# PROFIBUS and PROFINET System Design

PROFINET, PROFIBUS and IO-Link Seminar
MTC, Coventry,
25 February 2016

Andy Verwer,
Verwer Training & Consultancy Ltd
Accredited PI Training Centre

## System costs

- Most system designers and project managers look at the project procurement, installation and deployment costs when they price a project.
- However, the costs of an automation system spread over the life cycle of the plant and should include maintenance, fault-finding and health-checking.
- Perhaps most important is the cost in terms of loss of production should faults develop during the lifetime of the plant. Spending a little more at procurement time can repay many times over.
- Good fault tolerant design need not be more expensive. Sometimes fault tolerance can be achieved with just a little thought at no additional cost.

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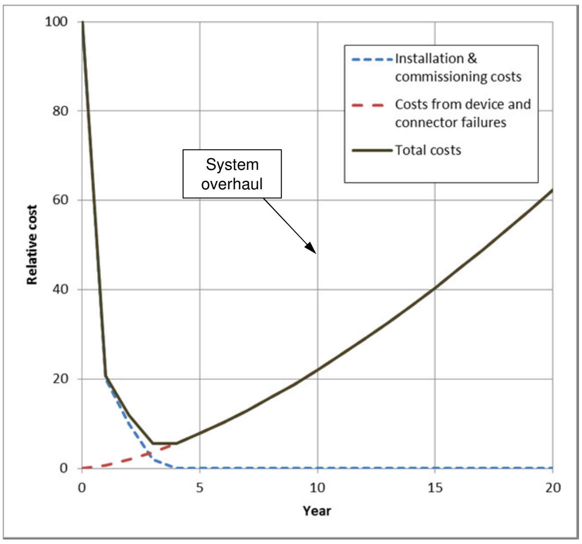
## Life cycle costs

VTC

- The procurement, installation and commissioning costs are only incurred at the start of the project.
- Costs from device failures increase as equipment gets older.



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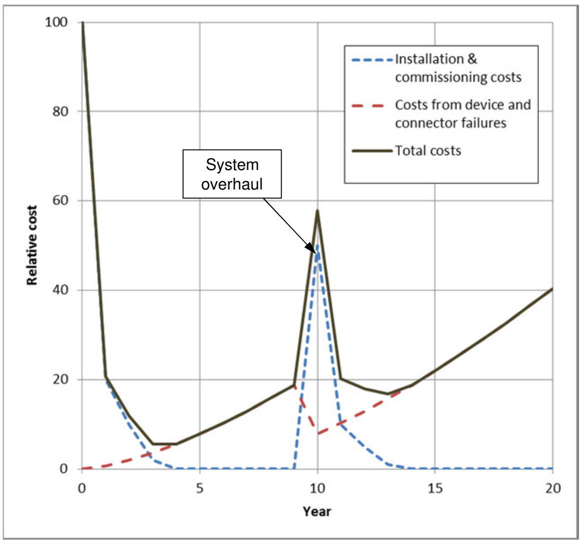
## Life cycle costs

VTC

- When system overhaul is undertaken this can partially reset the increasing cost of failures.



## Control system design

- Control system design normally proceeds by building on the experience obtained from previous designs.
  - But, designs which are based on badly designed systems will be bad!
  - Only by using experience from operations and maintenance staff can we develop good system designs.
  - In my experience it is rare for such feedback mechanisms to be present. Particularly when design is carried out by sub-contractors.
- Designers need to know about mistakes that have been made in the past.
  - Feedback from operations and maintenance is essential.



## System costs

- Maximising plant availability is critical in reducing the total costs of the system. It is essential that the System Designer understands:
  - That minimising plant down time when faults inevitably occur (i.e. maximising plant availability) is a key requirement.
  - The impact of the network layout on plant reliability.
  - That the incorporation of network health checking and fault finding facilities are essential.
  - How to appropriately use features such as redundancy and network monitoring and rapid fault location and repair to improve plant availability.

