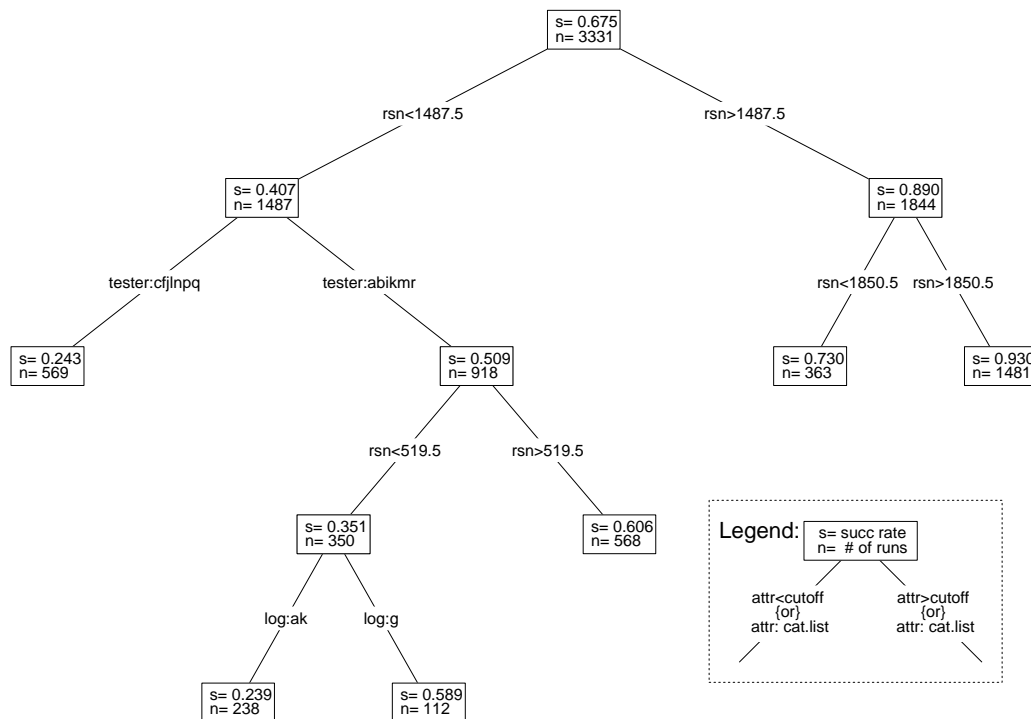   ▷ Example continued: Fig 14 (Tian 1998)
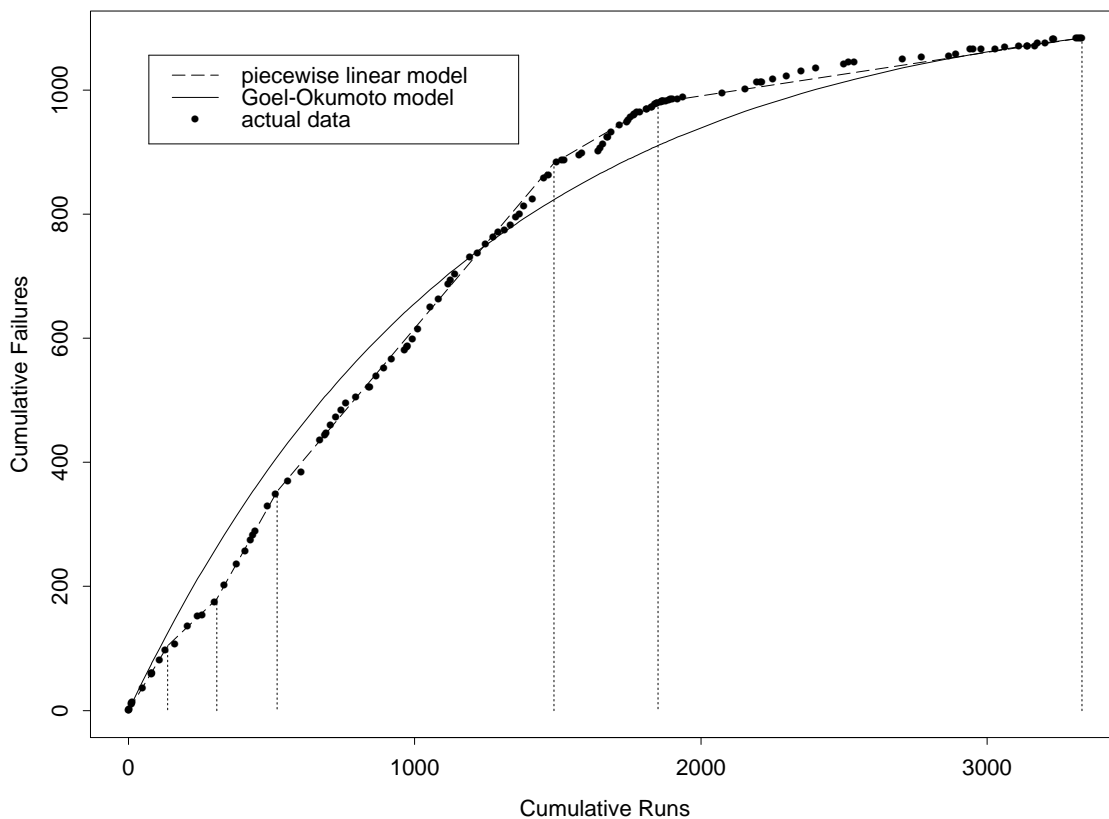
TBRM Example

