Module_5

Maintenance Management

Géza CS. NAGY

Sustainable engineering

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2022.

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INTRODUCTION

In order to understand the concept of sustainable maintenance and its growing importance, we need to take a broad perspective, both in space and time. To the scientifically literate, it is obvious that the Earth is a physically finite, self-regulating organic complex system, especially with regard to non-renewable materials and energy. Humanity can be seen as a sub-system of PPMthis system, which, abandoning harmony with nature, is disabling some of the regulating processes and producing exponential growth by using the resources of the living and non-living environment. This in fact brings us to the root cause of the global problem of our time - overuse and the anomalies that result from the lack of natural feedbacks that are eliminated.

1. HISTORICAL OVERVIEW

The process actually began with the emergence of humans in ever greater numbers and over ever larger areas. As communication within human communities and the refining use of tools over time allowed the group killing of large prey animals, they became the primary target of hunting. By the very nature of the natural order, it takes many years or even decades for these animals to mature or even become sexually mature. It is easy to see that, if the rate, size and frequency of the killing of animals is not adapted to the developmental cycle, there will be a catastrophic decline in numbers, initially in some small populations, then over an increasing area, and finally the species will disappear. It would be an exaggeration to assume that our ancestors hunted woolly mammoths with modern knowledge of game management, so that hunting of big game, which was relatively easy to kill but also yielded a considerable amount of meat, ceased due to lack of prey.

As human settlements increased, the foraging lifestyle gradually became impossible to continue, and settlement and the switch to agriculture and livestock farming became inevitable. During the Middle Ages, deforestation was the dominant activity in the creation of ever larger settlements.

Focusing on the events that brought about the disruption of the harmony of nature, the Industrial Revolution deserves to be mentioned as a milestone. The barely habitable towns and cities populated by the penniless masses who flocked from the countryside to the cities, the rapidly expanding road and rail networks, but above all the coal and ore mining industries and the resulting industrialisation of production, combined to transform our environment into a human environment, but far from a human environment.

The fighting of World War II in itself caused significant changes in our natural environment, but the situation today has been much more influenced by the economic and commercial changes of the post-war years. The war created an unprecedented industrial potential for military industrial development, and the technical, technological and management skills and methods that underpinned this potential spread rapidly throughout the world as reconstruction progressed, enabling the needs of populations deprived of their resources during the war to be met on an ever wider scale.

The consumer society has become a basic model, in which real needs have been replaced by an increasing emphasis on satisfying the apparent needs of advertising and marketing professionals. This model was perfectly suited to the basic rule of capitalist society, which is that the economy must function on the basis of continuous growth, i.e. surplus production. By its very logic, surplus production entails an accelerating consumption of raw materials and energy, but also an exponential increase in waste production.

Noteworthy is the Club of Rome, a private initiative set up in 1968 to explore the global nature of social and economic problems.

2. THE ROLE OF THE CLUB OF ROME

The Club's aim was to explore the boundaries of the earth's systems and their interactions:

- "Can the continued exponential growth of the Earth's population and fixed capital be based on Earth's resources and ecosystems? What could happen if we overstress these resources?

- How does the existence of hunger zones fit in with national economic policies and the international market for food? What economic-political solutions can alleviate hunger?

- Is it possible to meet the basic needs of the world's population in the coming decades? How?"

Their first report, entitled "The Limits to Growth", was prepared by the MIT Working Group (MEADOWS, Donella H. - MEADOWS, Dennis L. - RANDERS, J. - BEHRENS, W. W. III. and co-workers, 1972), a pioneering computer-based world model.[4]

The result was formulated as follows on figure 1.

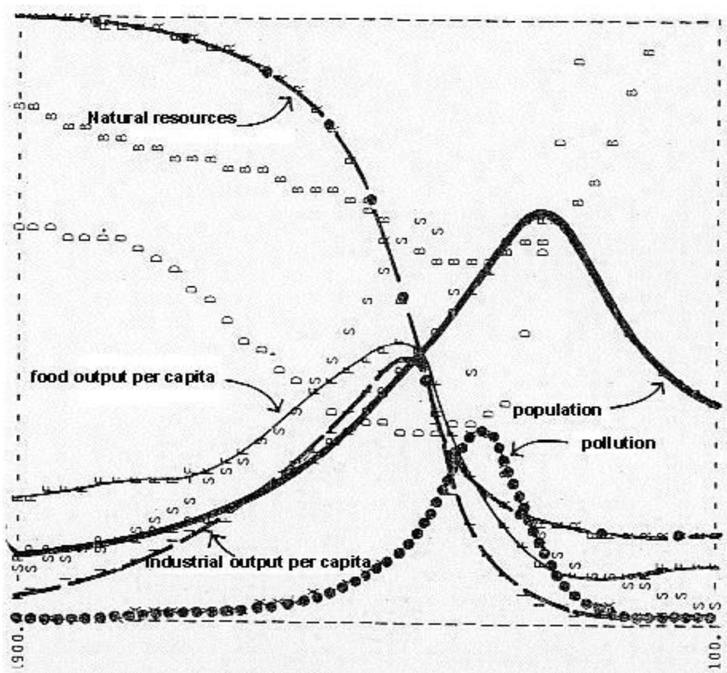


Figure 1. The Club of Rome forecast [4]

The collapse of growth is mainly due to the depletion of non-renewable resources, followed by a decline in industrial and food production, a lag in pollution, and a combination of these factors that leads to a sudden drop in the Earth's population.

As expected, the report was received with mixed reactions:

On the one hand, it has shocked responsible members of the scientific community and the public, and many other research, studies and initiatives that are still in place today owe their existence to the report, On the other hand, the vast majority of societies seemed unwilling to confront the conclusions outlined in the report, which called into question the adequacy of the current socio-economic order. Those in power have alternated between degradation, misinterpretation and simple disregard.

The explanation is of course obvious. The main aim of the vast majority of people is to maintain, or even enhance, their comfort. Any economic or political programme of self-limitation is a sure recipe for failure for its proponents.

3. THE FIRST CRISES ON A GLOBAL SCALE

The first crises to be accepted as global in scale were the oil crises of 1973 and 1979. This was the first time that an organisation (OAPEC, the International Organisation of Arab Petroleum Exporting Countries) used the fact that oil, the main source of energy, was unevenly distributed over the world and finite in quantity as a political weapon.

The OAPEC member states, using their monopoly position, raised the unit price of oil fourfold against all states that supported Israel in the then Yom Kippur war.

This decision was extremely sensitive for the United States and all Western European economies, but long-term analyses suggest that it also played a significant role in the subsequent disintegration of the Soviet Union and the Eastern Socialist bloc.

The report does not yet include facts and projections on climate change, but change was coming. Towards the end of the 1970s, more and more scientifically-based projections predicted that climate change would intensify. The effects of increasing global warming from the burning of fossil fuels were being felt in other parts of the world, with reports of droughts, poor harvests and floods in Burma, Pakistan, North Korea, Costa Rica, Honduras, Japan, Manila, Ecuador, the Soviet Union, China, India and the United States, among others, in the early 1970s. Few people have seen these events as part of a coherent process, even though it is clear that a population that is becoming unlivable and is already large and growing will be sent out into the world as subsistence migrants, creating a multitude of new crises.

4. THE EMERGENCE OF THE CONCEPT OF SUSTAINABILITY

It is perhaps clear from the above that when we talk about sustainability in the broadest sense of the word, we are in fact forced to question the sustainability of human civilisation at its current level.

