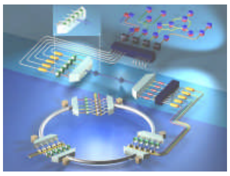
Ticking Time-Bombs in Electronics and Photonics Systems and Networks & Mitigation thereof



Nihal Sinnadurai

- The current financial and survival pressures on companies to cut costs, creates an environment to release products without adequate reliability assurance (we have moved from over-engineering to under-qualifying)
- This removal of reliability assurance creates serious risks downstream
- Outsourcing to the ignorant aggravates the problem and does not obviate ownership of liability (IEEE Reliability and Liability Workshop)

- Symptoms are starting to show:
  - ❖even the great history of cost-effective reliability of electronics is being dented by failures, now appearing, of outsourced and cheap manufactured products
  - ❖network outages are occurring
- The track record of enduring high reliability of components' will cease if OEMs continue to dumb-down
- Products so delivered are time bombs when installed in networks, requiring that the networks be more robust and fault tolerant and over-engineered (system mitigation).

TUESDAY, MARCH 27, 2007 | THE DAILY TELEGRAPH

'Desire to make profits' led to Ladbroke Grove rail disaster

A catalogue of failures, triggered in part by a desire to maintain Railtrack's profitability, caused the Ladbroke Grove rail disaster in which 31 people died, a court was told yesterday.

Network Rail, which took over the legal responsibilities of the privatised infrastructure company, faces a massive fine after admitting health and safety offences.

Thames Trains, whose driver passed a red signal and drove into a First Great Western express, has already been fined £2 million for its part in the disaster in 1999.

The extent of the fine imposed on Network Rail will be announced at Blackfriars Crown Court by Mr Justice Bean today.

Philip Mott, QC, prosecuting, outlined a litany of omissions and errors that led to the crash. He said the failings started at the top of Railtrack and filtered down through the organisation. He outlined a series of warnings both within and beyond Railtrack that highlighted problems with the signal and that portion of line.

Nigel Sweeney, QC, representing Network Rail, apologised unreservedly for the failings of Railtrack but denied that the errors were motivated by profit or cost saving.

Public domain examples of "Qualification" that did not provide Reliability Assurance:

- Fujitsu HDDs; 3.5-inch HDDs mounted internally in PCs failed to spin up.
- Cirrus Logic: drive controller, IC package failed.
- XXX Corp: failures in its analog IC test systems

One manufacturer commented: "It's something that cannot be detected by existing reliability tests"

These publicly known examples are just the tip of the iceberg. There are many private arbitration cases resulting from unreliable product failures that have led to major compensation

Most equipment and IC manufacturers perform "standard" reliability tests on new devices and technologies.

Exception: Bookham Technology plc, whose reliability engineers were trained to assess the validity of 'standards', to extract the relevant clauses and durations and to develop 'fit for purpose' methods and Reliability Assurance plans and Qualification plans.

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IFA
CONSUMER ELECTRONICS UNLIMITED
Berlin, 4.–9. Sept. 2009

GERMANY BEATS DOWNTURN BY BUYING QUALITY

First, I think the German economy is still performing a little bit stronger than some other economies, especially those in Central Europe. Second — and perhaps more important — many Germans have household products that now older than 10 or 15 years, which gives us a huge domestic replacement market. Added to that, when Germans spend money in insecure times, they tend to spend it on fewer but better products — products that they believe will give them better service, are of better quality and will last them for longer. I think this is also one of the reasons why the domestic-appliance industry has done better in Germany than it has in some other European countries.

Dr Reinhard Zinkann, Chairman of the home-appliances division ZVEI

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Reliability non-Assurance

- There is non-practitioner ignorance that products are not identical and that processes may develop flaws that are not trackable by, or responsive to, quality control.
- Desk-based 'simulation' using theoretical 'data' to predict reliability and release products into use without the essential practical and statistically valid information.
- Dumbing-down of reliability 'standards' makes them inadequate for high reliability systems.
- Products so 'qualified' can be time bombs when installed in networks, requiring that the networks be more robust and fault tolerant and over-engineered.

