DESIGN FOR MAINTENANCE

Guidelines to enhance maintainability, reliability and supportability of industrial products

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Design for maintenance. Guidelines to enhance maintainability, reliability and supportability of industrial products

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FOREWORD

Design for maintenance is a discipline that has become increasingly important in recent years. In the capital intensive industry, maintenance expenditures can add up to several times the initial investment. In order to stay competitive in their business, owners and users of these capital goods focus on the total life cycle cost at investment and renewal decisions for their installations. Therefore, this interdisciplinary way of thinking in terms of life cycle performance gets special attention in the research and education programmes that we provide at our department.

One of the most important sources of inspiration for our research is the world around us. Profoundly studying products, processes and the interactions between them, gives a lot of insight into both good and bad practices. The acquired insights help us to develop methods and tools that are useful for practitioners. The ultimate goal is that this will eventually lead to systems with a considerable better life cycle performance and to a substantial decrease in the engineering effort required.

This booklet, in our opinion, is a good example of how university and industry can complement each other. The authors with their strong theoretical background, were very much inspired by the insights from experts in industry. This has resulted in a set of rules and examples in which theory and practice are successfully combined. We hope that this booklet will be a source of inspiration for product development and maintenance engineers in their actual practise. We will also use it to educate and inspire our engineers of the future.

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INTRODUCTION

The design of products strongly influences the performance during later stages of the product life cycle. How easily products can be produced, used, maintained or disposed, depends on the characteristics designed into the product. In order to optimise the performance of a product for a particular life cycle stage, many design approaches are available. Design for maintenance is one of them and focuses on influencing the future maintenance efforts that are required to keep the product in good condition. This booklet focuses on design for maintenance of industrial products. A number of guidelines is presented that show how through design the future maintenance efforts of those products can be influenced.

INVESTMENTS AND MAINTENANCE COSTS

Industrial products are used in systems that produce other goods or provide services. Examples of those products are machines, trains, aircrafts and ships, often referred to as capital goods. During the life time of these goods, large expenditures for maintenance are made. Figure 1 shows a number of examples of investments and maintenance costs for several products. In general can be said that how larger and more complex a product is, how larger the maintenance costs are as part of the total life cycle costs.

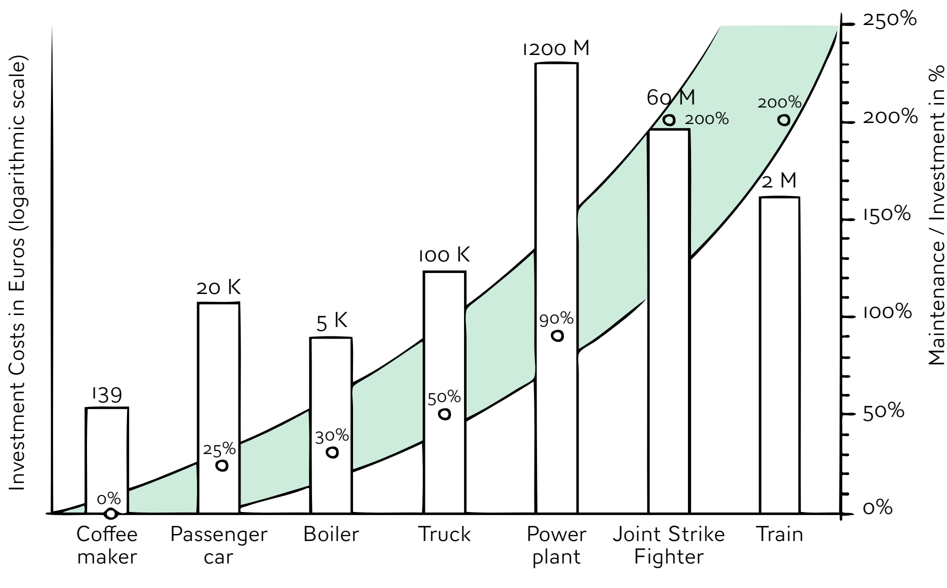


Figure 1: Maintenance and investment costs (based on: Van Dongen, L.A.M. (2011). Maintenance engineering: maintaining links. University of Twente, Inaugural lecture 9th June 2011)

PERFORMANCE INDICATORS PRODUCTION SYSTEMS

The performance of production systems is expressed in terms of how capable the systems are in performing its jobs, producing value-added products or providing services. It may be expressed in terms of the system's cost-effectiveness. This performance indicator relates the technical factors, which determine how effective the system is in performing the functions it is designed for, to the total life cycle costs. It can be expressed in various ways, depending on what one wishes to evaluate.

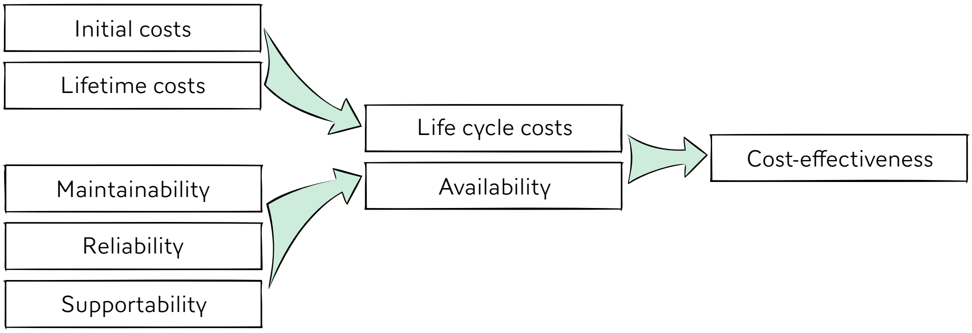


Figure 2: Factors influencing the cost-effectiveness of a production system

For users of capital goods it is often interesting to maximise the system's availability while minimising the total life cycle costs. To realise a certain availability, the system's maintainbility, reliability and supportability are major factors of influence. They respectively affect the time it takes to perform a maintenance task, the time until a failure occurs, and the time between the occurrence of a failure and the start of a maintenance action. The guidelines in this booklet show how the maintainability, reliability and supportability can be enhanced. (See Figure 2)

In order to find a proper balance between availability and life cycle costs, usually trade-offs need to be made between the initial investment and the expected life time costs. Higher initial investments could go together with lower maintenance costs. Cutting down on the initial investments could lead to additional maintenance costs during the equipment's life time.

INFLUENCE OF DESIGN

The product's reliability, maintainability and supportability are characteristics that are designed into the product. Design decisions therefore have a large influence on the final performance of the product. The actual expenditures are made during the equipment's life time, but those costs are already, for a large part, committed during the development stage of the equipment's life cycle. Moreover, re-design of components and parts during one of the later life cycle stages can have a strong influence on the maintenance efforts.

In order to design the right characteristics into the product, different design strategies may be followed. Within the context of design for maintenance two main strategies are distinguished: designing-out maintenance and designing for the ease of maintenance. On the one hand, designing-out maintenance aims at minimising the required corrective and preventive maintenance actions. On the other hand, designing for the ease of maintenance focuses on simplifying the remaining maintenance actions. Within the former strategy, enhancing the reliability of the product is of main importance. Within the latter, the focus lies on design for maintainability and supportability.

DESIGN FOR MAINTENANCE GUIDELINES

Designing a product is not an instant event. It is an iterative process of generating possible solutions, analysing their performance and evaluating them against the set requirements and alternative solutions. During those activities the characteristics designed into the product are determined.

In order to support the designer, numerous design methods and tools are available, among which the design guidelines presented in this booklet. Design guidelines are statements about design decisions to be made in particular situations and therefore serve as a kind of shortcut in the design process. They represent a form of explicit knowledge, which can be based on basic engineering principles, experiences from users or a combination of both. (See Figure 3)

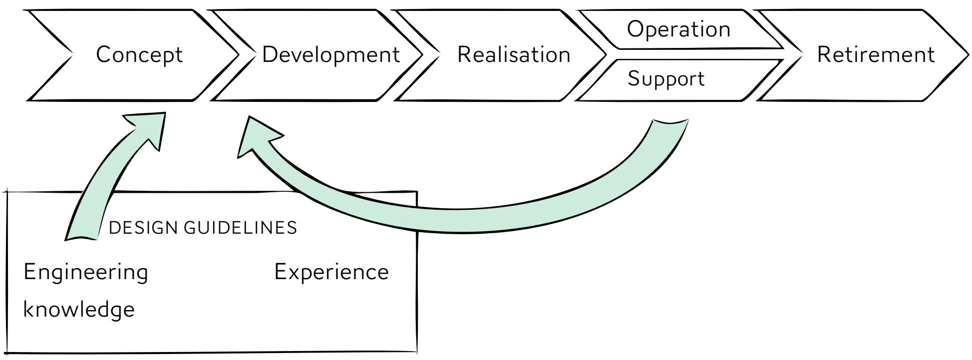


Figure 3: Use and origin of design guidelines

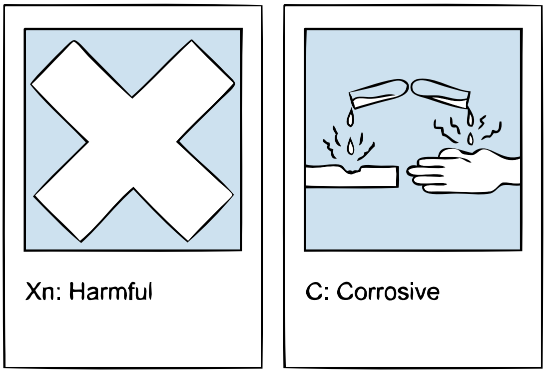
Design guidelines exist in many forms. On the one hand they are general design principles. On the other hand, they serve as standards in certain industries. The design guidelines in this booklet are relatively general and appropriate in a variety of situations. The guidelines are meant to support the product development and maintenance engineers to oversee the many design possibilities to reduce the required maintenance efforts.

In this booklet, each guideline is illustrated by three examples. They show situations in which the design guidelines are applied. Besides examples of industrial products, consumer goods are used to illustrate the guidelines. The design practices applied in these products serve as a source of inspiration for the development of industrial goods.

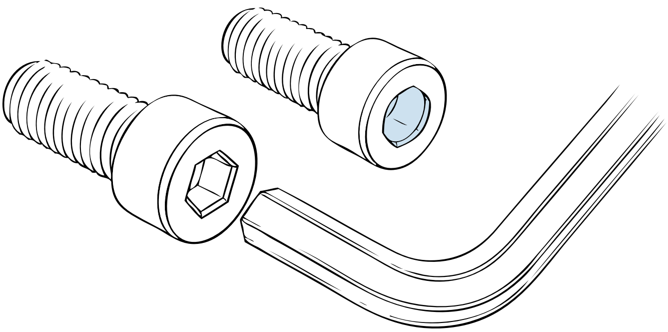
Guidelines to enhance

MAINTAINABILITY

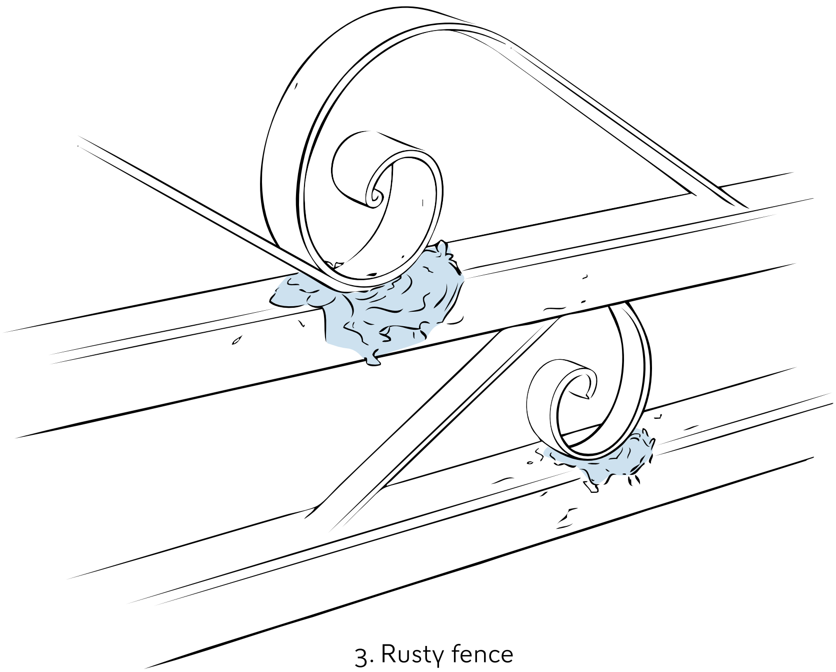
The product's maintainability influences how quickly maintenance activities can be performed. The maintenance tasks, both corrective and preventive, of maintainable products are relatively easy to execute and therefore require less time and labour hours.



1. Hazard pictograms



2. Hex key and screws



3. Rusty fence

Maintainability

USE MATERIALS THAT DO NOT PROLONG MAINTENANCE ACTIVITIES

Avoid non-corrosion resistant materials in moist environments

INTRODUCTION

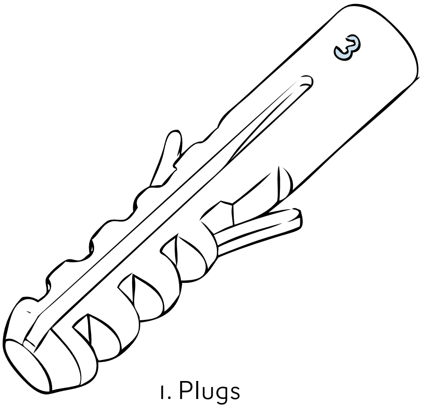
The choice of the materials for the construction of an installation depends on a number of factors. It is, for example, influenced by the required functionality, the environmental circumstances, the requested endurance, safety issues, material price and costs of maintaining the material. When selecting a material, the effects on future maintenance activities should not be neglected.

EXAMPLES

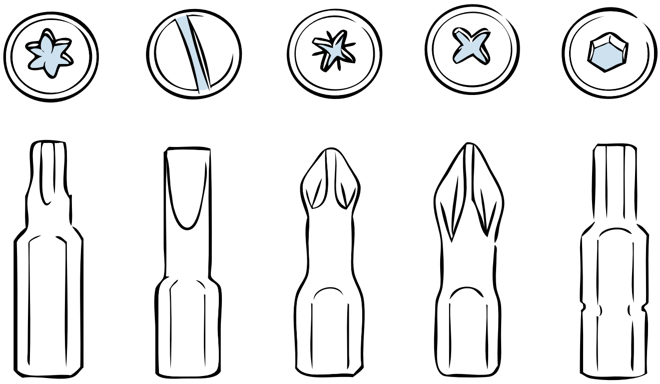
1. Hazard pictograms; avoid that extra safety and health precautions for maintenance activities, like protective clothing, gloves, glasses and special tools, are needed.

2. Hex key and screws; screws and bolts used to connect parts should be strong enough to withstand the forces when driving them.

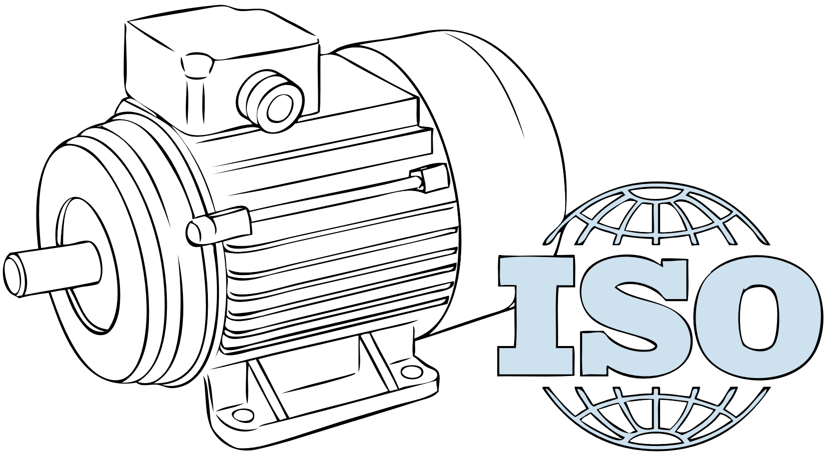
3. Rusty fence; welded areas are sensitive for corrosion if the surface is not well protected.



1. Plugs



2. Screw heads



3. Certified electric motor

M2

USE STANDARD, UNIVERSAL APPLICABLE COMPONENTS

They are widely understand, what makes it likely that they are easy to maintain or that technicians know how to maintain them

INTRODUCTION

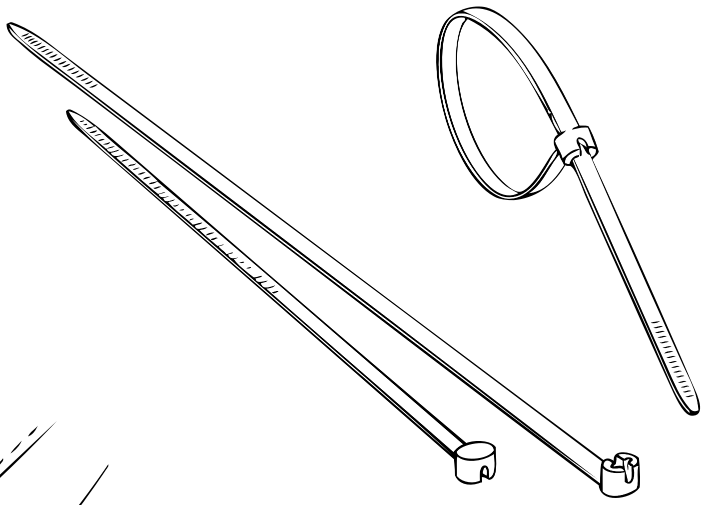
The use of international standardised components and parts has a number of advantages. Technicians recognise the parts, know their areas of application, know their performances and probably already have experience in maintaining them. This leads to less confusion and errors during execution of the maintenance tasks. Moreover, standard components are widely available and therefore easy to obtain when replacement is needed.

