Life After Construction

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The Scenario

- Your Facility is on line and running
- Construction and commissioning were completed several years ago.
- You have operated the facility as it was designed.
- Well, except for…

The Goals

- Achieve the highest levels of reliability and availability
- Operate at the lowest costs
- Recognize when equipment is near it's end of life and form strategies to manage replacement and/or retrofit

1996 Cost of Downtime Research Study

Source: Contingency Planning Research

Business	Hourly Downtime Cost
Brokerage	$6,450,000
Pay-per-view	$150,000
Catalog Sales	$90,000
Tele-ticket	$69,000
ATM fees	$14,500
Credit Card	$2,600,000
Home shopping	$113,000
Airline reservation	$90,000
Package shipping	$28,000

2001 Limited Update to Cost of Downtime Research Study

Source: Contingency Planning Research & Eagle Rock Alliance, Ltd.

- 46% of participating companies said each hour of downtime would cost their companies up to $50k
- 28% said each hour would cost between $51K and $250K
- 18% said each hour would cost between $251K and $1M
- 8% said each hour would cost $1M+

2001 Limited Update to Cost of Downtime Research Study

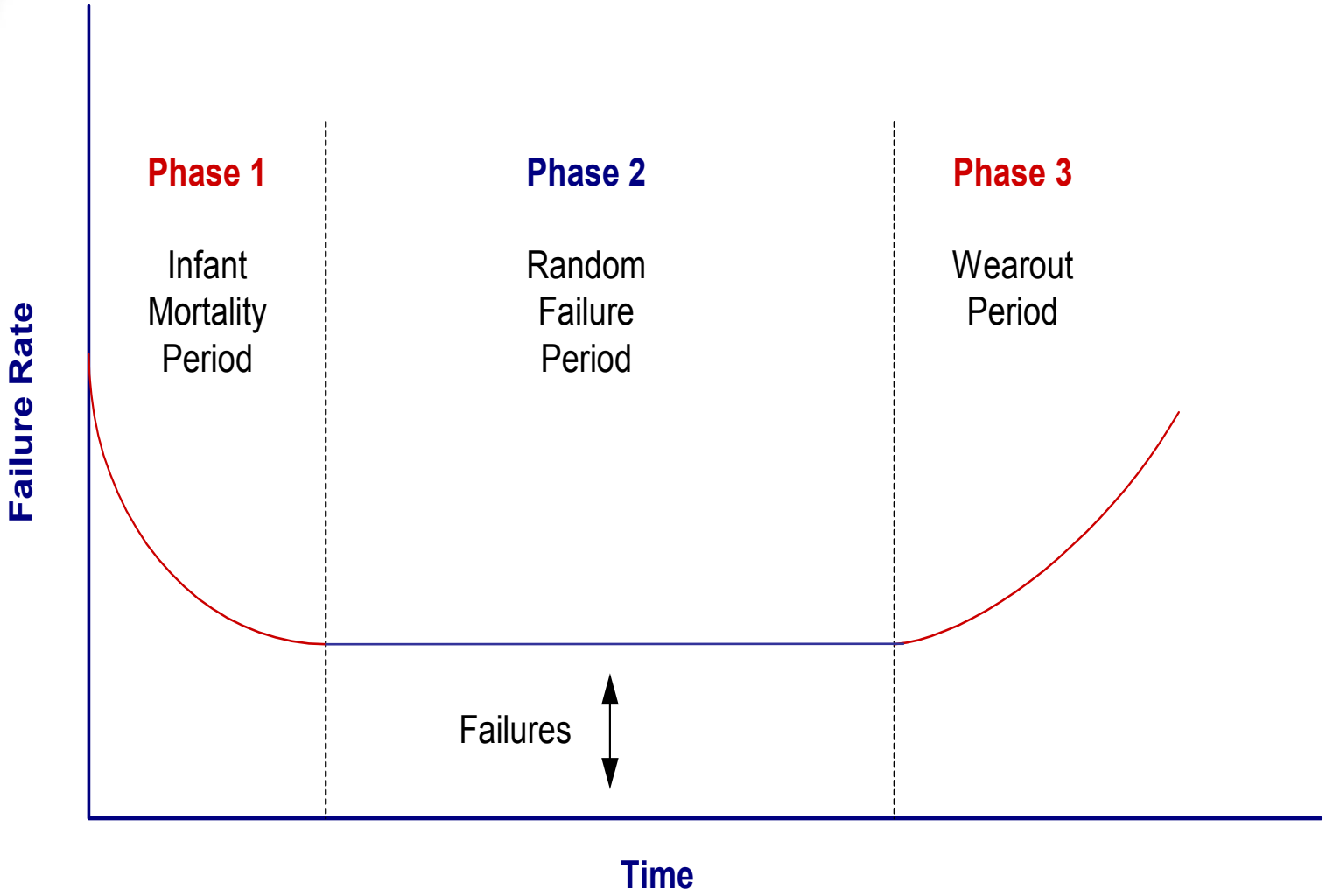
Source: Contingency Planning Research & Eagle Rock Alliance, Ltd.