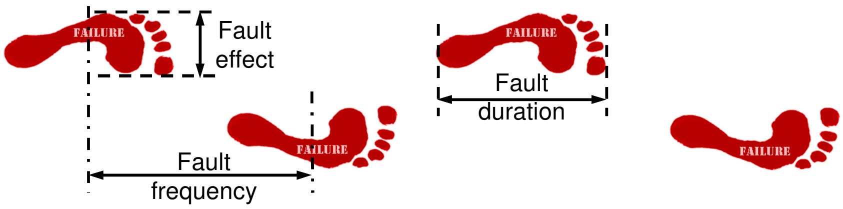
# Cost of failures

- The parts of a control system will fail whilst in service.
- The consequences of failures are often predictable, but the failures themselves are unpredictable.
- The design of a reliable control system is not simple.
- … and should be accompanied by analysis of how parts fail and of the consequences of these failures.



# Minimising the failure footprint

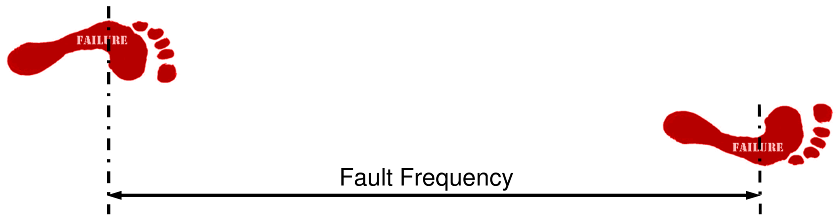
- A good network design will minimise the effect on production when inevitable failures occur.
- We can speak of minimising the "failure footprint".




- There are three basic ways to minimise the impact of faults:
  1. Make failures less likely – Minimise the ***Fault Frequency***.
  2. Restrict the ***Fault Effect*** when failures inevitably occur.
  3. Minimise the ***Fault Duration*** – Provide for rapid fault location and repair.

## Minimising the failure footprint

1. How can we minimise ***Fault Frequency***?




- Understand and implement the design and installation rules.
- Improve reliability - use good quality well tested (certified) and reliable devices, connectors and network components.
- Use manufacturers who carry out burn-in testing on devices.
- For PROFIBUS use the lowest possible bit rate that gives the required performance.



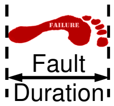
## Minimising the failure footprint

2. How can we minimise the ***Fault Effect***?


- Analyse the effects of failures on plant operation.
- Use well thought out network layout and design.
- Think about:
  - ✓ Using separate networks or different masters (distributed control),
  - ✓ Using different segments for different parts of the process,
  - ✓ Dealing with common cause failures.

# Minimising the failure footprint

3. How can we minimise the ***Fault Duration***?




- ✓ Provide facilities in the design for rapid fault diagnosis and fault location.
- ✓ Provide in the design for device hot swapping without reconfiguration.
- ✓ Use designs that allow for a quick fix.
- ✓ Provide redundancy when appropriate. Needs to be well thought out!
- ✓ Use standardised, vendor independent solutions rather than being locked into manufacturer specific solutions.



# Minimising fault impact in design

- Use pluggable devices that can be removed/replaced without impinging on network operation.
- Use appropriate network layout and segmentation so that physical layer faults allow critical plant operation to continue in the event of failure or device replacement.
- Provide for rapid troubleshooting and simple fault isolation.
- For PROFIBUS systems use:
  - Connector systems and layouts that do not break the bus or loose termination when disconnected.
  - Termination solutions that allow devices to be removed or replaced.
- Use appropriate solutions for redundancy.

## Reliability and availability

- Reliability is a measure of how a component, assembly or system will perform its intended function, without failure, for the required duration when installed and operated correctly in a specified environment.
- Availability is  a measure of reliability indicating the fraction of time in which a device or system is expected to operate correctly.
- It is important to remember that reliability and availability are statistical measures: they will not predict when a particular device will fail, only the expected rate based on average performance of a batch of test devices or on past performance.