The idea of sustainability was first formulated in the UN World Commission on Environment and Development's study, Our Common Future. According to the study, development is sustainable if meeting the needs of the present does not threaten the well-being of future generations.

the ability to meet your needs. The report expected continued accelerating economic growth and sought to reduce its environmental impact. [1]

The report did not include an assessment of the social impact of growth, although since its publication, the concept of sustainability has been broadened to include harmony between the economy, the natural environment and society (Figure 2).

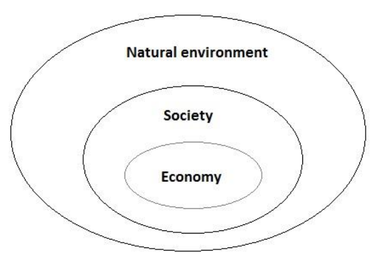


Figure 2. A nested system of sustainable development elements [1]

5. SUSTAINABILITY INDICATORS AND FOCAL POINTS

Since the focus has so far been typically and mostly on the sustainability of the economy, it is inevitable to examine the justification for using GDP as a generally recognised and used measure of growth. GDP is an indicator of macroeconomic performance, but it only measures performance that can be measured in monetary terms. It is not suitable for measuring the environmental and social impact of production and services. GDP is therefore an indicator of growth, but since growth is not the same as development, it is not a measure of social development or even of long-term economic development. According to Daly and Cobb: "Economic growth that is accompanied by an ecological deficit is economically damaging and will make us poorer, not richer, in the long run."

As mentioned above, humanity has never before in its history been confronted with such a vast and profound set of problems. It is almost impossible for a single person, or even a small group of people, to assess and evaluate the actual situation, let alone to develop in detail the concepts for solutions or the actual action. In view of this fact, it is perfectly understandable that

the detailed development of the activity. From this point of view, it is quite understandable that regional, national and international organisations, starting with small local communities, will look at one of the triad - natural environment, society, economy - and then specialise further depending on the degree of vulnerability. Local and national communities tend to focus on protecting the natural environment, giving rise to groups concerned with the state of living water, air and soil. At least national authority and economic potential are needed to reduce fossil fuel use and increase the share of renewable energy. So, while the protection of the natural environment and the sustainability of the economy seem to have found a taker, the development/development of society is still not a priority. The reasons for this are relatively straightforward: on the one hand, the material well-being of society, and therefore of individuals, depends to a large extent on the ecological carrying capacity of the environment, and on the other hand, on the quantity and quality of the material goods and opportunities provided by the economy. However, it is important to distinguish between material well-being and social well-being." By well-being we mean the existence of material goods, by well-being we mean a good life, a decent quality of human life." (Gyulai 1991,816) The latter should include health, security, the right to health care and education, a flourishing community life, etc. Many social scientists admit that in the past millennia only welfare has been improved, social well-being hardly at all. While the environmental awareness of individuals and communities is undoubtedly important, a global breakthrough, for example in reducing greenhouse gas emissions, can only be achieved by organisations with global participation and competence (climate summit).

6. THE CIRCULAR ECONOMY

In March 2020, the European Commission presented an Action Plan for the Circular Economy, which includes proposals for more sustainable product design and the reduction of waste and the right to repair. Particular attention is paid to energy-intensive sectors such as electronics and ICT, plastics, textiles and construction. [3]

The circular economy aims to keep a product, its components and materials in the economic circulation for as long as possible and at the highest possible quality, and consequently to reduce the need for new raw materials. However, in order to do this, products and equipment must be designed and manufactured in such a way that they are durable and can be repaired, renovated or converted. Unfortunately, today's consumer durables are mostly designed for a short lifetime, limited repairability, and often obsolescence and deterioration

is also factory coded. And recycling them is often difficult or impossible because the different components cannot be dismantled because they are glued or soldered together. In addition, technological innovations are rapidly rendering technical products or industrial equipment obsolete.

An important feature of the circular economy is the separation of the management of biological and technological materials. Biodegradable and organic materials (e.g. fibres or wood) in products can be safely returned to nature, while non-degradable inorganic materials (metals, plastics, alloys) can be refurbished, transformed or recycled into another product. In order to easily dismantle technical products and separate biological and technological components, attention must be paid to this from the design stage. More importantly, the products must be returned to the manufacturer.

That is why the circular economy is also about the fact that as a consumer you do not necessarily have to own technical products or household appliances, but only enjoy their services. Already today, we lease or rent many things (e.g. cars, tools or skis) instead of buying them. This saves us money and we only use these products when we need them. In a circular economy, you can rent a

TV, fridge or even a carpet, the manufacturer will take care of the repair and maintenance and when it is outdated or you get bored of it, they will provide a new one. And the old one will be taken back and recycled.

The circular economy is respectful of the environment and human health and well-being, so it avoids the use of toxic materials and seeks to minimise energy and water use in production, transport and distribution, and increase renewable energy use.[2]

For these changes to take place in the economy and at company level, a lot of external conditions still need to change, as our current system, market mechanisms, consumption patterns, legislation and tax frameworks are all fundamentally based on a linear economy. However, change has already begun and an increasing number of domestic and foreign companies have started product development, technical and business innovation towards a circular economy. But this alone is not enough and it is essential that more and more companies join forces and look for opportunities to cooperate with each other, even with companies in other sectors, because the essence of the circular economy is competition based on cooperation [3].

7. EXPANDING THE CONCEPT OF MAINTENANCE

Although the term maintenance is commonly used to refer primarily to the maintenance of production equipment and tools used in economic logistics, the increasing number of durable consumer goods and household appliances and their frequent replacement (discarding) can lead to a significant reduction in the use of raw materials and energy, and at least as much in waste production. The generalisation of the right to repair could bring about major changes in this sector of maintenance and repair.

8. THE RIGHT TO REPAIR

The European Parliament has been supporting the development of the consumer right to repair for more than 10 years and has made a number of concrete proposals to the European Commission to make repairs more systematic, cost-effective and attractive.

The following legislative proposal sets out the measures expected by MEPs:

- Make repairs more attractive to consumers, for example by offering bonuses for repairing a faulty appliance or providing a replacement for the duration of the repair

- Require manufacturers to provide free access to repair and maintenance information and guarantee software updates for a minimum period

- Ensure that devices are more durable, easier to repair and contain removable and replaceable parts

- Better information for consumers on the repairability of devices

- Extending warranties

9. THE IMPACT OF INDUSTRY 4.0 ON MAINTENANCE

Industry 4.0, which is already present in today's economy and is gaining ground at an accelerating pace, will have a significant impact on the content and delivery of maintenance activities. [7]

- Industry 1.0 Weaving machines, steam power

- Industry 2.0 Conveyor belts, mass production, use of electricity

- Industry 3.0 Electronics PLCs IT applications in automation

- Industry 4.0 Using cyber-physical tools to connect real devices to data processors via information networks

In recent years, in addition to other sectors of the economy (Fintech, eHealth, etc.), production processes have also been conquered by networked, interconnected and, in some cases, decision-capable tools: a technological revolution has also been launched in the field of industrial production. These changes are collectively referred to as the 4th industrial revolution, or Industry 4.0 for short, by economic, IT and industrial professionals.

Digitalisation technologies (cloud computing, Big Data, artificial intelligence, etc.) are creating new value by breaking down physical barriers: through the extensive collection of data and knowledge acquired via the internet, products and services that previously existed only in physical space can be extended and completely rebuilt. Digitising processes makes it easier to optimise them and to produce more efficiently and competitively[7].

