DESIGN 1ST

Design for Maintainability

Principles, Modularity and Rules

Design for Maintainability

Basic Principles

Maintainability is the degree to which a product allows safe, quick and easy replacement of its component parts. It is embodied in the design of the product. A lack of maintainability will be evident as high product maintenance costs, long out-of service times, and possible injuries to maintenance engineers. One measure of maintainability is Time to Repair (TTR, also known as 'turn-around time'). In a public payphone for example, the target Time to Repair might be 15 minutes (on-site time) to restore a faulty payphone to full working order. In large pieces of equipment, maintenance times might be listed for different tasks on individual parts of the equipment. Two kinds of maintenance activity can be identified for any product:

1. **Preventative maintenance,** for example replacing engine spark plugs every 30,000 km, or changing the oil filter. Preventative maintenance requires the replacement of parts that are still working but are expected to fail soon. It is also undertaken where degradation of a component endangers components elsewhere in the product. For example an old oil filter may cause serious engine damage by starving bearings of oil, or allowing abrasive metal sludge into clean areas.

2. **Remedial maintenance (repair),** for example fitting a new vehicle starter motor where the existing motor has burned out. Remedial maintenance is performed after the product has failed.

If the anticipated life of a component is known, failure can be avoided by scheduled replacement. In certain instances, wholesale preventative maintenance is cheaper than piecemeal remedial maintenance. For example, replacing all the fluorescent lights in an office once a year can be cheaper than replacing lights individually as they fail, because labor is used more efficiently.

Since maintainability is designed in, it is important to specify both reliability and maintainability targets early in the design cycle. This in turn requires early knowledge of the anticipated life of the product and its constituent parts, and the degree to which the parts are to be made replaceable. *See the ballpoint pen example under Design for Reliability.*

Modularity and Lines of Repair:

A further consideration is *where* the components are to be replaced. This could be at the point of use, at a repair depot, or at the point of manufacture. Car maintenance enthusiasts will replace spark plugs at the point of use (their home). Most people will have them replaced at a repair depot (their local dealer or garage). It would clearly be costly and inconvenient if the car had to be returned to the manufacturer for replacement of spark plugs. These geographical points of repair are often referred to as 'lines of maintenance' as follows:

- **1st line maintenance** occurs at the point of use. It could be at home, wherever a vehicle breaks down, on the tarmac in the case of an aircraft, or at the coalface in the case of mining equipment. It is appropriate to the replacement of small modular items that require a minimum kit of tools and can be replaced within minutes.

- **2nd line maintenance** occurs at a nearby maintenance depot. This could be railway workshops, a car dealer, or your local domestic appliance service centre. It is appropriate where an extended toolkit or special skills and processes are required, where adjustments must be made, where special handling is required, where the time to repair may be lengthy, where reassembly is complex, or where protection against the weather is important.

- **3rd line maintenance** is undertaken by the manufacturer. It is rare for volume products to be returned to the manufacturer for repair, but does happen in the case of bespoke equipment or where the repair process requires skills and equipment beyond those available at the local service centre. Examples would be aircraft re-wiring or engine rebuilds, and specialist equipment servicing and repair. For volume products, 3rd line maintenance is not usually economically viable.

This raises the issue of modularity. If the toolkit at 1st line is limited in size, then it may be more convenient to replace not the failed component, but the entire module in which the failed component is fitted. For example, a public address system consisting of separate mixer, CD player, amplifier and loudspeakers is modular. The amplifier module can be replaced at 1st line without the need to disturb other modules, and no special tools are required. The failed amplifier can then be sent to 2nd or 3rd line for repair while the replacement is in use.

Modularity improves maintainability, but carries cost penalties. This is one reason why consumer electronics manufacturers are moving away from separate modules towards 'all-in-one' entertainment systems. There are also weight penalties to consider – modularity adds mass -a potential headache for aircraft manufacturers. Software can also be made modular. A typical approach is that of 'structured programming', where the main programme consists solely of a list of 'go to subroutine' commands, each command pointing to a self-contained sub-routine or 'module'.

General Rules - Design for Maintainability:

The rules are largely common sense. Put yourself in the place of the maintenance engineer, and try to design out any obstacles to easy maintenance:

- Maintainability is created during the design process. It cannot be added later.
- Establish the maintenance philosophy in terms of 'repair versus disposal' of the product or components. Do this before starting any design work.
- Consider where maintenance will take place (1^{st}. 2^{nd} or 3^{rd} line).
- Consult the maintenance engineer during the design phase and agree upon a set of documents to be handed over to the maintenance people.
- Keep it simple. Complex arrangements are usually harder to maintain.
- Make it testable. Reactive (fault finding) tests often reveal latent problems that will become faults in the near future. Include diagnostic test points in electrical circuits. Include mechanisms that provide early warning of impending failure.
- Design reliability into items that are difficult to maintain (such as components deep within an engine), to reduce the need for maintenance access.
- Reduce maintenance frequency overall by ruggedizing and over-specifying components to withstand occasional overload.
- Provide warning labels where a maintenance engineer may be exposed to danger. For example on hot or heavy items or where there is stored mechanical or electrical energy.
- Provide maintenance instructions and information panels if the routine is difficult to remember, and fix them as close to the point of maintenance as possible.
- Design equipment to fail-safe so that risk of injury to maintenance engineers is reduced.
- Avoid the requirement for special tools.