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Reliable operation requires assurance that products will not fail early or at an unacceptable rate during useful life or degrade and cause system failures before the required lifetime is required.

- Reliability assurance is not an exact science
- The only **certain** assurance is obtained by operating the full population over the required lifetime and obtaining data with hindsight.
- This is impractical
- Therefore, reliability is assured by infant mortality screening and 'accelerated ageing' whereby statistically significant samples extracted from the manufactured population are subjected to specific 'overstress' tests in accordance with proven relationships ('models') for the predetermined durations, i.e. **'Evidence based reliability'**

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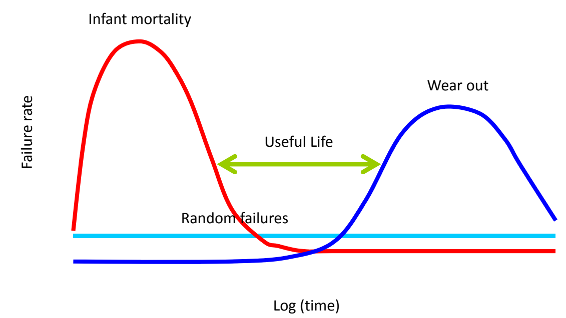
Reliability Regimes



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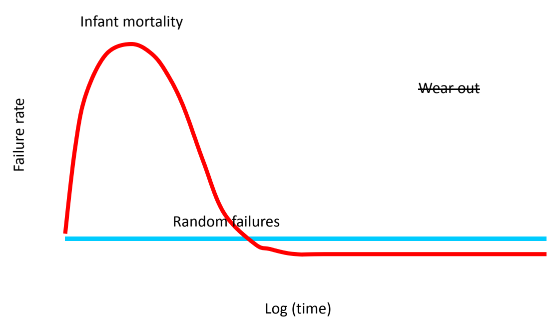
Reliability Regimes



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The causes of hardware component unreliability are not 'in your face'. They can be subtle as:

- oxide or passivation stress,
- proton inclusions in nitrides or inclusions of extremely low levels of ionic elements incorporated into the bulk semiconductor to form charge or recombination centres at the junctions
- the dissolution of a small quantity of gold into a lead-tin solder joint due to the wrong specification for plating or a minor process glitch, causing brittle joints
- an unknown Pb and Pb-free combination in the solder joints
- a variation of 0.1% of the accelerator of an adhesive preventing a full and lasting cure
- a curing oven being timed the wrong way

These may look and perform perfectly well in quality control, but will progressively degrade the product in time

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Partitioned code from disparate sources is integrated and correctly managed under configuration management (i.e. interdependences). This ensures that the impact of changes of code are traceable. Assurance against faulty code is by validation and verification testing. In principle, test sequences could be infinite to ensure all code is exercised. This is not practical. So, there is always risk. It can be quantified. Strictly, this is a measure of quality, although the encounter with the faulty code downstream allows it to be called software reliability.

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Genuine degradation arises from damage/degradation of cells of a memory. A cause of damage arises from Radiation (space or package sourced) penetrating the cells. Rad upsets do not lend themselves to quality control. Radiation hardness can be built-in, designed-in or achieved by shielding. Rad hardness can be verified by exposure to particular doses for specified times.

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- Processes performing within the predetermined statistical process control parameters can still affect reliability.
- Such variations are detected by ongoing vigilance through Maintenance of Qualification (MoQ) by ongoing sampling from production and reliability testing.

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- Mitigation of soft faults is achievable using circuit hardening techniques, e.g. Built-in Soft Error Resilience. BISER implements two redundant memory elements and a C-element at the output (increased hardware) to block error propagation. This has advantage over Dual interlocked cell (DICE) schemes.
- Because code does not wearout, MoQ is not relevant. Changes in code must of course be validated and verified.
- Rad hard devices must be subjected to MoQ

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So, what is “Qualification”?