EXAMPLES

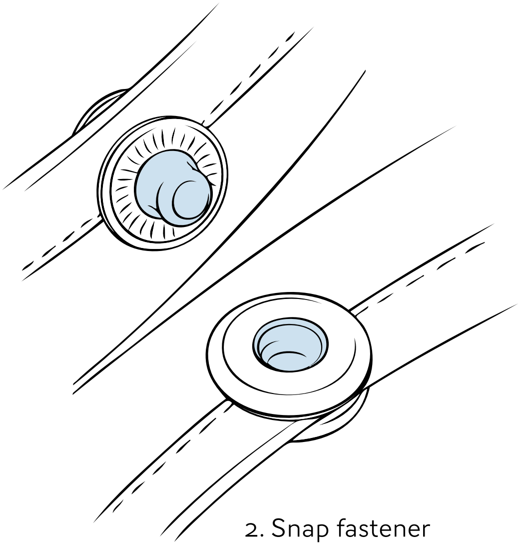
1. Plugs; they are standardised in terms of their diameters and lengths and areas of application.

2. Screw heads; there are many types of screw heads. Selecting and using only a limited number of them, induces that maintenance is easier and quicker to execute.

3. Certified electric motor; many products are designed according to international standards.



1. Cable tie



2. Snap fastener

3. Ski binding and boot

M3

USE FASTENERS THAT ACCELERATE MAINTENANCE ACTIVITIES

In the ideal situation no tools are required to open or remove components

INTRODUCTION

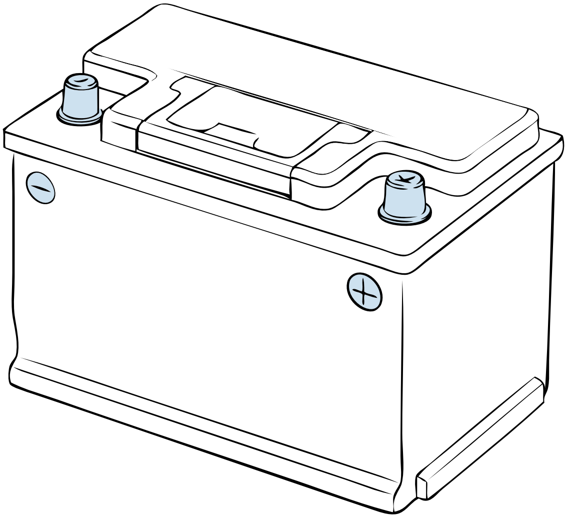
A fastener is a device for joining two or more parts together. A wide variety of fasteners, each with their own strength and area of application, exists. Selecting a fastener that is strong enough and is also easy in use, enables quick release and fastening. In the ideal case no tools are required to open machines and to replace components.

EXAMPLES

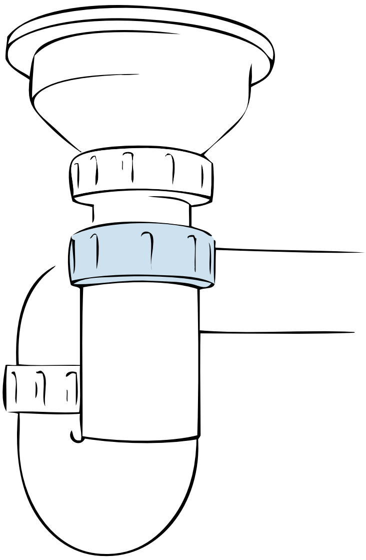
1. Cable tie; bounding several cables or wires together is possible in one single operation. However, most cable ties are not designed to be reused.

2. Snap fastener; often attached to clothing, allowing for quick opening and closing.

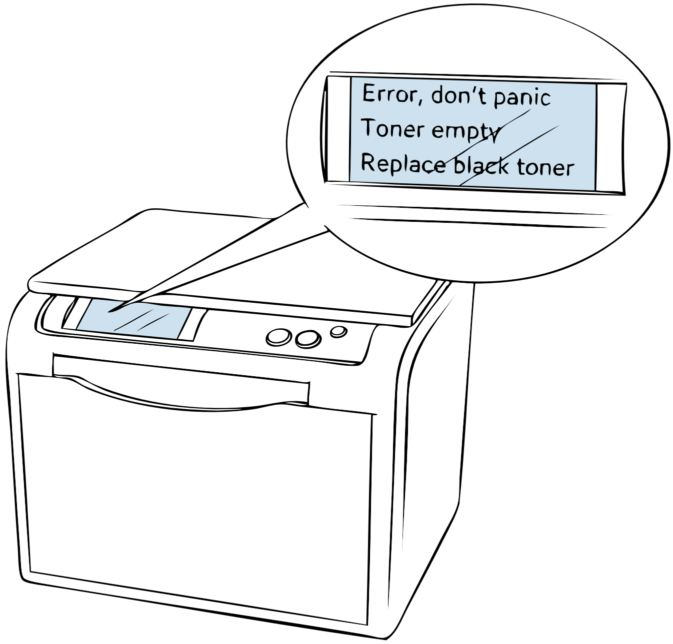
3. Ski binding and boot; the binding used to anchor a ski boot to the ski is easy in use and can be adjusted to a person's preference. Moreover, the boot clamps can be opened and closed in one movement.



1. Battery



2. Pipe sections



3. Instruction display

Maintainability

M4

ENSURE THAT THE OPERATORS OF INSTALLATIONS ARE ALSO ABLE TO MAINTAIN THEM

Maintainable equipment is often user maintained

INTRODUCTION

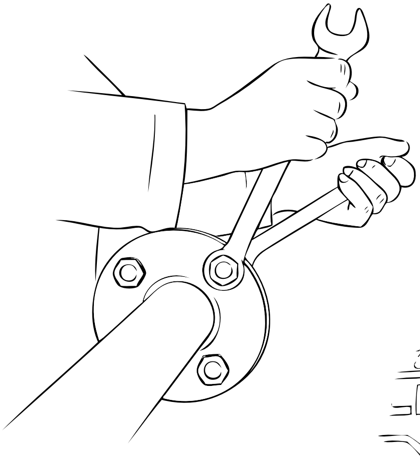
When the operator is able to execute maintenance on the system that he or she is operating, no technicians need to be called up for maintenance activities. To enable this, the system should be designed in such a way that no special tools are required, parts are quick and easy to access and the maintenance work is not complex. Moreover, it should be clear to the operator how the maintenance tasks should be executed. This can be realised by using signs and instructions on the equipment itself.

EXAMPLES

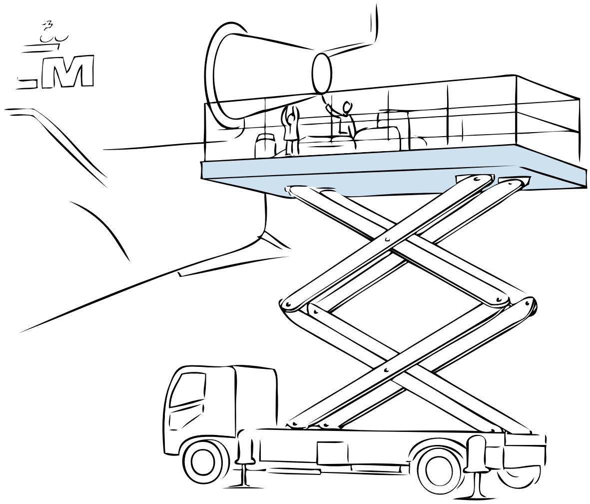
1. Battery; the plus (+) and minus (-) signs show how the cables should be connected.

2. Pipe sections; cleaning the drainage system of the sink is supported by easily and quickly demountable pipe sections.

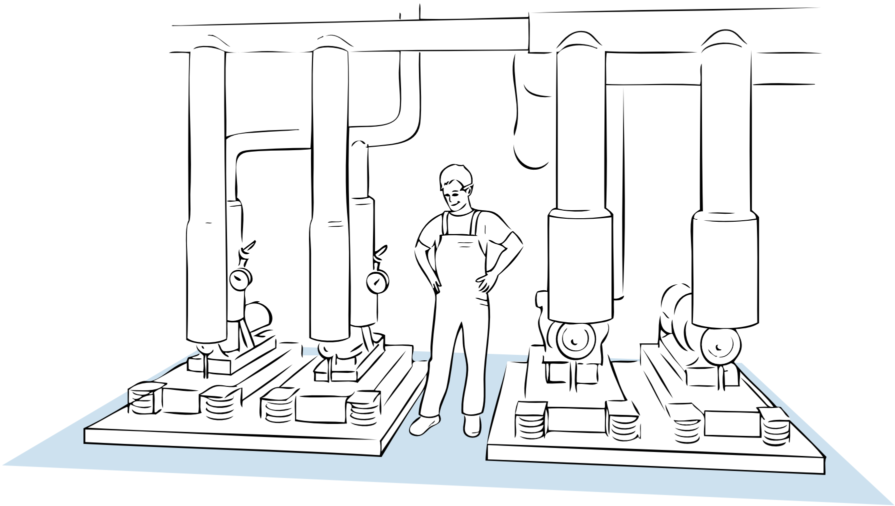
3. Instruction display; the display tells the operator what should be done.



1. Space for tools



2. Maintenance platform



3. Space between equipment

M5

PROVIDE SUFFICIENT SPACE AROUND THE MAINTENANCE POINTS

Maintenance personnel should be able to execute maintenance with good posture

INTRODUCTION

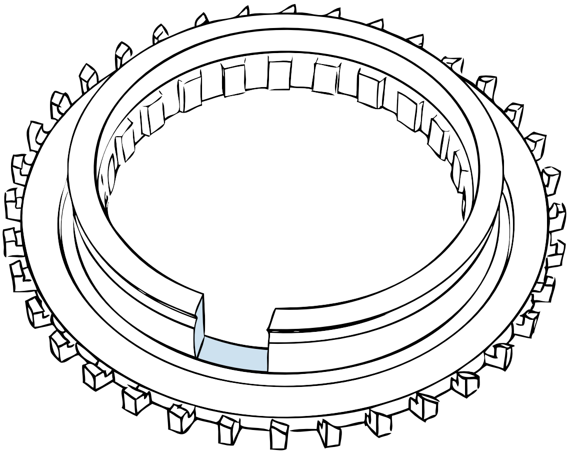
In order to enable that maintenance tasks can be executed efficiently, sufficient space should be available around the maintenance points. The location of the maintenance points should be accessible, allowing the technician to reach them. Also, in case of an emergency, the technicians should be able to get away quickly. Around the maintenance points themselves should be sufficient space so that maintenance can be executed with good posture.

EXAMPLES

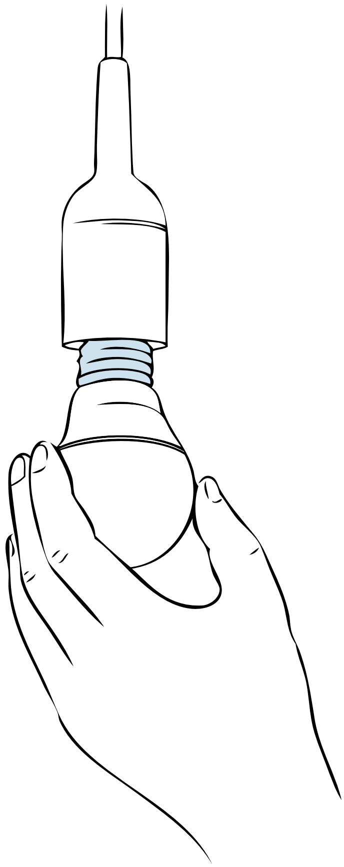
1. Space for tools; when tools are required for maintenance activities, sufficient space should be available to operate them in an efficient way.

2. Maintenance platform; an artificial, temporary floor enables that maintenance work can be done ergonomically and efficiently.

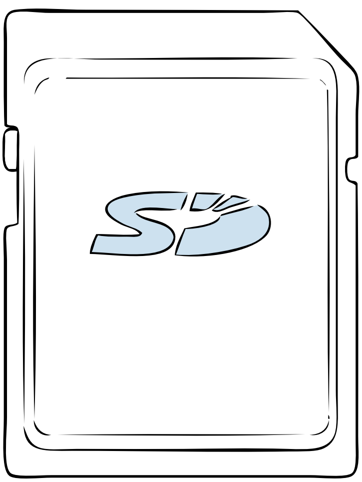
3. Space between equipment; sufficient spaces between the pieces of equipment enable that the machines are accessible for the technician.



1. Asymmetrical part



2. Light bulb



3. SD-cards

M6

DESIGN EQUIPMENT IN SUCH A WAY THAT IT CAN ONLY BE MAINTAINED IN THE RIGHT WAY

An unambiguous design induces that no mistakes can be made when executing maintenance

INTRODUCTION

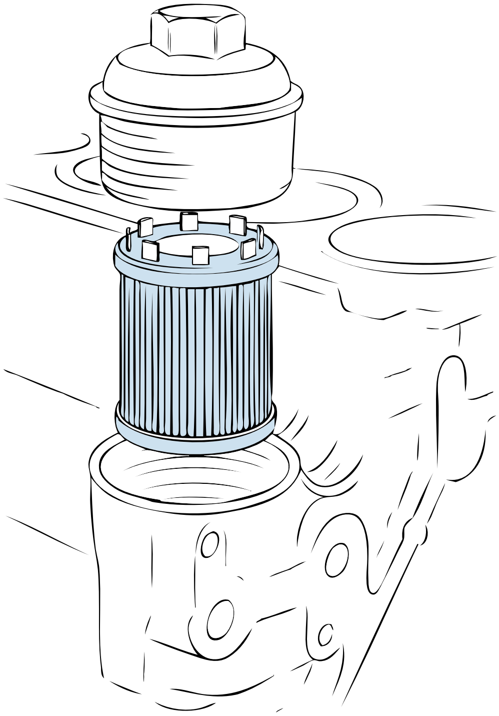
When maintenance actions can be performed without requiring specific experience or expertise, fewer mistakes will occur. Installations can, for example, be built up out of a limited number of sub-assemblies by integrating different parts into one module, allowing them to be replaced as one unit. Moreover, the arrangement of these modules and other parts should be possible at one way only.

EXAMPLES

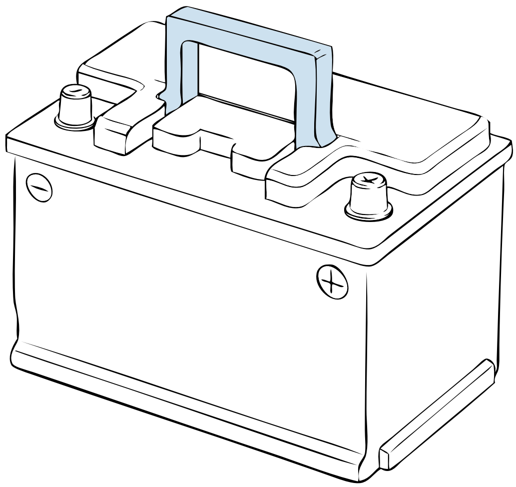
1. Asymmetrical part; mounting the parts is possible in only in one way

2. Light bulb; due to the design of the socket and fitting, it is almost impossible to replace a light bulb incorrectly.

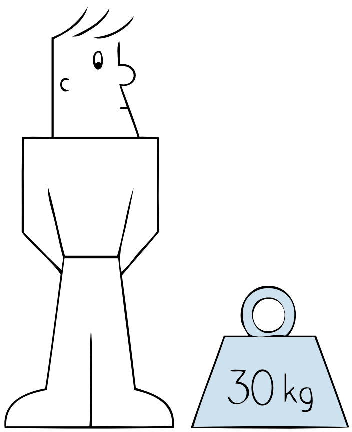
3. SD-cards; the bevelled corner ensures that SD-cards can only be put in a computer in the right way.



1. Filter



2. Handle



3. Limit weight

Maintainability

M7

COMPONENTS THAT ARE REGULARLY REPLACED NEED TO BE EASY TO HANDLE

Standard size and weight, no sharp edges and easy to transport

INTRODUCTION

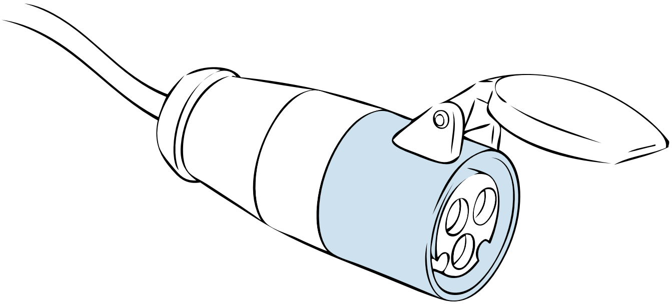
Removing, holding, moving and installing parts, especially the ones that regularly need to be replaced, should be possible without bad consequences for the health of the technician. Parts that are light-weight and have limited sizes can be easily handled by one person. Sharp edges should be avoided, because they can hurt the person when replacing the part.