"As to the indirect cost factors most critical to their company's survival, an overwhelming 57% said that the combination of "Customer Service or Expectations" and "Competitive Advantage" were most critical"

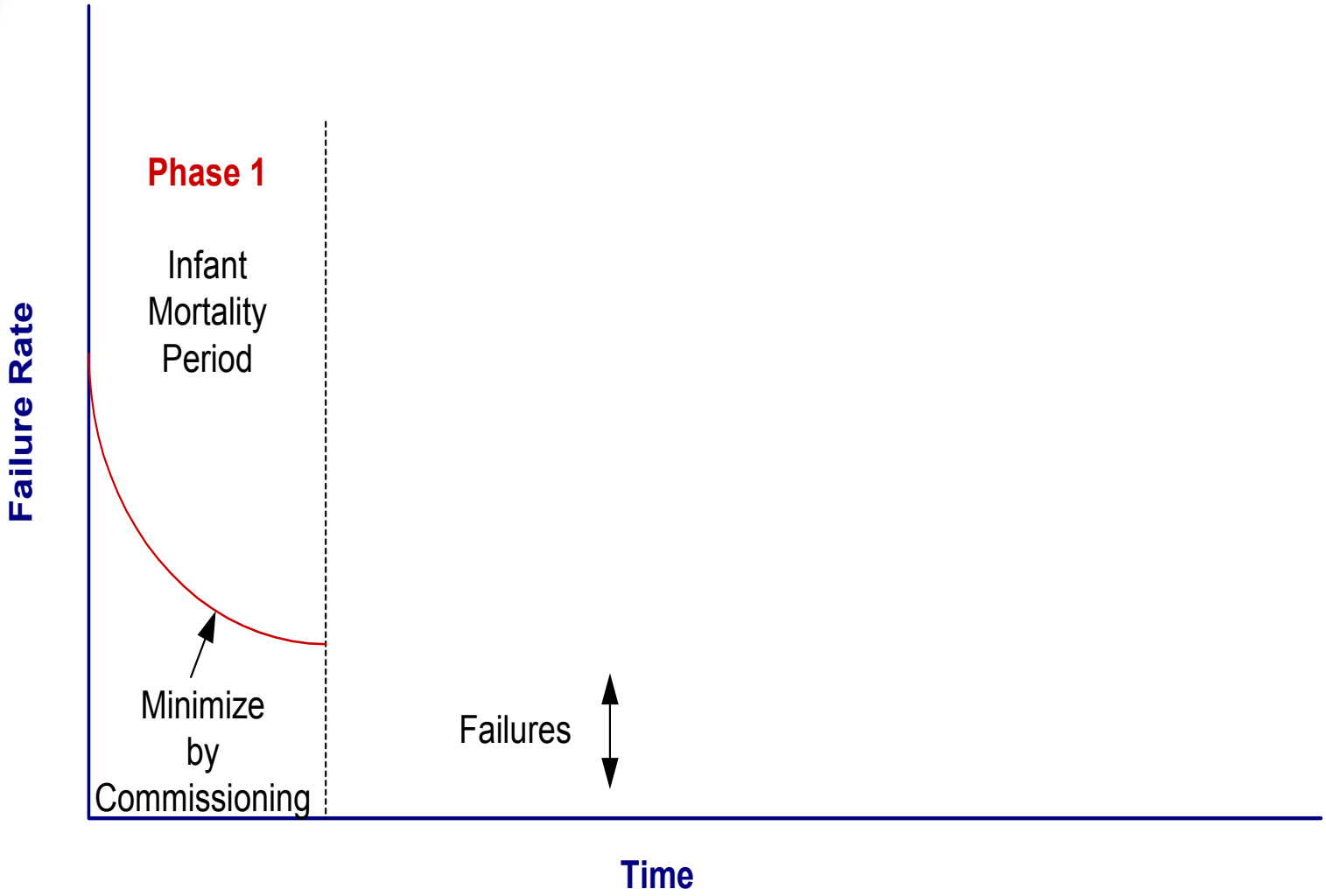
The Scenario continued

- OK, so you've cheated 'a little' here and there over the last few years.
- The economy has been down, so you restructured your maintenance operation

The Life of a Facility



The Life of a Facility



Phase 1
Commissioning

Commissioning is the process of ensuring that the systems are installed, functionally tested and capable of being operated and maintained in conformity with the design intent.

Commissioning begins with planning and includes design, construction, start-up, acceptance and training, and can be applied throughout the life of the building.

Phase 1

Commissioning is your one and only opportunity to:

- Control the transfer of knowledge
- Effectively eliminate infant mortality failures before you accept the facility
- Assure proper installation
- Assure calibration and performance
- Assure component/sub-system/system interoperability

Phase 1

Knowledge Transfer

- Documentation of design intent
- Documentation of basis of design
- Establish equipment/system test specs
- Establish equipment/system baselines
- Assure appropriate O&M documentation

Phase 1

Effectively Eliminate Installation & Infant Mortality Failures Before You Accept the Facility By:

- Rigorous factory acceptance tests
- Site inspections and verification of correct installation, point-to-point wiring, mounting, etc.
- Performance testing to maximums of equipment specifications

