Mean Time Between Failures:

Input data to Availsim simulations

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Estimating MTBFs

- Statistical (no absolutes) ➔ Expected Value + Variance

- Common estimating methods in industry
  - Projections based on the technical design and standardized data for individual parts
  - Projections based on accelerated life testing
  - Comparisons with similar equipment that have 'known' MTBFs
  - Actual data on failure rates of equipment in the field

- Statistically significant estimates come from cumulative operating hours that are much greater than the MTBFs

RDR and SB2009 approaches to choosing MTBFs for the Availsim models

RDR starting point

- Most component MTBF numbers were derived from actual operating experience at SLAC and Fermilab (actual numbers and best estimates)
- Representative of what has been achieved at operating HEP accelerator facilities

Availability WG for SB2009 (chose an more aggressive approach)

- Adopt the best MTBFs we think we can reasonably defend
- Survey the community/industry for best-in-class MTBFs achieved, eg
  - Recent experiences in accelerator labs (eg light sources, 'factories')
  - Industry norms for COTS and standard industrial components

In both cases…

- Where necessary, individual Starting MTBFs were adjusted based on results of Availsim simulations in order to achieve the desired overall accelerator availability

RDR

Needed ILC MTBF Improvements

Device	Needed Improvement factor	Downtime (%) due to these devices	Nominal MTBF (hours)	Nominal MTTR (hours)
power supplies	**20**	0.2	50,000	2
power supply controllers	**10**	0.6	100,000	1
flow switches	**10**	0.5	250,000	1
water instrumention near pump	**10**	0.2	30,000	2
magnets - water cooled	**6**	0.4	3,000,000	8
kicker pulser	**5**	0.3	100,000	2
coupler interlock sensors	**5**	0.2	1,000,000	1
collimators and beam stoppers	**5**	0.3	100,000	8
all electronics modules	**3**	1.0	100,000	1
AC breakers < 500 kW		0.8	360,000	2
vacuum valve controllers		1.1	190,000	2
regional MPS system		1.1	5,000	1
power supply - corrector		0.9	400,000	1
vacuum valves		0.8	1,000,000	4
water pumps		0.4	120,000	4
modulator		0.4	50,000	4
klystron - linac		0.8	40,000	8
coupler interlock electronics			00	1
vacuum pumps			00	4
controls backbone			00	1

Have these higher numbers already been achieved?

Tom Himel

For SB2009: consider five categories of equipment...

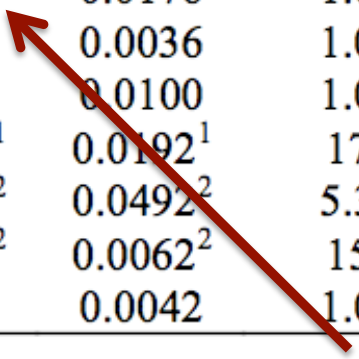
- **Technical systems with large operating base** — Accelerators
  - Magnets, power supplies, controls,...
  - Sufficient data for making reasonable reliability (in many cases)
- **Technical systems with little or no operating base** — Hmm...
  - Newly developed parts, challenging specs
  - Insufficient data for estimating MTBF
- **'Standard' accelerator components** — Accelerators + industry
  - COTS parts
  - Vacuum pumps, flow switches, ...
- **Industrial equipment with extensive installed base** — Industry
  - Eg, electrical utilities
  - Published data is available on in-service failure rates
- **Commodity equipment** — Industry
  - Eg controls backbone network, computing infrastructure
  - We buy the quality of service we want (or can afford)

IEEE Gold Book: power distribution reliability data from in-service surveys (Estimated Times To Failure)

Table 4.5. Reliability of industrial components.[37]