Rules Concerning Modules:

- Wherever 2 components are joined is a potential future maintenance point. The method of joining should reflect the likely frequency of replacement.
- Modularize where appropriate.
- It should not be necessary to disturb a healthy unit in order to replace a faulty unit.
- Do not use permanent fastening techniques (adhesive fastening, riveting or welding) where separation of components will be required for maintenance.
- Where any one of a number of acceptable alternative components can be used, design the interface to allow any of the viable alternatives to be fitted.
- Where only one unique component should be fitted, design the interface to defeat the attempted installation of unacceptable alternatives.
- Where component orientation is important, use a unique pattern of fixing points, or add locating pins or baffles to prevent wrong orientation during assembly. Design every interface so that parts can only be fitted the correct way round.
- Adopt structured programming for software code.
- Build self-test and diagnostic routines into complex data-oriented products and systems.

Handling and Access Rules:

- Adjustment should not require the removal of components to access the adjustment point, the exception being where an entire module is easily removed for adjustment on the workbench.
- ‘Access’ means enough space for the component, tools, hand, arm, and possibly head or head and body of the maintenance engineer.
- Where a tool is required to remove a component, there must be access for the tool and the engineer’s hand, in normal grasp. Where tool access may be restricted, as a last resort add tool guides to steer the tool into a mating position.
- Consider reducing the number of fasteners used by ‘hooking’ modules into position and fastening at one edge only (but beware vibration risk).
- Design access holes and spaces for the full range of human body shapes and limb sizes, not just the average.
- It must be possible to see the maintenance point while hand and arm are manipulating components, tools and fasteners. Access hatches must allow for this, and must not restrict the opening to that required to accommodate hand or arm only.
- Access hatch covers and doors should open through 180 degrees and have a fasten-back clip, or be wholly removable. Doors that open to 90 degrees cause obstruction.
- The most comfortable working height is between waist and chest height. For more difficult modules, allow them to be removed to a workbench.
- Units with the lowest life expectancy should be the easiest to access, and components requiring frequent routine maintenance should be at the outer edge of the product in a position suitable for convenient access. This includes points requiring routine lubrication or visual inspection.
- Lighting and visibility. No peering into the gloom. Visibility must be direct, not needing mirrors or cameras. Light levels must be appropriate to the level of detail inherent in the task – fine detailed work requires bright light.
- Dexterity becomes impaired at arm’s length compared to up close. If fine positioning is required, get it up close, otherwise use a less position-sensitive mounting arrangement or add locating guides.
- Large modules should be mounted on hinges, slides, or runners so that they can be pulled or swung into a position offering better all round access. Rack mounted modules in electronic cabinets are an example of this approach – fit travel stops.
- Do not design access in such a way as to require heavy lifting by the maintenance engineer. Fit weight indicator labels where manual lifting is expected.
- Consider handling and lifting of units, especially the location of grab handles and lifting eyes. Fit lifting / hoisting points on large heavy items. Show where lifting straps should go – a heavy module may have weak points.
- Ensure that there is room enough to maneuver parts and tools into position without causing secondary damage by fouling on adjacent components. *See Physical Access under Human Factors -Anthropometric Data.*

Component Considerations:

- Do not use 'select on test' components. For example, you may have designed a circuit to require a 290Ω resistor at a certain point. You may then ask the production line, and the maintenance engineer, to measure all resistors in a box and fit only the ones that show exactly 290Ω resistance. This is the 'select on test' approach and it is bad design. Tolerance your design (mechanically or electrically) to accommodate all delivered components within the specified tolerance band (for example 270Ω±10%).
- Do not use 'made to measure' components. The 'made to measure' philosophy belongs to the arts & crafts movement and has no place in industrial production. Design your product to accept all delivered components within the specified dimensional tolerance band.
- Ensure that preset adjustment devices are locked after correct adjustment, to eliminate drift caused by vibration during transport or use. Use locking nuts, screws, tabs or thread locking paste. Use a dab of locking paint on preset potentiometers.
- Select fasteners with a view to the number of likely replacements during the anticipated product life, and availability of tools at the point of replacement. Use inserts where frequent removal and replacement of screws is expected.
- Chamfer the leading edges of mating features where possible, for easier alignment during assembly.
- Use captive dust covers on connectors to prevent the covers coming adrift and causing foreign object damage.
- Don't use permanently sleeved or trussed wiring harnesses where cables have to be frequently separated – use quick-fit spiral plastic or split tube cable management arrangements.
- Don't hide cable runs within tubular chassis or frame members, even if this seems to offer more protection.
- Nut locking tabs – use standard sizes and never use tabs more than once. Alternatively, lock fasteners with locking nuts, thread locking paste, shake-proof washers, screws or wire ties.
- Use captive fasteners to prevent loss of screws and washers that could cause foreign object damage by fouling moving parts.
- Minimize toolkit and spares carrying by minimizing the number of different fastener types and sizes used on the product. Avoid exotic fasteners requiring special tools if at all possible.
- If paint finishes are to be changed, consider the best way of avoiding damage to the underlying material. Aircraft use a protective epoxy base coat and a polyurethane top coat. The top coat can be stripped off by bead blasting without damaging the soft underlying metal bodywork.

Links and Resources:

(US) Maintenance World: www.maintenanceworld.com/index.htm

(US) Maintainability of mining equipment: www.cdc.gov/niosh/mining/hfg/mantain.html

(US) Center for System Reliability, HF and Maintainability:
http://reliability.sandia.gov/Human_Factor_Engineering/human_factor_engineering.html

(US) Plant Maintenance Resource Center: www.plant-maintenance.com/index.shtml

(US) Humantech Inc site: http://www.humantech.com/

For General Design Tips and Resources, visit:
http://www.design1st.com/Design-Resource-Library/design-resource-center.html

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