Fan Inlet

Installation Problem

VFD installed at fan inlet causing restriction and turbulence

Installation Problem

Loose Connections/Incorrect Washer/Signs of Corrosion or Electrolytic action

Infant Mortality

Blown SCR Section
of

Rotary UPS

Cabinet Screw into UPS Input Transformer

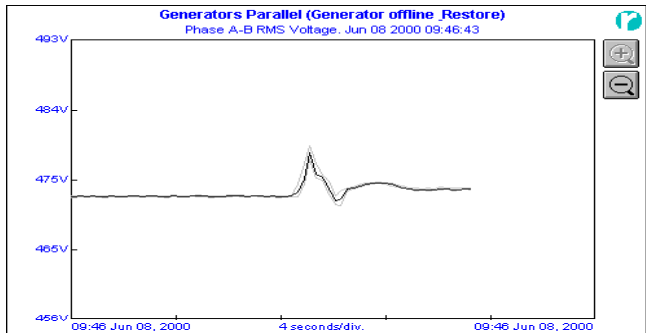
Phase 1

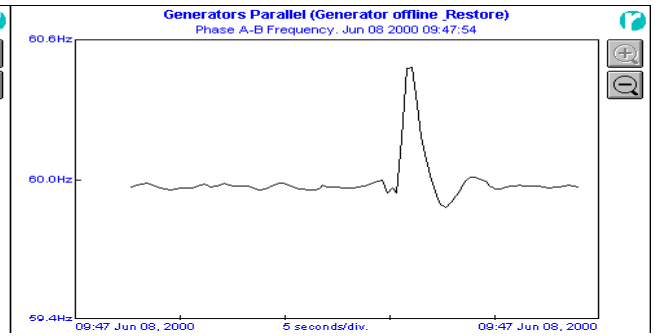
Assure Component/Sub-system/System Interoperability

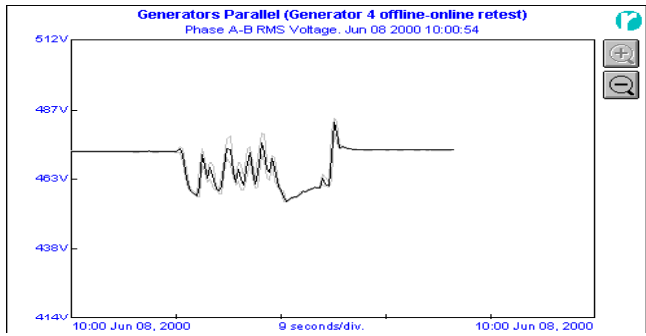
- Verify engines/paralleling gear/UPS/transfer devices/STS/ chillers/pumps/CRAC/BMS/life safety systems work together in all normal, emergency and maintenance modes