- n mixed predictors and 1 response:

  ▷ full TBRM
  ▷ Example: Fig 11 (Tian 1998)

```
                        s= 0.675
                        n= 3331
              rsn<1487.5        rsn>1487.5
          s= 0.407                      s= 0.890
          n= 1487                       n= 1844
   tester:cfjlnpq   tester:abikmr   rsn<1850.5  rsn>1850.5
  s= 0.243            s= 0.509      s= 0.730    s= 0.930
  n= 569             n= 918         n= 363      n= 1481
                rsn<519.5  rsn>519.5
            s= 0.351          s= 0.606
            n= 350            n= 568
      log:ak    log:g
    s= 0.239   s= 0.589
    n= 238     n= 112
```

Legend:
```
          s= succ rate
          n= # of runs
attr<cutoff          attr>cutoff
   {or}                 {or}
attr: cat.list       attr: cat.list
```

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.
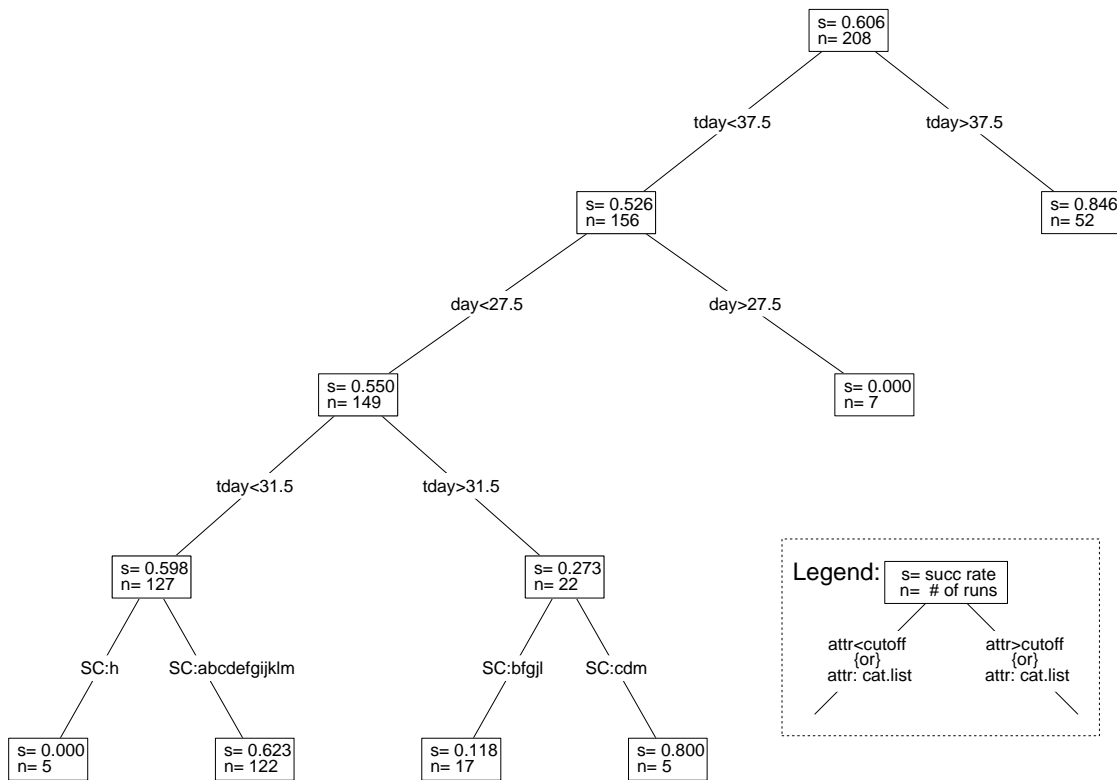
  ▷ Guide for remedial actions.