## Some definitions

- Mean Time Between Failures (MTBF) is the expected or average time that a device will be free of failure.
- Typical MTBF for a well designed and manufactured electronic device might be 10 to 20 years.
- Mean Time To Repair (MTTR), is the time taken to repair a failed device.
- In an operational system, MTTR generally means time to detect the failure, diagnose and locate the problem and replace the failed part.

## Availability

- Availability can be calculated from MTBF and MTTR:

$$\text{Availability}, A = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

- Remember that availability is a statistical measure and represents an average probability of being in operation.
- There is little point in trying to be accurate with these figures since actual failures are unpredictable.
- Availability is typically specified in “nines notation”. For example 3-nines availability corresponds to 99.9% availability. A 5-nines availability corresponds to 99.999% availability.



## Availability and downtime

- Downtime is an alternative way of understanding the availability:

$$\text{Downtime}, D = (1 - A) = \frac{MMTR}{MTBF + MTTR}$$

| Availability, *A* | D = (1-*A*) | Downtime |
|---|---|---|
| 0.9 = 90% (1-nine) | 0.1 ($10^{-1}$) | 36.5 days/year |
| 0.99 = 99% (2-nines) | 0.01 ($10^{-2}$) | 3.7 days/year |
| 99.9% (3-nines) | 0.001 ($10^{-3}$) | 8.8 hours/year |
| 99.99% (4-nines) | 0.0001 ($10^{-4}$) | 53 minutes/year |
| 99.999% (5-nines) | 0.00001 ($10^{-5}$) | 5 minutes/year |
| 99.9999% (6-nines) | 0.000001 ($10^{-6}$) | 5 minutes/10years |
| 99.99999% (7-nines) | 0.0000001 ($10^{-7}$) | Not feasible! |
| 99.999999% (8-nines) | 0.00000001 ($10^{-8}$) | Impossible! |

Normal range for automation (2-nines to 5-nines)

## Availability and downtime

- Note that the availability of a device can be improved by decreasing the MTTR.
- This can be accomplished in several ways:
  - Faster detection and location of faults. (Accomplished by diagnostic reporting facilities, availability of fault finding tools and training of maintenance personnel).
  - Faster repair of the fault. (Accomplished by availability of spares and all of the above).
  - Fault tolerant design.



## Example

- Consider a remote IO unit with a MTBF of 10 years.
- When the device fails, it could take several days to recognise, diagnose and locate the fault. And then, if not held as a spare, several more days to obtain a replacement. The MTTR could be one week, giving an availability of:

$$A = \frac{MTBF}{MTBF + MTTR} = \frac{10 \times 365}{10 \times 365 + 7} = \frac{3650}{3650 + 7} = 0.998$$

- That is approximately 3-nines availability, or a downtime of about 16 hours/year.
- Consider the availability when the MTTR is reduced to ½ day:

$$A = \frac{10 \times 365}{10 \times 365 + 0.5} = 0.99986$$

- The availability is now 4-nines and the downtime has reduced to about 1hour/year.

## Reliability modelling

- The system designer must understand the methods of modelling and analysis of reliability and availability in systems.
- In particular how system availability can be predicted from the individual parts.
- Also understand how standby systems, redundant solutions and common cause failures impact the overall system reliability.
- We often find that redundancy is inappropriately used and sometimes results in no real improvement in system availability.
- Careful network layout can have a major effect on the fault footprint and significantly improve the overall availability of the plant.



## Standby and redundant systems

- We often see standby or redundant systems used to try to improve plant availability.
- Here we have two or more devices working in parallel.
- Should a fault occur in the operational device then the standby device can take over.
- The switch over can be manually activated or can be automatic. The switching time should be considered when estimating the overall system availability.
- This scheme achieves high availability because the system function is maintained whilst repairing the failed device.