- For hardware, it is the formal legal demonstration of survival to a series of stress tests conforming to recognised international standards, during which specific characteristics are measured to determine the product behaviour within or beyond the specified end-of-life limits (Black box approach).
- In the photonics industry, the established standards are those drafted by Telcordia (formerly BellCORE). More recently IEC is increasingly favoured by the telecommunications service providers.
- In the electronics industries the standards are IEEE, JEDEC, IEC, CECC, EIA, AEC, MIL (MIL is less authoritative)

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- The standards do not absolve the supplier company from proving that their products are fit-for-purpose. Hence the need for long term reliability assessment.
- Because qualification tests and reliability tests of hardware are intended to consume actual life, and demonstrate the product does not fail, such tests are deemed “destructive”, i.e. the components cannot be sold on (*as some non-technical executives seem to expect*).

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Reliability Engineering

- by Design,
- by Process,
- by Model proving,
- by Confidence building through testing and improving

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- Single Telcordia standards do not fully cover the range of products now offered by photonics component companies and therefore Qualification Plans must adopt relevant parts from different standards and even create tests from in-house expertise.
- Applying a full set of Telcordia specifications to a high level product imposes a draconian range of tests requiring considerable parts to be tested (adding cost and time) and sometimes over-severe stresses – which may destroy the high-level product.
- Therefore Telcordia and IEC stress tests are applied most effectively at the level of build at which the tests remain relevant

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A structured example of a Product Qualification build-up is by assuring the elements (blocks) of a full system and thereby creating a library of qualified Building Blocks. The alternative to this approach is to Qualify all legs of the full product at the top level which will be extremely expensive, time consuming and some of the tests will probably destroy the product.

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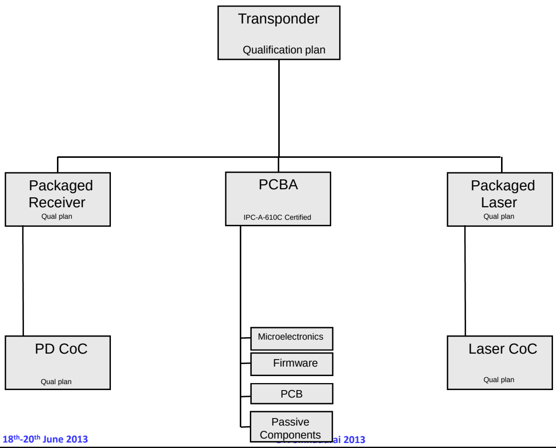

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Calibre of evidence: Electronics

In the High-Rel Telecommunications industry, the reliability of electronics and microelectronics was achieved by applying a range of overstress tests based on well characterised models of ageing and sampled to a required statistical standard of better than 1% LTPD (Lot Tolerance Percent Defective) which is a measure of the statistical confidence in the result. Typically, 235 electronics devices are overstress tested per test condition (i.e. total devices reliability tested per qualification > 1500)

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Technical Evidence

The correct equation (model) for Highly Accelerated Stress Testing (HAST):

$$t_{amb}/t_s=\exp\{X[(RH_s)^n - (Rh_{amb})^n] +(E_A/k)(1/T_{amb}-1/T_s)\}$$

Verified by 150 x 10^6 device hours of practical stress testing

When applied to semiconductor devices, the empirical S-H Model expression is:

$$t_s=175000/\exp\{0.00044[(RH_s)^2 - (Rh_{amb})^2]+7000(1/T_{amb}-1/T_s)\}$$

where 175000 hours is 20 years and is the required lifetime (t_{amb}) at the ambient condition, RH_s is the applied humidity stress, RH_{amb} is the humidity at the application ambient, T_s is the applied stress absolute temperature and T_{amb} is the application ambient temperature, E_A is the activation energy for the specific failure mechanism, X is the humidity activation coefficient and "n" is the humidity activation exponent

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The operating environments

10 Year OPERATING CLIMATES
(for long-term reliability)

Region	Climate
Temperate (Europe, North America)	12ºC & 72% RH
Sub-tropical (99% of locations)	29ºC & 86%RH
Full tropical (Rainforest regions)	35ºC & 90% RH