Looking back at the evolution of industry from 1874, the date of the first industrial revolution, to the present day, we can see that over time we have witnessed the continuous incorporation of new technologies - electricity, PLCs, electronics, Big Data, the internet.

Not surprisingly, however, the basic definition of maintenance has remained relevant for more than two hundred years:

The actual content of maintenance

For the sake of a uniform interpretation, maintenance and the operations of maintenance of fixed assets can be summarised as follows: - maintenance is understood to be the maintenance activity comprising all the operations that need to be carried out in order to ensure the serviceability and proper use of fixed assets.

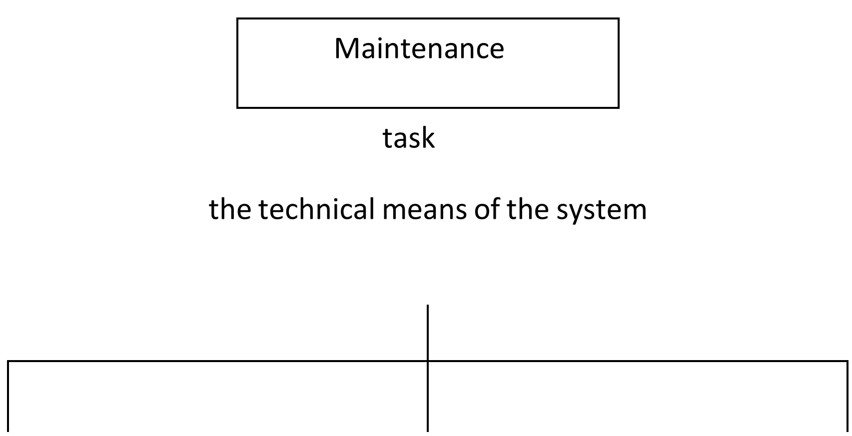
Maintenance includes all the activities, according to the current situation of the unit under inspection (e.g. production or repair), by means of which the required condition can be maintained or restored and by means of which the actual condition can be determined, assessed and qualified.

The maintenance of the original utility value can be defined as the implementation of measures to keep wear and tear below the permitted level. This includes care, maintenance, cleaning, lubrication, drainage, aeration, preheating and compliance with the prescribed operating procedures.

Restoration to original service life is understood to mean actual maintenance, preventive maintenance, replacement and troubleshooting. Increase in the original service life means the installation of more modern machinery and equipment as part of the general repair.

For organisational reasons, the system can be divided into continuous tasks (cleaning, cleaning, maintenance, etc.) and intermittent tasks (all repair operations). In practice, both continuous and intermittent tasks have developed into a well-established system, and there are several ways of combining them. It is clear that, if well organised, continuous maintenance operations (e.g. lubrication) will cause little or no disruption to production, while repairs will almost always interrupt the operation of a plant.

The grouping of maintenance measures is illustrated in Figure 3.



maintaining the required condition	establishing and assessing the actual condition	restoring (repairing) the required condition
Operation and maintenance	Supervision and inspection	Repair and maintenance
-Proper use	– control inspections	– various types of repairs
- cleaning	– measurements	– replacements
- adjustment,		
- lubrication	– inspection	– renovation
- preservation		

Figure 3. Parts of maintenance (general maintenance actions)

However, as the industry developed, the technologies and tools that meant the development of the industry were also introduced into the toolbox of maintenance. It goes without saying that, in parallel with the preceding process, there was a need for "handyman maintenance technicians", and later specialists, with an ever-wider range of skills.

All the above-mentioned elements of maintenance are aimed at preserving the functional capacity of the equipment and installations entrusted to our care and, ultimately, at preventing any failure,

9.1 THE FAILURE

According to ISO IEC 50(191):1992, a failure is a condition of a product in which it cannot perform its intended function, unless this condition occurs during preventive maintenance or other planned activity, or is due to a lack of external resources. Thus, the product goes from a working state to a failure state following a failure, so that the failure is also understood as a process

In the course of wear and tear, various failures (technical faults which do not represent a failure of the system as a whole) may occur which affect the components of the system (machine). In assessing the failure process, the following conclusions can be drawn:

- various technical failures occur in the process for some reason,

- the technical defects that have occurred vary according to their manifestation (wear, stretching, deformation, cracking, breaking),

- they interact, but only one of them causes a malfunction or a change in quality.

Failure is therefore an indicator of a change in the quality of a component or part during operation. The change is the result of a cause or causes that can be determined and, as a result, is interpreted as an oc¬osity. Failure is indicated by the number of changes involved in the process, which reduce the technical reliability of the component or sub-assembly and affect its serviceability. Failure is therefore not the same as a technical defect, since a technical defect can also occur during manufacture or repair, where it is not necessarily a failure. A technical defect is merely a precondition for a failure.

Although undesirable, failure is a necessary and natural part of operation. Reliability is linked to failure, because if a structure does not work as intended, it is a failure by definition. Logically, the higher the reliability, the lower the probability of failure.

In order to reduce the probability of a failure occurring and to identify the root cause of the failure that has occurred, it is important to know the most common causes of failure.

10 TYPICAL FAILURE MODES

One of the most important tasks of failure analysis is to identify the causes of failures. The wide variety of failures requires a systematic approach, both to identify the cause of the failure and to examine the causes of the failure in order to compare the results.

In the literature, failure modes are classified according to a number of criteria. The causes of errors can generally be divided into two broad categories:

- direct causes: primary causes of failure which directly lead to the inability to perform a function:

- Indirect causes: triggers of damaging effects which are preconditions or reinforcers of the direct cause.

In other respects, the causes of failure are simple or complex. Simple (single) defects are those where the failure is homogeneous, caused by a single cause. In practice, we can usually speak of complex faults caused by several, mostly indirect, causes. For example, in the failure process of brake discs, wear leads to a reduction in size and mass, a change in the macro- and micro-geometry of the friction surfaces, and possibly to indentations. The direct cause is the abrasive effect of friction brake pads. Indirect causes influence this effect. These include the material of the brake lining, the size of its surface, the clamping force, the frictional force generated, the precision of the assembly, etc.

It is difficult to provide a generalised categorisation of failures applicable to all cases, but a system can be established to help identify the causes and to support a systematic review of the damaging processes that lead to failure. Its basic principle is a fault grouping: it classifies those faults that occur as a result of different causes, i.e. different failure modes. In this way, a direct link can be established between the nature of the faults and the faults that cause the system to malfunction at a higher level..

This system can be extended as necessary, on the basis of experience, to provide a relatively complete overview of the possible causes in a specific case.

1. Faults caused by external factors ¬(occurring independently of the manufacturer's or user's actions or intentions)

    1.1. Natural disaster

    1 2. Unauthorised, incorrect intervention (e.g. defect during transport)

1.4. Failure caused by other external factors

2. Product defects (occurring within the scope of the manufacturer's activities)

2.1 Design defect (e.g. defects due to design method, sizing, choice of materials, assembly of components and sub-assemblies, etc.)