Description	λ_P (per year)			MTTR (hours)		
	Low	Typical	High	Low	Typical	High
Liquid Filled Transformers	0.0053	0.0060	0.0073	39	300	1000
Molded Circuit Breakers	0.0030	0.0052	0.0176	1.0	5.8	10.6
Drawout Breakers	0.0023	0.0030	0.0036	1.0	7.6	232
Disconnect Switches	0.0020	0.0061	0.0100	1.0	2.8	10.6
Switchgear Bus	0.0008[1]	0.0030[1]	0.0192[1]	17	28	550
Cable (not buried)	0.0014[2]	0.0100[2]	0.0492[2]	5.3	7.0	457
Cable (buried)	0.0034[2]	0.0050[2]	0.0062[2]	15	35	97
Cable Terminations	0.0003	0.0010	0.0042	1.0	2.8	10.6

[1]Failure rates for switchgear bus are per circuit foot.
[2]Failure rates for cable are per 1000 circuit feet.



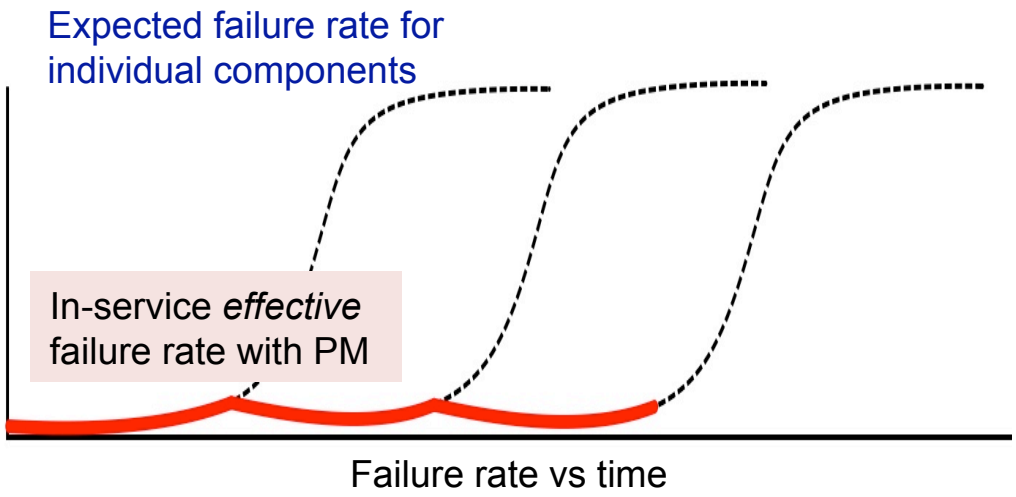
“Crude estimates” of some MTBFs for Advanced Photon Source storage ring

	Number of beam loss events										
System	2003	2004	2005	2006	2007	2008	Total	Num units	Unit-hrs	MTBF (khrs)	
PS	18	9	14	4	11	18	74	1600	4.0E+07	541	Multipoles and correctors are included
Network	2	4	0	1	2	0	9	40	1.0E+06	111	Assume one network 'system' per sector
Interlocks	16	18	5	8	4	2	53	61	1.5E+06	29	Accelerator MPS + 40 beamline MPS
Electrical		1	1	0	1	0	3	80	2.0E+06	667	Assume 2 transformers per sector
Controls	1	8	1	3	2	2	17	250	6.3E+06	368	Assumes 250 front-end controllers (IOCs)

Crude numbers!

- Total run time is ~30,000 hrs (5000hrs/year)

Preventative Maintenance (Increase effective Availability)



Basic premise

- Take advantage of scheduled downtime to increase the effective availability during scheduled uptime