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Generating the evidence

THB Reliability tests for 20 year survival in different climatic conditions

"Uncontrolled" average operating climate ⇓	The overstress conditions to be applied				
	85°C & 85%RH	95°C & 95%RH	108°C & 90%RH	125°C & 90%RH	125°C & 95%RH
	Humidity chamber	Humidity chamber	HAST	HAST	HAST
	Time (hrs)	Time (hrs)	Time (hrs)	Time (hrs)	Time (hrs)
Temperate general (12°C & 72%RH)	500	130	100	50	Too short
Tropical coverage of 99% of sub-tropics (29°C & 86%RH)	5100	1300	1000	500	320
Tropical severe (35°C & 90%RH)	10000	2600	2000	950	630

Based on the S-H model

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Ignorance or Cavalier?

WARM & DAMP CLIMATE HARDWARE RELIABILITY ASSURANCE

But, is one condition valid for all?
Massive errors arise by assuming the wrong activation energy or wrong S-H Humidity Coefficient.

HAST ACCELERATION FOR 0.9eV AND 0.6eV ACTIVATION ENERGIES FOR STATION AMBIENTS OF 70°C & 15% RH AND 50°C & 41% RH vs 130°C & 85% RH

Activation Energy eV	Base Station Environment	Calculated Acceleration Factor	Predicted Lifetime for 96 hour test
0.9	70°C & 15% RH	2020	194000 (**22.1 years**)
0.9	70°C & 16% RH	1990	191000 (21.8 years)
0.9	50°C & 41% RH	7100	673000 (77 years)
0.6	70°C & 15% RH	455	43700 (**5.0 years**)
0.6	70°C & 16% RH	450	43200 (4.9 years)
0.6	50°C & 41% RH	850	82000 (9.4 years)

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Dangerous irrelevance

Vendor	Mil-Hdbk-217 MTTF (hrs)	Observed MTTF (Hours)
A	7247	1160
B	5765	74
C	3500	624
D	2500	2174
E	2500	51
F	2000	1056
G	1600	3612
H	1400	98
I	1250	472

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- The LTPD of a sampling plan determines the level of faults that may escape detection when manufactured parts are subjected to quality or reliability tests.
- It is generally defined as the percent defective (number of defectives per hundred units X 100%) that the sampling plan will permit 90% of the time.

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LTPD Sampling Table

Max % Defective	20%	15%	10%	7%	5%	3%	2%	1.5%	1%	0.7%	0.5%
Acceptance Number (c); rejects=c+1	Minimum Sample Size Needed										
0	11	15	22	32	45	76	116	153	231	328	461

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Recent calibre of evidence:

With photonics products and recent poor practise by some microelectronics companies, the cost reduction regimes have led to a poor level of statistical sampling resulting in an LTPD of 20%, arising from the qualification testing of only 11 devices per overstress condition (no failures permitted).

It is a legal obligation to declare and report on all components placed on test and all failures that occur. Padding the population is practiced in the industry to achieve the minimum of 11 survivors. However, strictly, all failures must be reported. Note that 1 failure in less than 18 devices does constitute qualification failure of even the low statistical demands of these products.

Qualification reports globally are strewn with reports to excuse specific failures (e.g. "fibre inadvertently broken during handling for measurement" "cause of failure not due to device" ???).

This is a new breed of CEO-driven 'reliability engineer'

Another CEO-driven pressure

Software in products:
'I have paid the coders to write good code. We have no need, budget or time for test code development or additional testing. Get the damn product shipped'

The parameter for System Reliability = the FIT

- 1 FIT = 1 Failure in 10^9 Device Hours
- Why?
- Because major systems use millions of components required to function 10-20 years (hundreds of thousands of hours) with few failures.
- Therefore the failure rates must be in parts per billion device hours. Even small failure rates will lead to frequent equipment failures and cause significant down-times and high maintenance costs
- So, the calibre of evidence gathering must be robust and not dumbed down!