- Results interpretation:

  ▷ Progression of trees & tree types.

  ▷ Usage as exit criteria.

TBRMs at Different Times
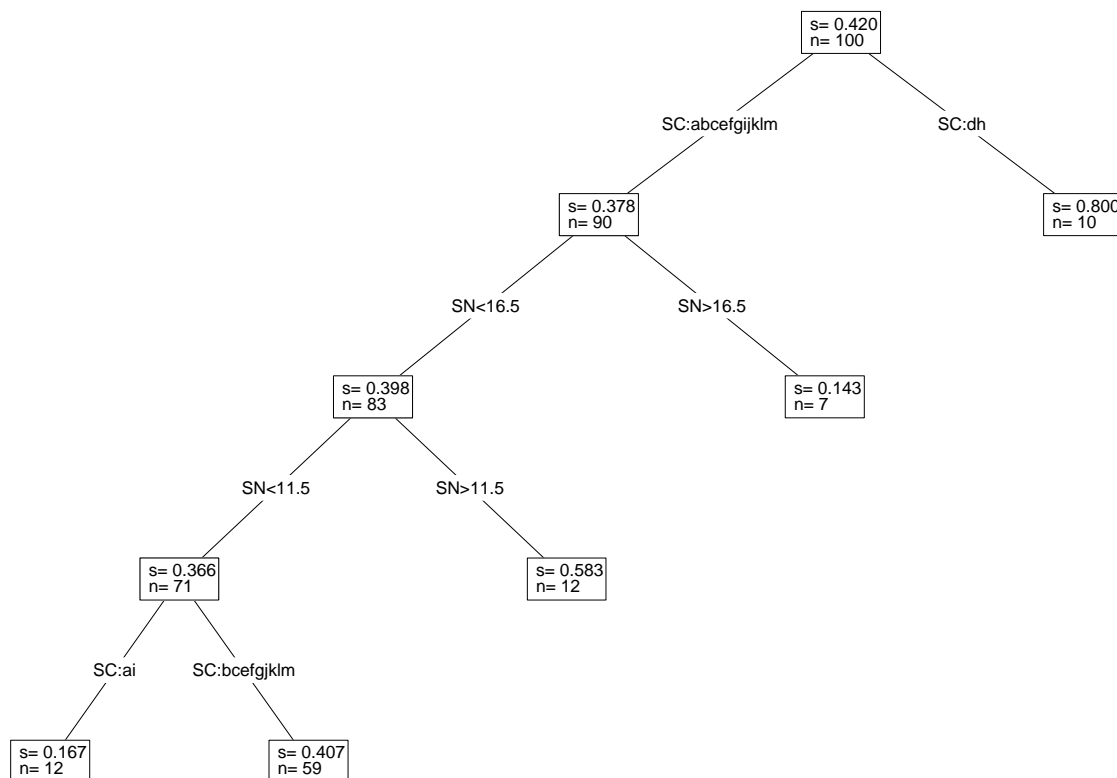
- Fig 12a (Tian 1998): an early TBRM.

  ▷ 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:

  $\triangleright$ Trend of reliability growth.
  $\triangleright$ Stability of failure arrivals.
  $\triangleright$ Estimated reliability.
  $\triangleright$ Product purity level at exit.

- Process changes & improvements:

  $\triangleright$ Failure detection and fault removal.
  $\triangleright$ Long term effect on development.

- Ultimate test: in-field problems.