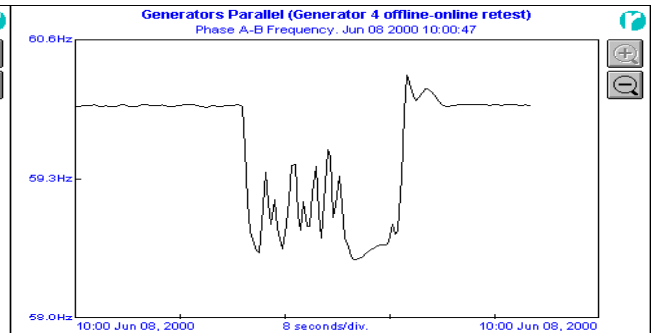
Interoperability Problem

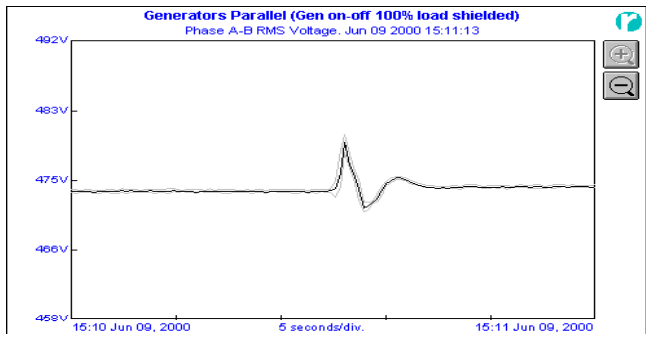
Generator Paralleling Bus Disturbance

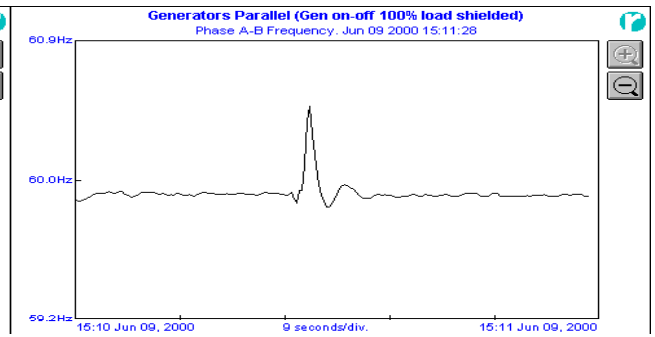












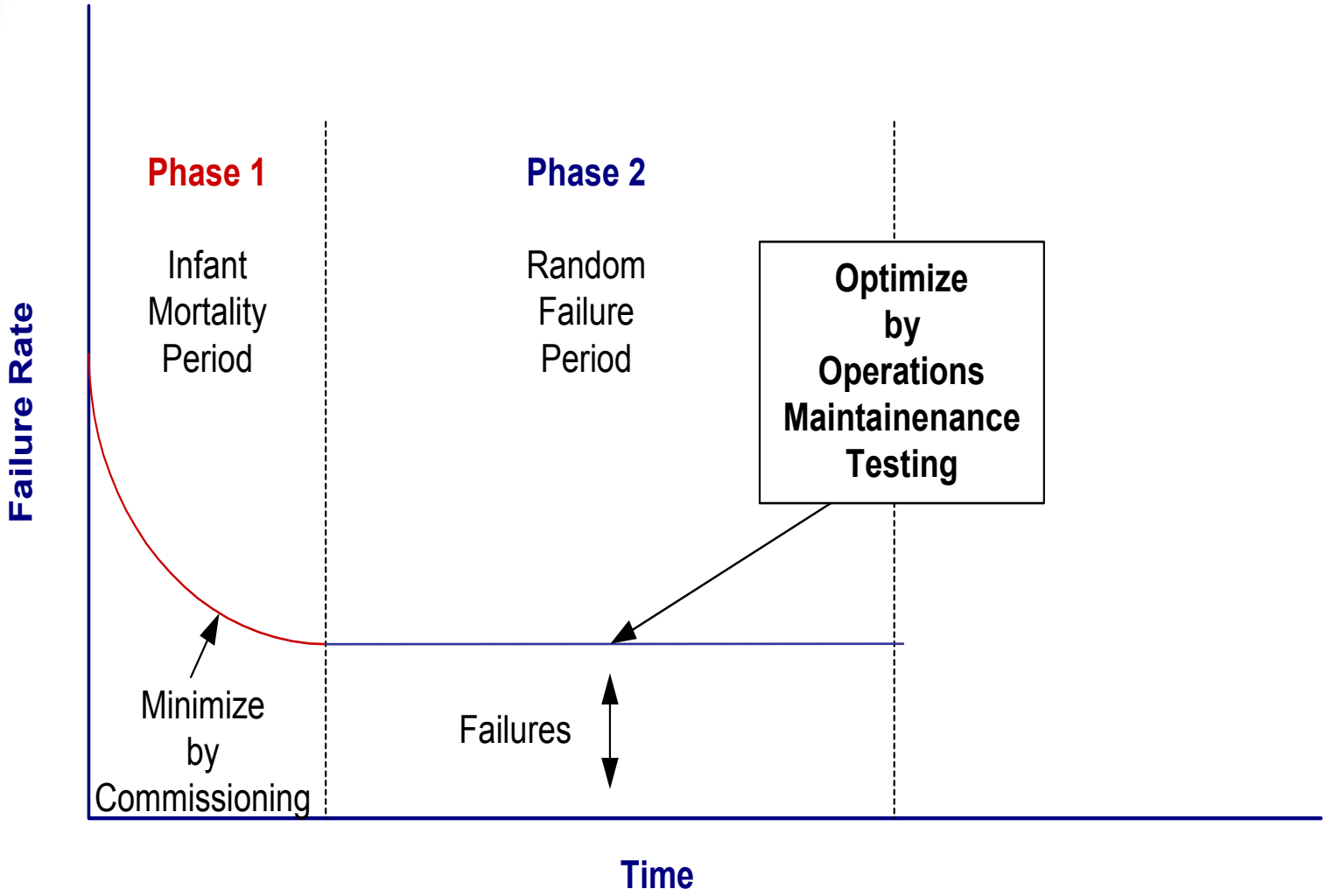
Accept the Facility After Phase 1 Is Complete

Phase 2 begins and costs now transfer from construction to operations

The Scenario continued

- OK, so you've cheated 'a little' here and there over the last few years.
- The economy has been down, so you restructured your maintenance operation.
- Some of those originally trained are no longer there.
- The smaller staff reduces opportunity for training.

The Life of a Facility



Phase 2

- Operate
  - Effect the transfer of knowledge from the construction phase
    - Maintain document control program
  - Select the right staff
    - Management
    - Technical

Phase 2

- Operate
  - Train
    - Craft skills
    - Site specific equipment & systems skills
    - Project & management skills

Phase 2

- Operate
  - Control the human factor errors for:
    - Staff
    - Vendors
    - Others

Phase 2

- Human factor errors:

Source: *Human Factors and Operator Errors*
P.L. Clemens *February 2002* 2nd Edition

  - Operator error is inevitable
  - Human error rates are high
  - Error rate "controls" are available, e.g.:
    - Training retraining/drilling
    - Using checklists/inspectors/backups
    - Using Performance shaping factors
    - Exploiting "stereotypical" behavior

Phase 2

- Classes of human factor errors:
  - Errors of Commission
    - Performing correct step on wrong item
    - Performing step incorrectly on right item
    - Performing correct step at wrong time
  - Errors of Omission
    - Skipping a necessary step
    - Failing to communicate to a fellow worker (spoken or written)

Phase 2

- Classes of human factor errors:
  - Cognitive Task Errors
    - Forming an incorrect diagnosis
    - Making a decision unsupported by available information