FIT Rates may be obtained from Qualification tests or Reliability tests

Duration	Sample Size	Actual Failures	CL	FIT Estimate	Comments
5000	11	0	60	16728	Typical "standard" life test low sample size gives high FIT rate
5000	368	0	60	500	High reliability sample size to achieve 500 FITs at 60% CL

With such poor calibre evidence of products supplied, which sells the customer and end-user short, the consequence is that system must be made more robust – to mitigate the risks arising from their elements.

Hence, the Essential Solutions:

Robust Modern Systems

Essential Solutions: Robust Modern Networks

- **Smart Systems**
- Smart Networks
- Managed Networks
- Robust Networks

or

- Competently Qualified Network Products

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Essential Solutions: Robust Modern Networks

- Smart Systems
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- **Robust Networks**

or

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Essential Solutions: Robust Modern Networks 1

Primary protection is intended to be rapid and is based either on built-in redundancy or through real-time dynamically reconfigured mesh using cross-connect . This provides for fast resilience in the event of concurrent outages. Mesh involves high connectivity in which the protection paths are shared and is therefore dependent on availability.

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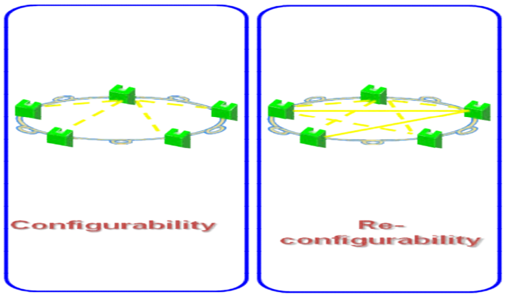
Essential Solutions: Robust Modern Networks 1



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Essential Solutions: Robust Modern Networks 2

Secondary protection provides back-up in the event that primary protection fails to deliver 100% restoration. Secondary restoration can be achieved through the control plane and can adapt to outages by reconfiguring and reusing available capacity in the network. Accordingly, the provision of such protection requires that network intelligence is collected dynamically.

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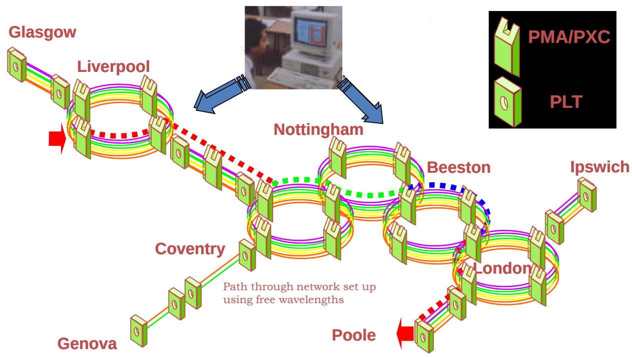
Essential Solutions: Robust Modern Networks



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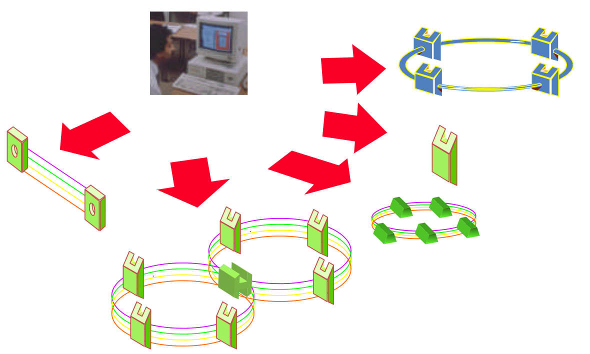
Essential Solutions: Robust Modern Networks 2