Approach

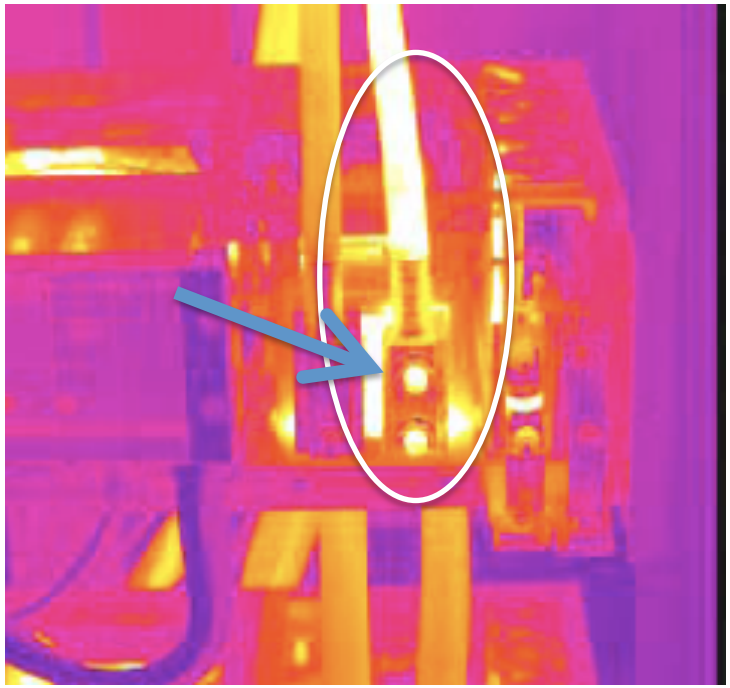
- Preemptively replace or service components that degrade or have finite life
- Assumed for both RDR and SB2009

Power converter examples

- Replace water hoses before they rot and cause a leak
- Use thermal imaging to identify loose joints on busbars, poor contact between power transistors and heatsink, etc
- Replace power transistors that show signs of leakage
- Perform 'stress tests' on power converters during downtime periods to deliberately cause the weakest ones to fail
  - Example of stress test: repeatedly cycle power converter output from low to maximum output at a rate that causes maximum thermal cycling.

PM on APS power converters using thermal imaging (examples of problems)

One of the four filter capacitors failed open circuit and is running cooler than the others. This causes stress on the other caps, which will eventually fail and cause downtime.



Loose cable connection causing excessive heat in lugs and cables

Cost Impact of adopting the higher starting MTBFs…?

- (Some discussion needed by Availability TF)
- Electrical utilities
  - Eg, Industry norms assume some derating
  - Compare with SB2009 criteria…
- Commodity computing / networking
  - ‘We buy the Availability we need’
  - Cross-checking of SB2009 criteria…
- APS magnet power converter MTBFs
  - Additional costs are largely manpower for QA processes