EXAMPLES

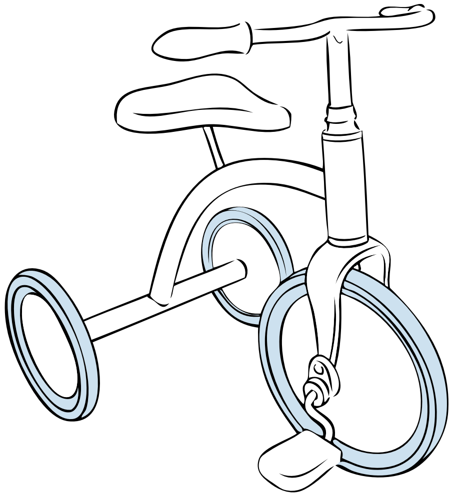
1. Filter; an air filter for a car is a small, lightweight and easy to handle part.

2. Handle; the integrated handle makes lifting and transport of the battery more convenient.

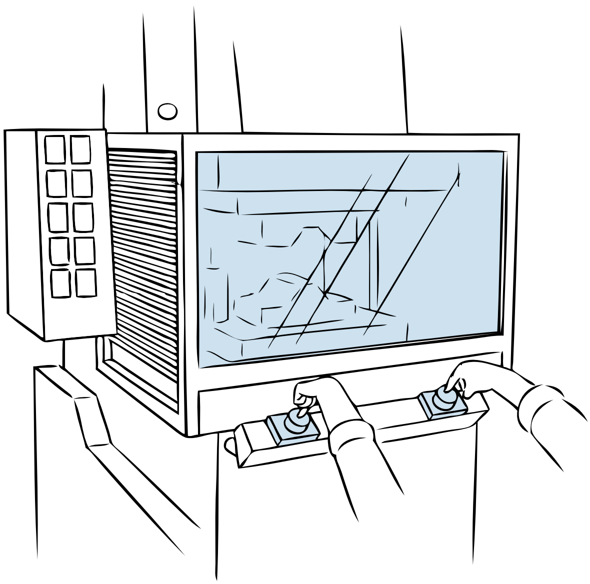
3. Limit weight: due to ergonomic reasons, the weight of parts needs to be restricted.



1. Plug and socket



2. Tricycle



3. Safety shield

M8

GUARANTEE SAFETY BY THE DESIGN ITSELF

Instead of using warning labels and colour codes

INTRODUCTION

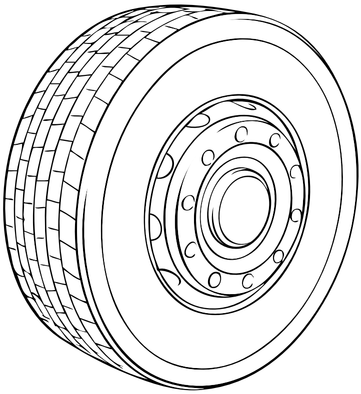
Warning people about the risks associated with operating or maintaining is often done by attaching warning labels to the installation. These signs indicate hazards that may not be readily apparent to the user, for example high electricity voltages, high temperatures and toxic materials. When those warning methods are necessary, possibilities for incorporating safety into the design itself should be considered.

EXAMPLES

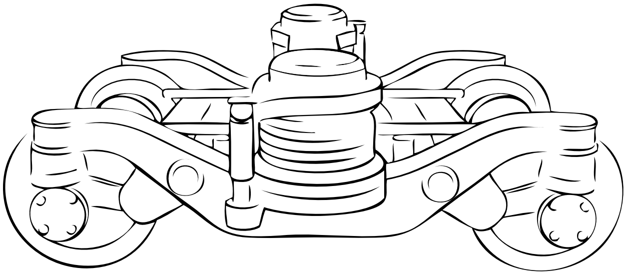
1. Plug and socket; the design itself assures that the electrical wires are unreachable.

2. Tricycle; the three wheels guarantee stability, preventing the child from falling.

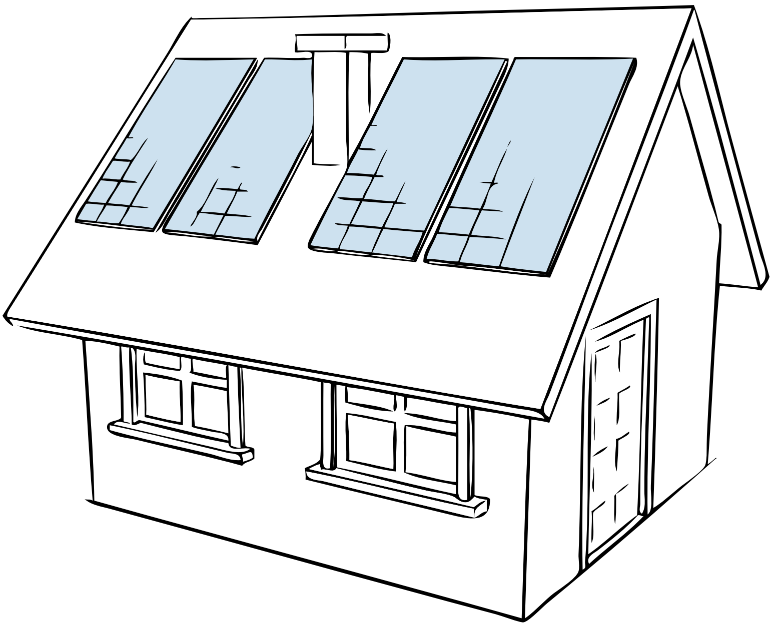
3. Safety shield; only when the safety shield is closed and the two buttons are pushed simultaneously, the machine will do its job.



1. Tyre assembly



2. Bogie



3. Solar panels

Maintainability

M9

DESIGN MODULAR

Modular systems enable complete replacement of a broken module to repair it at a different place

INTRODUCTION

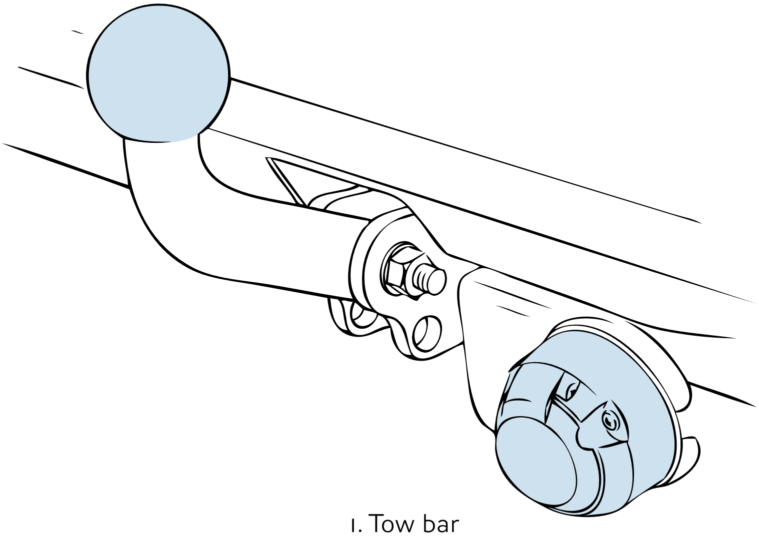
A modular designed system is a system that is built-up out of a number of smaller sub-systems, so-called modules. Each of this modules has its own function, contributing to the functioning of the whole system. They can be independently created and are usually interchangeable so that they can be used in different installations. Designing the system modular induces that complete sub-systems can be replaced. The broken one can be repaired by a technician at a convenient time and location.

EXAMPLES

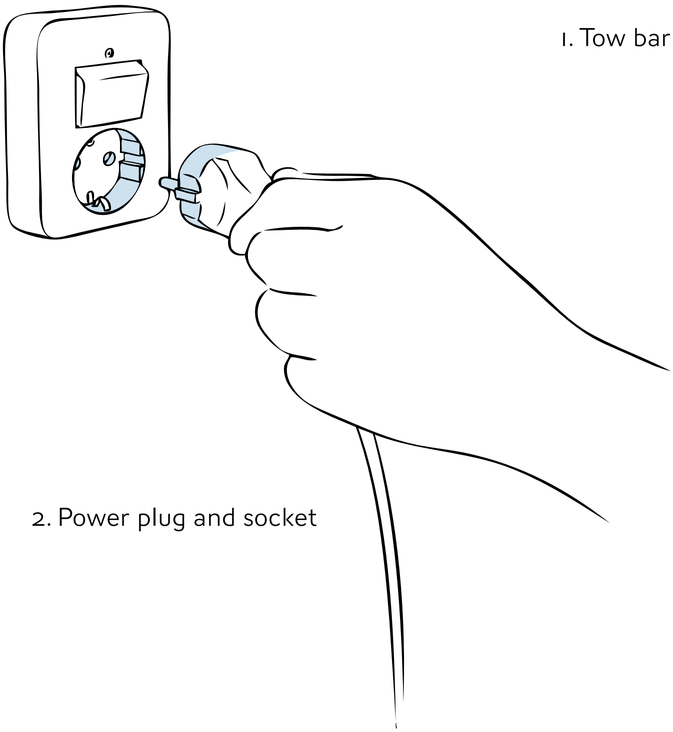
1. Tyre assembly; the complete tyre assembly of a truck, as well as, the mounting construction are modular. It makes them interchangeable and therefore a quick replacement is possible.

2. Bogie; the frame assembly beneath each end of a railroad car. It can be replaced in one piece.

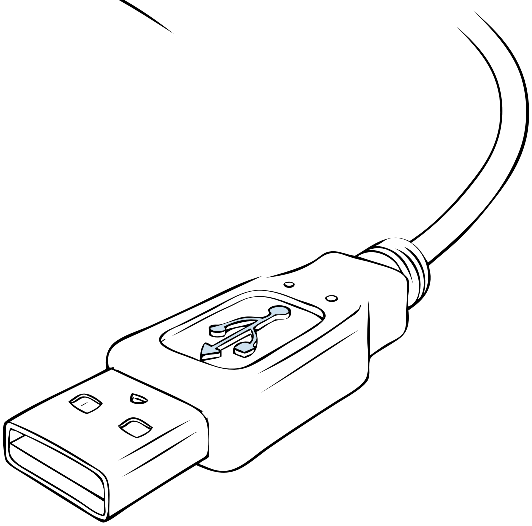
3. Solar panels; a number of solar panels together form a system for generating and supplying electricity. The panels can be replaced separately.



1. Tow bar



2. Power plug and socket



3. USB

M10

USE STANDARD INTERFACES

To enable quick connection between modules and sub-systems

INTRODUCTION

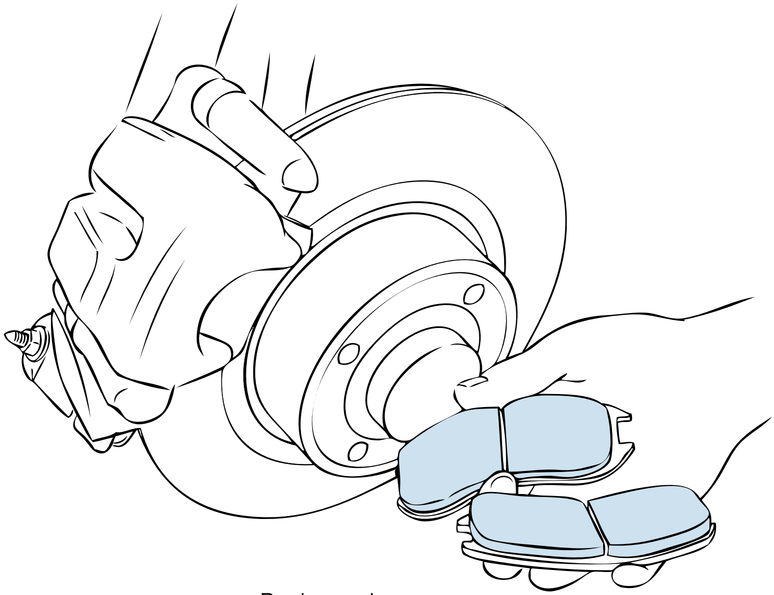
Interfaces are the points where components, modules or parts meet and affect each other. At those points, material, energy and information is transmitted from one sub-system to another. Standardising the way how this is realised, enables that different modules can be interchanged with each other. The standard interfaces are also widely known and therefore a wide range of people knows how to use them.

EXAMPLES

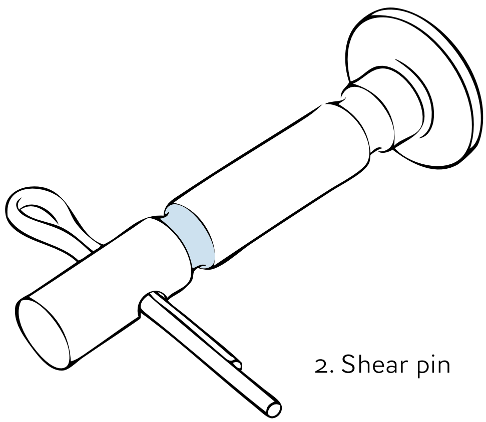
1. Tow bar; the tow ball matches with the size of the coupling of the trailer being towed. Moreover, the electrical connection sockets adjacent to the tow ball are standardised.

2. Power plug and socket; used for connecting devices to the alternating current power supply. Although different types of plugs and sockets are used over the world, within regions the same ones are applied.

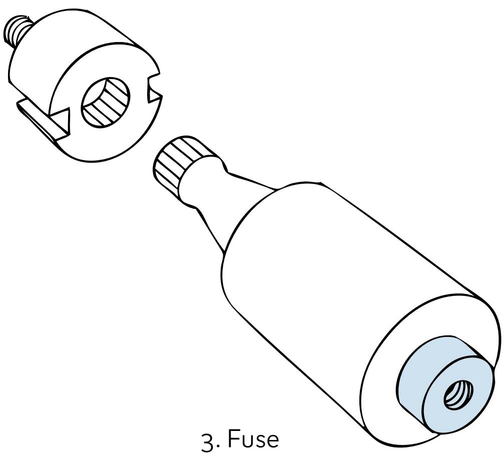
3. USB: a standard that defines the cables, connectors and communication protocols for connection, communication and power supply between computers and other electronic devices.



1. Brake pads



2. Shear pin



3. Fuse

M11

DESIGN THE WEAKEST LINK

Every system has a weakest link, which should be a relatively cheap and easy replaceable component

INTRODUCTION

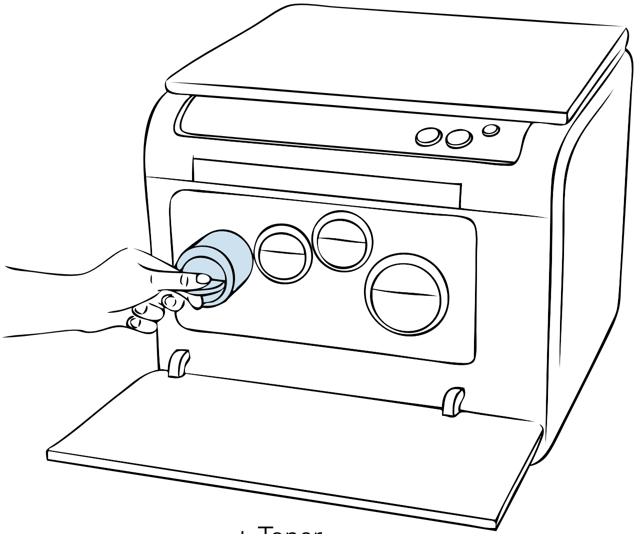
A chain is only as strong as the weakest link. Knowing the weakest link of a system induces that you know where it breaks and what components need to be repaired and replaced. By designing an installation in such a way that the weakest link is a relatively cheap and easy replaceable component, a failure will not have major consequences. It can be easily repaired and other, more expensive or difficult replaceable, parts are prevented from being damaged.

EXAMPLES

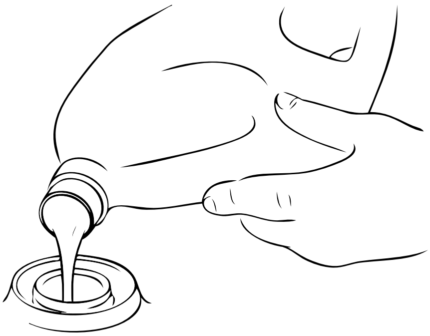
1. Brake pads; use of the disc brakes causes that the pads wear out, while the disc does not. After a particular time only the pads need to be replaced.

2. Shear pin; designed to break in case of a mechanical overload.

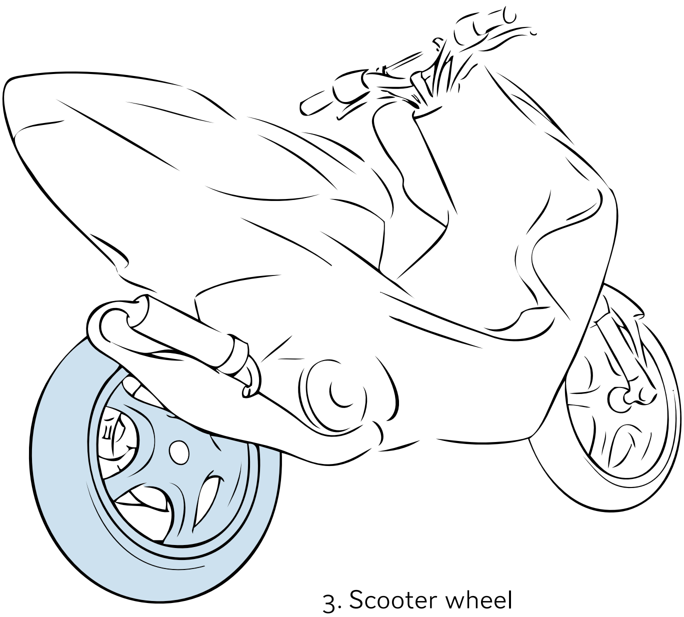
3. Fuse; used as the weakest link in electricity networks to stop the current if the flow of electricity is too strong.