2.2 Manufacturing defect: a defect occurring in any part of the overall product manufacturing process (e.g. machining, heat treatment, assembly, storage, commissioning, testing, inspection)

2.3 Material failure (failure due to defects in the material used, e.g. deviation from the specified quality, inclusions, rolling defects, etc., when the material quality is correctly selected in accordance with known sizing procedures and planned requirements)

2.4. failure of another component (failure of one element due to a specificity of the construction, caused by a failure of another element which would not otherwise have occurred)

2.5. Other product failure

3. defects due to natural wear and tear (defects due to processes which occur naturally on machinery correctly designed and constructed at the relevant state of the art and under the prescribed operating conditions and maintenance)

3.1. Wear

3.2. Fatigue

3.3 Ageing (occurs outside the technological processes)

3.4 Corrosion

3.5 Other

4. maintenance defects (defects resulting from deficiencies in the maintenance activity)

4.1 Maintenance design failure (failure in the design of the maintenance system and maintenance operations)

4.2 Maintenance, daily maintenance failure

4.3 Technical inspection, diagnostic failure

4.4 Repair failure (material, component, technology, unprofessional repair)

4.5 Failure to modify (e.g. planned modification, alteration, extension, completion)

4.6. Storage, warehousing failure

4.7 Error by external service provider

4.8 Other maintenance failure

5. Operational error

5.1. Handling error (error occurring during use by handling other than in the normal way of operation, but for the intended purpose)

5.2 Abnormal use (failure to use in a manner not in accordance with its intended purpose or suitability)

5.3. Other operational failure

The definition of maintenance is:" "Maintenance is understood to be the maintenance activity which includes all the work necessary to keep fixed assets in working order and in their intended use." The scope of these tasks is expanding rapidly as production and service activities develop, and their overall coordination is a hopeless undertaking without the application of an appropriate management principle. The set of principles applied to the maintenance of a given piece of equipment is called a maintenance strategy. It is important to note that, although practical needs have led to the emergence of new strategies over time, it is not possible, nor should it be, to establish a qualitative ranking of these strategies, since each asset, and sometimes even each sub-assembly or component, may have a different strategy for optimal maintenance.

11.MAINTENANCE SYSTEMS

Given that the failure of machinery, equipment and individual components, their repairability, the consequences of failure and the technological options available can be extremely varied, a number of different maintenance systems have evolved. Taking into account economic requirements, the following systems can be used to ensure the availability of machinery:

- on-demand maintenance and repair (point-of-failure replacement, "fire-fighting"),

- planned preventive maintenance () (time-based or performance-based),

- maintenance based on technical condition testing (diagnostics),

- Total Productive Maintenance

- Reliability Centred Maintenance (RCM)

11.1. MAINTENANCE AND REPAIR AS REQUIRED OR AS A REPLACEMENT FOR FAULTS

In this maintenance system, repairs are only carried out after a failure has occurred. The failed component or main part is repaired or replaced with a new one. Care and lubrication operations must also be carried out regularly in this form of maintenance.

Its advantage over other maintenance systems is that certain sub-parts and sub-units of the equipment can be used to the limit of their wear and tear.

The disadvantage is that the intervention and repair time cannot be planned in advance, so that the downtime is generally longer, depending on the load on the repair capacity, as their load is unplanned and highly variable.

Immediate replacement of unexpectedly failed machinery is usually not possible and therefore usually causes problems, and late detection of unexpected failures can create further deterioration between components. Accordingly, a relatively large stock of spare parts is required to ensure timely rectification of the fault.

The above may result in high maintenance costs.

Necessary repairs should only be used in cases where the impact of the above-mentioned drawbacks is minor. These are:

- no data are available on the expected occurrence of the failure,

- the failure does not pose an accident hazard,

- the loss of production due to an unexpected failure does not represent a major financial loss,

- failure to detect the fault in time will not cause further damage,

- the fault can be easily and quickly rectified by the operator,

- spare parts can be stored during operation in order to rectify the fault within a short time, and the relatively large quantities of spare parts stored do not cause major financial burdens.

In summary, the use of on-demand repair is primarily appropriate for simple machines with low complexity.

11.2 PLANNED PREVENTIVE MAINTENANCE

The industrialised countries recognised the importance of maintenance at an early stage. This has led to the development of planned preventive maintenance (commonly known as preventive maintenance, or PPM), which replaces the previous system of simply repairing faults that have occurred. This maintenance system focuses on preventing faults and eliminating unexpected failures.

The PPM system is widespread in industry, services and public transport. In all these industries, regular and preventive inspections and repairs have been carried out in technical practice since earlier times. For example, the foundations of the maintenance system for railways date back more than 100 years and have been refined on the basis of many years of experience.

The permanent operational condition of machinery, equipment and rolling stock is achieved by regularly scheduled inspections and repairs. Inspections and repairs are carried out in accordance with a rigidly defined schedule - the cycle schedule - as part of the maintenance regime, which specifies the type and extent of the work carried out, the sequence in which it is to be carried out, and the other parameters (time, performance, etc.) and their scope between inspections and repairs.

During maintenance, the machines would be cared for, looked after, inspected, any necessary adjustments would be made and major repairs would be carried out. Repairs, on the other hand, involve the partial or complete dismantling of the machine and the repair or replacement, irrespective of the extent of the failure, of parts or components whose remaining life is likely to be shorter than the time until the next repair. This measure is intended to prevent unexpected failure before the next scheduled repair. In addition to repair, renovation may also involve modernisation, new utility and advanced technical standards.

In 's system, equipment is taken out of production on a scheduled basis, thus reducing the cost of unexpected breakdowns, balancing the burden on repair capacity, while at the same time causing unnecessary waste by replacing parts that are still in working order.

In general, the PPM system has the following tasks:

- to develop a repair system which, knowing the stresses and life expectancy of the components, seeks to prevent failures proactively, thus ensuring the continuity of the plant within the tolerated time,

- designing a repair system where the starting and finishing dates of repairs can be reasonably estimated in advance,

- the establishment of a maintenance and repair organisation which, if it is functioning correctly, will only take machinery and vehicles out of productive service for the shortest possible period, and

- the organisation of repair work in such a way that production is not altered by the machinery and vehicles being taken in for repair,

- to ensure the quality of repairs so that the serviceability of machinery, equipment and vehicles is satisfactory at all times,

- the modernisation of equipment, which reduces the repair work, reduces the cost of the equipment, improves the performance of the equipment and improves the quality of the product.

In summary, PPM's mission is to maintain reliability, the target level of which is determined by the necessary safety and economic considerations.

The advantage of a PPM system, provided that a well-established and correct cycle schedule is established, is the ability to plan repair tasks over a longer time interval, to reduce the resulting downtime and to increase the service life of machines and vehicles.

In areas where it is important to maintain a specified reliability value and where there is not yet adequate diagnostics, this method can provide the best results.

The above results can only be ensured by a cyclical approach based on continuous research prior to implementation and during operation.

There are two basic types of maintenance cycles:

- time-based (time-dependent), which does not take into account the actual demand,

- performance-based (performance-dependent), which adjusts the time of interventions to the demand.

The economic impact of PPM can be easily measured by the reduction in production costs, the increase in the life of machinery and equipment and the reduction in scrap for machinery in good working order. The operation and productivity of machines and vehicles that are maintained in a planned manner is almost uninterrupted, with hardly any breakdowns. As a result, the repair cost per unit of production and the repair cost ratio of the production cost decrease.

In summary, the use of a PPM system is essential for the reliable operation and prevention of accidents in the case of complex and high-value installations.

11.3. PREVENTIVE MAINTENANCE BASED ON A TECHNICAL HEALTH CHECK (DIAGNOSTICS)

Preventive maintenance (PM), which follows a relatively rigid maintenance cycle, is based on the analysis of component wear and tear and the resulting laws of logic. However, the wide range and detailed analysis of rapidly evolving engineering and operational data does not always provide an accurate answer to the question of component durability, failure-free operation and lifetime.

The service life of components is influenced by many factors, including the quality of manufacture and repair, highly variable operating conditions (loads), premature dismantling, careless maintenance, etc. The expected service life is uncertain if the component is made of new materials with little known history, the equipment is new, there is no operating experience, etc.