("leaping to conclusion: reliance on flawed intuitive skills)

Phase 2

- Factors influencing the probability of of human error:
  - Experience
  - Stress
  - Training
  - Fatigue
  - Level of burden
  - Ergonomics (placement of critical controls)

Phase 2

- Factors influencing the probability of of human error:
  - Conscientiousness (self discipline)
  - Realization of error on prior attempt
  - Perception of error consequences (to self/others)
  - Character of task (complexity/repetitiveness)
  - Environment (temperature/noise /“comfort”)
  - Task violation of stereotypical behavior

Phase 2

- To reduce error probability:
  - Make system “forgiving” – give the operator fault annunciation, time, and the opportunity to revoke errors
  - Use documented procedures/checklists
  - Exploit stereotypical behavior
  - Adjust operator burden – apply “pacing”
  - Use “backups,” inspectors/checkers
  - Train, examine, simulate, drill, retrain
  - Automate, Automate, Automate

The Scenario continued

- OK, so you've cheated 'a little' here and there over the last few years.
- The economy has been down, so you restructured your maintenance operation
- Your customers have been demanding, so some areas of your data center chronically run 'hot' because of the spot loads added.

Phase 2

- Maintain
  - Utilize Reliability Centered Maintenance (RCM) over calendar base maintenance concepts to:

Maximize effectiveness of $ spent for maintenance

Definition

Reliability Centered Maintenance (RCM):

A process used to determine the maintenance requirements of a physical asset in its operating context

Applying RCM

Develop a broad based approach to gathering information:

- What equipment exists – equipment, motor, control systems, etc.
- Gather data
  - Age
  - Use
  - Replacement
  - Where do the pumps operate relative to their point of optimum performance?

Applying RCM

- Baseline the existing condition of the equipment
- Establish a data collection scope and frequency
- Establish meaningful trends of the data
- Establish training required to operate, maintain, trouble shoot, and repair equipment

Then, ask questions!

Functions and Performance

What are the functions and associated performance standards of the pumps in their present operating context?

- Operating Context
- Primary functions
- Secondary functions

Functional Failures

In what ways does it fail to fulfill its functions?

- Identify what circumstances amount to a failed state
- Then identify what events can cause the pumps to get to a failed state

Functional Failure Modes

What causes each functional failure?

- Identify all the events which are likely to cause each failed state

- A failure mode is any event which causes a functional failure, such as:
  - Falling capability
  - Increase in desired performance
  - Initial incapability

Failure Effects

- What ways (if any) it poses a threat to safety or the environment
- What ways (if any) it affects production or operations
- What physical damage (if any) is caused by the failure
- What must be done to repair the failure

Failure Consequences

In what way does each failure matter?

- What are the consequences of each failure, that is in what way does each failure matter?

Failure Consequences

Hidden failure consequences:

- Have no direct impact but they expose the organization to multiple failures with serious or catastrophic consequences

Failure Consequences

Safety and environmental consequences:

- If it could injure or kill someone or lead to a breach of any corporate, regional or international environmental standard

Failure Consequences

- *Operational consequences:*
  - If it affects production (output, product quality, customer service or operating cost in addition to the direct cost of repair)
- *Non-operational consequences:*
  - Failures which affect neither safety or production, so they involve only the direct cost of repair

RCM Task Selection Process

For operation consequences:

A proactive task is only worth doing:

if the total cost of doing it *over a period of time* is less than the cost of the operational consequences and the cost of repair over the same period.

RCM Task Selection Process

For operation consequences:

- If it is not justified, the initial default decision is *no scheduled maintenance,*
- If the operational consequences are still unacceptable the secondary default decision is redesign

Failure Management

Default actions:

- These deal with a failed state, and are chosen when it is not possible to identify and effective task. Default actions include:
  - *Redesign*
  - *Run-to-failure*

Default Actions

Redesign:

- Making one-off changes to the built-in capability of a system. This includes modifications to the hardware and also covers once-off changes to procedures

No scheduled maintenance (run-to failure):

- As the name implies, this default entails making no effort to anticipate or prevent failure modes, so that failures are allowed to occur and then be repaired