1. Toner



2. Engine oil



3. Scooter wheel

M12

POSITION COMPONENTS THAT OFTEN NEED TO BE MAINTAINED AT AN EASILY ACCESSIBLE PLACE

Location of components could be based on the number of times they need to be maintained

INTRODUCTION

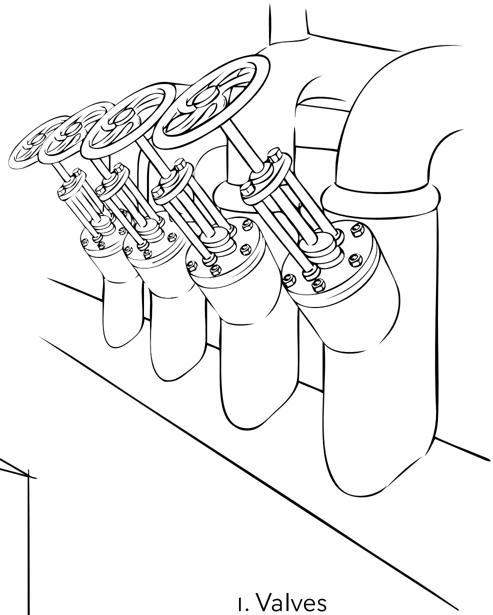
Maintenance operations usually consist of replacement and service of a limited number of components of a system. For example, replenishment of materials that have been used for operation or replacement of the weakest link in the system. When those parts are located at an easily accessible place, the maintenance task can be executed easily without consuming a lot of time. Performing those tasks should not be obstructed by parts of which maintenance is expected less frequently.

EXAMPLES

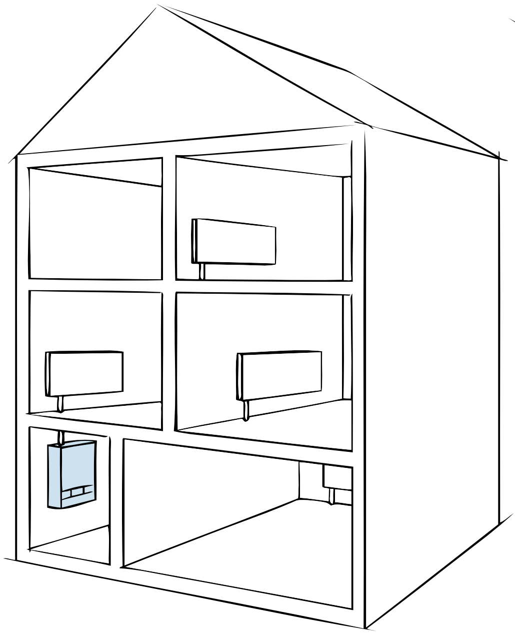
1. Toner; the toner is accessible from the front side of the printer.

2. Engine oil; oil of engines needs to be replaced and replenished regularly. Filling oil is a simple operation when the fill opening is accessible and there is sufficient space around it.

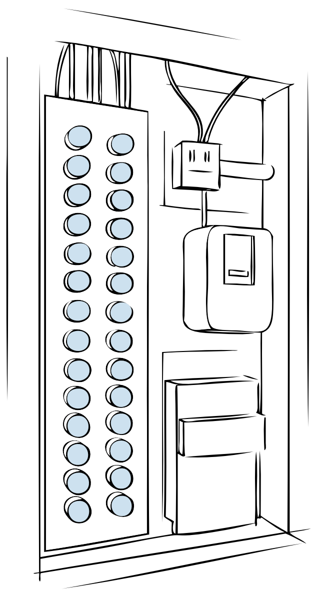
3. Scooter wheel; the single-sided rear suspension allows the wheel to be mounted easily.



1. Valves



2. Central heating



3. Meter cupboard

M13

POSITION THE MAINTENANCE POINTS NEAR TO EACH OTHER

The maintenance location is known beforehand.

INTRODUCTION

Locating the maintenance points of a system near to each other, or even at the same place, enables that failures can be easily detected. The technicians know the location of the failure beforehand. Moreover, only at maintenance points it is necessary to reserve space for executing the maintenance tasks. Therefore attention can be paid to creating an easy accessible and safe workspace.

EXAMPLES

1. Valves; controlling the flow of fluid is possible at a single location.

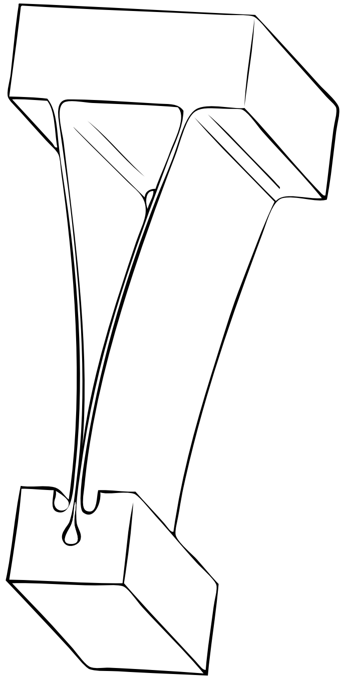
2. Central heating; the active components in central heating systems, boilers and pumps, are located at one place.

3. Meter cupboard; the weakest links of the electricity networks in a house, the fuses, are located in the same cupboard.

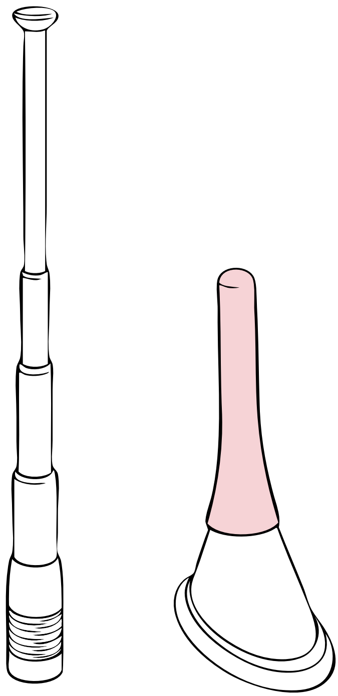
Guidelines to enhance

RELIABILITY

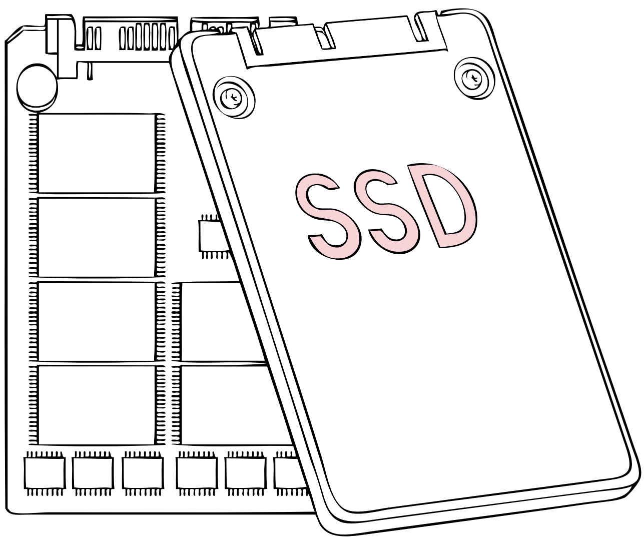
The product's reliability influences the failure rate and the probability of proper functioning for a specified period of time. High reliable products can be counted on to function when needed.



1. Flexure hinge



2. Antennas



3. Solid-state drive

R1

DESIGN-OUT MOVING PARTS

Unnecessary movements need to be avoided

INTRODUCTION

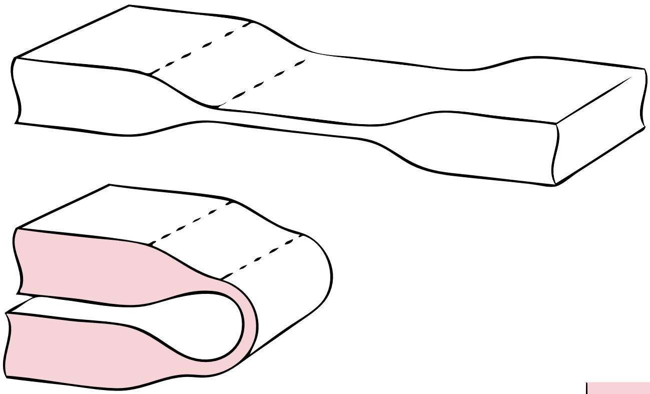
Equipment usually contains moving or movable parts. Due to friction between them, losses in efficiency occur and in time the components start to wear, influencing the precision of the machine. To overcome this, moving parts are lubricated and designed in such a way that there is only a small area of contact with other parts. Further minimisation of wear can be realised by combining components in one single part: avoiding the necessity of moving parts.

EXAMPLES

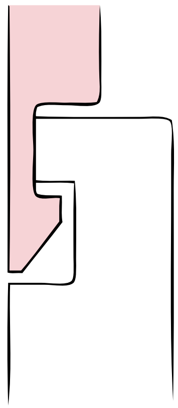
1. Flexure hinge; flexure hinges allow motions by bending the load elements and therefore have very low friction.

2. Antennas; the flexible rod of the nowadays used whip antenna is less susceptible to damage than the extendable parts of the traditional one

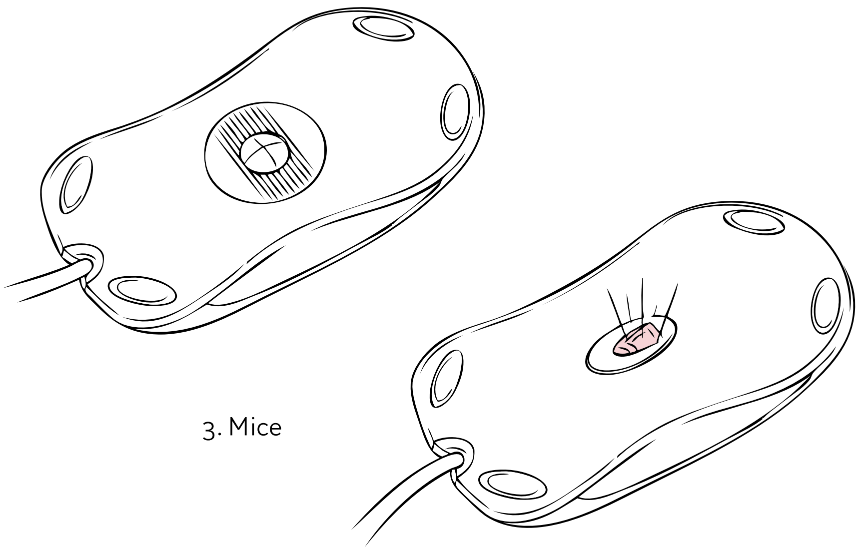
3. Solid-state drive; in contrast to hard disk drives with spinning platters, solid-state drives do not have moving components to read or write data.



1. Plastic hinge



2. Snap connection



3. Mice

R2

AVOID UNNECESSARY COMPONENTS

Limit the number of components by eliminating the non-essential ones

INTRODUCTION

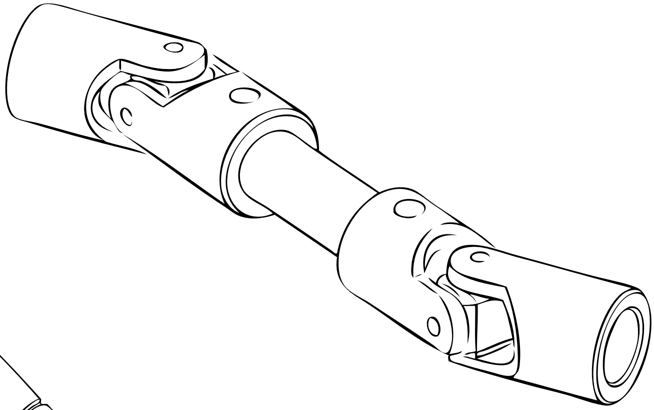
All components within a product have a chance to wear out and to cause a system to break down. Developments in technology have made it possible that fewer components are needed to fulfil the function of a product. Moreover, due to developments in production techniques, more complex parts can be manufactured with different functions designed into a single component. For example, injection moulding enables us to integrate guiding channels, points to fix screws and hinges into the main part.

EXAMPLES

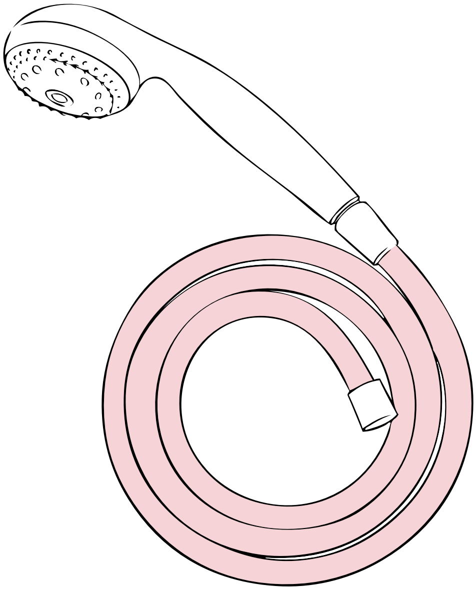
1. Plastic hinge; allows the same movements as a barrel hinge, but consists only of one part.

2. Snap connection; no screws or bolts are needed to keep parts connected together.

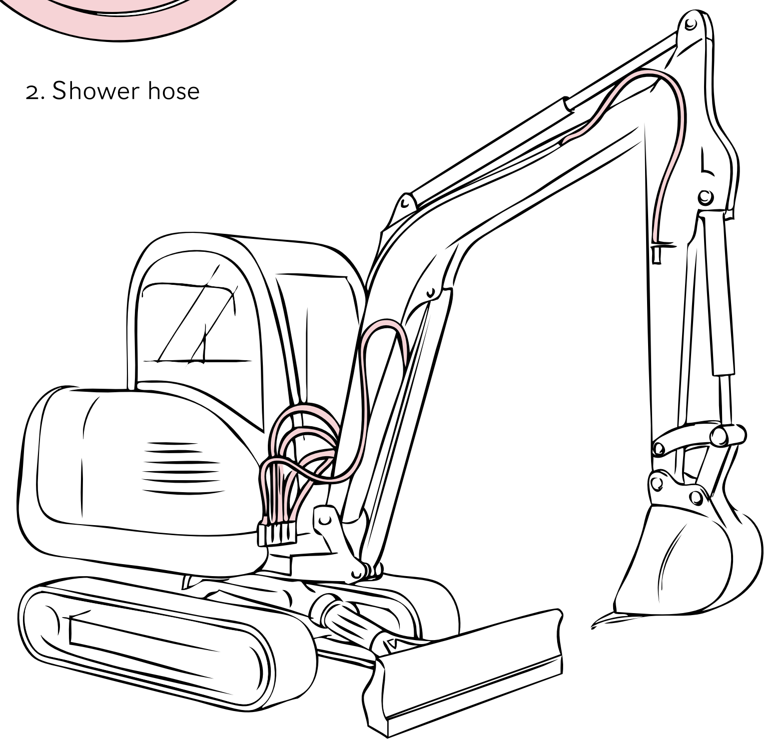
3. Mice; optical mice are not susceptible for dust and other dirt, that can prevent the mechanical mice of proper functioning.



1. Drive shaft



2. Shower hose



3. Hydraulic excavator

R3

AVOID NON-RIGID PARTS / AVOID RIGID PARTS

Use tubes instead of hoses / used hoses instead of tubes

INTRODUCTION

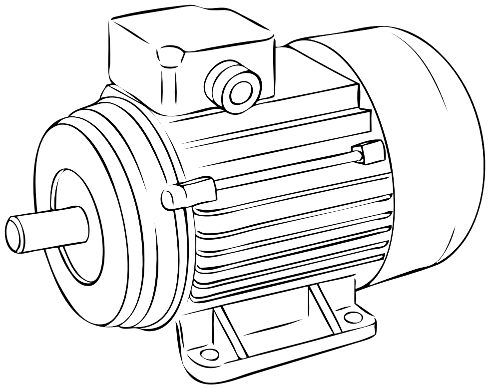
In general, rigid parts can last for a longer time than non-rigid parts. However, when parts need to move with respect to each other or need to be flexible, it may be necessary to use non-rigid parts. Also when vibrations or expansion of materials cause small variations in the distance between components, flexible connections could be preferred. For example, conveying fluids and gases can both be realised by tubes and hoses. Tubes achieve a better pressure resistance, but hoses are portable and flexible.

EXAMPLES

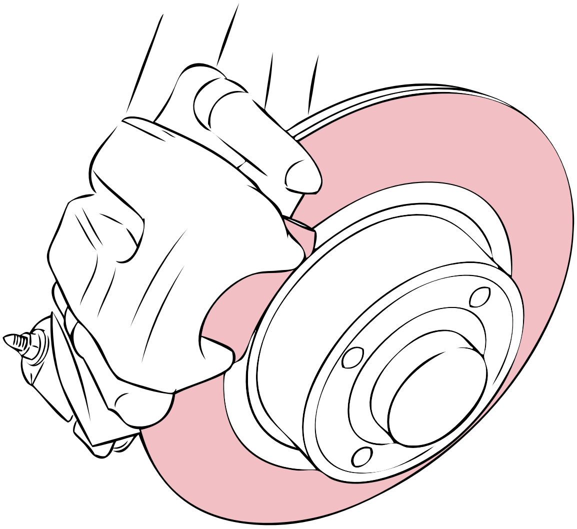
1. Drive shaft; used for power transmission between components in a powertrain because of the distance and the need to allow for relative movements between them.

