MAINTENANCE LECTURE

LOGISTICS

Logistics was originally a military term for the art of moving and quartering troops, it has moved into general terminology as:

"1) The organizing of everything needed for any large scale operation.
2) The control and regulation of the flow of goods material staff etc. in a business,"

Chambers 20th Century Dictionary

In systems engineering "Logistics" is the term used for all the activity in support of the system during the operational phase. It involves:

- the distribution of consumables and spares to the system in the field;
- the management of support personnel
- the maintenance of the system;
- any validation exercises;
- anything else done to the system.

The first three are primarily related to maintenance. This lecture looks at maintenance, what it is, and some aspects of how it influences design.

MAINTENANCE

Maintainability:

"the probability that a system will be retained in, or restored to, a specified condition in a given period, when maintenance is performed in accordance with prescribed procedures and resources."

MIL STD-721B

Note these implications in this definition:

- Both "retain in" and "restore to" are covered, leading to at least two different types of activity.
- Success is defined as maintaining a specified state, i.e. a system's quality.
- Implies maintenance is a designed function in the system.

The last two factors make it a systems engineering activity.

TWO BASIC CLASSES OF SYSTEM

1 - Mean time between system failure >> Specified operational life.

Either because:

the system has inherent reliability over its lifetime, and therefore we expect little or no maintenance. Normally cheap, short life items where maintenance is not worth doing.

Or because:

the system cannot be maintained and therefore high reliability has to be built in. e.g. launch Systems and spacecraft.

For complex systems these circumstances are rare.

2 - Mean time between system failure << Specified operational life.

That is we do expect to have to do maintenance. Applies to almost every complex engineered product particularly with moving mechanical components.

In the real world maintenance is almost always a critical design issue.

THE IMPORTANCE OF MAINTENANCE

Maintenance has a special role in the system lifecycle as it is the thing that blurs the boundary of the hand over from the Supplier (producer) to the Customer (user). It means the supplier cannot "wash his hands" of the system after he has got the money, and it means the customer has to undertake some technical tasks (however simple and menial). So after delivery:

the Supplier has to	- supply spares - issue warnings and recalls - support maintenance capability
the Customer has to	- undertake specified servicing tasks - maintain contact with the supplier,

Consider the implications when a supplier (think Microsoft here) withdraws support for a product.

Another example, which was a contributing factor to the withdrawal of Concorde, was that Airbus (who inherited the product) stated it was unwilling to support the product.

TYPES OF MAINTENANCE

We have already seen that maintenance means actions during the operational life that either retain or restore system performance. This leads to two separate activities, servicing and repair. These are also called:

i - **Preventative Maintenance** (servicing)
and
ii - **Corrective Maintenance** (repair).

There is a third type of maintenance where a system that still meets its original specification is upgraded to meet a new specification. This is called **Adaptive Maintenance**.

All three have an impact on the system design activity.

PREVENTATIVE MAINTENANCE
(Servicing)

This is the actions that are conducted during the system's operational life as a nominal part of the system design and whose function is to maintain the system's quality.

Servicing Function	**Example (Car)**
- Replace Consumables	- Fill with petrol
- Replace parts with limited life	- Spark plugs
- Adjust system	- Timing
- Inspect areas of concern	- Tracking

This class of maintenance can be conducted when the degradation of the system elements is predictable, either because it is gradual or because it is well defined.

Because it is a normal and intended part of the system function, preventative maintenance does not fall outside the system specification. Therefore it is not grounds for a legal complaint against the producer. After all you could hardly sue BMW because your Mini ran out of petrol.

Note: that the above implies Preventative Maintenance requirements must be included in the Requirement Specification (or at worst in the Design Specification). This actually is not done in detail but will be defined in terms of time the total maintenance activity takes (see **Availability** later).

The exception is modifications to the system to correct an identified design weakness (car recalls is a classic consumer example). Because it is done to reduce the risk of failure, rather than as a response to an actual system failure, it is called preventative maintenance. However; as it is a response to what is effectively a failure to meet the specification fully it is legally the responsibility of the producer to put it right and is logically a type of "corrective maintenance".

CORRECTIVE MAINTENANCE
(Repair)

These are the actions that are conducted during the system's operational life which are not a nominal part of the system design but a response to a system failure to meet specification and whose function is to restore the system's quality.