## Multiple controller systems

- Multiple PROFIBUS masters or PROFINET controllers with automatic duty-standby switching are available from a number of suppliers.
- These can drive different networks to provide redundancy down to the field level. However, separate power supply and network cable routing are advisable to minimise common-cause failures.
- Sometimes dual slaves can be used in the field with a simple “wired-OR” voting system driving the final actuator or connecting two redundant sensors.
- However, more often we find such redundant controllers are using the same field devices and actuators.
- Such systems must be carefully designed, taking account of the consequences of all possible failures.



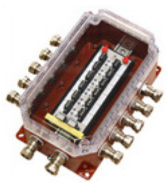
## Redundancy solutions for PROFIBUS

- Solutions for redundant PROFIBUS cabling are available from many manufacturers:

Siemens Y-Link

PROCENTEC ProfiHubs

COMbricks modules

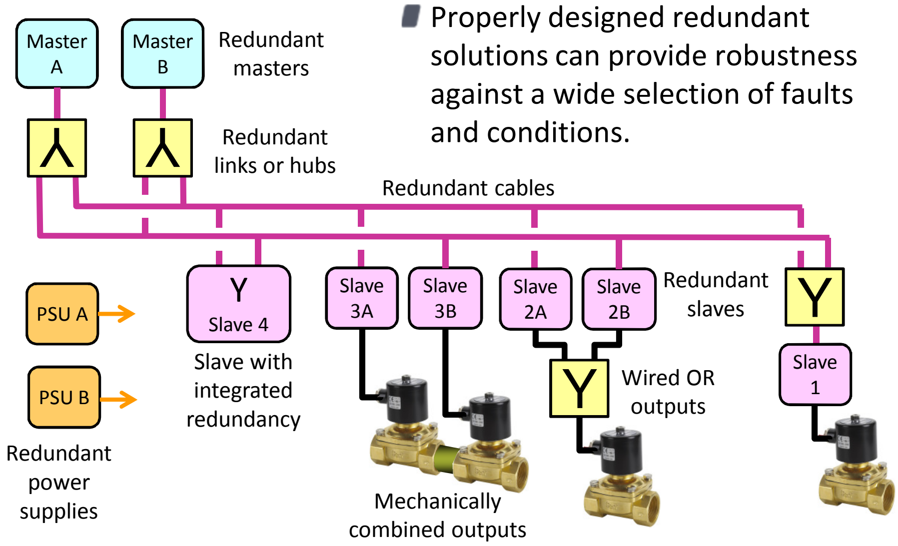


Moor-Hawke
Redundancy for PA

ABB Redundancy
Link Module

## Redundancy solutions for PROFIBUS

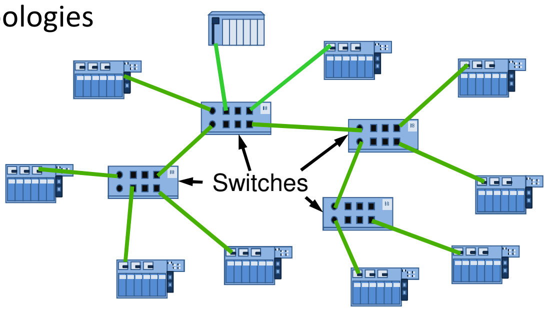
- Properly designed redundant solutions can provide robustness against a wide selection of faults and conditions.



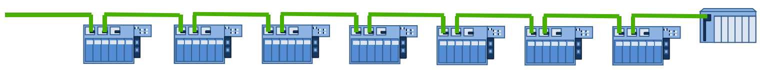



## PROFINET system layout

- PROFINET systems can be laid out in a number of ways:
  - Star and tree topologies using switches:




  - Line topology using two-port devices:



  - Or a combination of both.

## PROFINET system layout

- There is a clear advantage of the star topology in terms of system availability in that any device can be replaced without affecting the other devices.
- However, the system cost will be significantly greater because of the number of switches required.
- The line topology is much lower cost, because separate switches are not required.
- But removal or replacement of any device will cause all downstream devices to fail.