The quality of manufacture and repair depends, among other things, on the accuracy of machining and fitting, surface quality, heat treatment and care in assembly.

The operating conditions are determined by the weather, the environment (dust content, humidity, etc.), changing and often unforeseen stresses and the handling of machinery. Because of the many factors that increase uncertainty, it is advisable to establish a maintenance regime that determines the time for maintenance and repair on the basis of periodic or continuous instrumental technical condition tests (e.g. measuring the wear and tear of components) during operation and ensures that the equipment is in a fit state for use.

With the appropriate measuring and recording equipment, the instrumental technical condition test (technical diagnostics) can be used to determine the wear characteristics of individual components and sub-assemblies (e.g. compression pressure, vibration, insulation level of electrical equipment, position of bearings, valves, other electrical faults, etc.) without dismantling.

Regular monitoring of the technical condition of the machinery and evaluation of the results of the monitoring will help to understand the laws of wear and tear. This knowledge of the wear and tear patterns will make it possible to determine in advance when and to what extent repairs will be necessary.

For example, in internal combustion engines, the compression end pressure decreases in proportion to the wear of the cylinder and piston, which depends on the power and operating conditions. Knowing the wear rate, the wear rate allowed for economical and serviceable operation and the compression pressure associated with the wear, the repair date can be determined in advance.

In other cases, the wear rate can be inferred from the amount of wear product in the lubricating oil or its increase in relation to the previous measurement.

The condition of the oil filter is characterised by the difference between the pressures measured before and after. The condition of the integral roller and plain bearings can be monitored by vibration measurement. Measurements of the parameters of the electrical active and passive components - or the amplifiers, filters, modulators, demodulators they are made up of - provide information on the current state of the component or module and the need for and time of re-setting or possible repair.

The unexpected failure of increasingly sophisticated, but more productive and relatively expensive machines, produced as a result of technological progress, is causing ever greater losses. A maintenance system based on a technical health check can help to reduce the rate of downtime.

The availability of regular information on the technical condition of machinery and equipment not only reduces the number of unexpected breakdowns, but also reduces the time between overhauls. cycle time can be increased or the number of major repairs can be reduced. Depending on the nature of the machine, equipment or vehicle and its role in the production process, major overhauls in the classical sense can be dispensed with.

The system provides the right information for planning. The choice and quantity of the parts required for the repair can be determined on the basis of the expected failure rate, thus ensuring optimum stock levels. The number of repairers and maintenance staff required in each period can be determined on the basis of the expected number of repairs, and the legal and actual preparation of maintenance work by external companies can be made.

The preventive maintenance system, based on diagnostic tests, provides an opportunity to increase the organisation of repairs, to introduce more modern repair methods, such as the replacement of main parts and the replacement of functional units (modules) for equipment that is subject to replacement.

On the basis of the above, the establishment of a maintenance system based on technical condition testing appears to be the most economical, but its effectiveness depends to a large extent on the quality of diagnostic methods and the error of forecasts.

The procedures and methods of technical condition assessment (diagnostics) are very diverse. Some test methods are considered traditional and are in general use, others are only occasionally used in practice.

Traditional procedures include: length measurement, pressure measurement, temperature measurement, flow rate measurement, mass (flow through mass) measurement, force measurement, power measurement, torque measurement, electrical measurement, hardness measurement, etc.

New methods not yet in general use: vibration measurement, vibration analysis, pulse measurement, ultrasonic methods, sound source analysis, noise measurement, stethoscopy, radiography, radioactive isotopes, potential probe method, magneto-pore method, endoscopy, spectroscopy, pulse counting, photogrammetry, etc.

The third group of techniques includes methods whose theoretical foundations have been established but which require further laboratory development before they can be applied technically and economically in practice. This group includes, for example, holography with its four main directions, holographic optical imaging, holographic interference measurement, holographic data processing, acoustic and microwave holography.

A further obstacle to the uptake of technical condition testing is the scarcity of mechanical diagnostic equipment available today. This is reflected in the fact that

- in most cases significant dismantling is required to apply technical diagnostics,

- the accessibility of the connection points to the diagnostic sites is difficult,

- the mechanical equipment does not have test equipment connection points,

- the size and shape of the connection points are not standardised,

- quality and safety characteristics important for operation are only partially verified by technical diagnostic methods.

Technical health checks can be carried out at specified intervals or continuously. The former is also referred to as a search method. In more advanced systems, the tests are carried out automatically according to a predefined programme, which first measures the main In the continuous inspection - the so-called indicator method - the instruments and data recorders mounted on the machine or equipment continuously measure and record the parameters indicating the technical condition. These characteristics are evaluated at specified intervals by a computer which, after comparative analysis, indicates the time, extent and probable causes of the expected failure.

The cost of introducing diagnostic tests for maintenance purposes is relatively high. However, it is justified in cases where the equipment:

- is of particularly high value and complexity and the cost of downtime due to failure is high, or

- high reliability requirements.

11.4 TPM

Total or complete maintenance is a concept that has become familiar in Japanese industry, the content of which is essentially preventive maintenance involving all employees in the form of small group activities.

The modernisation of maintenance in Japan began in 1951 with the adoption of preventive maintenance from the USA. Its first user was Nippondenso Co Ltd, part of the Toyota group, the largest Japanese manufacturer of automotive accessories. In 1960, the company introduced American-style preventive maintenance, whereby operators produce and maintenance is carried out by the maintenance staff. As production processes became increasingly automated, maintenance became critical. Traditional maintenance staff were no longer able to maintain the increasing number of automated machines. The company decided to make the operators responsible for the routine maintenance of their own machines.

Nippondenso had already introduced a system of quality circles in which all employees participated. This experience was also used to develop total maintenance.

These are included in the 12 steps recommended for the development of the programme:

- Improve the utilisation of each machine;

To do this, it is advisable to set up planning teams to identify the tasks needed to eliminate losses and optimise the use of each piece of equipment.

- introduce autonomous maintenance by machine operators, using a small-scale, step-by-step approach;

- establish a system of planned maintenance in the maintenance department, with the necessary scheduling, provision of spare parts, tools, technical instructions, etc;

- a training programme to improve the production and maintenance readiness of operators and maintenance staff;

- to establish a system for the design and manufacture of reliable, maintainable and economical life-cycle cost machinery and equipment.

The "five essential elements" (steps 7 to 11) can only be introduced after proper preparation. A detailed plan should be developed on when and in what order to proceed. Although the time needed varies from company to company, the preparation phase usually takes 3-6 months and the total time needed for implementation 2-3 years.

The worker is assessed at every step by managers or technicians. If a step is judged to be completed, a certificate is awarded and the worker moves up one step. This process has also improved the appearance of the equipment.

The number of unexpected equipment failures at Nippondenso has been reduced from one thousand to twenty per month. Equipment utilisation has improved by 50%. The failure rate in the production process has been reduced from 1.0 to 0.1. The number of complaints has decreased by 75% and the cost of arm maintenance by 30%. Standby stock halved and productivity increased by 50%.

TQM (Total Quality Management) is conceptually related to the concept of total maintenance, which means that the entire management process is covered by a quality approach, from purchasing to sales, i.e. from the quality of the raw materials, semi-finished products and components supplied to the quality and quality of the sales points and people.

Both are in fact a management philosophy that requires continuous data collection and evaluation, and that decisions should be based on this and not on opinions and assumptions. Involving people in the process is essential.