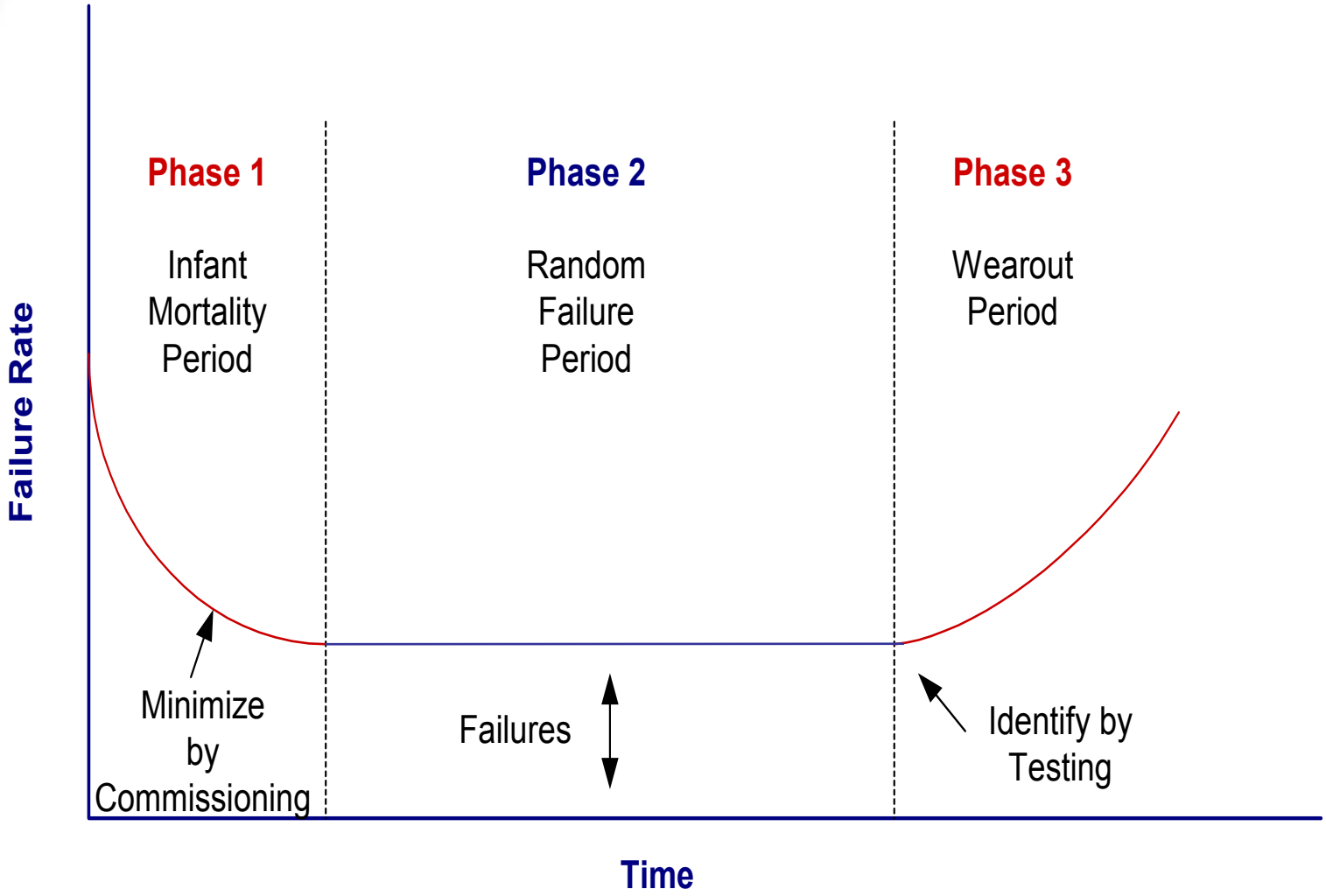
What RCM Achieves

- *Greater safety and environmental integrity*
- *Improved operating performance*
- *Greater maintenance cost-effectiveness*
- *Longer useful life of expensive items*

The Scenario continued

- OK, so you've cheated 'a little' here and there over the last few years.
- The economy has been down, so you restructured your maintenance operation
- Money has been tight, so spending has been limited in maintenance to accommodate capital investments to support more customers.