TBRM Result Comparison
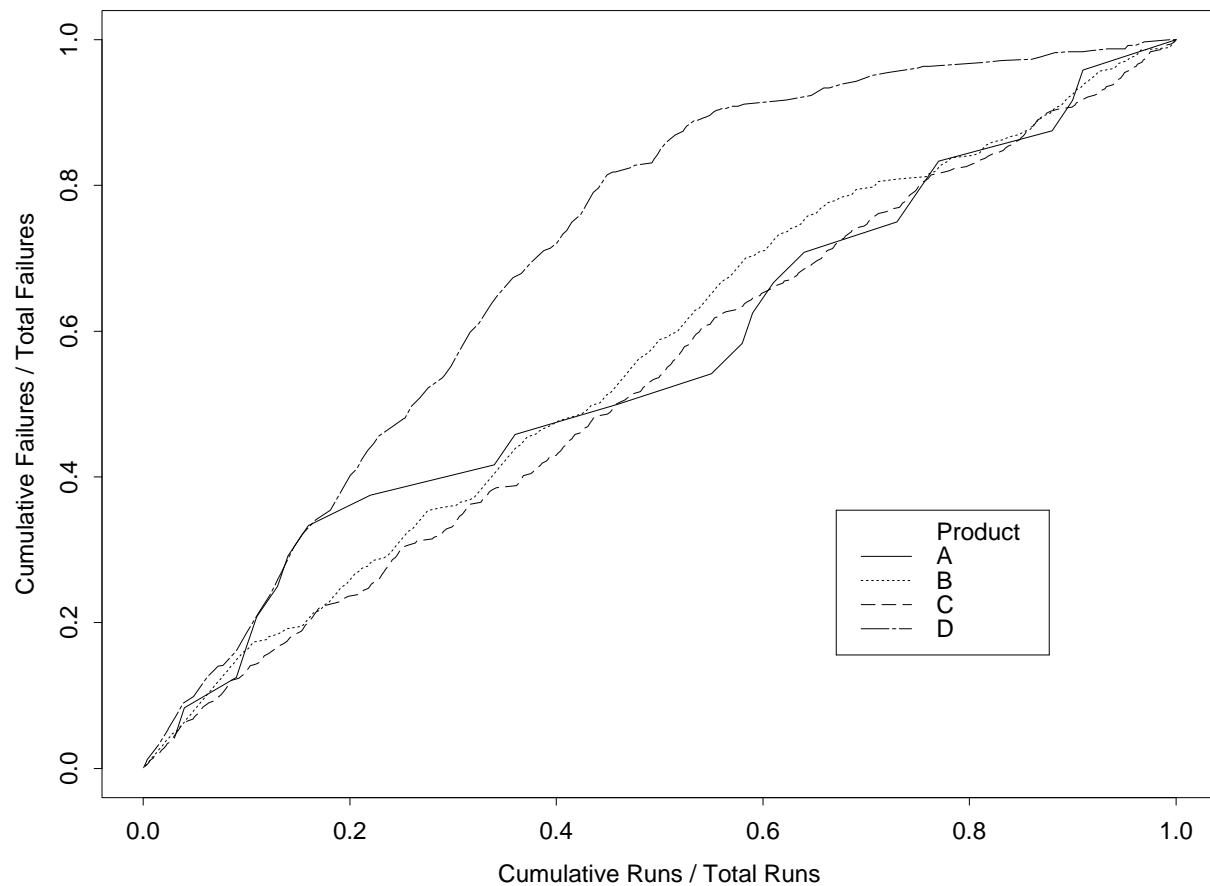
- Fig 22.6 (p.384): TBRMs used in D

  ▷ 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

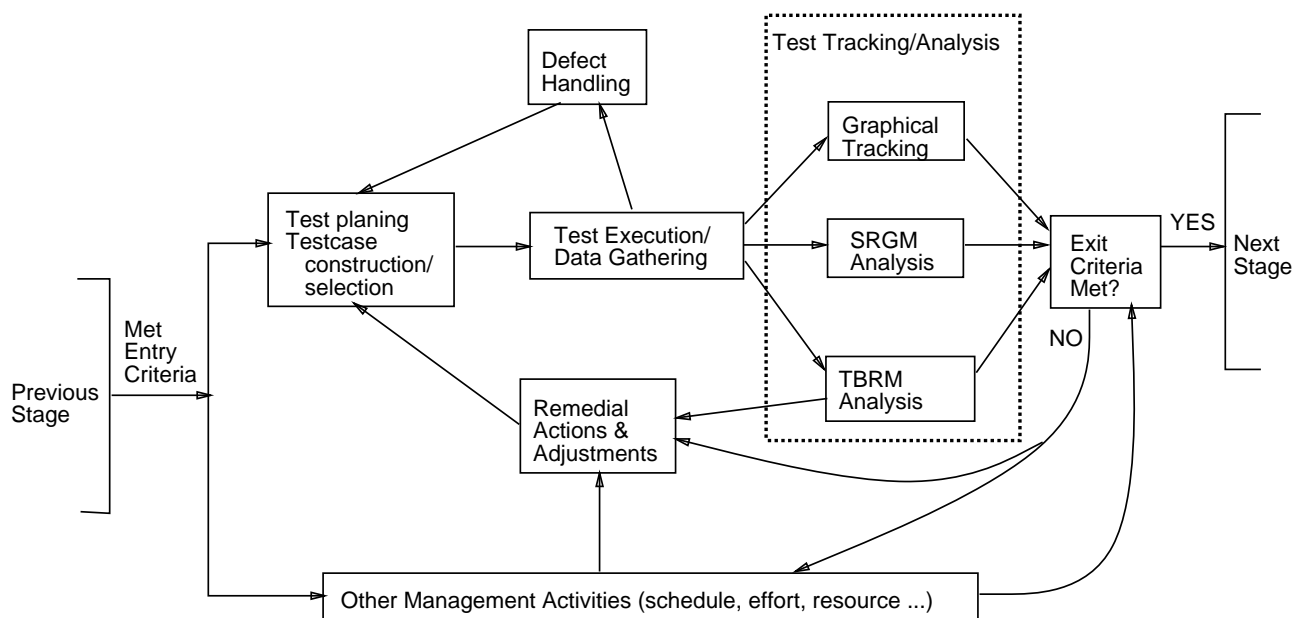| Purification	Product			
Level ρ	A	B	C	D
maximum	0.715	0.527	0.542	0.990
median	0.653	0.525	0.447	0.940
minimum	0.578	0.520	0.351	0.939