Single Management System



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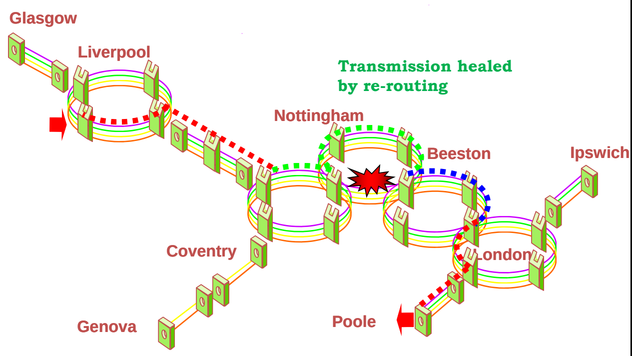
Essential Solutions: Robust Modern Networks 2



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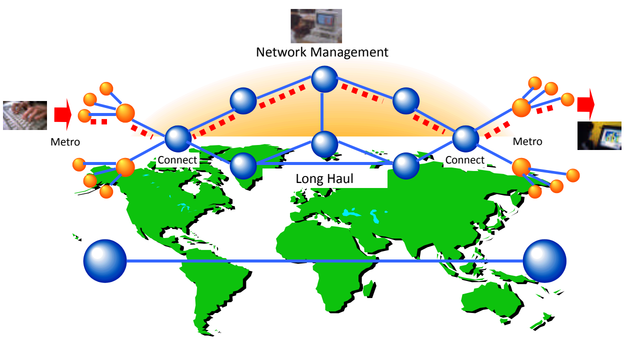
Example Long Haul Network Diagram



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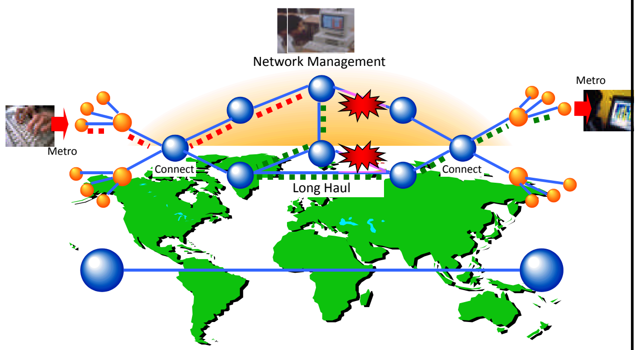
Long Haul Network Fault-Tolerant Recovery



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Design Reviews, Design Reviews, Design Reviews ………

IN driven packetised voice

Rapid growth from 200 to 350 SW engineers

Interviewed for skills, responsibility and integrity

System Requirements objective-driven partitioned by supervising team. All interfaces specified

Requirement included whole life robustness from external attack.

Partitioned development in teams, tested, integrated, tested.

Placed under configuration management (manage hierarchical impact of changes)

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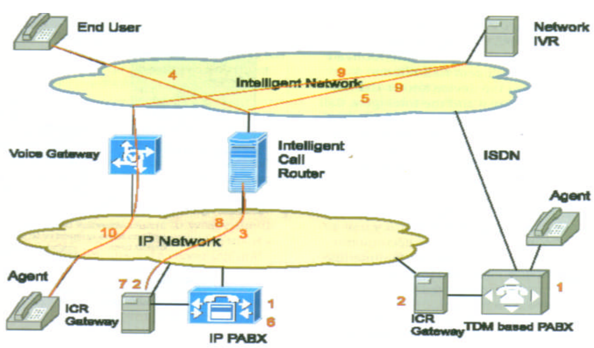
IN driven packetised voice



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Essential Solutions:

- Smart Systems
- Smart Networks
- Managed Networks
- Robust Networks

or

- **Competently Qualified Network Products**

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CONCLUSION

- Either the networks are built to be more robust
  - Adding cost value at the system level, but with significant unknowns remaining in the network

Or

- Product reliability is built-in and proven
  - requiring investment at the component level

Who pays?

- In a market economy, the consumer must pay the cost or suffer the penalty. If we keep going for the cheapest, we may get the worst.

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Cost cutting, drive to cheapness time-bomb =

Future Blackouts

Future communications outages

Tragedies: - aircraft , life-support , emergency call-out - failures

Solution = Constructive cost-effective approach to reliability . Build and assure reliable blocks ✓