Repair can be one of two forms:
- Rework the originally installed item until it works.
- Replace the originally installed item with a new one.

Like Safety Hazard control, a key element of Corrective Maintenance is the detection of the failure. Some failures do not show up directly in the overall system performance until secondary and normally more expensive failures occur.

REPAIR - A DESIGN ISSUE!

Corrective maintenance is by definition unexpected. But one can design to expect the unexpected.

Detection - Monitors that alert maintenance process that Corrective Maintenance is required (can be part of preventive maintenance,)

Protection - Barriers preventing hazards potentially causing failure reaching sensitive components.

Access - Design access routes that enable components to be reached and replaced.

Removability - Design elements to be removed if required (e.g. bolting an electronic box to the main system - as opposed to welding it in.)

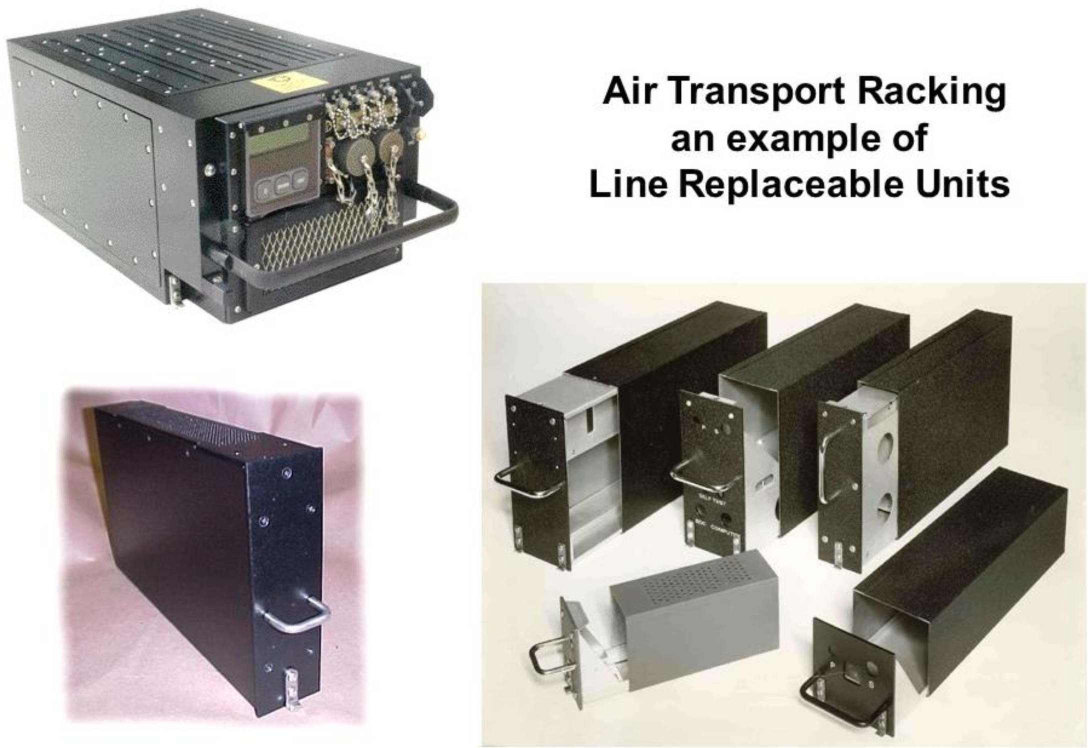
Weak links - Design weak links into the system so failure will occur in cheap accessible components rather than expensive inaccessible components - (e.g. fuse box.)

MAINTENANCE DESIGN ON AIRCRAFT - AN EXAMPLE

One of the key concerns in designing for maintenance on Aircraft is to minimise the time spent on the aircraft, when it cannot fly. This is measured by "availability" (covered later). A key philosophy on aircraft avionics is to identify the unit to be replaced (without establishing what is precisely wrong with the unit) and remove and replace the whole unit. The unit removed can then be worked on without effecting the aircraft operations.