This new management philosophy means change:

- changes in vision, changes in strategy;

Customer satisfaction becomes the measure of performance.

- Changes in the manager-employee relationship;

Increasing the level of knowledge, decision-making, autonomy and creativity of subordinates.

- Changes in formal structures;

Consistency of planning, organisation, stakeholder, organisation and information systems become crucial.

In the light of the strategies that can be applied, it seems appropriate to examine how the range of strategies has expanded since the beginning of industrialisation and what the trend is in the emergence of successive methods.

12. CHANGES IN STRATEGY CHOICE CRITERIA

12.1. INDUSTRY 1.0

In the early days, the individual or small-scale production of spare parts did not allow for the continuous production and distribution of spare parts, so that a high degree of creativity was a legitimate expectation for the operating staff. The precision and general quality of the tools used in the production of the machines, the fittings available during assembly and the quality of the materials used for the parts meant that there was a multitude of potential errors during production. At the same time, the relatively simple equipment, consisting of lever, articulated and linkage mechanisms, simplified the work of operators and maintenance staff, with the exception of the steam engine, which was linked as a power machine, but was usually looked after by separate staff.

Regular maintenance activities at this time were mainly adjustment and lubrication to correct dimensional changes due to wear. Although unexpected breakdowns obviously caused production losses and sometimes even serious accidents, there was no comprehensive

maintenance strategy to prevent unexpected breakdowns, the aim being to rectify the problem as soon as possible. For assets in a subordinate role, failure of which does not cause significant material damage, accidents and can be repaired locally with a minimum of expertise. It was widely used until 1950. but it is still used today, under the right conditions, as an 'on-demand repair'.

12.2. INDUSTRY 2.0

Mass production, assembly line production and electricity are the words that best describe this era and explain the changes that have taken place since the previous period. The explosion in the size and complexity of production lines has brought with it the emergence of a new element of maintenance costs, and their growing importance. This has been recorded as a lost profit or a loss of output. If a single piece of high-priority equipment, or one of its components, failed, the whole line became inoperable, unable to generate a profit. The 'operate until failure' method, which was generally used in the beginning, could not have a positive impact on this form of loss and the introduction of a strategy to prevent failures became desirable.

The solution was a planned preventive maintenance regime, with all its advantages and disadvantages. It has undoubtedly reduced downtime losses due to unexpected failures, made maintenance activities more predictable, reduced the workload of maintenance staff, planned outages and the use of spare parts and repair material. A clear disadvantage, however, is the unnecessary replacement of parts that sometimes still have a considerable wear reserve.

In the meantime, there have been significant qualitative and quantitative changes in certain sectors of the economy, and even the emergence of entirely new sectors. The aeronautical industry had undergone a huge expansion during the Second World War and this expansion continued after the end of the war, but now concentrated on civilian freight and passenger transport. The problem was that

the lack of any meaningful impact on improving aviation safety and reducing the increasing number of air accidents by any form of modification to the exclusively used Planned Preventive Maintenance. The number of accidents and the amount spent on maintenance have been steadily increasing. In order to remedy this unsustainable situation, working groups set up by the Aircraft Manufacturers Association have used failure analysis methods to investigate all possible failure modes of all components of a given type and to develop inspection and control methods to detect failure at an early stage. The strategy developed in this way became commonly known as Reliability Centred Maintenance. The process has subsequently gained widespread acceptance in all in areas where the expectation is that the equipment or component will perform its function without failure over a given period of time under certain conditions.

Another challenge of the era for maintenance specialists was the explosion in the number of nuclear plants and nuclear installations. In these cases, the failure of certain components, even very simple ones, could have unforeseeable and serious consequences. In this case, too, it is inevitable that the failure mechanism of each component should be accurately assessed and, on the basis of this knowledge, a risk priority number, the risk matrix, should be determined, which will form the basis for the development of a necessary and sufficient maintenance regime for the component in question.

12.3. INDUSTRY 3.0

Although there is no doubt that the Industry 4.0 sector is increasingly present in today's economy, there is no doubt that the majority of the economy is characterised by the characteristics of Industry 3.0. One of the characteristics of maintenance strategies is that they do not become obsolete and can coexist harmoniously according to the needs of the time. Also due to the unprecedented scale of economic entities, the exclusive use of a single strategy would not be appropriate, and their combined use, the so-called maintenance mix, has become accepted. The specificity and novelty of the period is the widespread use of technical diagnostic tools and methods. In addition to sensory diagnostics and analogue and then digital instruments for measuring and displaying basic technical condition characteristics and parameters, various types of thermo-visual, acoustic and acoustic instruments were increasingly used and were available at affordable prices,

vibration and shock pulse instruments. The rapid proliferation of these instruments has been greatly facilitated by the fact that manufacturers are increasingly equipping their instruments with standardised connection points to allow the connection of these instruments. Although it stands out from the previous list in terms of the way it is used and the results that can be obtained, used oil diagnostics, which, like blood tests in human and veterinary medicine, provide detailed information on the state of the equipment as a whole, provided that the tests are performed in a sequential trend and the operating conditions of the machine are known. Following the emergence of PLC and IT in manufacturing and operation, which were previously mentioned as the hallmark of the era, these technologies have now also been introduced in maintenance, enabling online diagnostics to be used, which represents a major advance in areas where a constant human presence and therefore monitoring of the evolution of technical parameters is not feasible or undesirable (wind turbine).

12.4. INDUSTRY 4.0

New or innovative technologies in the field of production and operation must inevitably be part of the maintenance toolbox [6]. In the case of Industry 4.0, this has reached such an extent that a new concept has been born for the maintenance of the tools of economic organisations that embrace the principles and technology of the latest industrial revolution, "Maintenance 4.0". The minimisation of human labour, as a key cost factor in economic activity, and of human beings as the weakest link in the economic process chain, started with automation in Industry 3.0 and continues today with real-time access to large databases, optimisation algorithms, artificial intelligence and robotics. The maintenance of a system built in this way requires a maintenance system at the component level. Accordingly, each part of the device or equipment that provides the relevant technical parameters is equipped with the appropriate diagnostic sensors and transmitters, and the data is transmitted via the communication channels used in the basic operation to the sensor-intervention expert system, which, on the one hand, by means of its self-learning capability and, on the other hand, by means of its knowledge of the entire history of the device, makes a recommendation or decision for the appropriate correction of the deviation.

Maintenance costs

An analysis of the costs of maintenance has already shown that, depending on the installation, around 60% of maintenance and repair expenditure is due to damage and loss caused by frequent faults. In other words, an analysis of the "life history" of the equipment shows that a considerable proportion of breakdowns are not caused by wear and tear, but by a large number of faults in the manufacture and installation of the equipment.

The industrial research institutes involved in these studies are looking for a new maintenance strategy to replace the current systems, the aim being to identify and eliminate probable faults. This strategy is justified by the fact that, at present, the costs of maintenance can hardly be reduced, while the theoretical possibility of eliminating malfunctions is almost non-existent.

Few companies have yet realised that the time and costs involved in preventing faults are much lower than those involved in actually repairing the faults that occur. Most companies' machine shops are characterised by the fact that they consider it far more important than maintenance considerations not to exceed the (often tight) budgeted procurement margins. Little attention is therefore paid to the operating costs of equipment selected at the cost of trade-offs.