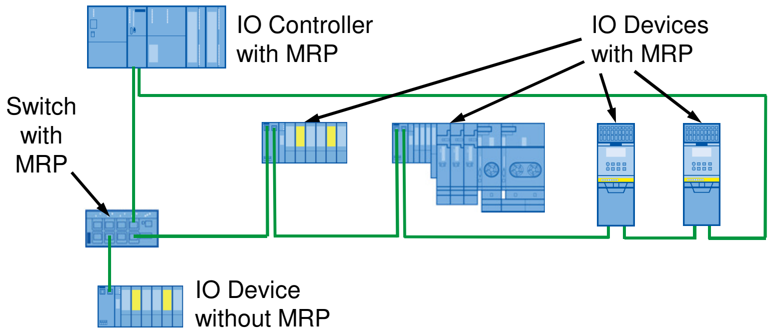


## Redundancy solutions for PROFINET

- One of the big advantages of PROFINET is that it incorporates a specification for media redundancy.
- The standardised Media Redundancy Protocol (MRP) provides manufacturer independent redundancy which can be used over copper or fibre cables.
- PROFINET redundancy can provide:
  - Controller redundancy.
  - Transmission media and switch redundancy.
  - IO device redundancy.
- Redundant PROFINET systems are relatively easy to implement and can be used across different manufacturers.

## PROFINET redundancy

- Standardised Media Redundancy Protocol (MRP) can be used on PROFINET systems to give media redundancy.

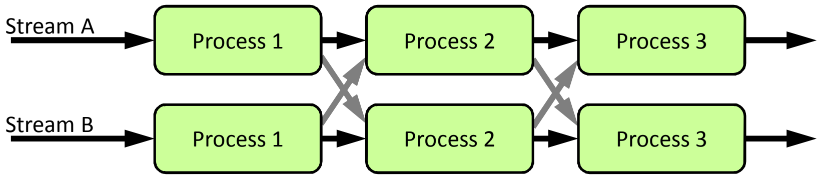



- But the system must still be properly designed, considering all possible failures and their likelihood. Common cause failures must be properly dealt with.



## Other ways to improve availability

- The careful design of networked systems can improve their availability.
- In particular by organising the system so that selected parts of the system can be independently shut down for maintenance without affecting the remaining production.
- A simple example of this is seen with streamed production.




- A stream can be taken out of service without affecting the other stream.
- But only if the system design allows this.

## Automation islands or units

- The concept of dividing the plant into Automation Islands or Automation Units is well established.
- Each automation unit is considered as being functionally separated from the rest of the plant so allowing it to operate (and to be shut down) independently.
- A good network design will facilitate the isolation of these automation units using:
  - Different controllers;
  - Different networks or subnetworks;
  - Segmentation.
- Careful choice of various architectures for automation units is a key stage in the design process which can impact on the overall reliability and maintainability of the control system.



## Certified System Design course

- A new Certified PROFIBUS System Design course was developed last year and is fully accredited by PI.
- This 3-day training course is suitable for managers, designers and engineers who are involved in the planning, specification, design and procurement of PROFIBUS systems.
- The course covers the optimum design both DP and PA systems for availability and maintenance.
- The 1-day Certified PROFIBUS Installer course is an essential pre-requisite which is normally run together with the design course making 4-days of training.
- The course is also available for cost-effective on-site delivery for between 6 and 12 people.

# Training

- Certified PROFIBUS and PROFINET training including the new Certified PROFIBUS System Design course is available from the UK's accredited training centres:
  - PROFIBUS International Competence Centre
  - Manchester Metropolitan University.
    - in Manchester, or a location of your choice.
    - (www.sci-eng.mmu.ac.uk/ascent/).
  - PROFIBUS International Training Centre
  - Verwer Training & Consultancy Ltd
    - In Manchester or on-site.
    - (www.VerwerTraining.com)