On aircraft the ARINC400 ATR units are designed for this. Generically any unit designed for easy removal during maintenance is called a **"Line Replaceable Unit"** (**LRU)**. In space if a unit is designed for removal by space suited astronauts it is called an **Orbital Replaceable Unit (ORU).**

With the move to "Integrated Avionics" where cabinets contain standard electronics cards it is the cards that are replaced. In this case the cards are called **"Line Replaceable Modules" (LRM).**



ADAPTIVE MAINTENANCE
(Upgrade)

This is the actions that are conducted during the system operational life to change the performance such that it meets a new requirement (i.e. allows a redefinition of the system's quality). It may sound that this is of no concern during the initial system design but expandability can be specified. If the customer wants expansion potential he/she must put the requirements in the Requirement Specification.

This involves leaving capacity in the system (beyond what is required to meet its objectives) and entry points to give access to the capability, which are called "hooks and scars".

Examples of Hooks and Scars.
- Towing hook on a car.
- Expansion slots on a PC.

In one paper I saw somebody describe "Hooks" as physical connection points and "Scars" as software entry points but I am not sure this is a widely used distinction. I think a better distinction is that Hooks are the accommodation allowances generally and Scars are the openings allowing connection into the system.

MAINTENANCE TIME

Somewhat obviously when a system is being serviced it cannot be used to perform its function. We need a measure of maintenance time, indeed since is often specified we need a way to predict maintenance times. Called Maintenance Down-time it has three components:

Waiting or **Administration Time -**The time from the detection of the need for maintenance to the start of active maintenance excluding any Logistics Time

Logistics or **Supply Time -**The time for the items required for maintenance (parts, tooling and facilities) to become available for use.

Maintenance Time -The actual time when active maintenance of the system is being performed.

In theory Administration time and Logistics time should only apply to corrective maintenance, since the system can be operational while preparation for the preventative maintenance is being performed. Any car owner will know the practice!

AVAILABILITY

Availability is a measure of how much of the overall operational lifetime the system can actually be operational - i.e. either in use or ready for use. In other words it is a measure of the time lost to maintenance activities compared to the total time the system lifetime.

It is measured as a probability. So an availability of 50% would mean that for half the lifetime of the system it is in for maintenance. Aircraft with low availability are often called "Hanger Queens" and in 1980s some fighter aircraft could only achieve availabilities of 14%.

AVAILABILITY TYPES

Inherent Availability is a measure of the availability under ideal conditions and without consideration of preventative maintenance activity (in short how often does it go wrong). It is expressed as a probability and can be found from.

$$A_i = \frac{MTBF}{MTBF + MTTR}$$

Where MTBF = Mean Time between Failures
and MTTR = Mean Time To Repair (Failures)

This is the availability that corresponds closest to reliability.

Achieved Availability is a measure of the availability under ideal conditions after considering all maintenance activity (Corrective and Preventive), however it does not include real life effects like Administration time and Logistics time. It is expressed as a probability and can be found from.

$$A_a = \frac{MTBM}{MTBM + MMT}$$

Where MTBM = Mean Time Between Maintenance
and MMT = Mean Maintenance Time

This is the availability that best defines how good the system design is.

Operational Availability is a measure of the availability under actual conditions after considering all maintenance activity; including real life effects like Administration time and Logistics time. It is expressed as a probability and can be found from.

$$A_o = \frac{MTBM}{MTBM + MDT}$$

Where MDT = Mean Down-time

This is the availability that ultimately is of interest to the systems user.

MAINTENANCE AND RELIABILITY REQUIREMENTS

The way a Requirement Specification defines the Reliability and Maintenance requirements depends upon the
- the type of system
- how many are to be bought
- the traditions of the industry

Examples: Air Forces and Airlines are normally concern with operational availability of their aircraft systems. But to the aircraft manufacturer they would have to specify achieved availability because the manufacturer does not have control of the maintenance activity.

Complex electronic systems are concerned with probability of failure i.e. inherent availability.

Small Domestic items are concerned with Mean Time Between Failures; hopefully MTBF is bigger than the guarantee period.

Spacecraft are generally specified by reliability (as no maintenance is possible).

Although spacecraft customers normally ask for a calculated reliability figure they would be better asking for an absolute guarantee. The producer can then insure the system performance based on the reliability figure to pay any compensation for loss of performance. This is done in some commercial communications satellites.