Where: $\rho = \dfrac{\lambda_0 - \lambda_T}{\lambda_0} = 1 - \dfrac{\lambda_T}{\lambda_0}$
λ_0: failure rate at start of testing
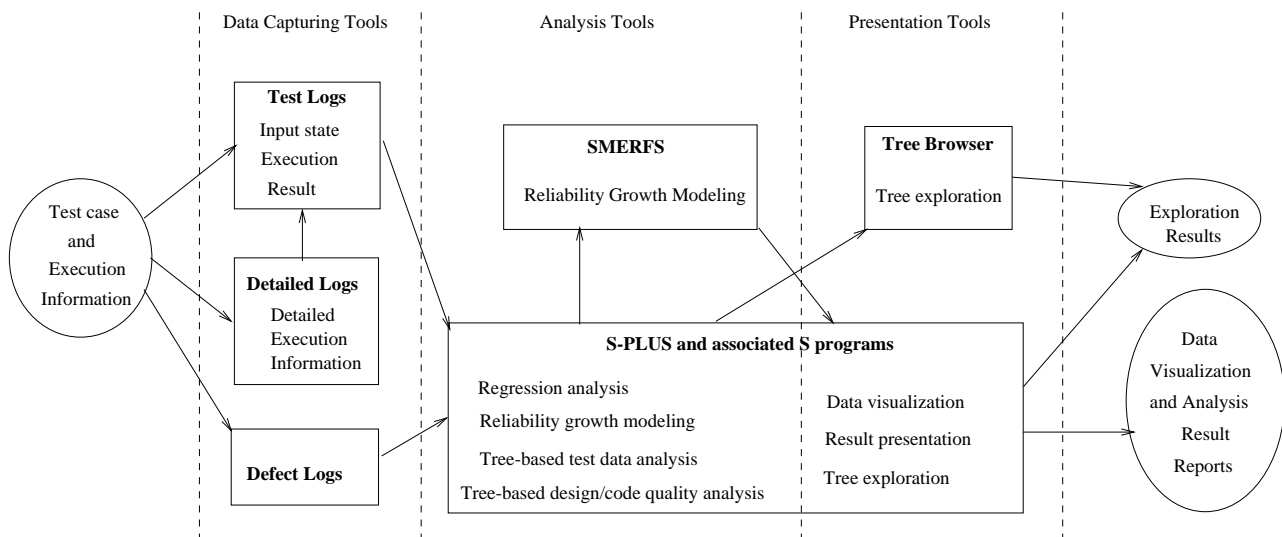λ_T: failure rate at end of testing

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

Data Capturing Tools   Analysis Tools   Presentation Tools

Test Logs
Input state
Execution
Result

SMERFS
Reliability Growth Modeling

Tree Browser
Tree exploration

Test case
and
Execution
Information

Exploration
Results

Detailed Logs
Detailed
Execution
Information

S-PLUS and associated S programs

Regression analysis
Reliability growth modeling
Tree-based test data analysis
Tree-based design/code quality analysis

Data visualization
Result presentation
Tree exploration

Data
Visualization
and Analysis
Result
Reports

Defect Logs

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.