MTBFs in Availsim model

Device	RDR starting MTBF	RDR table A factor	RDR adjusted (Final) MTBF	SB2009 adjusted MTBF	SLC MTBF	FNAL Tevatron MTBF	FNAL Main Injector MTBF	APS MTBF	other MTBF
mttf_electronic_module	1.0E+05	3	3.0E+05	**3.0E+05**	3.0E+05				
mttf_PS_controller	1.0E+05	10	1.0E+06	**3.2E+06**	8.0E+04	1.8E+05	1.1E+05	1.1E+06	
mttf_controls_local_backbone	1.0E+05	3	3.0E+05	**1.0E+06**					
mttf_magnet	1.0E+06	20	2.0E+07	**2.0E+07**	5.0E+05		2.0E+06		
mttf_sc_magnet	3.0E+07	1	3.0E+07	3.0E+07		1.6E+06			
mttf_small_magnet	1.0E+07	1	1.0E+07	1.0E+07	3.4E+07				
mttf_PM_magnet	1.0E+07	1	1.0E+07	**3.4E+07**					
mttf_PS_corrector	4.0E+05	1	4.0E+05	**1.1E+06**	4.3E+05	1.8E+05	1.1E+05	1.1E+06	
mttf_PS	2.0E+05	5	1.0E+06	**3.2E+06**	4.3E+05	1.8E+05	1.1E+05	1.1E+06	4.0E+04
mttf_kicker	1.0E+05	1	1.0E+05	1.0E+05	1.0E+05				
mttf_kickpulser	7.0E+03	5	3.5E+04	**3.5E+04**	6.6E+03				
mttf_modulator	5.0E+04	1	5.0E+04	5.0E+04	6.4E+04				
mttf_dr_klystron	3.0E+04	1	3.0E+04	3.0E+04					
mttf_mb_klystron	4.0E+04	1	4.0E+04	4.0E+04	5.0E+04				
mttf_DRFS_klystron	1.2E+05	1	1.2E+05	1.2E+05					1.7E+05
mttf_X_klystron	2.5E+04	1	2.5E+04	2.5E+04					
mttf_cavity	1.0E+08	1	1.0E+08	1.0E+08					
mttf_coupler_intlk	1.0E+06	5	5.0E+06	**5.0E+06**	9.6E+04				
mttf_coupler_intlk_electronics	1.0E+06	1	1.0E+06	1.0E+06	9.6E+04				
mttf_mover	5.0E+05	1	5.0E+05	5.0E+05	5.1E+05				
mttf_VacP	1.0E+07	1	1.0E+07	1.0E+07	3.8E+06				
mttf_VacP_power_supply	1.0E+05	1	1.0E+05	1.0E+05					
mttf_valve	1.0E+06	1	1.0E+06	**5.0E+06**	1.0E+06				
mttf_vac_valve_controller	1.9E+05	1	1.9E+05	**9.5E+05**	1.9E+05				
mttf_fs	2.5E+05	10	2.5E+06	**7.5E+06**	2.2E+05				
mttf_pulsed_cable	2.0E+05	1	2.0E+05	2.0E+05					
mttf_xfrmr	2.0E+05	1	2.0E+05	2.0E+05					
mttf_waterpump	1.2E+05	1	1.2E+05	1.2E+05	1.2E+05	1.3E+05			
mttf_water_instr	3.0E+04	10	3.0E+05	**3.9E+05**	3.0E+04	1.3E+05			
mttf_elec_small	3.6E+05	1	3.6E+05	**1.6E+06**	3.6E+05				1.6E+06
mttf_elec_big	3.6E+05	1	3.6E+05	**1.6E+06**	3.6E+05			6.7E+05	1.6E+06
mttf_vac_mech_device	1.0E+05	5	5.0E+05	**5.0E+05**					
mttf_laser_wire	2.0E+04	1	2.0E+04	2.0E+04					
mttf_wire_scanner	1.0E+05	1	1.0E+05	1.0E+05					
mttf_klys_preamp	1.0E+05	1	1.0E+05	1.0E+05					
mttf_vacG_controller	1.0E+05	1	1.0E+05	**4.7E+05**	4.7E+05				
mttf_cavity_tuner	1.0E+06	1	1.0E+06	1.0E+06	5.1E+05				
mttf_cavity_piezo_tuner	5.0E+05	1	5.0E+05	5.0E+05					
mttf_power_coupler	1.0E+07	1	1.0E+07	1.0E+07					
mttf_SLED	1.0E+05	1	1.0E+05	1.0E+05					
mttf_cryo_leak	1.0E+05	1	1.0E+05	**1.0E+06**					
mttf_JT_valve	3.0E+05	1	3.0E+05	3.0E+05					
mttf_cryo_big_prob	1.0E+07	1	1.0E+07	1.0E+07					
mttf_target	4.4E+04	1	4.4E+04	4.4E+04					
mttf_MPS_region	5.0E+03	1	5.0E+03	**3.0E+04**	5.0E+03			3.0E+04	

(Updated since Albuquerque meeting)

- Starting MTBFs and (final) adjusted MTBFs used in simulations

- **Bold**: had to improve it above start value. Means that if MTBF is worse it WILL make availability worse.

- Improve>10
- Improve>3
- Improve>1
- Improve<=1
- White: no data

For the SB2009 proposal document….

- The document should not have to defend RDR data / MTBFs
  - Address only changes from the RDR

Changes

- New components / configurations
  - DRFS, Klystron cluster
  - MTBFs required…
- 'Starting MTBFs' that have been increased based on new information or change in philosophy for SB2009, eg
  - Electrical utilities
  - Magnet power converters, ps controllers

(Some details need additional discussion by Availability TF)

APS Run Statistics '97 – '09

(5000hrs/yr, 3 runs/yr)