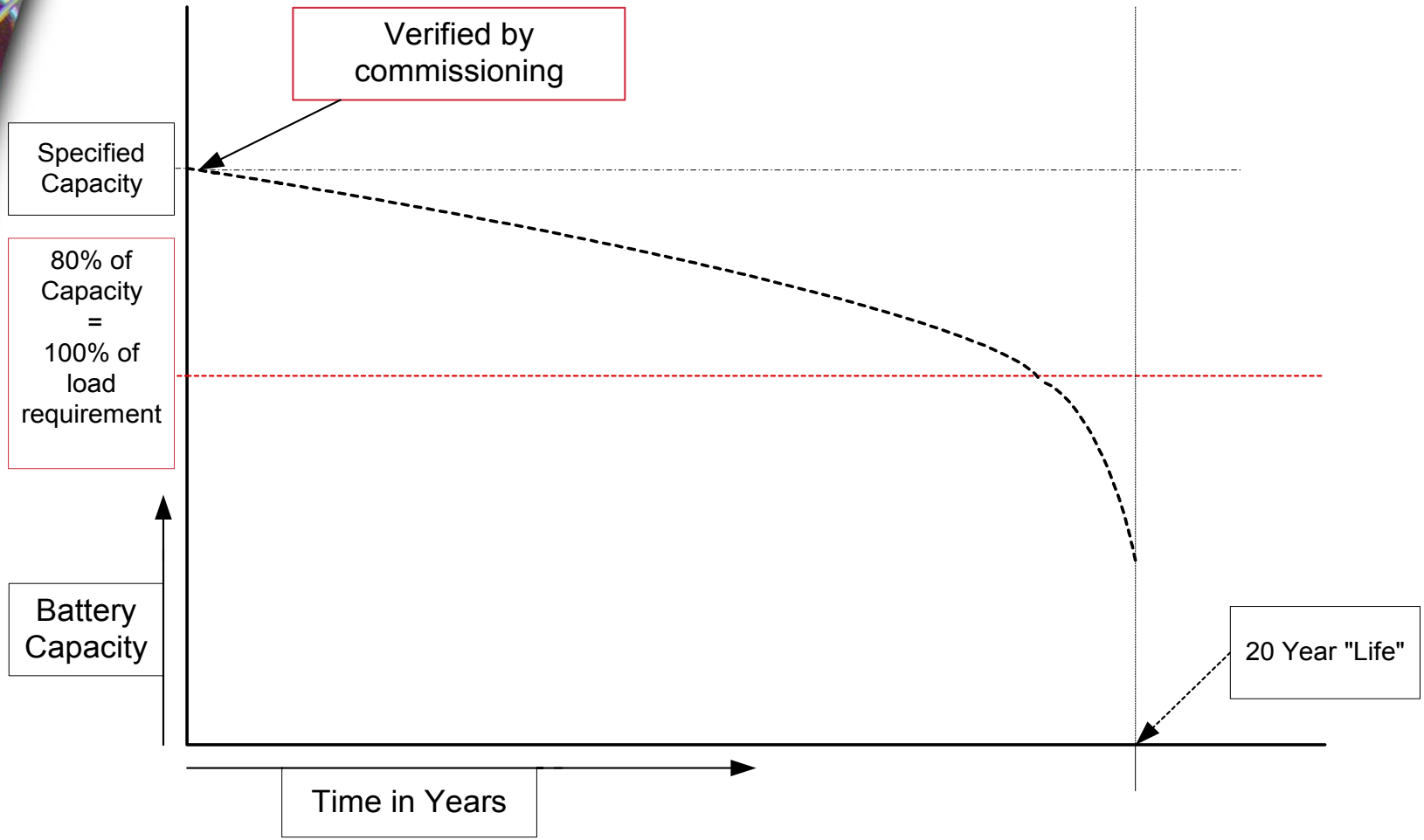
The Life of a Facility



Phase 2-3

- Test
  - System functionality tests
  - Equipment/system performance tests

Battery Testing



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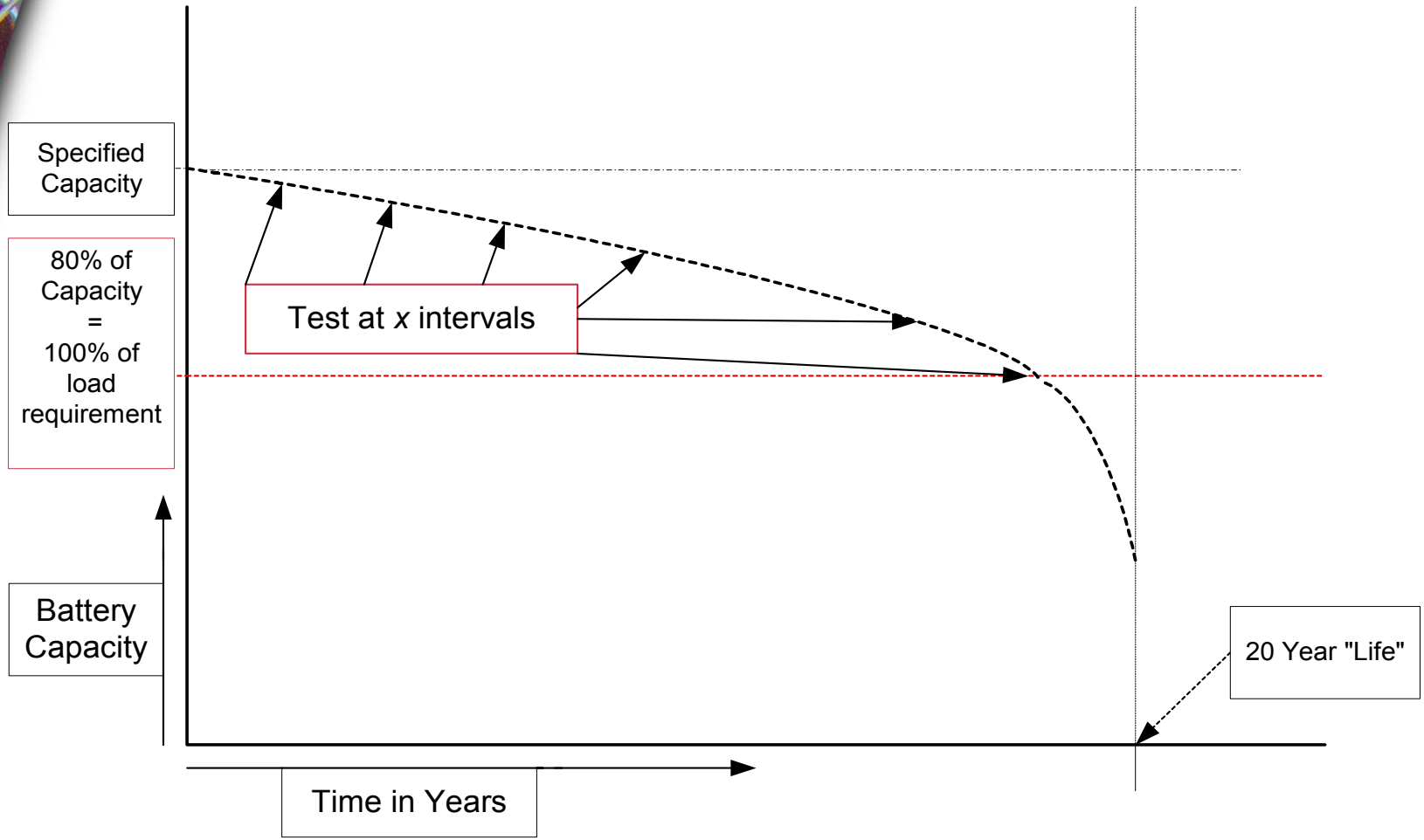