In addition to the financial constraints, investors are also forced to race against time. Often the decision making and pre-decision processes are lengthy, and they try to compensate for this by shortening the time to commissioning. There is not enough time to identify the faults and weaknesses of the new equipment, which can multiply the subsequent maintenance costs. In order to reduce maintenance, the following three requirements for new installations should be observed:

- before putting new machinery or equipment into service, any faults identified should be rectified,

- as many "teething problems" as possible should be identified and eliminated by a careful commissioning procedure,

- identify any remaining defects and faults within the warranty period (3-6 months).

Surveys have found that the established maintenance organisations are not yet functioning as organisations responsible for fault prevention. Another obstacle to the introduction of the concept is that the costs of maintenance are not well measured in many places, and any analyses carried out often lead to erroneous conclusions.

The actual maintenance costs include, among others: technical inspection, care and maintenance, refurbishment, repair of worn and worn parts. However, there are some typical errors in the definition of these costs and in their separation:

- the additional costs caused by the faults and weaknesses of the machinery are not correctly separated from the actual maintenance costs,

- these costs - caused by the failure points - are only possibly recorded,

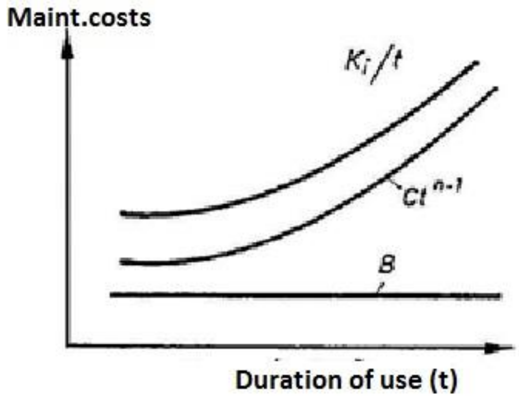
- the precise identification of the maintenance costs incurred is often not carried out (broken down by machine, by failure),

- variable and fixed cost elements are often identified together.

The analysts also suggested that maintenance orders should be highlighted as those requiring repairs or troubleshooting due to known weaknesses in the equipment. This new approach does not require additional numbers or greater expenditure for the majority of companies.

It is an established organisational principle that the head of maintenance must monitor the weaknesses of both existing and new equipment.

Maintenance costs are thus composed of a constant and a fraction depending on the usefulness of the equipment.



$K_i = Bt + Ct^n$

where K_i is the maintenance cost;

Bt is the expenditure proportional to the useful life, e.g. on prevention (maintenance, overhaul, etc.);

Ct^n is the expenditure increasing with the life of the asset, mainly for repairs;

t is the time of use of the working equipment;

n is an exponential exponent which depends on damage behaviour and maintenance.

This amount can then be related to the availability of the equipment monitored or to the quality of the service provided or product manufactured.

The situation is somewhat more complicated when it comes to assessing the sustainability of maintenance, or rather of individual maintenance activities. In a first approach, it seems appropriate to the cost of materials and energy for maintenance, as both the reduction in materials and energy use points towards sustainability, but it does not tell us the proportion of environmentally friendly lubricants and additives, renewable energy, etc.

In order to get a clearer picture, it seems appropriate to examine the sustainability aspects of some elements of maintenance as a generic term:

13. SUSTAINABILITY ASSESSMENT OF THE ELEMENTS OF MAINTENANCE:

13.1 CARE

Practical experience has shown that this group of maintenance elements represents only 10% of maintenance costs, but its impact on the technical condition and lifetime of the equipment is far greater.

13.2 CLEANING: this is extremely important to ensure that even the smallest leakage or damage is immediately visible, thus preventing more serious breakdowns. The energy requirements of the operation are virtually zero, while a number of highly effective biodegradable cleaning agents are commercially available, so their adverse environmental impact can be minimised.

13.3 LUBRICATION: This is certainly one of the most important maintenance activities. Until the mid-1970s, roughly until the full impact of the oil crisis, the amount of lubricants used was used as a measure of a country's industrial development. This was changed by both a sharp rise in oil prices and a greater emphasis on environmental protection. As not only the market price of lubricants but also their professional disposal and destruction cost considerable sums, the earlier tens and sometimes hundreds of litres of lubricating oil baths were replaced by centralised lubrication systems, which delivered the much smaller quantities of lubricating oil in the form of droplets or compressed air spray to the lubrication points. For grease lubrication, the more economical central lubrication system is also being used, and sealed bearings with lifetime lubrication are becoming more common, reducing the need for continuous refilling and grease consumption. So the technical solutions are already there to make lubrication more sustainable, but the right choice of lubricant and lubrication method can still offer a wealth of opportunities. The use of synthetic lubricating oils may be justified in some cases, but they are of vegetable origin or petroleum derivatives, their environmental impact varies.

13.4. MONITORING, INSPECTION

These elements of maintenance are essential for their safe and proper use. Some of the inspections are of an official nature, such as periodic technical inspections of motor vehicles, annual contact hazard checks of mains-powered small electrical appliances, or annual inspections of lifting machinery. As can be seen from the list, the legislator has provided for mandatory inspections for equipment classified as "dangerous plant" and the equipment can only be used after a successful inspection. The prescribed condition or suitability for the intended use is checked, for example, during the periodic precision inspection of machine tools. The result of this test will determine the tolerances to which the machine tool can be expected to be capable of achieving. Inspection and testing procedures generally involve a minimum use of materials, with maintenance implications only in terms of the energy consumption of testing equipment and infrastructure, which can only be reduced by reducing the frequency of inspections and therefore requires careful consideration.

13.5. RESTORATION, REPAIR

In common parlance, repair and maintenance are used almost synonymously. This is an obvious exaggeration, but there is no doubt that repair is the most visible part of maintenance. There are basically two ways in which this type of procedure is used

- In the event of an unexpected failure, the primary objective is to restore the equipment to the specified condition as soon as possible and to ensure that it is in working order. In this case, sustainability considerations usually take a back seat, and the fault must be repaired using the tools and materials available at the time.

- The situation is quite different in the case of a fault discovered during a planned maintenance operation, where we can consider and determine the optimal repair method, taking into account both technical, economic and sustainability aspects.

We can have a much wider scope to enforce sustainability in an environment approaching the operating conditions of a circular economy or Industry 4.0. In this case, the issue of repairability and installability is already taken into account in the design of the construction,

in particular the easy accessibility and recyclability of components (seals, bearings) that wear quickly and need to be replaced several times during the lifetime of the device.

Smaller value assets often end up in landfills because of the unrealistically high cost of spare parts and/or specialist service charges. For manufacturers, it is the distribution of the complete product that generates the higher profits and branded service centres operate accordingly. Given these facts, it is clear that making the right to repair universal would be a huge step towards sustainable production and maintenance.

13.6. REPLACEMENTS: the best way to restore the functionality of a device as soon as possible is often to replace the faulty part. In addition to the technical and economic sustainability considerations just mentioned, there is another important condition to be met: the necessary replacement parts must be available. The maintenance of any warehouse entails the commitment of financial resources, logistical tasks and the provision of staff and infrastructure. In view of all this, it is understandable that every business organisation strives for a minimum stock level until the introduction of the Just in Time system. This is no different for spare parts warehouses. Fortunately, it is possible, based on long experience, to define a minimum stock level for each type of spare part, below which the number of spare parts should not fall. This can be easily done by activating the monitoring function of the stock control software.

Further stock reduction can be achieved by building up a fleet of machines belonging to the same product families, as manufacturers also strive to have interchangeability of parts with the same function in a modular system in their different devices.

13.7. REFURBISHMENT: a procedure used in the event of failure of valuable components of higher value equipment, typically in the following cases:

- Replacement part not available within the expected time.