2. Shower hose; a hose is needed for free movement of the showerhead.

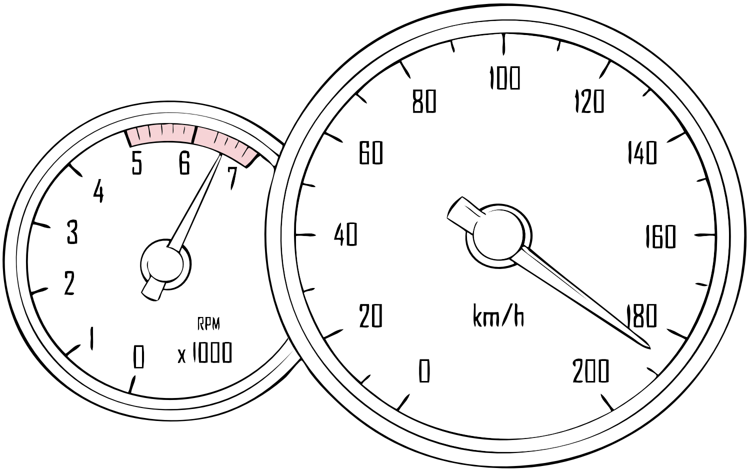
3. Hydraulic excavator; to convey hydraulic fluid throughout the machine, tubes are used when possible. For rotations, hoses are used. They tend to leak less than swivel joints.



1. Electric motor



2. Disc brake



3. Internal-combustion engine

R4

DESIGN FOR UNDERSTRESSED USE

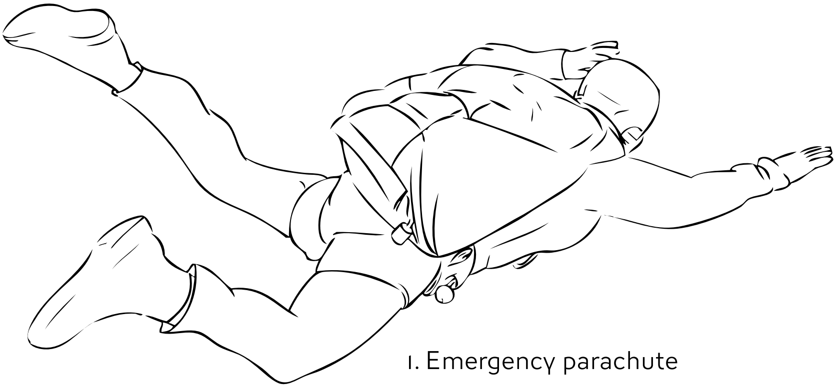
In normal situations the system is used at less than full capacity

INTRODUCTION
It must be prevented that overload will damage components and lead to equipment failure. Therefore, the load capacity of the equipment should be properly sized for the conditions under which it will be used. When both normal loads and peak demands can be handled, it is less likely that the system breaks down. It induces that only in a few situations the equipment is operating at full capacity and therefore wear of equipment is minimised.

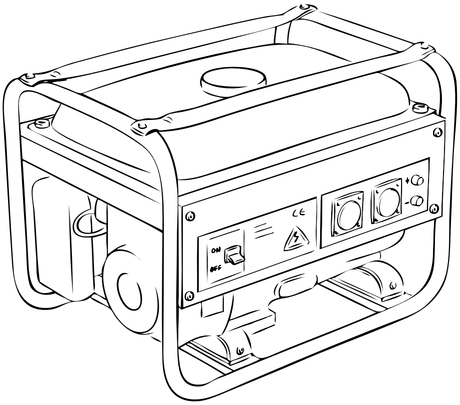
EXAMPLES
1. Electric motor; an electric motor can only handle a higher current than its nominal current for a short time.

2. Disc brake; slamming hard on the brakes is possible when really necessary, but not constantly.

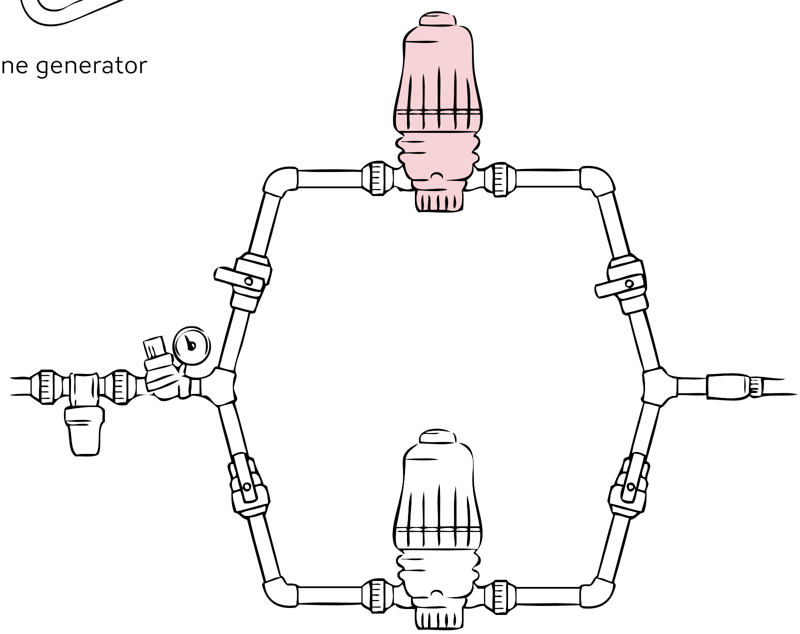
3. Internal-combustion engine; can be used at a high rotational speed for a short period.



1. Emergency parachute



2. Engine generator



3. Redundant pumps

R5

PROVIDE REDUNDANCY

Standby systems can take over the operation when necessary

INTRODUCTION

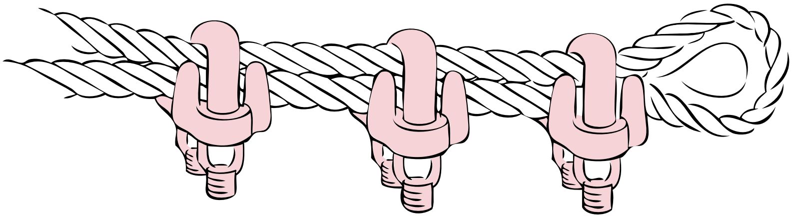
Reliable systems are typically built with redundant elements. These redundant elements can perform the same function in parallel to one another. When the active component fails, they come into use and prevent failure of the system as a whole. Especially, critical components in installations are duplicated. Redundancy also enables the system to stay operating in situations when one of the components cannot be used, for example when it is maintained.

EXAMPLES

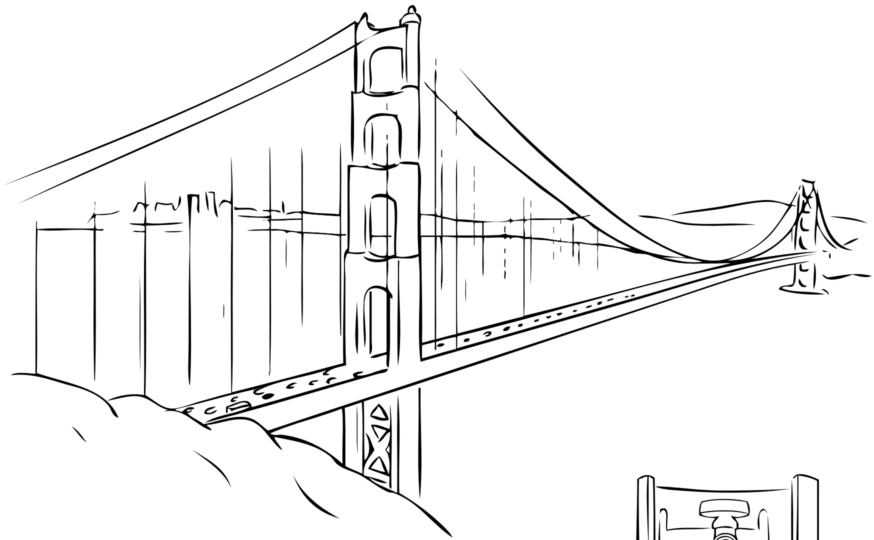
1. Emergency parachute; when the main parachute fails to unfold correctly, another is available to prevent the parachutist from crashing.

2. Engine generator; among others used to supply electrical power during temporary utility power interruptions.

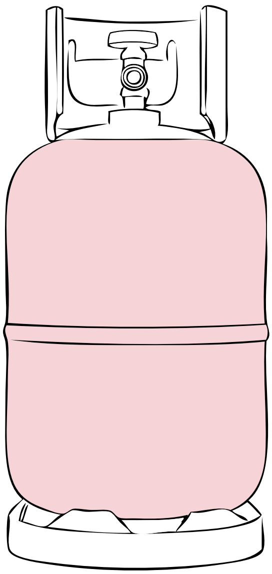
3. Redundant pumps; if it is possible that failure of a pump affects production, often a redundant pump is installed.



1. Wire rope termination



2. Bridge



3. Gas cylinder

R6

OVERDESIGN COMPONENTS

Dimension critical components larger than minimal required

INTRODUCTION

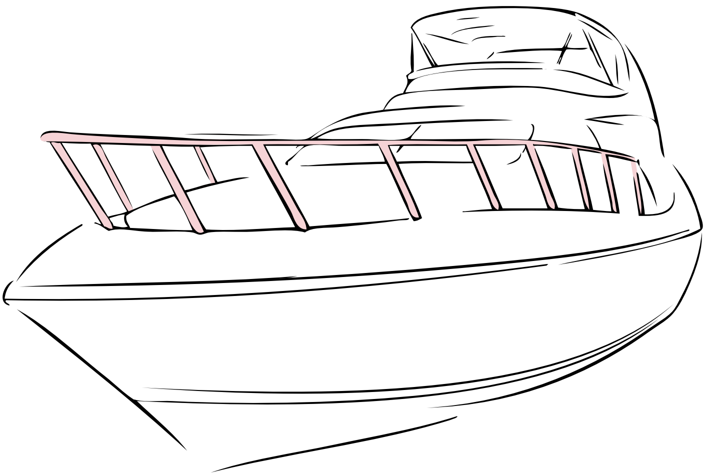
In order to be prepared for unknown situations., products are often designed more robust than necessary for their application. Mistakes in predicting imposed loads and environmental conditions can be made. Moreover, properties of the used materials may vary or may not be well understood. To offset the potential effects of these unknown situations, safety factors are applied to minimise the probability of failure. Usually, these safety factors are achieved by adding material and extra components to the system so that they are constructed stronger than is required for normal use.

EXAMPLES

1. Wire rope termination; the number of clamps should be sufficient for a load that is of greater weight than the loads that are expected during use.

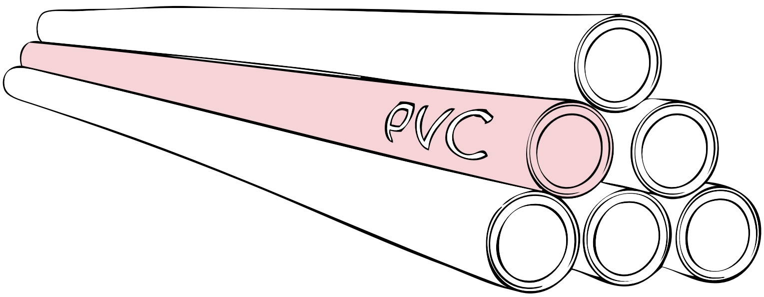
2. Bridge; the consequences of bridge failure can be catastrophic. Therefore, safety factors are applied to for example the dimensioning of the cabling and the struts.

3. Gas cylinder; can withstand pressures that are much higher than the maximum operating pressure.



1. Stainless steel rail

2. Glass



3. PVC gas pipes

R7

CHOOSE MATERIALS THAT CAN WITHSTAND ENVIRONMENTAL INFLUENCES

The equipment should withstand the environmental conditions in which it is used

INTRODUCTION

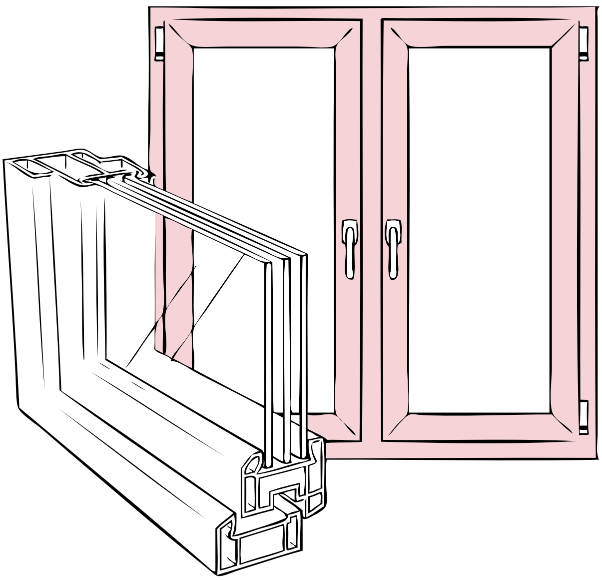
The influence of environmental conditions on an installation can be immense. For example, desert sand, sun, humidity, temperature and sea water have a large effect on the wear of materials. Also less extreme conditions or micro climates can have a large impact on the degradation speed of installations. A well understanding of the environmental conditions, the degradation mechanism of the installation and the involved costs should guide the choice of materials.

EXAMPLES

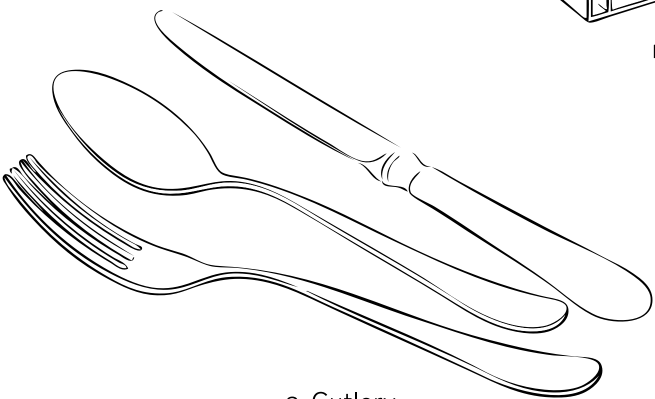
1. Stainless steel rail; rail constructions on yachts should withstand the maritime surroundings and the related weather conditions.

2. Glass; a material known for its property to be inert to a large number of substances. It is therefore used in many chemistry applications.

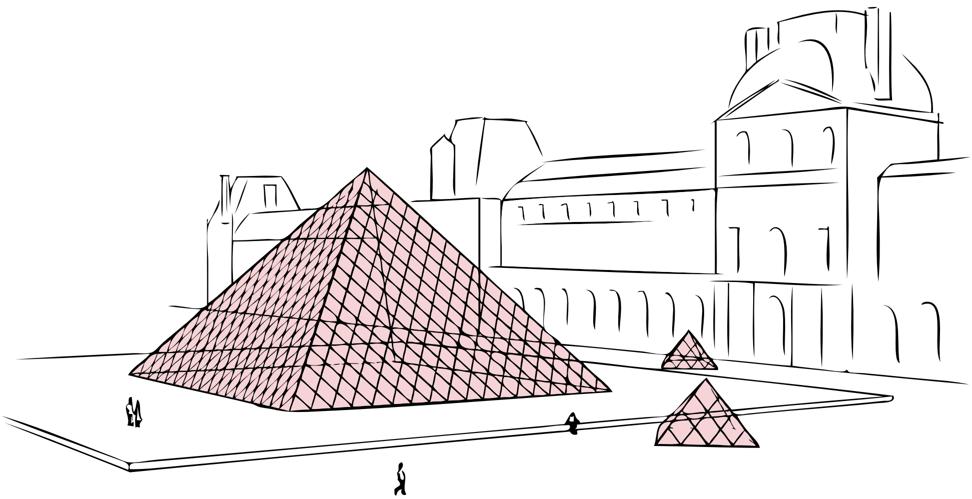
3. PVC gas pipes; nowadays cast iron pipelines for gas transportation are often replaced by PVC pipes. Buried PVC pipes exhibit almost no aging.



1. UV resistant plastics



2. Cutlery



3. Glass buildings

R8

DO NOT USE COATED, PAINTED OR PLATED COMPONENTS

They need to be maintained to keep them in good condition

INTRODUCTION

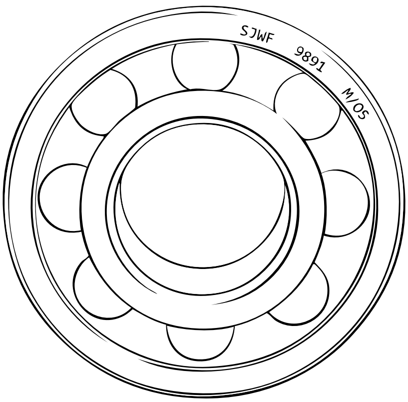
To withstand the environmental influences, materials are often coated, painted or plated. However, over time these protection layers will degrade or be damaged, usually causing the protected materials to degrade faster. If possible base materials that do not need any protection should be used. For example materials such as stainless steel or aluminium can be used in order to avoid corrosion.

EXAMPLES

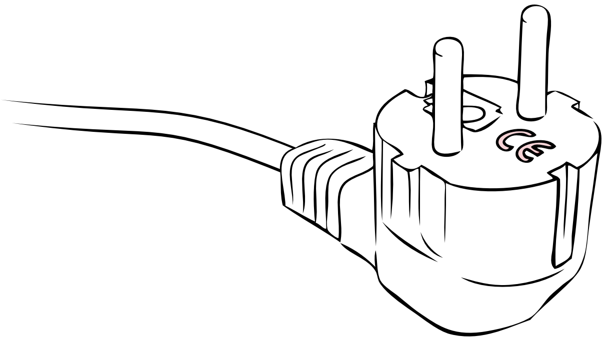
1. UV resistant plastics; plastic window frames are a good alternative to wooden frames. Recurring paint work is not necessary anymore.

2. Cutlery; stainless steel is the choice for cutlery because of degradation and hygiene aspects.

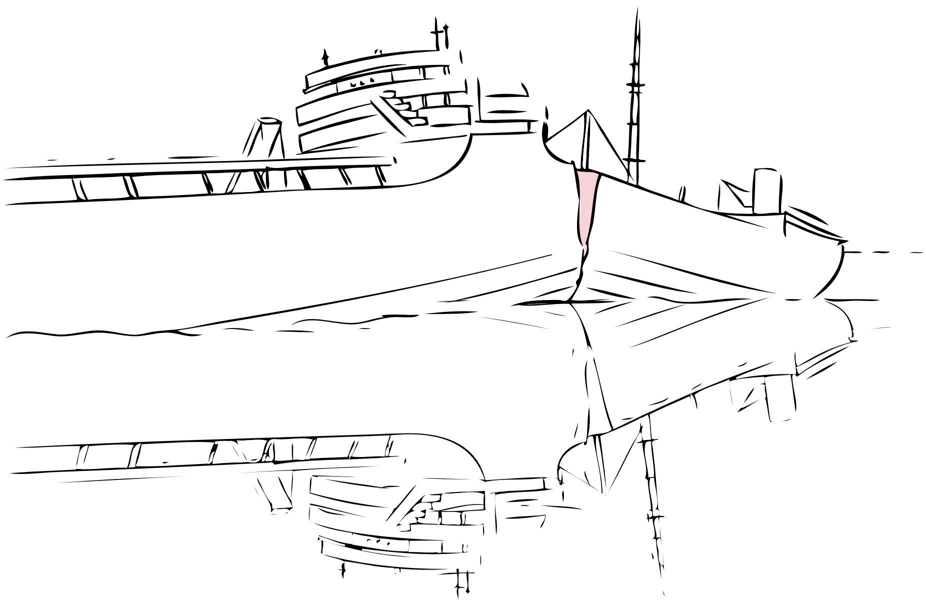
3. Glass buildings; in order to reduce maintenance of buildings, glass is used as construction material at the outside.



1. Ball bearing



2. Electrical connector



3. Liberty ship

R9

USE COMPONENTS AND MATERIALS WITH VERIFIED RELIABILITY

Proven technology minimises the chance of unexpected system behaviour

INTRODUCTION

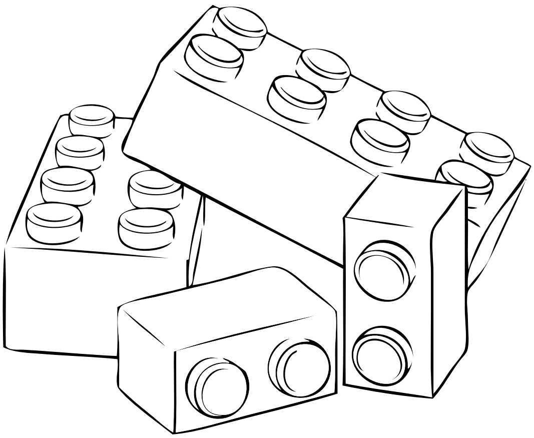
When components and materials meet certain standards, the degree of reliability is known. In addition a large number of components, parts and materials have certified versions that provide a guarantee of quality. The reliability of the installation is thus better secured.

EXAMPLES

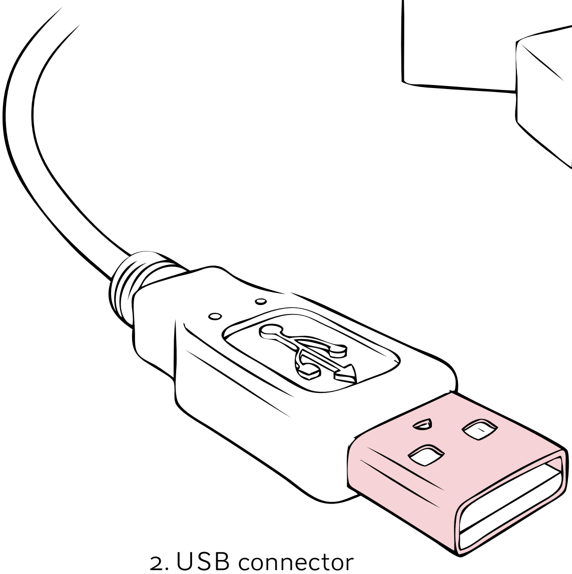
1. Ball bearing; different suppliers deliver, at first sight, the same components. However, the quality and reliability of the components can vary greatly.

2. Electrical connector; many products, such as well-known electrical connectors, meet standards. Certification bodies test and certify these products.

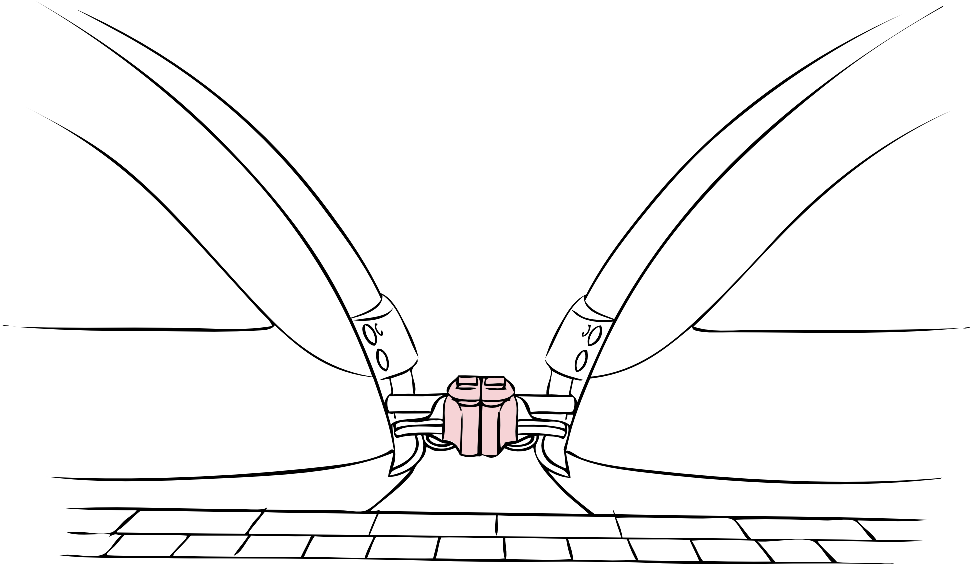
3. Liberty ship; an example of the application of non-proven technology is the used steel and the welding techniques in the Liberty ships, constructed during World War II. A number of ships has been lost by brittle fracture.



1. Lego bricks



2. USB connector



3. Automatic coupler

R10

DESIGN ROBUST INTERFACES BETWEEN COMPONENTS

The interaction between components has a strong influence on the reliability of the system

INTRODUCTION

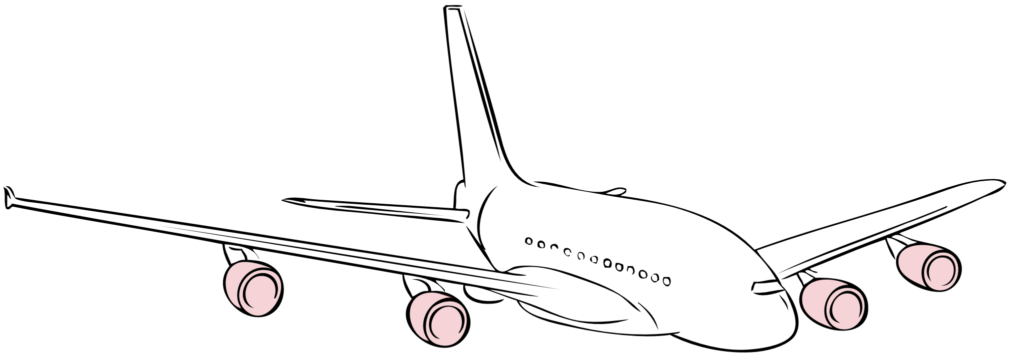
Each kind of contact between parts is an interface. So, not only connectors are interfaces, also gear contacts, bearings, hoses, clamps and flanges are. The quality of these interfaces strongly affects their wear and corrosion behaviour and therefore has a strong impact on the reliability of the system. High quality interfaces will not wear out or corrode.

EXAMPLES

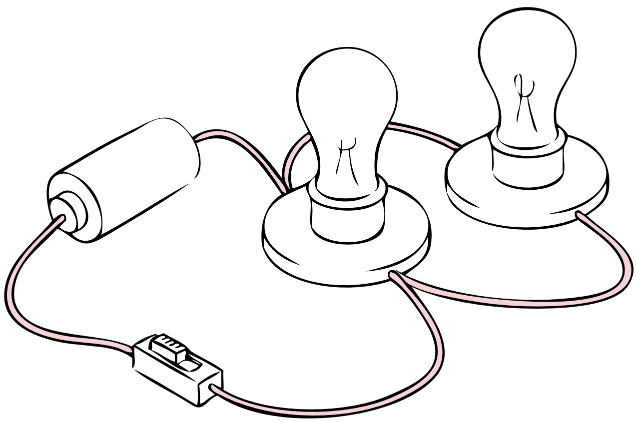
1. Lego bricks; the famous Lego bricks have a standardised robust interface.

2. USB connector; interfaces as well as the connectors for computers have evolved over time. Nowadays USB-connectors are widely used.

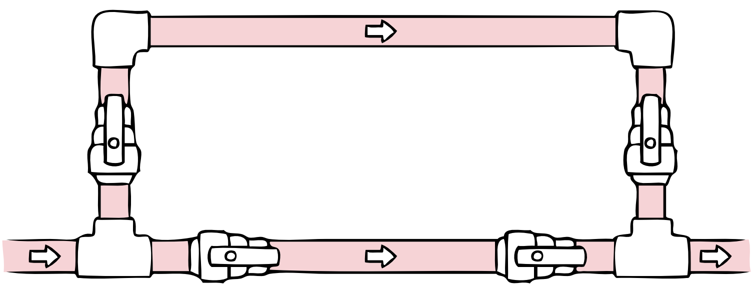
3. Automatic coupler; a robust mechanism for connecting rolling stock. Usually the coupler includes electrical and pneumatic connections.



1. Jet engines



2. Parallel electronic circuit



3. Parallel fluid transport

R11

USE PARALLEL SUBSYSTEMS AND COMPONENTS

Systems containing parallel subsystems, each with the same function, are less likely to fail completely

INTRODUCTION

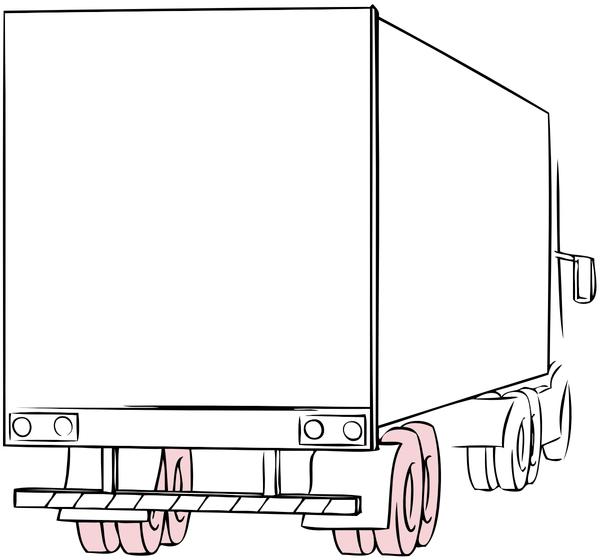
In general, solving a failure in one big pump is easier than solving a failure in four small ones. However, systems that contain parallel subsystems will not fail completely if one of the subsystems fails. An airplane with four jet engines will stay airborne if one of the engine fails. A passenger train with a distributed traction system can operate with less than all the traction motors functioning. Three parallel assembly lines will still produce if one line is shut down for maintenance.

EXAMPLES

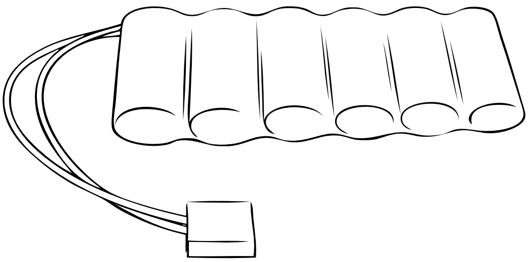
1. Jet engines; not only reliability in the sense of functioning may be important. Parallel subsystems may also enhance safety such as is the case for airplanes.

2. Parallel electronic circuit; if one lamp fails, there will still be light.

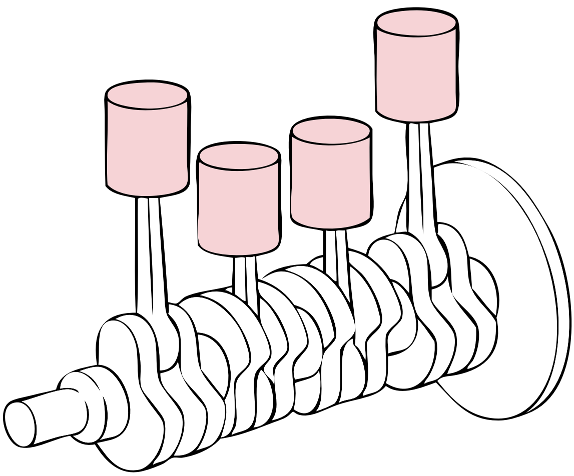
3. Parallel fluid transport; if one of the tubes is closed due to failure, supply will still be possible.



1. Rear axle truck wheels



2. Battery cells



3. Internal-combustion engine

R12

DISTRIBUTE WORKLOAD EQUALLY OVER PARALLEL SUBSYSTEMS OR COMPONENTS

Wear, and therefore behaviour, of both systems will be the same

INTRODUCTION

Load balancing is a technique to distribute workload evenly across parallel subsystems. This is often done in order to achieve optimal resource utilization, maximum throughput, minimum response time and to avoid overload. Load balancing across parallel subsystems will also result in the same level of wear of the subsystems, which can be useful for the planning of shutdowns.

EXAMPLES

1. Rear axle truck wheels; to avoid overload and to balance the load, more than two wheels are mounted to the rear axle of the truck. Normally, the wear of the tyres will be equally distributed.

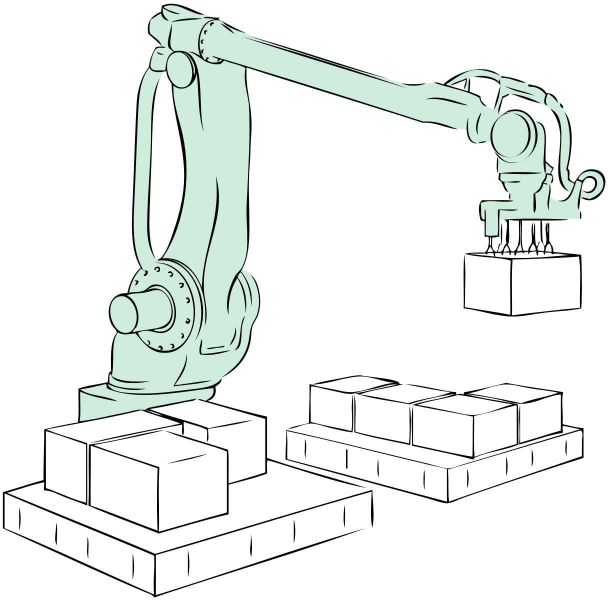
2. Battery cells; batteries often consist of multiple cells. Cells are charged equally and therefore aging is the same for every cell in the battery.

3. Internal-combustion engine; for various reasons, an internal-combustion engine generally has a number of cylinders. An additional advantage of the load balancing is the uniform wear.

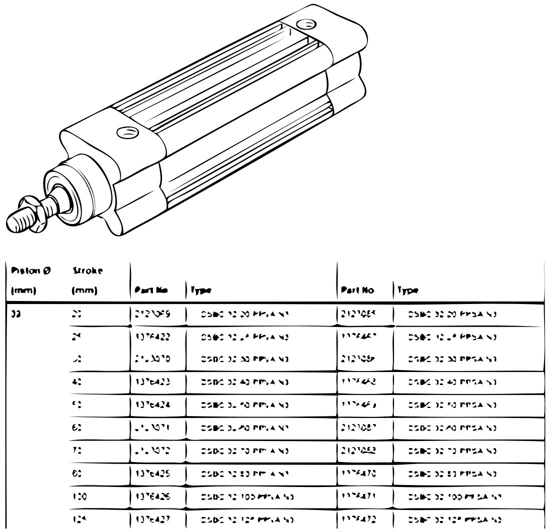
Guidelines to enhance

SUPPORTABILITY

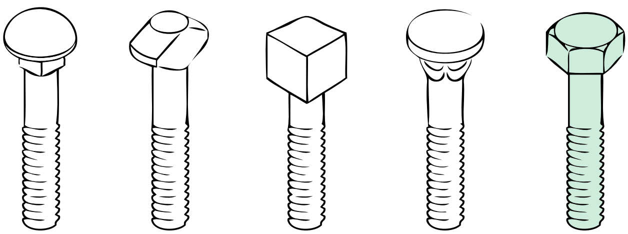
The product's supportability influences the easiness with which logistic resources can be available at the right time at the right place. Supportable products require a simple support system for having personnel, spare parts and equipment available when necessary.