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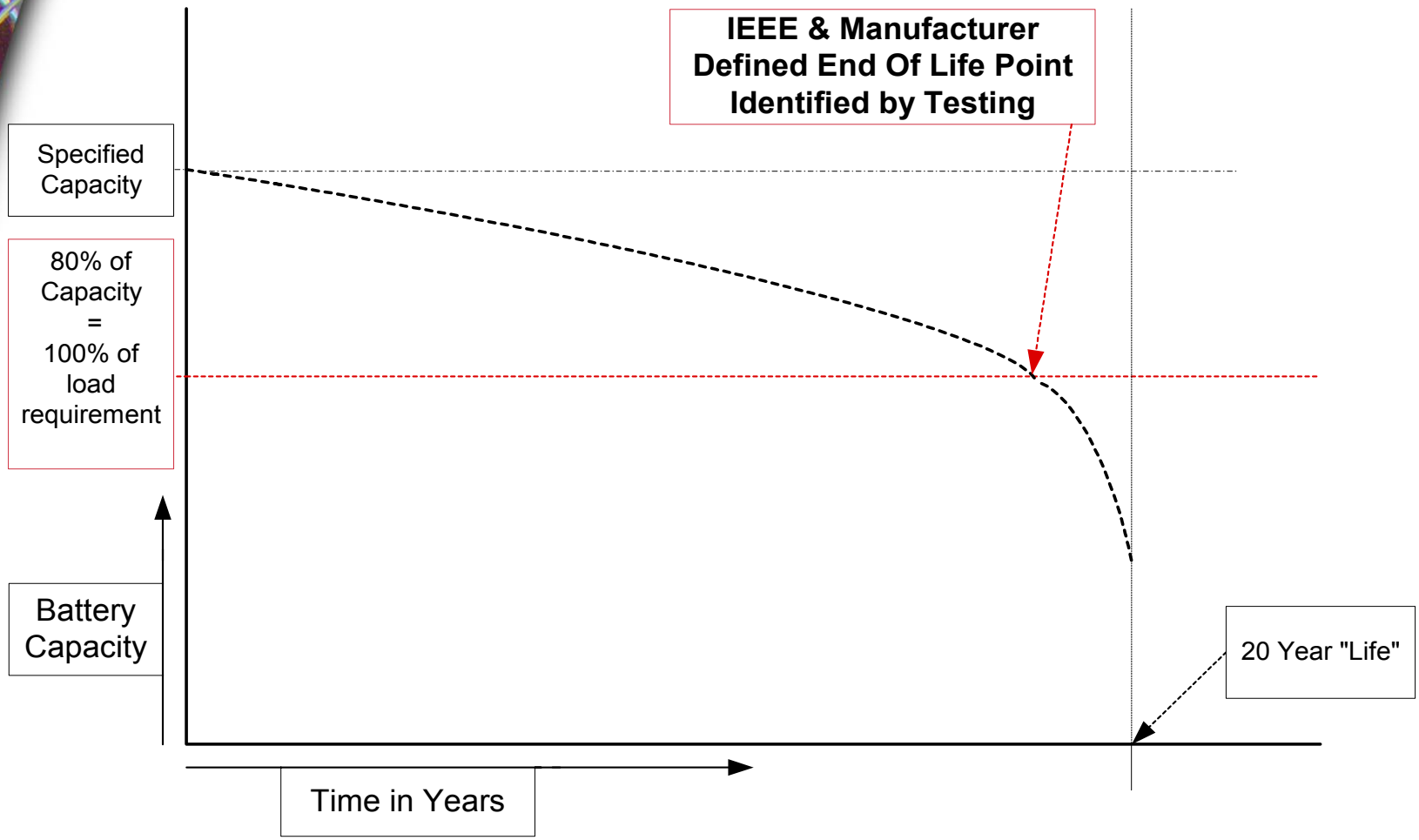

Conclusions:

- Commission your facility
  - Document design intent and basis of design
  - Assure proper installation
  - Verify equipment performance
  - Verify system interoperability

Conclusions:

- Operate, Maintain and Test Your Facility “Intelligently”
  - Transfer knowledge from construction
  - Hire the right staff with the right management model
  - Train, drill and retrain
  - Use procedures and checklists
  - Learn from experience

Conclusions:

- Operate, Maintain and Test Your Facility “Intelligently”
  - Utilize a RCM program
  - Test and identify equipment problems and identify current place in life cycle

The Scenario concluded

- OK, so you've cheated 'a little' here and there over the last few years.
- If you've cheated a little to make capital investments to accommodate customers, then
- You need to cheat a little to maintain the strength of your operations, maintenance and testing program.