- A replacement part is available, but its procurement should be considered for economic reasons

- The technology required for the refurbishment is available and the quality of the part is superior to the original.

The parts to be refurbished are of higher value because of their material, composition or special design, so that their refurbishment using economical technology is clearly a sustainable maintenance activity.

14. FAILURE ANALYSIS PROCEDURES TO SUPPORT SUSTAINABLE MAINTENANCE

Failure analysis is an attempt to determine the cost, consequences and, above all, the root cause of a failure with the aim of preventing it from occurring again. A thorough, reliable failure analysis is the result of a lengthy process involving several disciplines, so it is advisable to concentrate on the most significant failures. A Pareto chart can be of great help in determining the order of analysis.

14.1 PARETO ANALYSIS

A method for analysing problems. The analysis is based on the 80/20 rule, which states that 80% of problems are caused by 20% of the root causes. So it makes sense to prioritise the causes and deal with the relevant 20% first. This principle can be observed in many areas of life, for example: 80% of the time needed to do a job is 20% of the time needed to do it. In the case of breakdowns, this means that 20% of the parts cause 80% of the breakdowns, so it is advisable to deal with them first.

14.2. FMEA

Failure Mode and Effects Analysis (FMEA) is an increasingly common failure analysis method that provides quantifiable results. The advantage of FMEA is that it can significantly reduce the number of failures. It is commonly used in product design and process design. In particular, it can be used when investigating the impact of material, component and equipment failures on the next higher functional level of the system and the failure mechanisms at that level.

Product FMEA aims at eliminating expected failures at the beginning of the design phase, such as inappropriate material selection, incorrect geometry, wrong dimensional specifications. The results of experiments and material tests are taken into account. The mode of failure, its impact and the probability of detection in time are indicated by numbers from 1 to 10. The product of these numbers is the "risk priority number". It is agreed that intervention, i.e. risk reduction, may be necessary if this value exceeds 100. Thus, no mass production of the product should be undertaken until the construction risk priority number has been reduced below 100.

The aim of the process FMEA is to reduce the potential risk of the technological process. The failure mode may be inadequate assembly or high variability (variance) of the process. Similar to product FMEA, three factors need to be classified by estimation. Previous manufacturing experience can be of great help here. To carry out the FMEA, a team of experts should be established with a high level of experience in design, manufacturing, maintenance and quality. Potential defects should be considered on the basis of a well-established list of defect types.

The combined application of these two methods can thus significantly reduce the number of potential failures and prepare for the repair of those that cannot be avoided, i.e. those that are due to natural wear and tear, by introducing materials and technologies that are considered sustainable.

References

1 Magdolna Csath: Sustainability as human and social development, ACTA HUMANA 2020/1

2 https://qubit.hu/2022/04/22/jon-az-europai-green-deal-ami-2030-ig-kivaltana-az-osszes-oroszorszagbol-importalt-foldgazt (2020.07.18)

3 (https://circularpoint.com/mi-is-ez-a-korforgasos-gazdasag) (2020.07.18)

4 https://greenfo.hu/hir/a-romai-klub-elso-jelentese/ (2020.07.18)

5 János Szendrei, Gábor Grasseli, Dóra Nagyné demeter, László Szegedi, Edit Szűcs Innovative diagnostic methods for sustainable management of green technologies, Journal of Central European Green Innovation 3 (2015).

6 Malgorzata Jasiulewicz, Kaczmarek, Arkadiusz Gola: Maintenance 4.0 Technologies for Sustainable Manufacturing, Science Direct PapersOnline 52-10 (2019).

7 https://www.ipar4.hu/page/ipari-forradalmak-ipar-4-0 (2020.07.18)

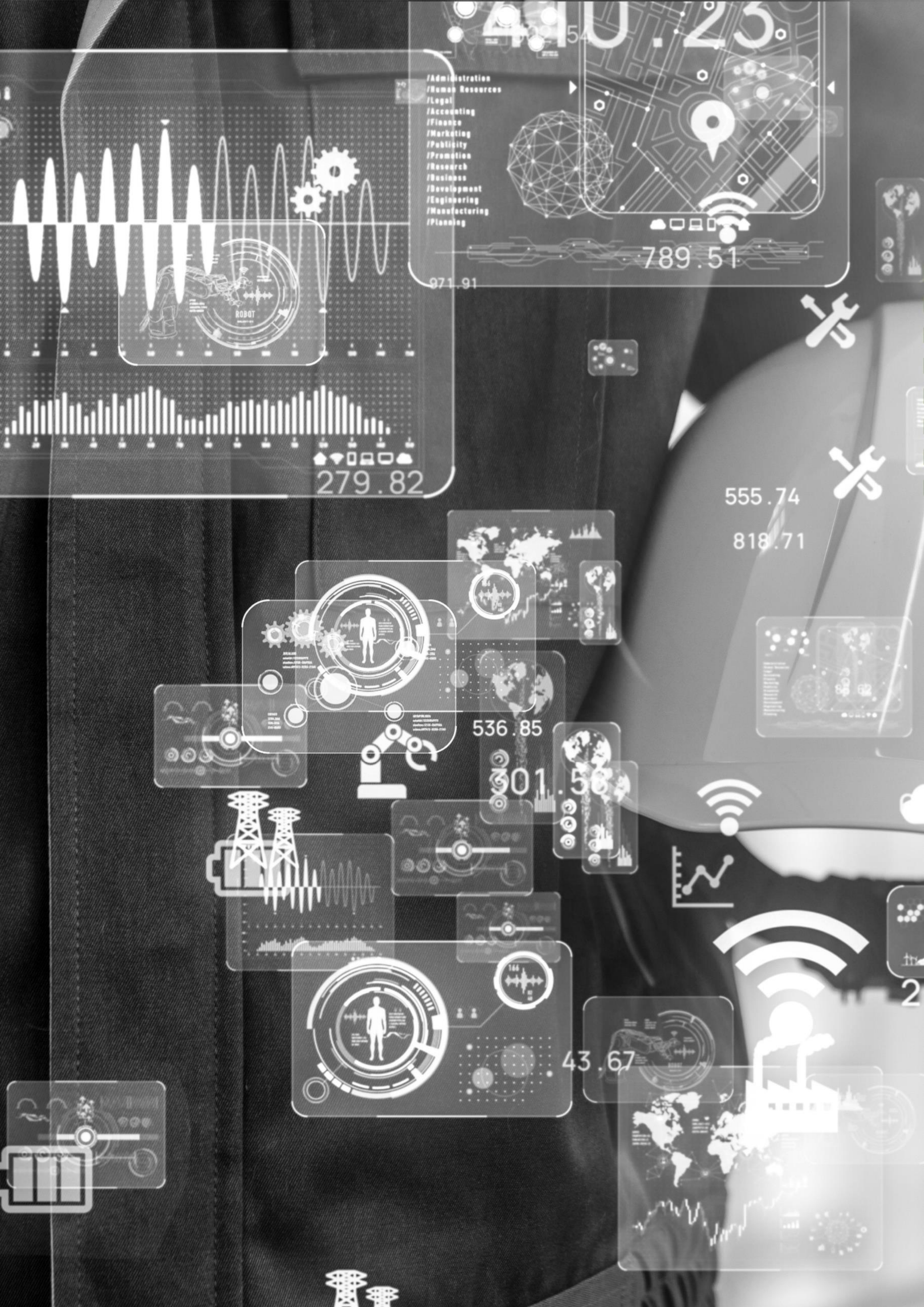
8 Chiara Franciosi, