

**Intelligent Infrastructures: Workshop on Failure and Diagnosis  
of Underground Power Distribution Cables**

**The Road to Reliability Starts with  
*Selection***

**February 2008**

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# Cable Diagnostic Focused Initiative

Supported by more than 25 organisations

Electric Utilities

Department of Energy

Service Providers

Manufacturers

Practical work: laboratory & field

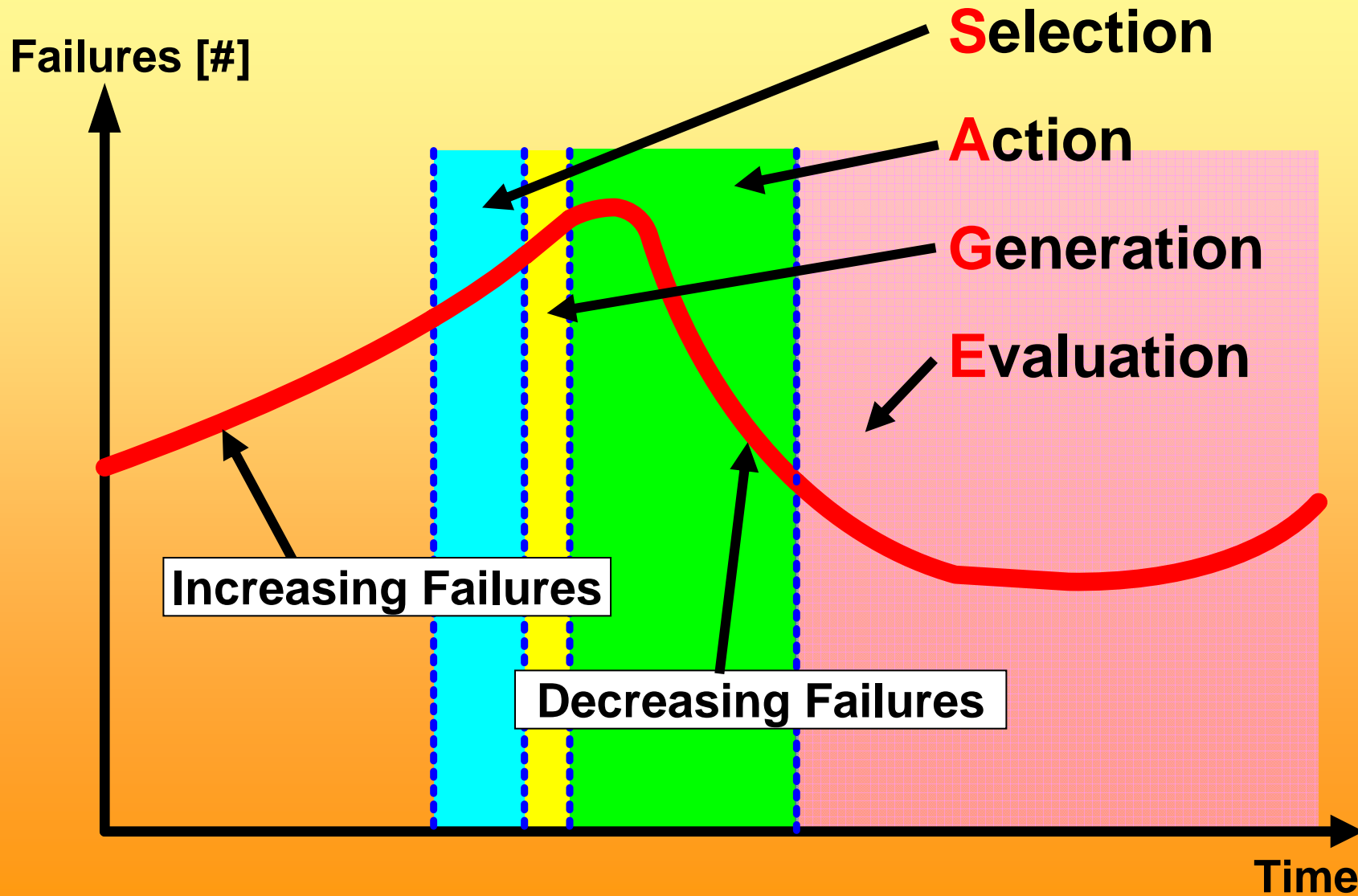
Analytical work: historical data, field data & lab data

Thoughts based on

- >5000 miles of cable system information
- 9 different diagnostic approaches / techniques

# Motivation

- Diagnostic programs are used to prevent service failures by identifying segments that will fail so corrective action can be taken.
- A Targeted Maintenance program uses diagnostic test(s) to identify these “weak” circuits within a target population.
- Diagnostic program should only be employed where positive benefit is achieved even with the upfront costs of testing.



# Issues

- How to select the target population?
  - Determines the maximum benefit the program can deliver.
- How to select suitable actions?
  - Actions dictate what diagnostic to employ.
- How to select the diagnostic test?
  - Accuracy is vital to obtaining benefit.

# Selection

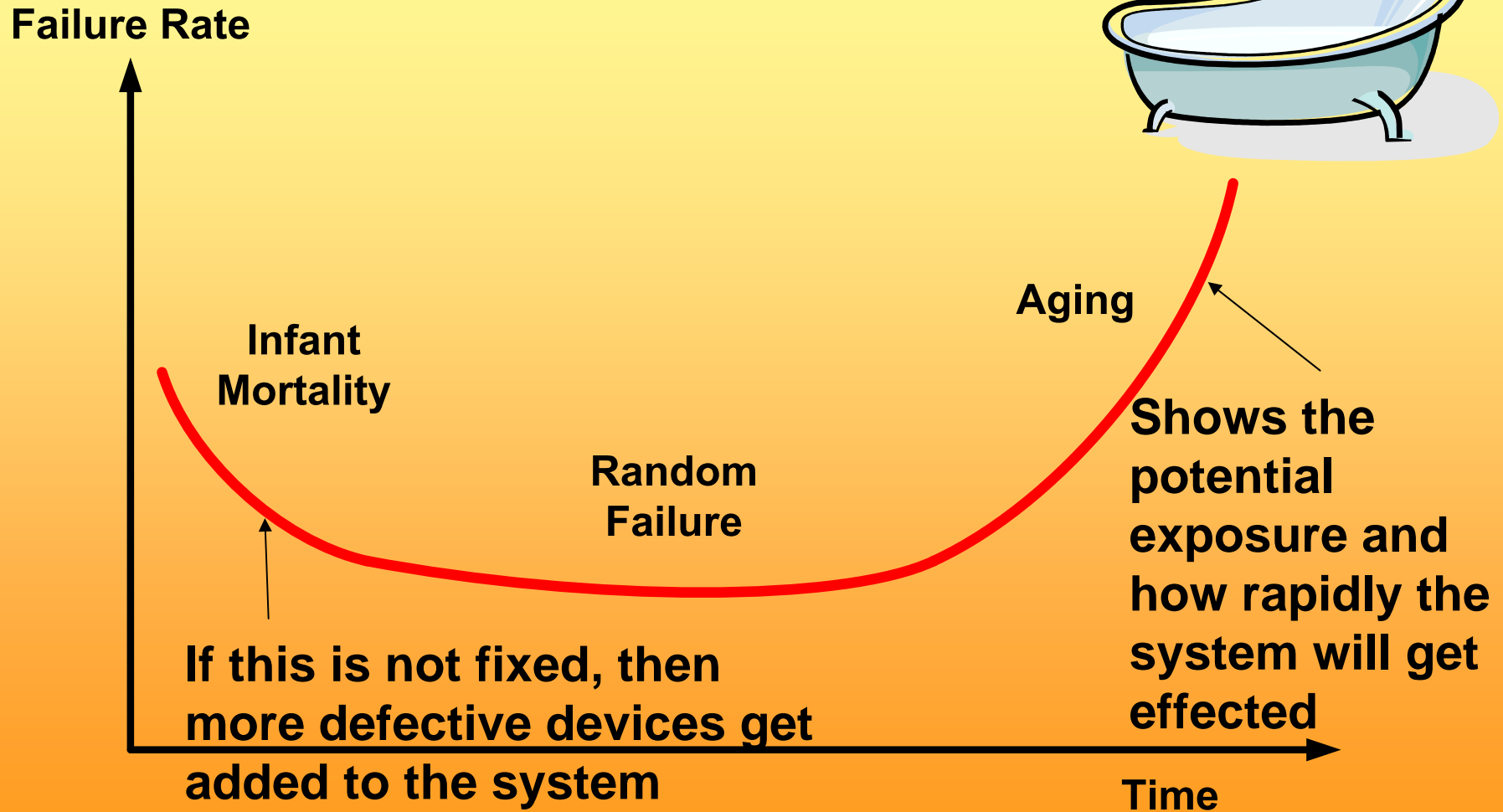
**When to start?  
Where to go?**

# When to start?

How to spot the trend?