1. Industrial robot



2. Pneumatic cylinders



3. Special bolts

Supportability

S1

USE STANDARD, UNIVERSAL APPLICABLE COMPONENTS

Those are widely available

INTRODUCTION

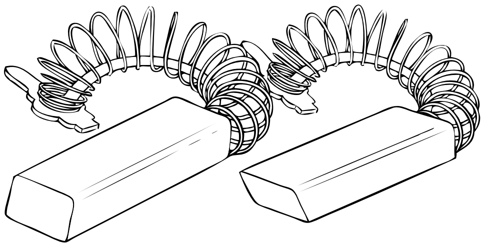
Parts and components of a system need replacement because of wear and breakdown. In order to enhance a quick repair, standard and universal applicable components should be used. They are, in general, widely available, easy to obtain and cheaper than unique components. Moreover, knowledge of the components and availability of skilled personnel is less of an issue than in cases that non-standard parts are used.

EXAMPLES

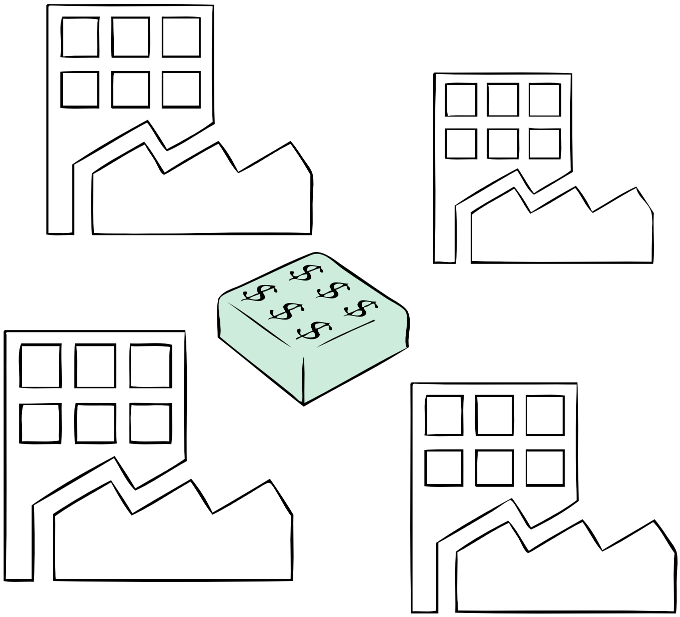
1. Industrial robot; because of the availability of knowledge and spare parts, the supportability of equipment from a catalogue is generally higher than for unique, custom-made machines.

2. Pneumatic cylinders; generally, there is a wide choice in standard components, such as pneumatic cylinders. When needed they are usually available from the shelf.

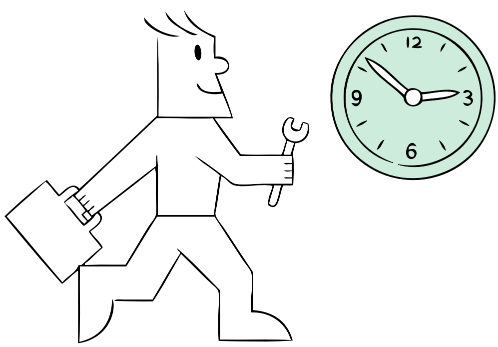
3. Special bolts; for each application a specific type of bolt can be developed. This does not improve the availability and supportability. Standardisation of the range of bolts to be used, is therefore desirable.



1. Carbon brushes



2. Joint spare parts



3. Service providers

S2

AVOID THAT EXPENSIVE SPARE PARTS NEED TO BE HELD IN STOCK

In order to reduce the inventory costs

INTRODUCTION

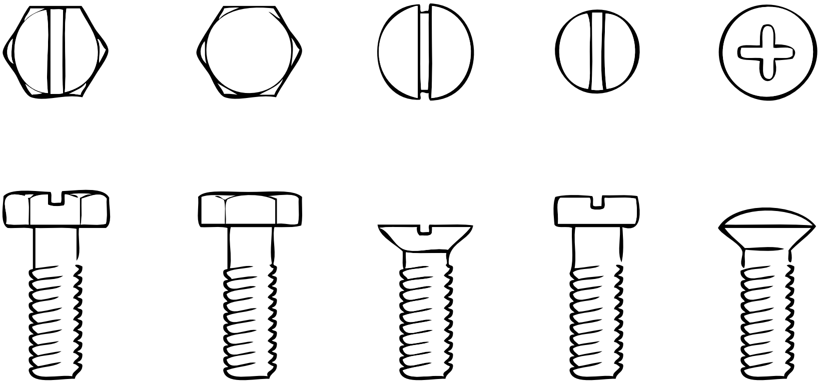
Because stocking spare parts involves space and capital, it is preferred not to have expensive parts in stock. First of all, expensive spare parts should be avoided by design. If this is not possible, avoiding expensive spares can be accomplished by realising a short repair time or to agree on a short delivery time with the manufacturer. Another way to reduce inventory costs is to share them with a number of parties by having a joint spare in stock.

EXAMPLES

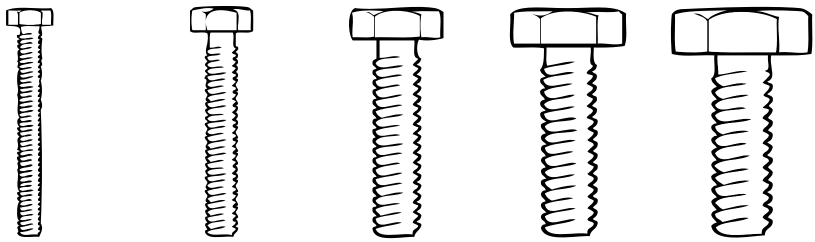
1. Carbon brushes; they are inexpensive wear parts. The replacement of a rotor is many times more expensive.

2. Joint spare parts; if a number of plants makes use of the same expensive compressor it is possible to jointly stock a spare.

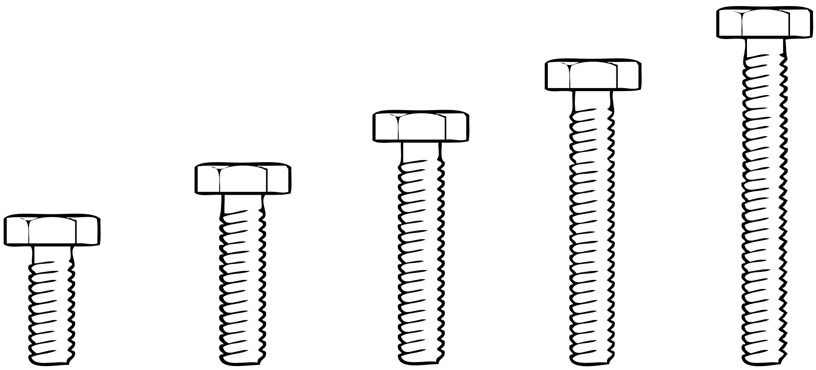
3. Service providers; they can assure a maximum repair or replacement time.



1. Bolt types



2. Bolt diameters



3. Bolt lengths

Supportability

S3

MINIMISE THE NUMBER OF DIFFERENT TYPES OF FASTENERS

Only those need to be held in stock

INTRODUCTION

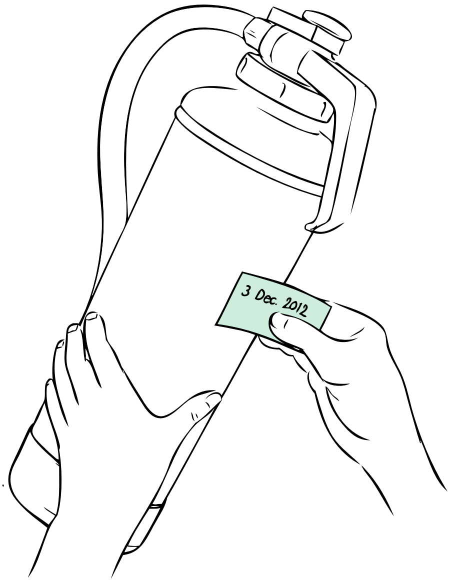
The number of spares needed for a large population is, in terms of percentages, lower than for a small population. When minimising the number of different types of fasteners the population of the used type is growing and thus less spares in total are required. Moreover, less different types of tooling are needed. This also helps to obtain a better overview of the workshop so that less time is wasted by looking for tools and parts.

EXAMPLES

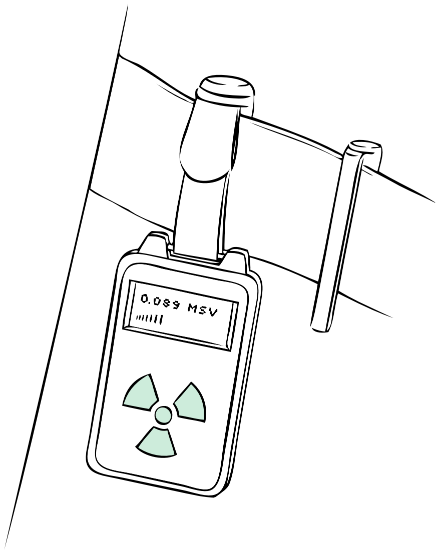
1. Bolt types; by reducing the number of different types, a reduction of the number of bolts in stock can be realised. This can also be done for other types of fasteners.

2. Bolt diameters; by standardisation the bolt diameters, the number and volumes of stock items can be reduced.

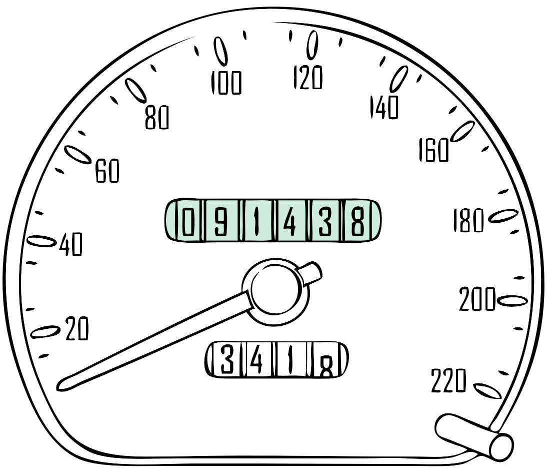
3. Bolt lengths; the lengths of the bolts may be restricted to a certain set, reducing the number and volumes of stock items.



1. Fire extinguisher



2. Radiation measurement device



3. Odometer

S4

SAVE THE RIGHT LIFE TIME DATA

The saved information can be used for planning maintenance or improvement of the design

INTRODUCTION

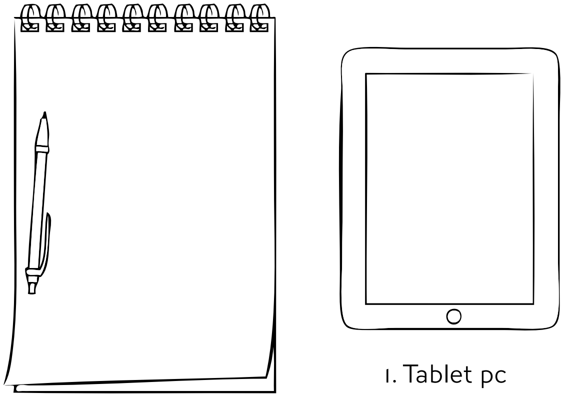
Information and data collected during the lifetime of an installation can significantly contribute to an adequate maintenance planning. Knowing at which moment maintenance is required, prevents failure and therefore unnecessary costs. Moreover, the knowledge gained, gives insight into the system's weaknesses. The information can help to improve the design of the installations.

EXAMPLES

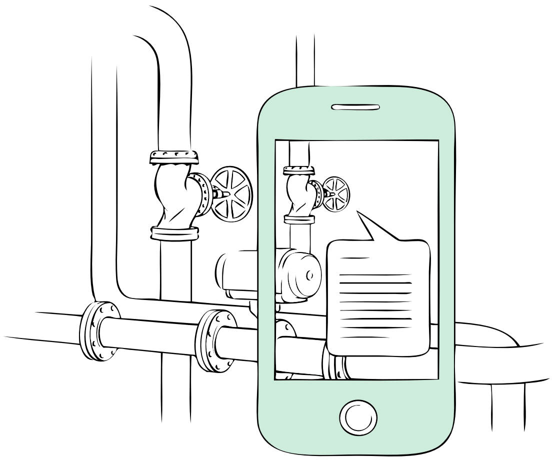
1. Fire extinguisher; labels indicate when the functionality is not longer guaranteed.

2. Radiation measurement device; used by operators and maintenance technicians of a system where radioactivity is involved. The detector registers the person's integral radiation level.

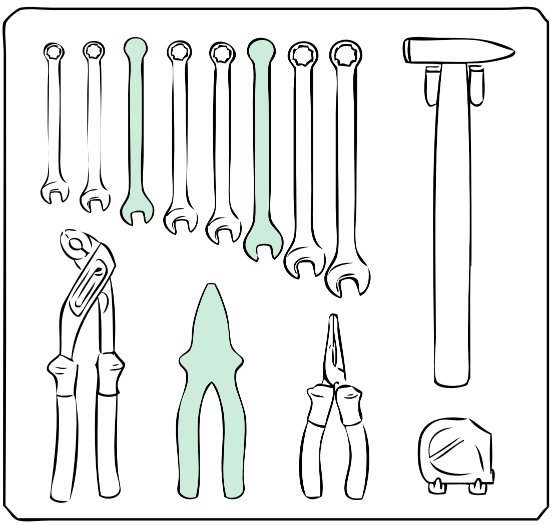
3. Odometer; an instrument that indicates the distance travelled by a car. At the car's garage it is known what type of maintenance is required after a certain number of kilometres.



1. Tablet pc



2. Augmented reality



3. Structured tool storage

S5

AVOID THAT SECONDARY TASKS CONSUME A LOT OF TIME

The main activity is executing maintenance

INTRODUCTION

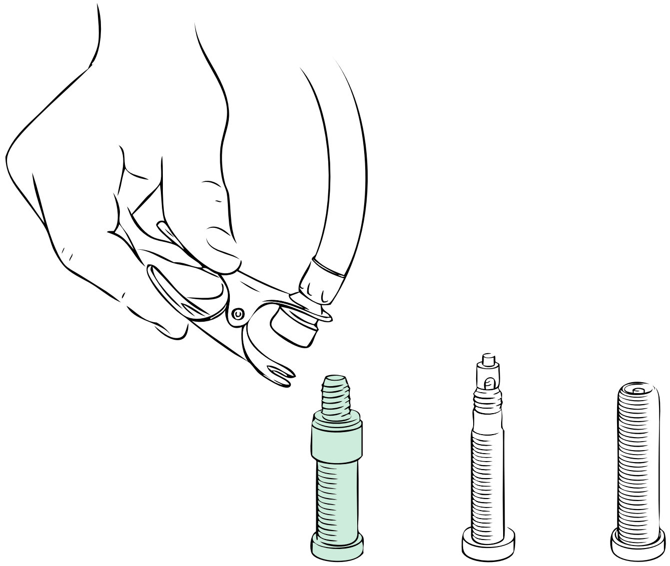
Secondary tasks, like registering data, administration work, cleaning and searching for tools can be rather time consuming and having the risk of overshadowing the primary maintenance tasks. Therefore, it is important to minimise the amount of secondary tasks. By structuring and planning the essential tasks as clear and lean as possible and staying up to date on the newest technology, the required time can be minimised.

EXAMPLES

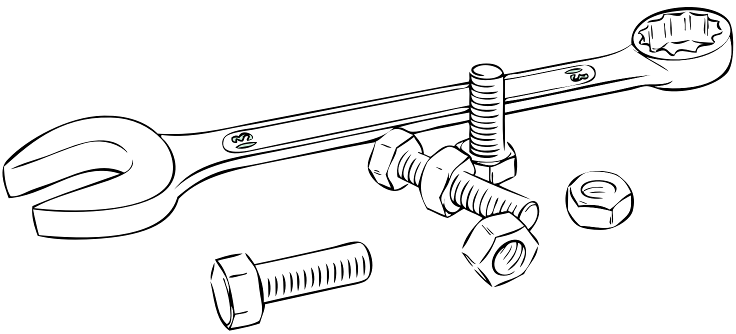
1. Tablet pc; using a tablet computer instead of pen and paper, results in an improved overview of notes and saves the technician from piles of paper.

2. Augmented reality; the technician receives all necessary data related to the picture shown on the tablet computer.

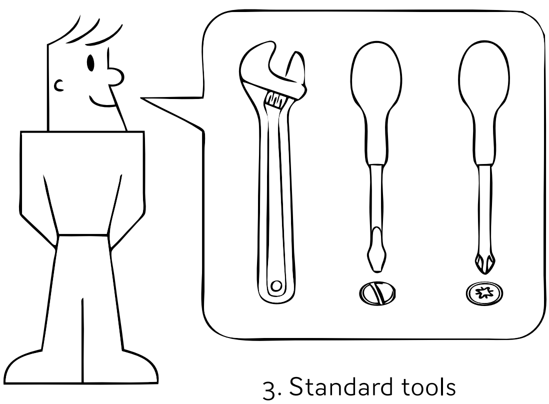
3. Structured tool storage; tools can be easily found and it is immediately visible when one is missing.



1. Valve stems



2. Bolts and nuts



3. Standard tools

S6

DESIGN FOR THE USE OF STANDARD TOOLS

Every technician is able to execute maintenance by having a standardised tool kit

INTRODUCTION

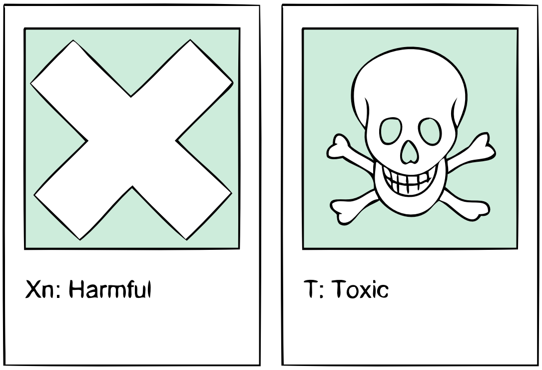
The use of standard tools saves a company both time and money. When maintenance of an installation can be executed by using standard tools, there is no need for having special, custom-made tools. Maintenance technicians also do not need to be trained in the use of them and spend less time on searching and cleaning.

EXAMPLES

1. Valve stems; different types of valve stems exist. By selecting the same one for all inner tubes, only one type of pump is required.

2. Bolts and nuts; when standard, universal, bolts and nuts are used, the technician only needs to have basic wrenches.

3. Standard tools; performing maintenance becomes easier when only standard tools are needed.



1. Labelling

2. Cleaning drains

3. Protective clothing

S7

DO NOT USE MATERIALS THAT AFFECT USER'S AND TECHNICIAN'S HEALTH

Avoid corrosive chemicals for lubricants and cleaning products

INTRODUCTION

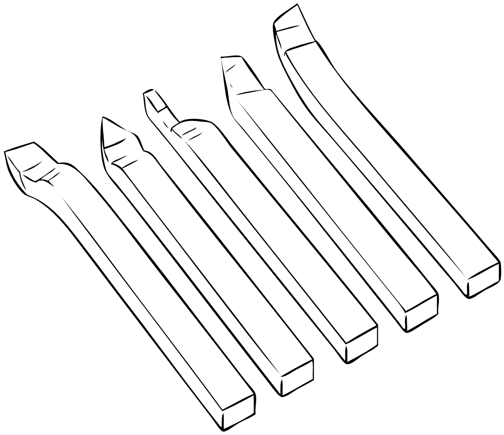
Safety and health of people are first priority. Therefore, hazardous materials like aggressive or toxic chemicals should be avoided. If the use of hazardous materials cannot be avoided, the operators and technicians should be warned by signs or symbols. Sometimes, also additional safety measures are required, for example wearing protective clothing. The persons themselves have to be aware of the properties of the materials they are working with and follow all obligatory safety regulations.

EXAMPLES

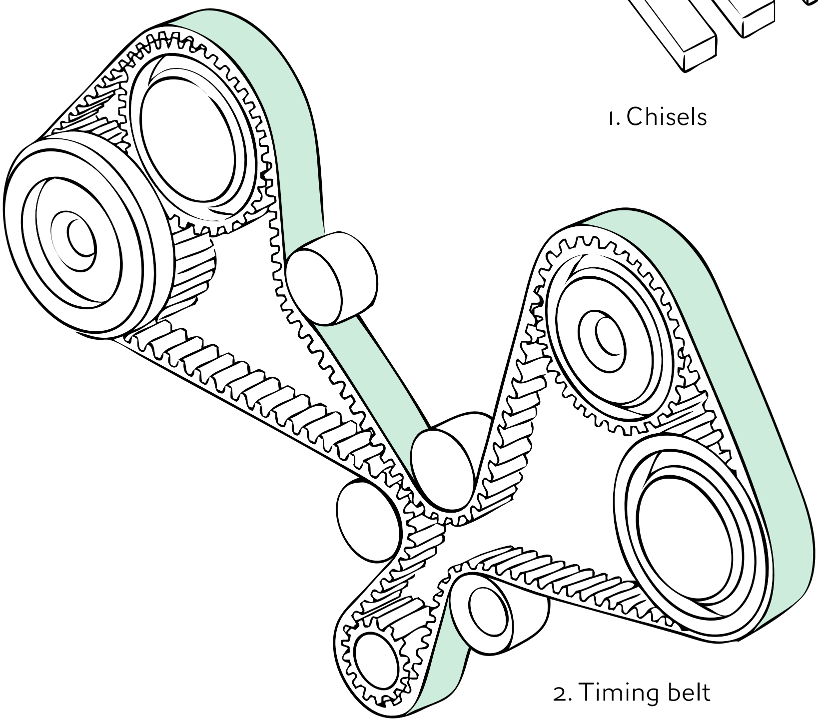
1. Labelling; in situations where the use of harmful materials cannot be avoided, clear and understandable labelling is very important.

2. Cleaning drains; when drains need to be cleaned, the use of a cleaning tool is preferred over the use of a harmful chemical solution.

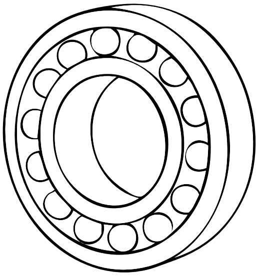
3. Protective clothing; if the technician has to work with hazardous materials or in a hazardous environment, protective clothing must be used.



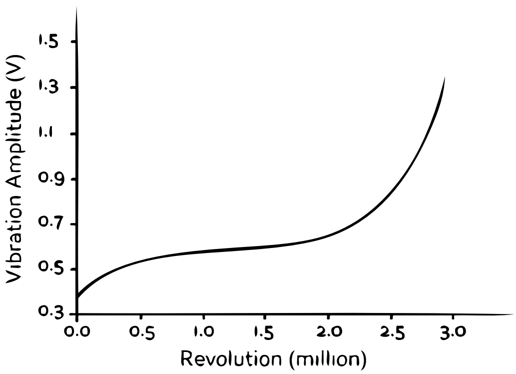
1. Chisels



2. Timing belt



3. Ball bearing



Supportability

S8

DESIGN THE SYSTEM IN SUCH A WAY THAT ADEQUATE FORECASTING OF MAINTENANCE IS POSSIBLE

Little variability in mean times to failure of components enables preparation of an adequate maintenance planning

INTRODUCTION

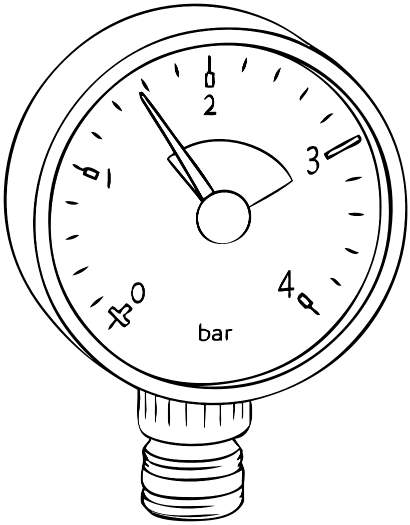
A system designed in a way that forecasting of maintenance is possible within certain boundaries, prevents both the owner and the technicians from unexpected surprises. For many components and materials, the behaviour over the lifetime is known. Therefore, failures due to aging and use can be predicted and prevented by regular maintenance sessions.

EXAMPLES

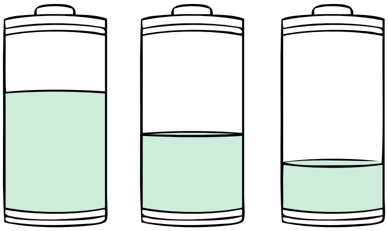
1. Chisels; because of known material properties and user experiences, operators know when chisels are worn out and need to be replaced.

2. Timing belt; the remaining lifetime of timing belts can be rather well predicted by the total distance the car has made.

3. Ball bearing; based on experience and experimental data, the bearing producer knows the behaviour of a bearing over its lifetime. By means of charts, they instruct users about the moment when replacement is necessary.



1. Pressure gauge



2. Battery indicator

3. Control room

S9

BUILD MONITORING EQUIPMENT INTO THE SYSTEM

In order to know if maintenance needs to be executed

INTRODUCTION

Monitoring equipment varies from simple pressure and temperature measurement instruments, to high-tech measuring systems communicating with remote control rooms. When a discrepancy is detected, the equipment gives a signal and the operator can determine which steps have to be taken to solve it. Based on the information given by the monitoring equipment, the operator can decide upon whether or not a technician needs to be send.

EXAMPLES

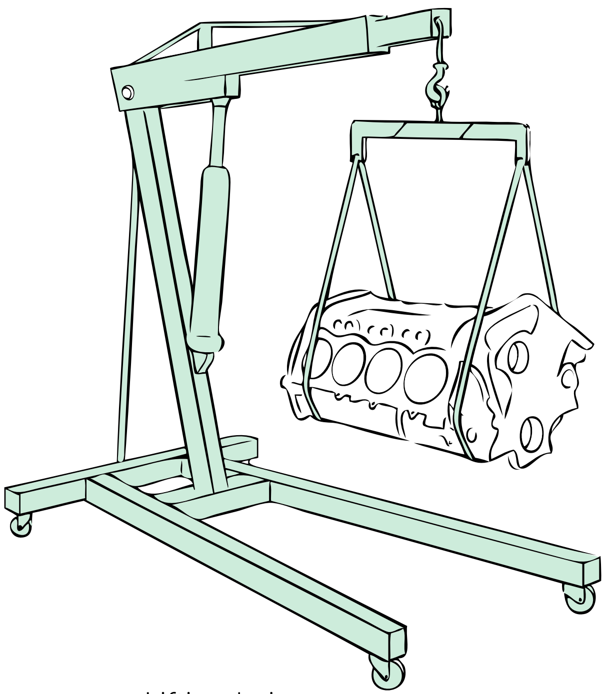
1. Pressure gauge; indicates the pressure of a system so that the operator sees whether or not it is within the right boundaries.

2. Battery indicator; a symbol on the display of an electrical device indicates the battery level. With this information, the user decides upon the moment of recharging the battery.

3. Control room; from a central location, maintenance assistance can be provided to locations all over the world.

1. Helmet light

2. Diagnostic device



3. Lifting device

S10

ENSURE THAT AS FEW AS POSSIBLE TECHNICIANS ARE REQUIRED TO PERFORM A MAINTENANCE TASK

Fewer personnel has to be available at the moment maintenance needs to be executed

INTRODUCTION

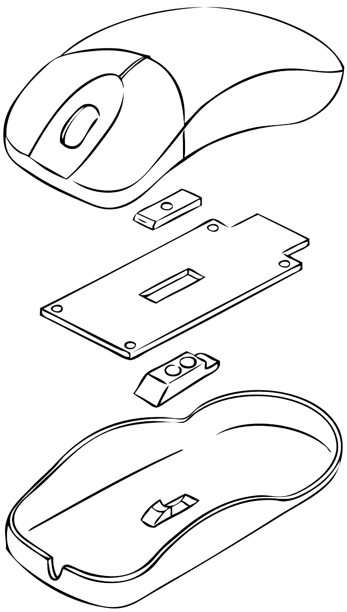
Performing maintenance tasks could require more than one technician. For example lifting of heavy machine parts cannot be done by one person. Also for executing maintenance in dark locations an additional person is required for holding a flashlight. The use of supporting equipment, like lifting or diagnostic devices, helps to reduce the needed number of employees. Developing equipment that can be maintained by one technician is recommended.

EXAMPLES

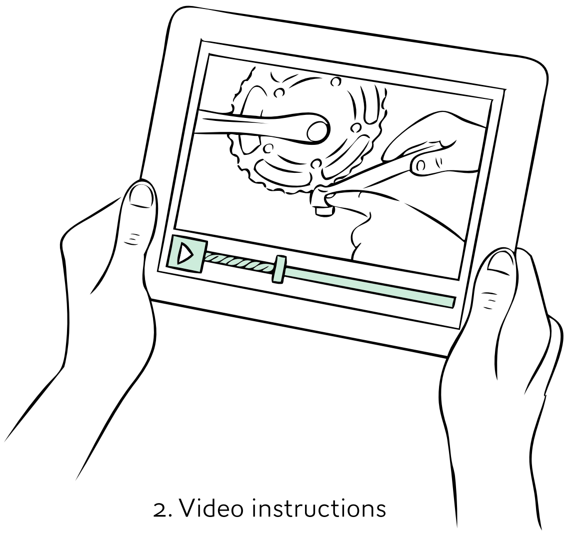
1. Melmet light; when a technician mounts a light on the helmet, both hands are available to perform maintenance tasks.

2. Diagnostic device; diagnostic devices are used to read data from on-board computers in, for example, cars or machines. The technician receives all required data from the system and does not need to check the condition manually.

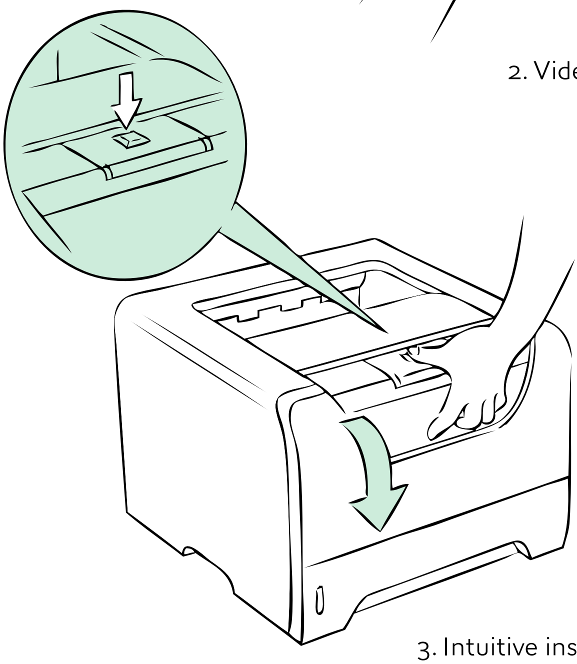
3. Lifting device; lifting devices are useful when heavy parts need to be moved. Instead of a team of mechanics, only one person is required to do the job.



1. Exploded views



2. Video instructions



3. Intuitive instructions

S11

PROVIDE UNDERSTANDABLE MAINTENANCE INSTRUCTIONS

The instructions need to be understandable by everyone who is expected to perform the required maintenance

INTRODUCTION

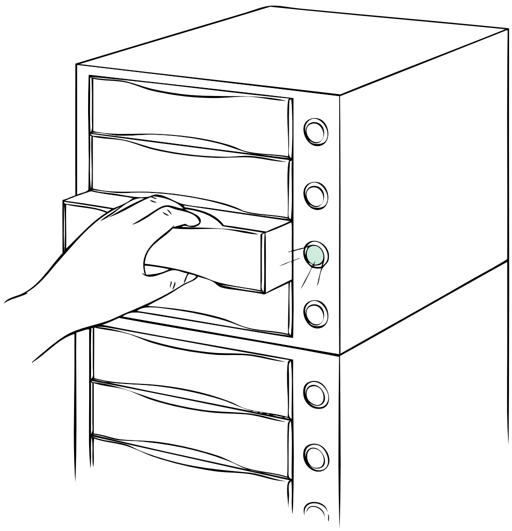
Intuitive, concise and unambiguously understandable maintenance instructions are essential to keep a system maintained at the right way. Perfect instructions result in a good understanding about how the installations need to be maintained. When it comes to writing instructions, the writer has to put himself in the position of the reader. Do you understand how the maintenance needs to be executed? If not, the instructions should be revised.

EXAMPLES

1. Exploded views; in order to gain a better understanding of a system. An exploded view shows the parts of a product, as well as how they fit together.

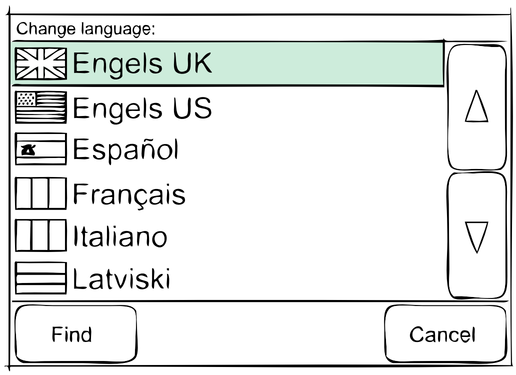
2. Video instructions; they can played on handheld devices like tablet computers and provide easily understandable, information-dense instructions.

3. Intuitive instructions; maintenance manuals with pictures only are easier to understand than text-based manuals.



1. Indication lights

2. Experts



3. Languages

S12

PERSONNEL WITH A VARIETY OF BACKGROUNDS SHOULD BE ABLE TO EXECUTE MAINTENANCE

For executing maintenance one should not depend on a single employee

INTRODUCTION

Employees usually have different backgrounds. Their educational background, level of expertise and langauge may differ. When it is clear to a wide variety of persons what is expected, the company does not depend on the expertise of a single employee or a group of specialised technicians. Basic instructions should be sufficient to maintain the system. In situations where the maintenance tasks are more complex, a team of experts could be available to provide step by step maintenance support.

EXAMPLES

1. Indication lights; an indication light on a server's hot swap bay emits when a hard disk needs to be replaced.

2. Experts; a readily available team of experts provides real time support to the technicians and operators.

3. Languages; maintenance instructions in a multitude of languages make it possible for all technicians to profoundly understand them.

LITERATURE

Numerous books are available on topics related to engineering design guidelines and maintenance. Some address general engineering issues, while others deal with a specific area of application. A number of those books are listed at this page.

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