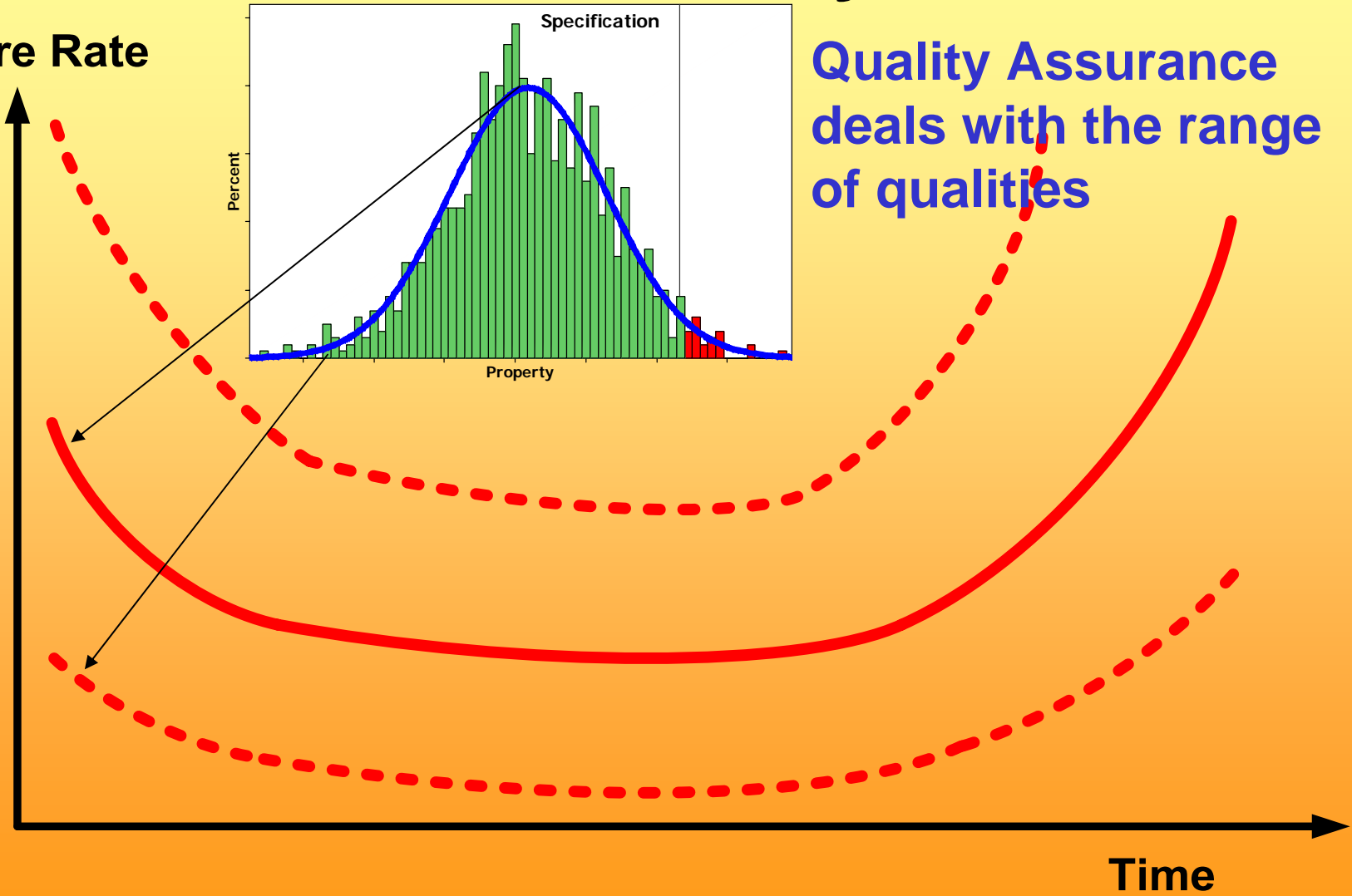
How late can you leave it before it is too late?

# Bathtub / Reliability Curve



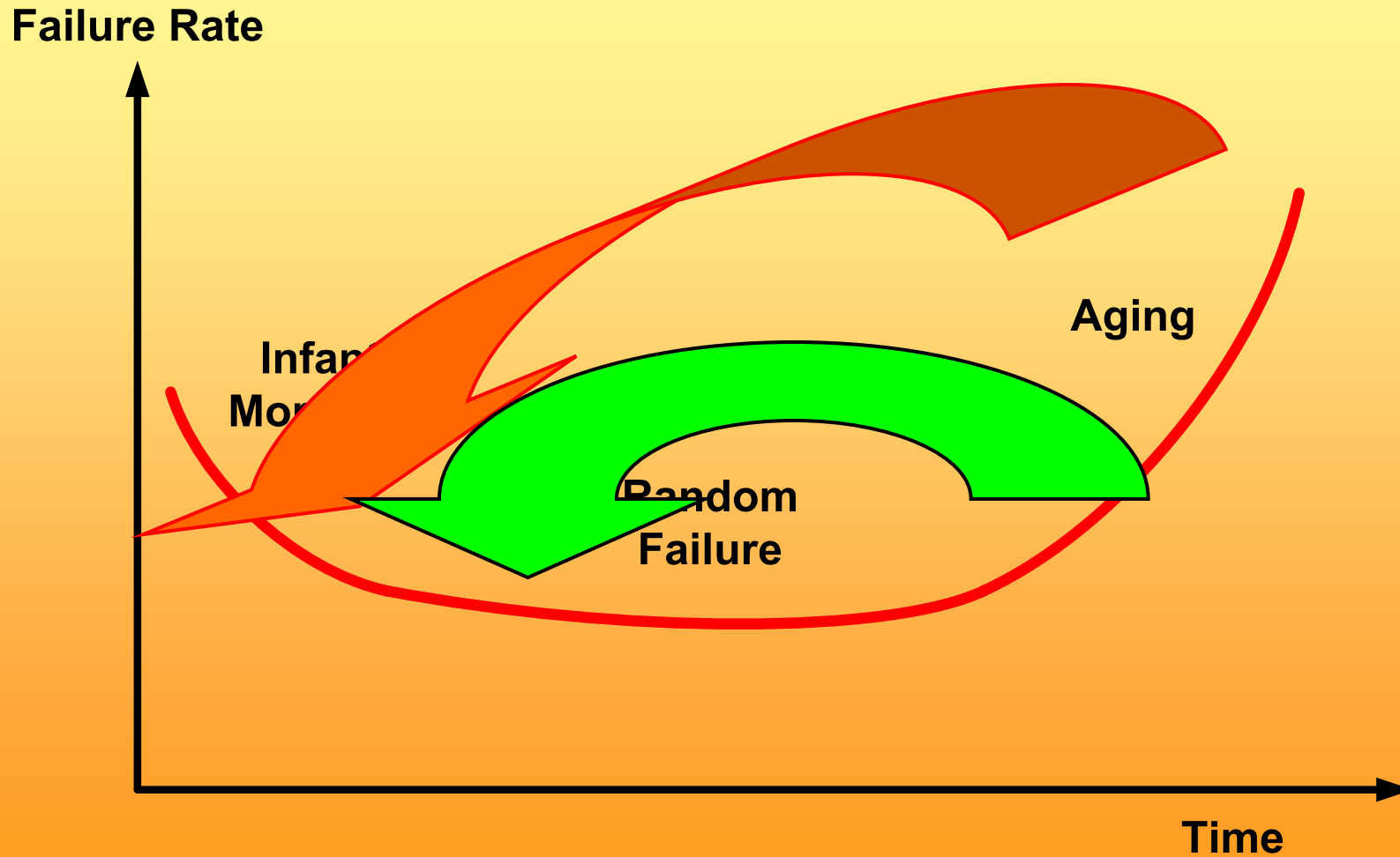
# Bathtub / Reliability Curve

Failure Rate

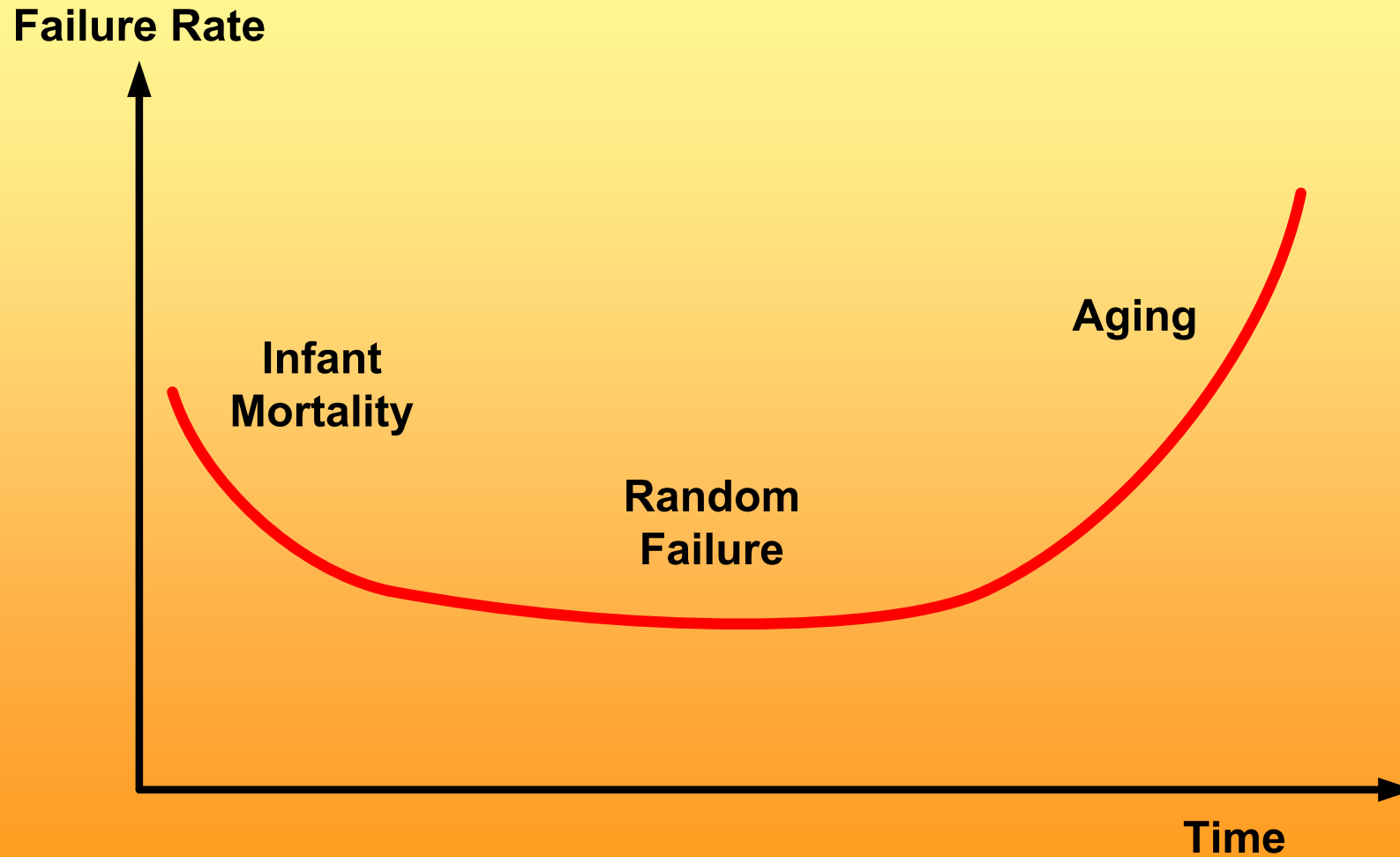


Quality Assurance  
deals with the range  
of qualities

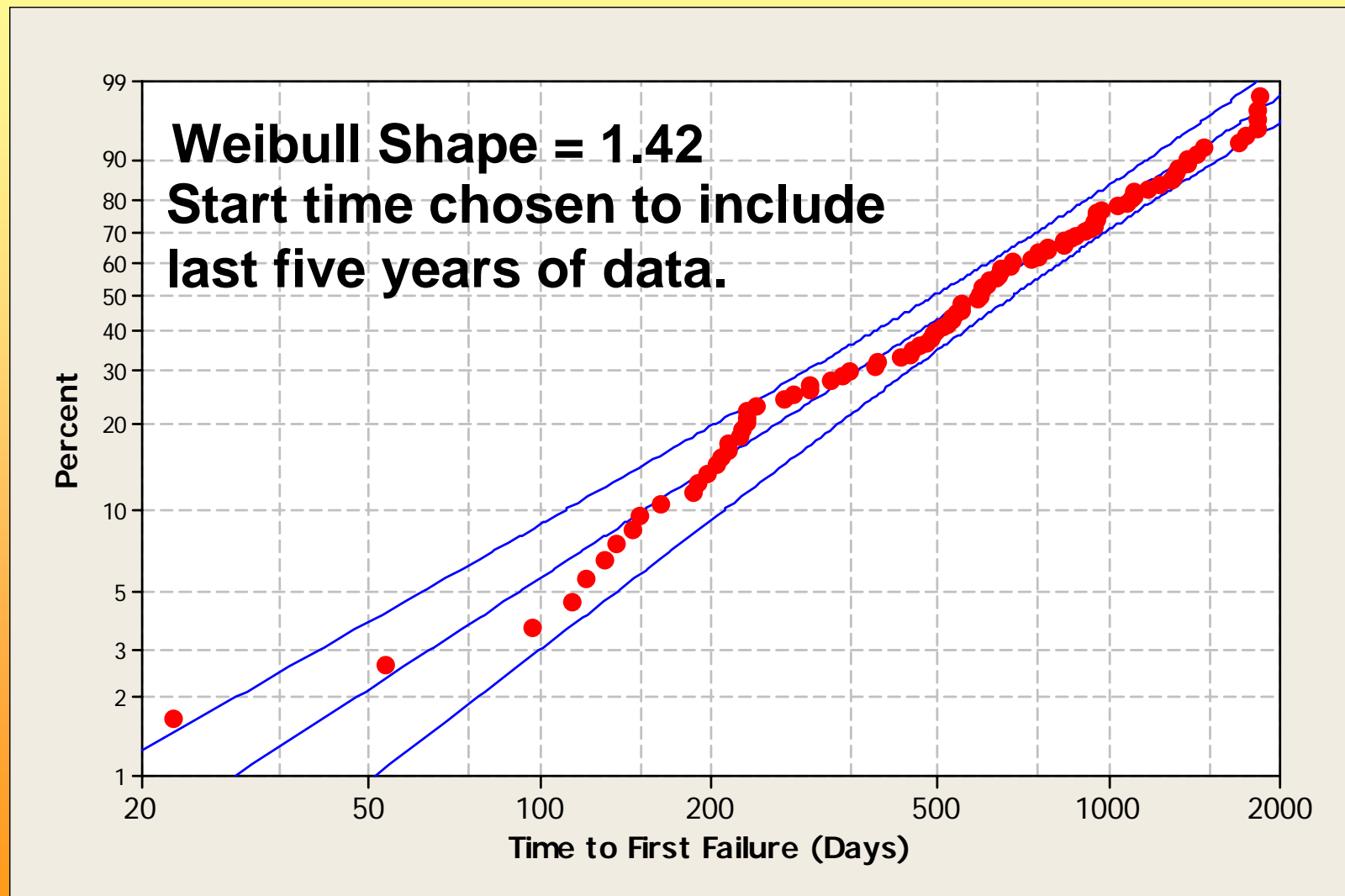
# New is not always better



# How do we spot the upswing?



# Sample Circuit Population



# Where to go?

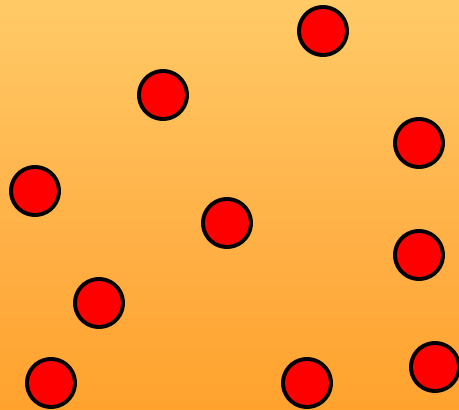
**The failure rate is not the same everywhere**

# Target Population?

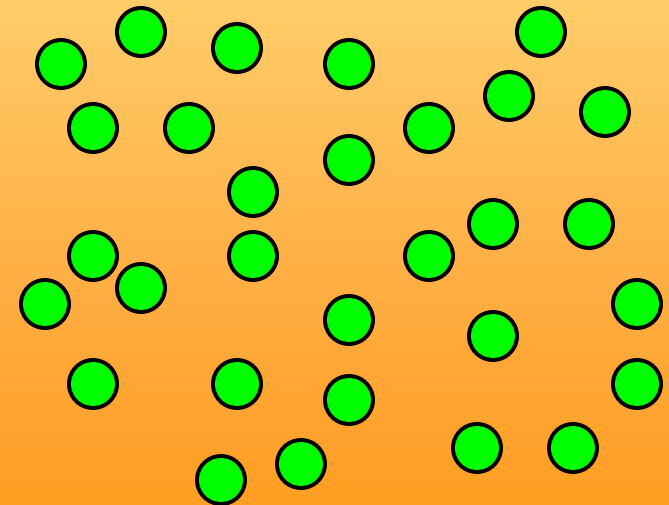
The target population is a subgroup of circuits and will likely contain both “Good” and “Bad” circuits

- “Good” – Will not fail within diagnostic horizon
- “Bad” – Will fail within diagnostic horizon

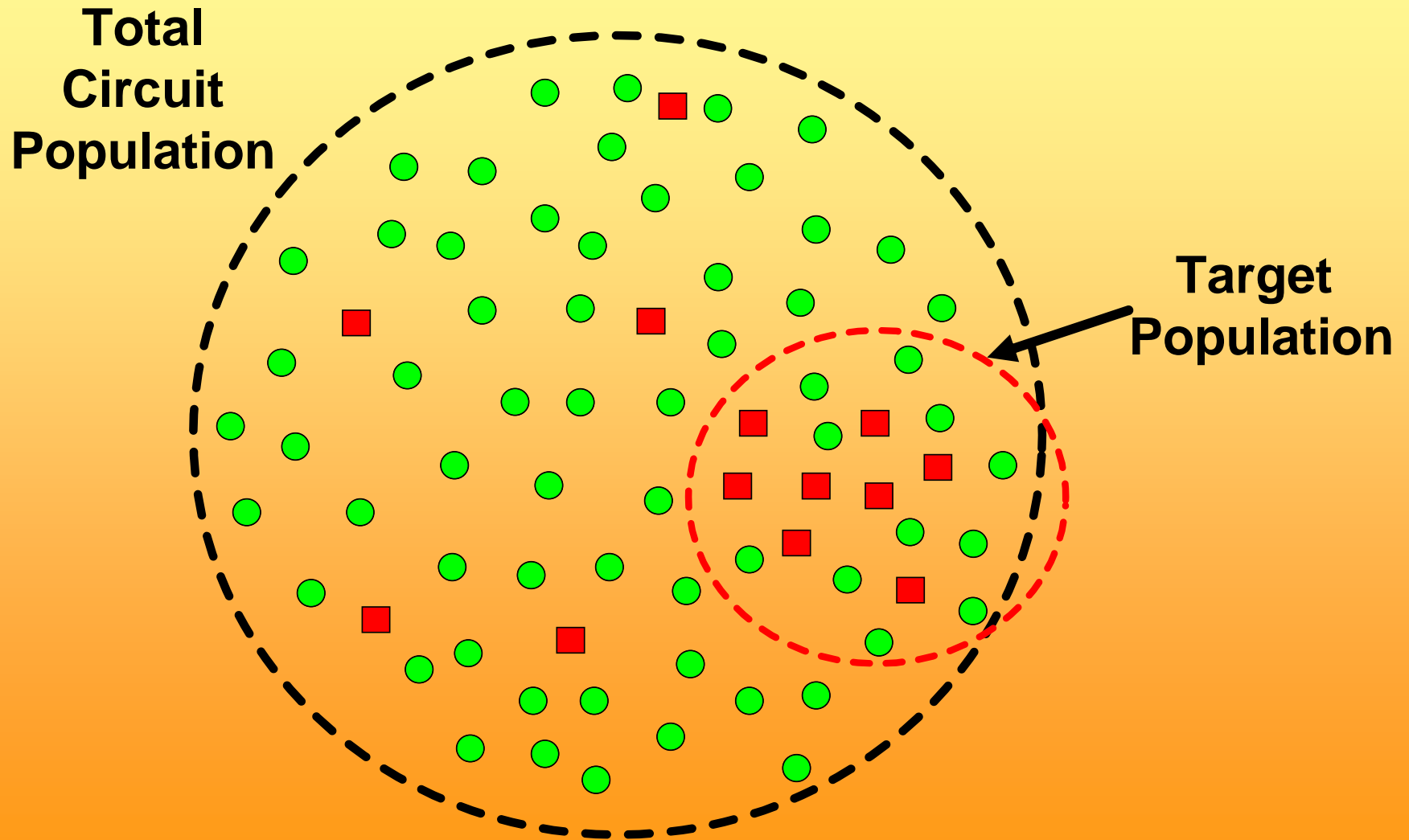
“Bad” Circuits



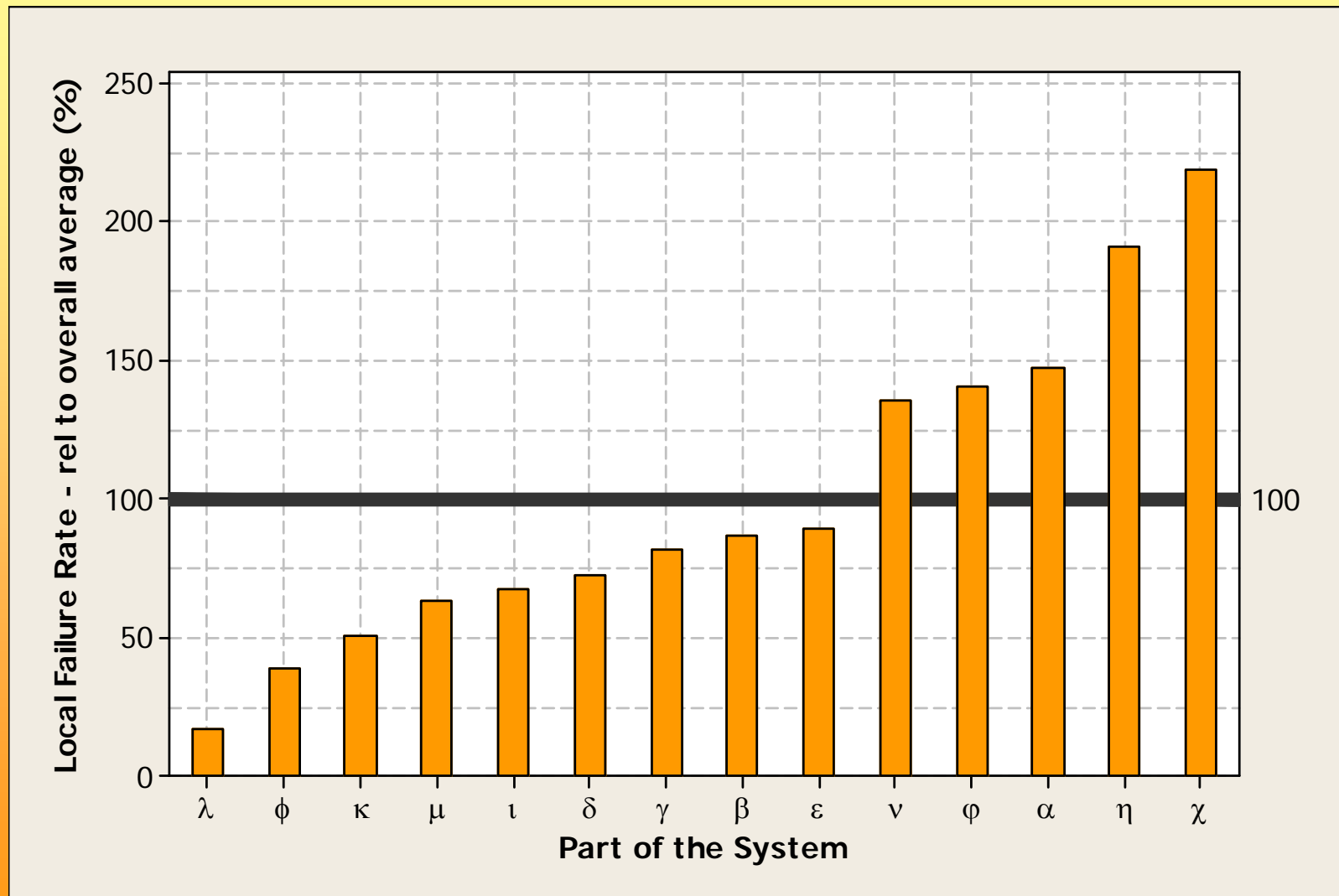
Target Population “Good” Circuits



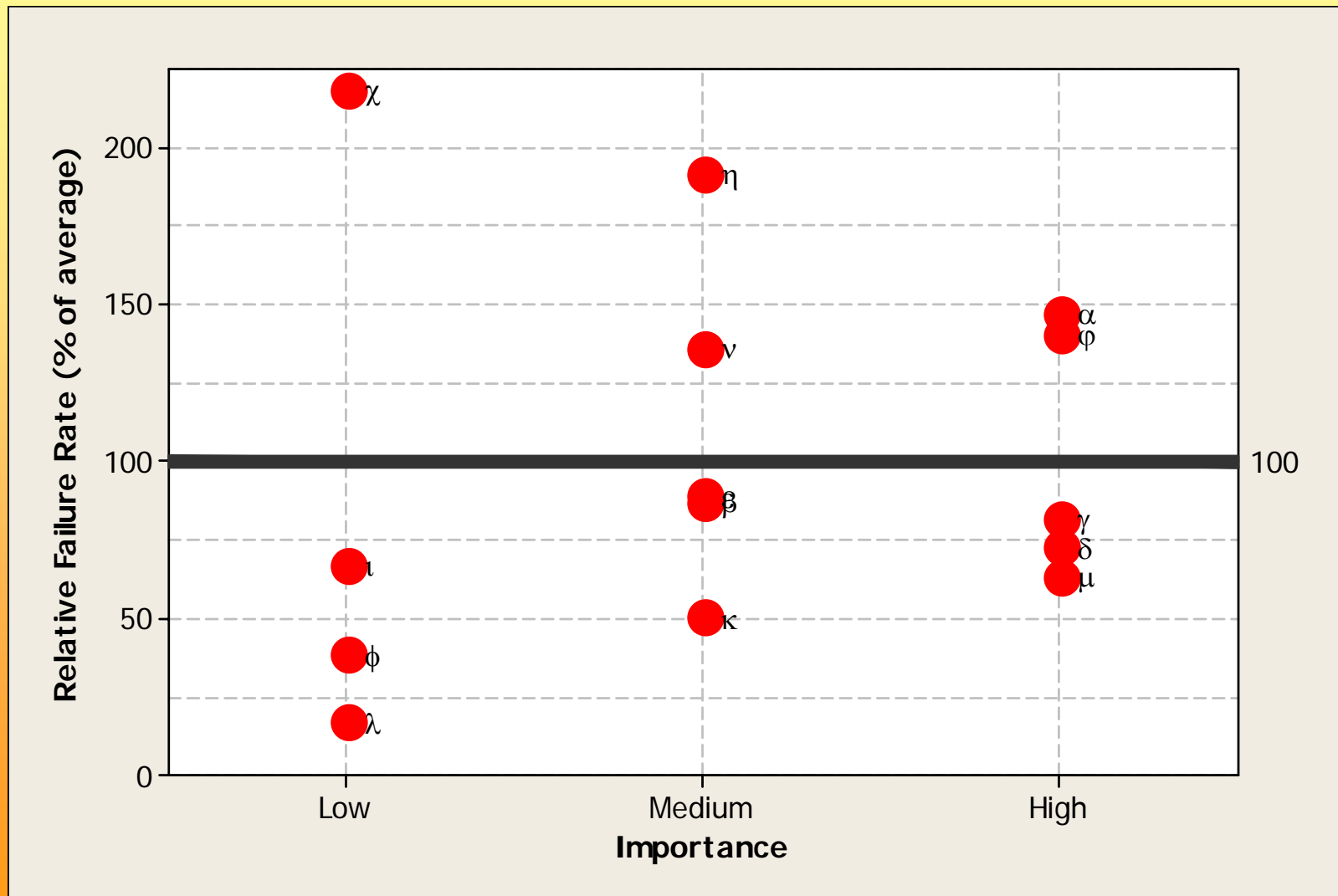
# Selecting from the Whole



# Local Failure Rates



# Importance & Failure Rate



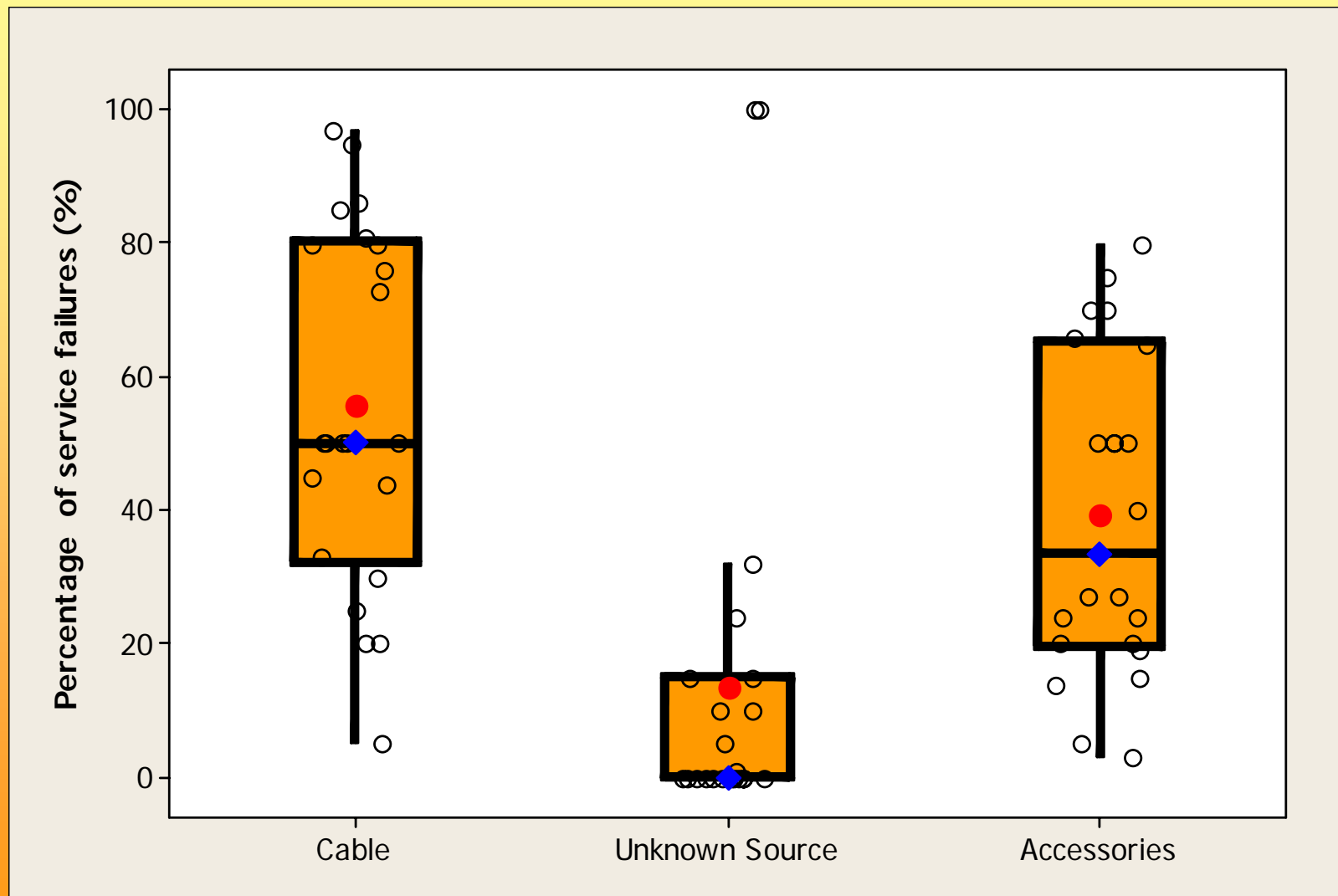
# Action

**How to fix things?**

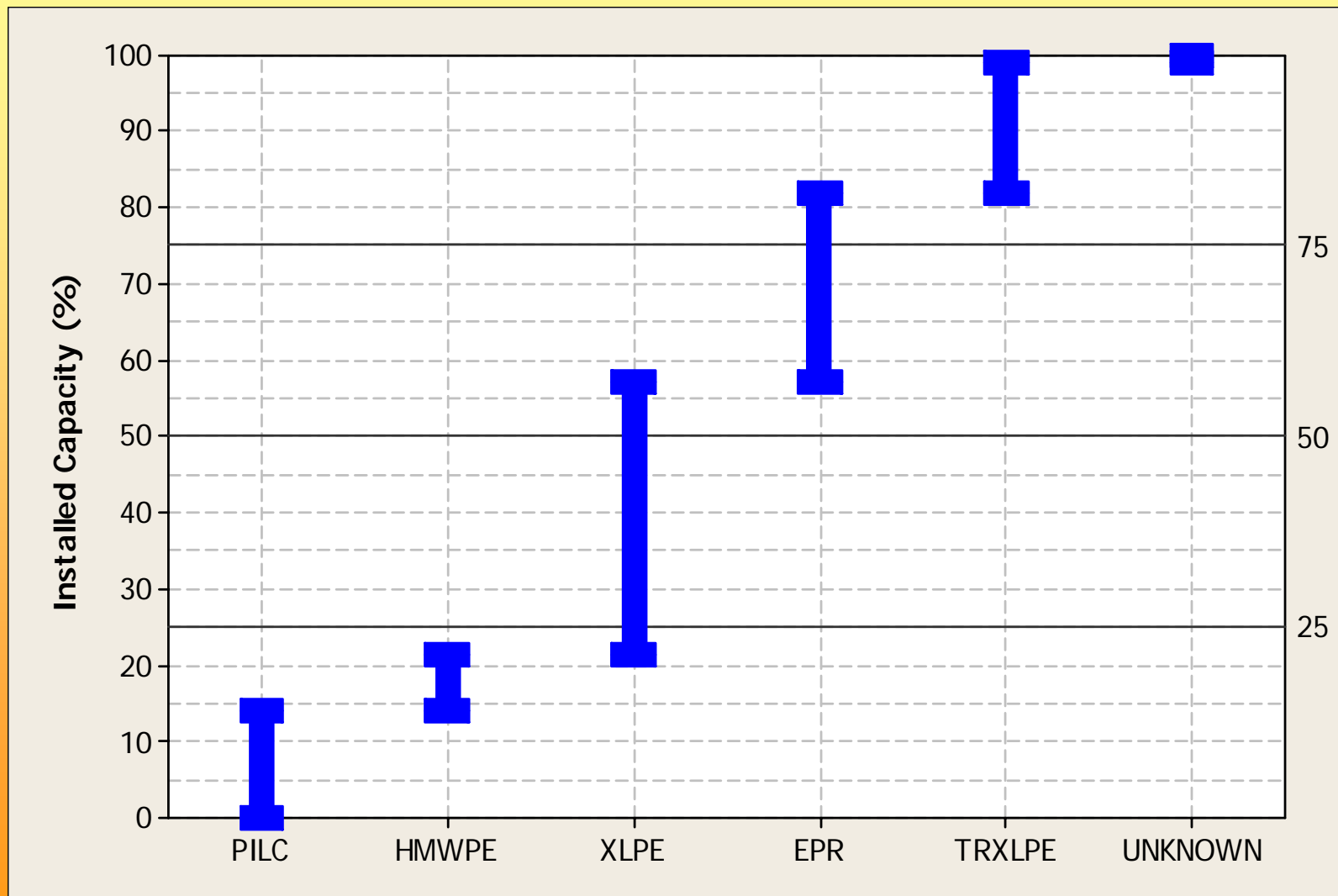
# Considerations

- Accessory versus cable failures
- Reliability of maintenance
  - Splice installation may be too unreliable
- Utility policies
  - Equipment or design upgrades
- Cost
  - Repair may cost as much as replacement
- New equipment has a long term value

# Equipment Type



# Cable Population



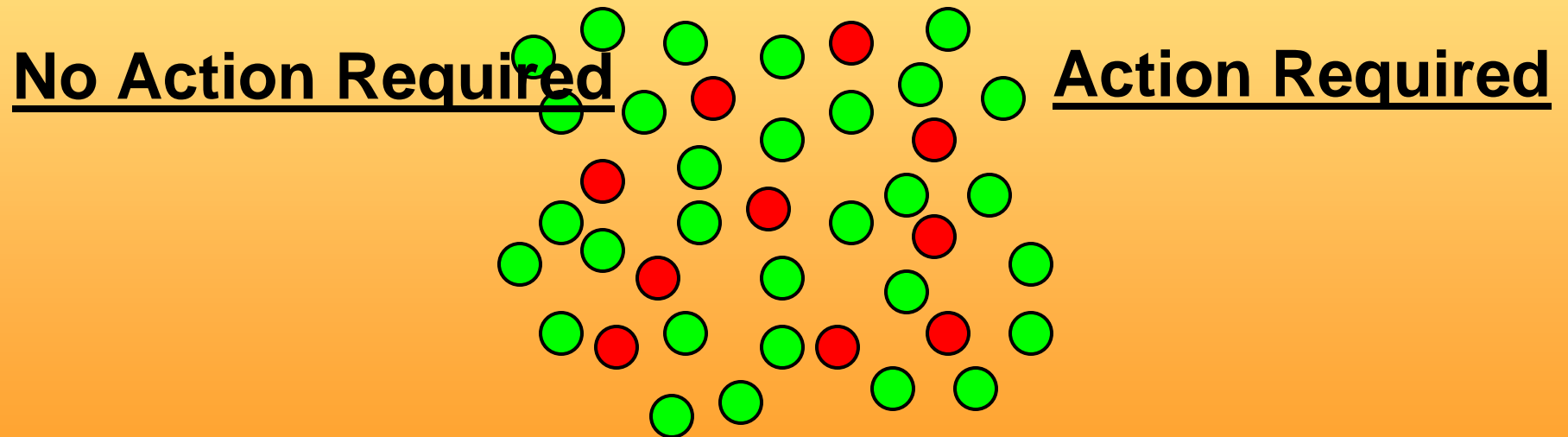
# Generation

How to choose the diagnostic?

# Considerations

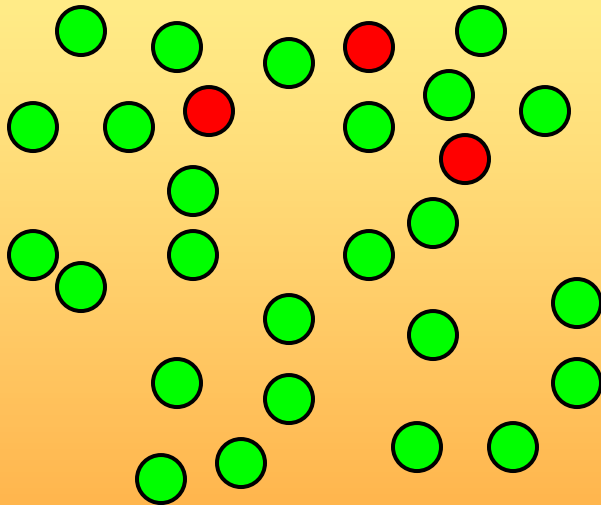
- Choose diagnostic that fits *your* choice of actions.
- Location of failures (cables or accessories?)
- Diagnostic must be sensitive to the prevalent problem in the target population (i.e. corroded neutrals, water treeing, insulation contaminants, etc).
- Accuracy must be sufficiently high for the target population failure rate to achieve a benefit.

# Diagnostic Operation

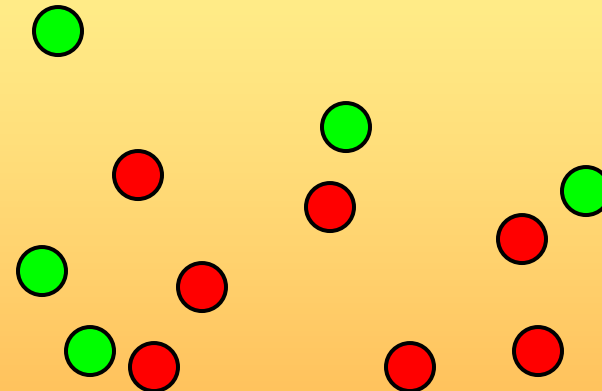


# Separation by Diagnostic

## No Action Required



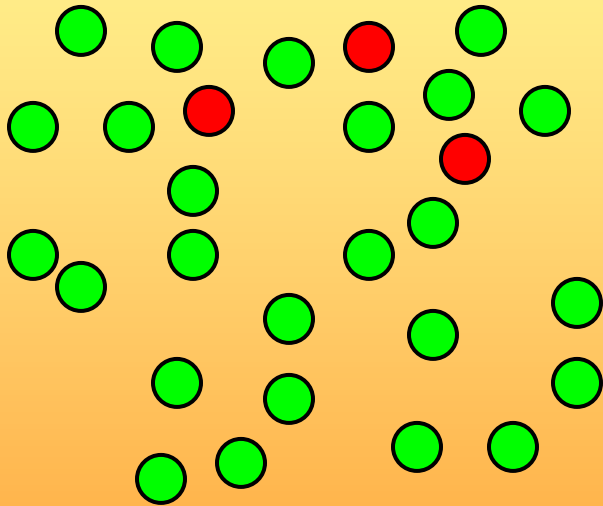
## Action Required



**Each group contains segments that will or will not fail. There are consequences to this mix**

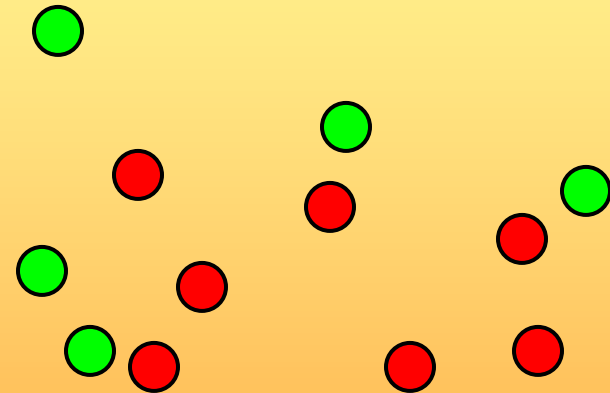
# Incorrect Diagnosis

## No Action Required



Future service failures

## Action Required



Unneeded Maintenance  
Actions

# Diagnostic Accuracies

Diagnostic was imperfect at separating “Good” from “Bad”...

Group	Correct Diagnoses [#]	Incorrect Diagnoses [#]	Accuracy [%]
No Action Required	25	3	89 %
Action Required	7	5	58 %
Overall	32	8	80 %

**Condition-specific accuracies** – They depend on the overall accuracy and the composition of the target population.

# Diagnostic Accuracies

Diagnostic was imperfect at separating “Good” from “Bad”...

Group	Correct Diagnoses [#]	Incorrect Diagnoses [#]	Accuracy [%]
No Action Required	25	3	89 %
Action Required	7	5	58 %
Overall	32	8	80 %

**Overall accuracy** - Not the average of the “No Action Required” and “Action Required” accuracies

# Which accuracy matters?

- Comparison of performance of diagnostic techniques

**Overall Accuracy**

- Calculation of economic benefits from diagnostic program

**Diagnostic  
Condition-Specific  
Accuracies**

# Accuracies

Group	Segments “Correct” [%]	Segments “Not Correct” [%]
Pass	94 %	6 %
No Pass	23 %	77 %
Overall	89%	22 %

# Compare to Whole Replacement

	Diagnostic Program	Wholesale Replacement
Maintenance Actions	12	40
% of Population Receiving Maintenance	30%	100%
Service Failures	3	0
Avoided Failures	7	10
Avoided Failures per Maintenance Action	<b>0.583</b>	<b>0.250</b>

Efficiency of Diagnostic Program is much higher than for Wholesale Replacement

# Consequence

	Diagnostic Program	Wholesale Replacement
Maintenance Actions	12	40
% of Population Receiving Maintenance	30%	100%
Service Failures	3	0
Avoided Failures	7	10
Avoided Failures per Maintenance Action	<b>0.583</b>	<b>0.250</b>

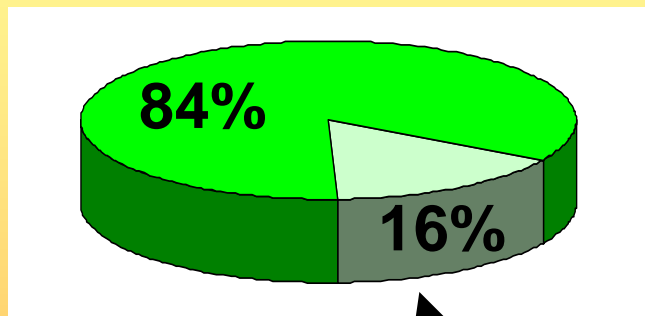
These failures are the Consequence of adopting a financially more efficient program.

# Comparing Different Diagnostic Approaches

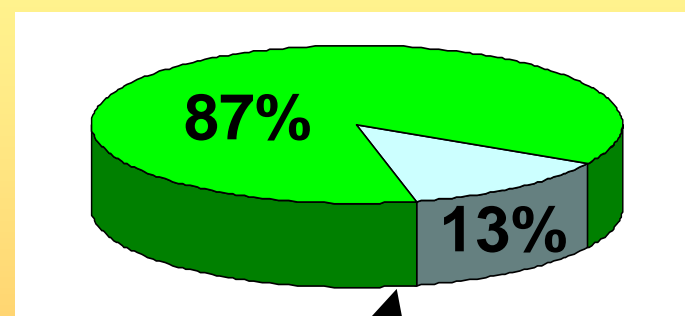
## Performance Rank

# Initial Analysis

## Average Cable Replacement

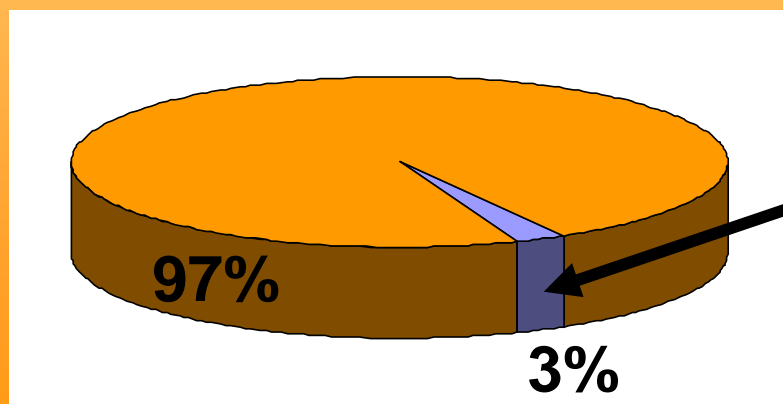


## Average Splice Replacement



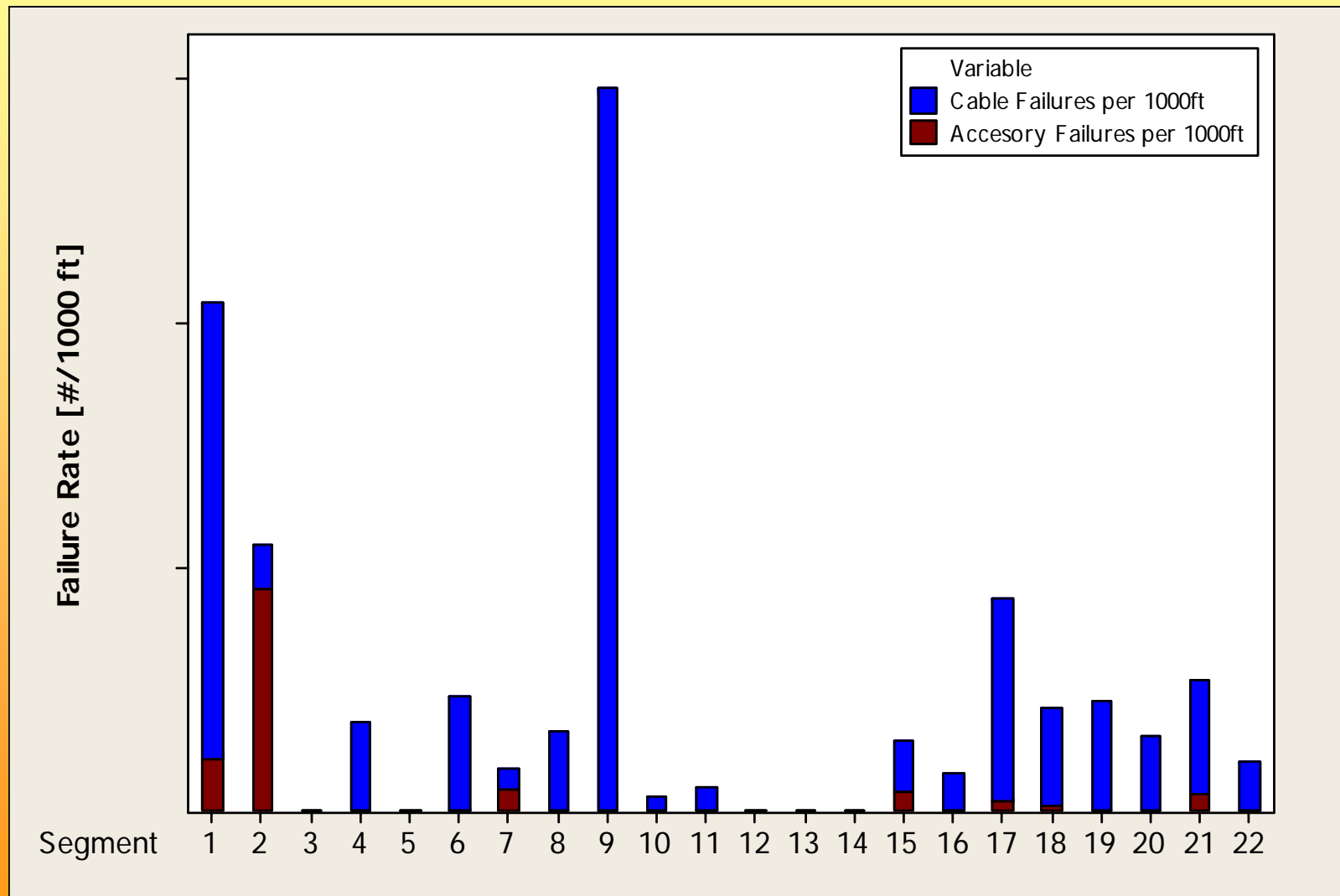
**Diagnostic Provider Recommendation**

## Actual Failures

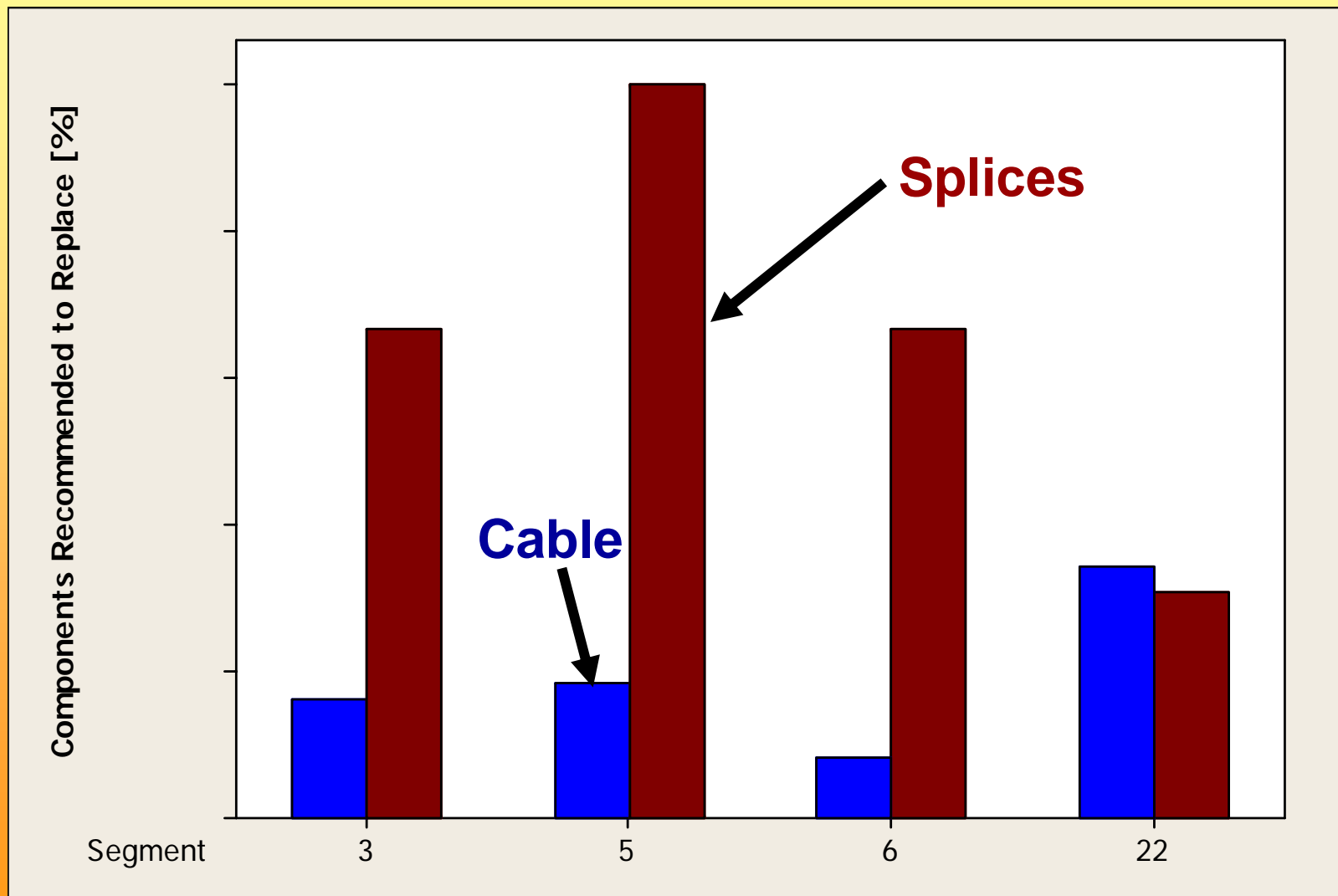


**Failures occurring in sections recommended for replacement**

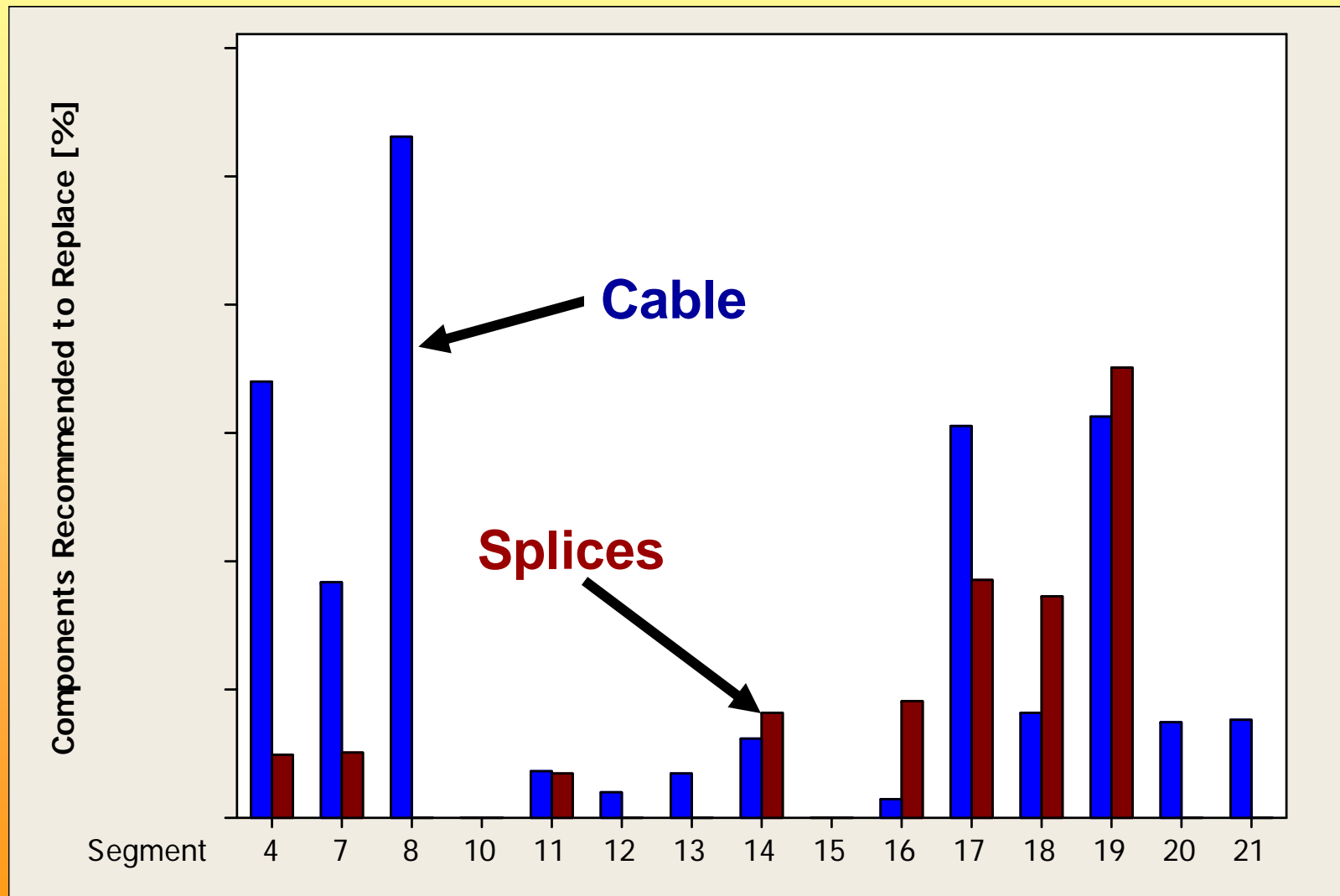
# Failure Performance



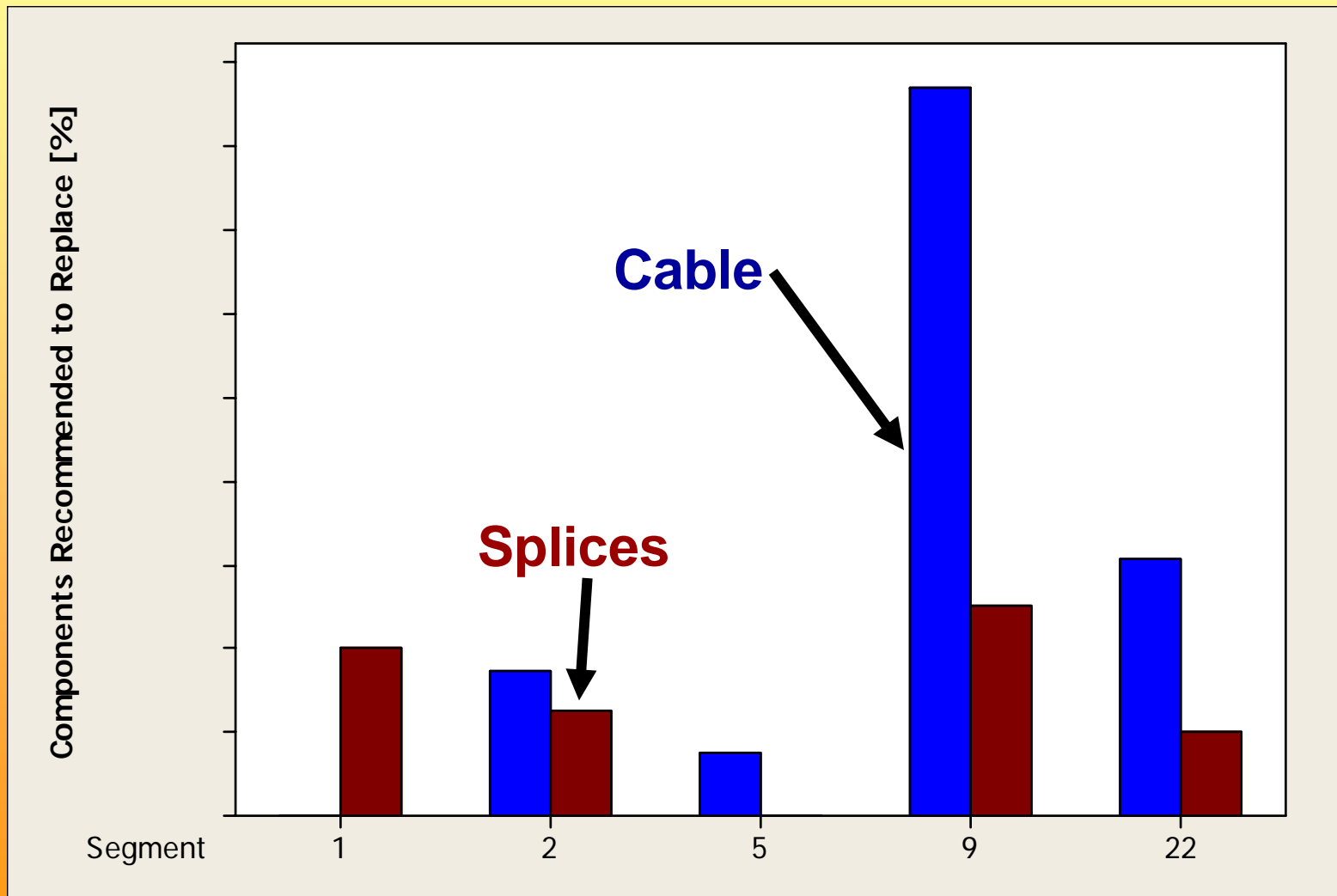
# Technique A Recommendations



# Technique B Recommendations

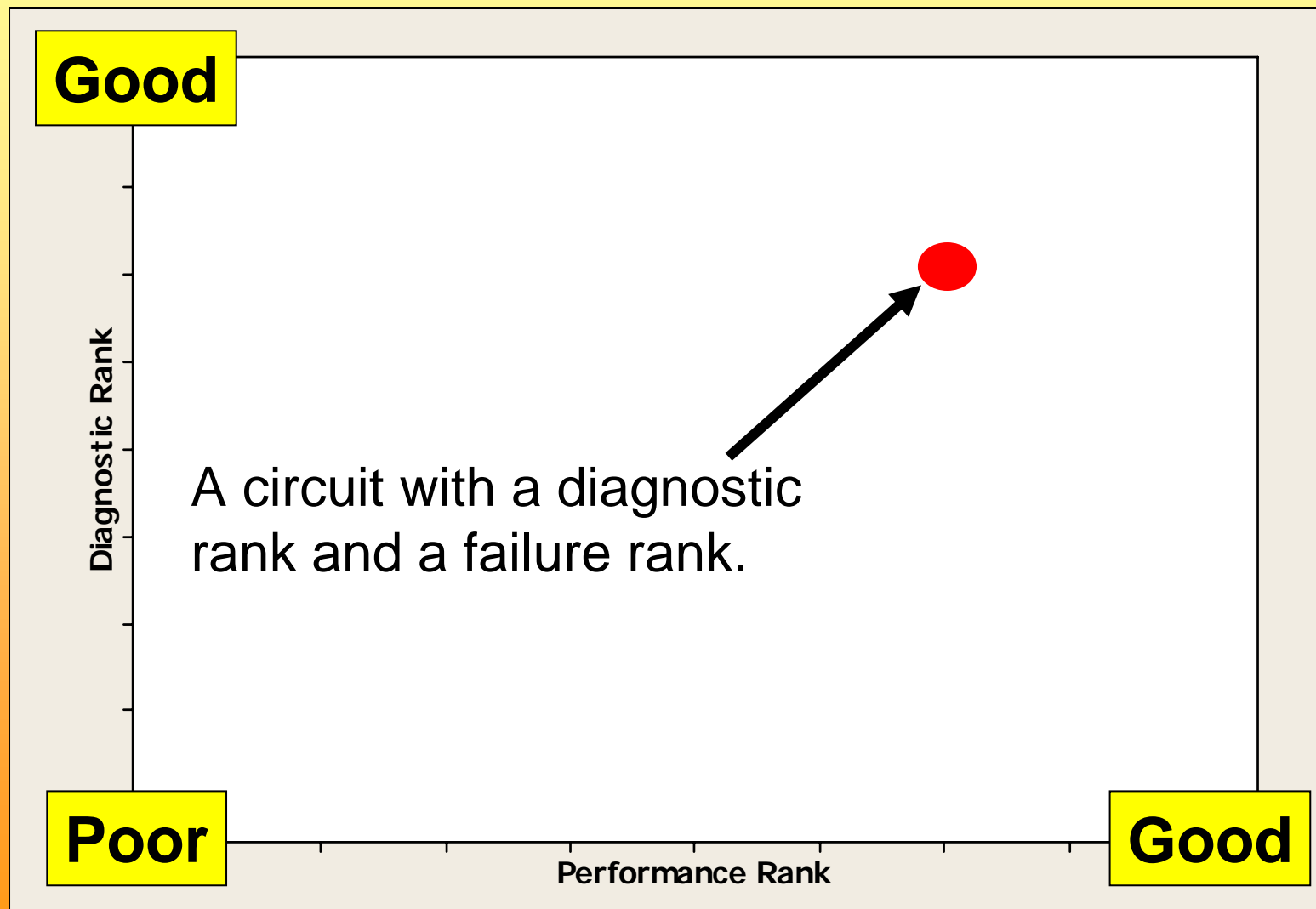


# Technique C Recommendations

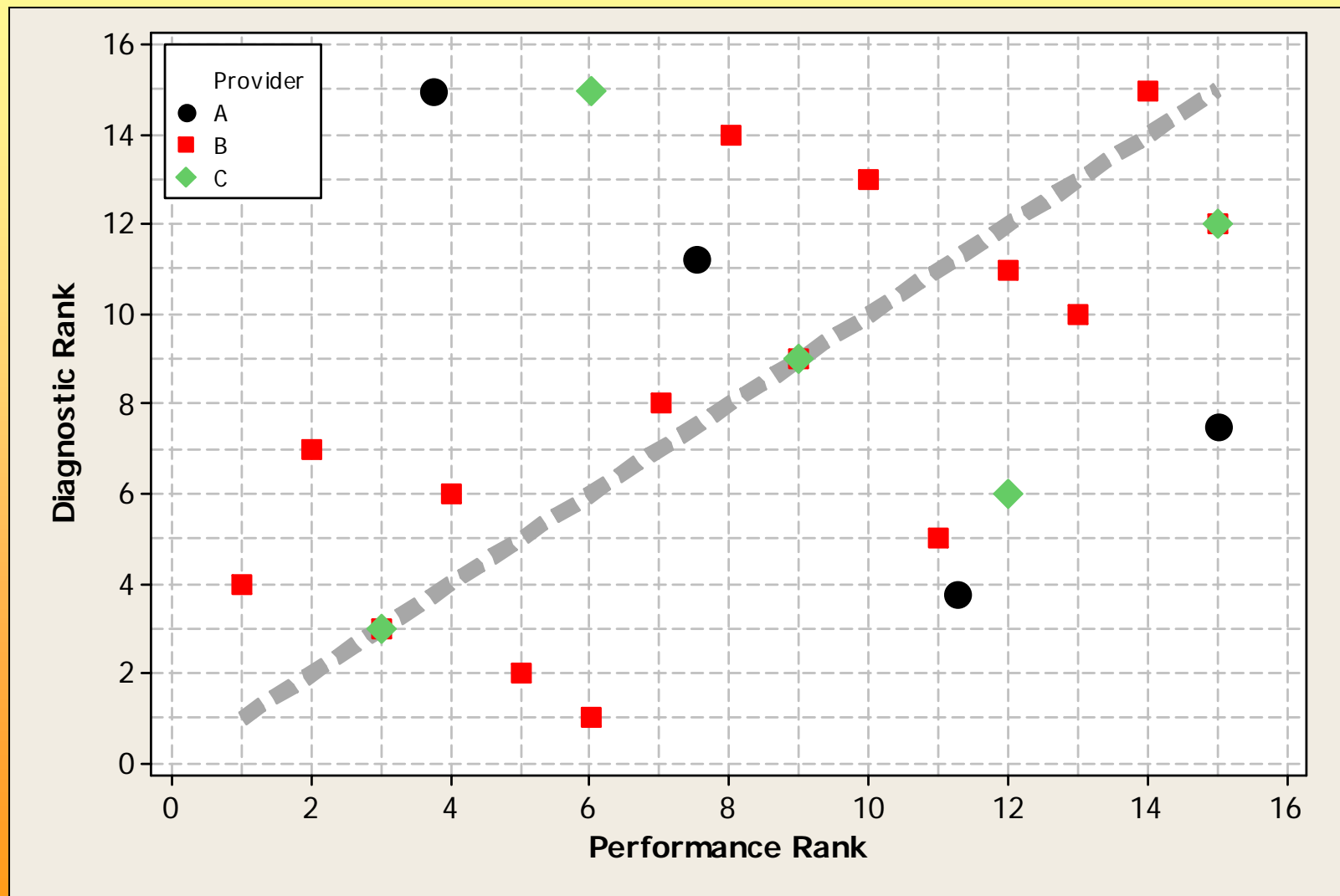


# Ranking Plots

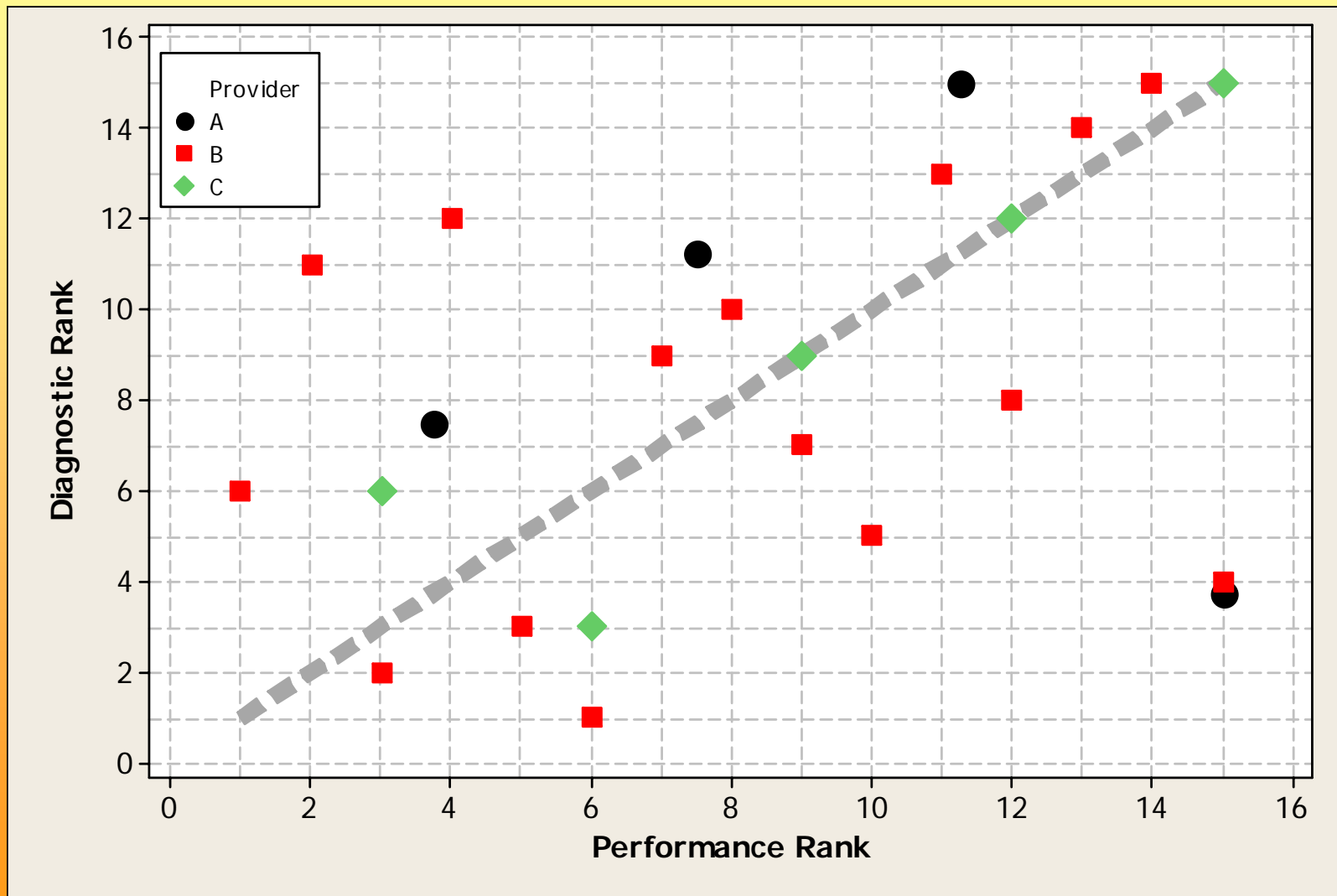
# Ranking Representation



# Cable Ranking



# Splice Ranking



# Correlation Coefficients

Component Type	Diagnostic Provider	Correlation Coefficient	Level of Significance
Cable	A	-0.800	>0.1
	B	0.689	<0.01
	C	0.300	>0.1
Splice	A	-0.200	>0.1
	B	0.321	>0.1
	C	0.900	<0.05

**The best performance on cable was Provider B while the best performance on splices was Provider C**

# In Conclusion

- Proper
- Prior
- Preparation
- Prevents
- Poor
- Performance

**If you take  
care in  
nothing else,**

**Take care in  
Selection**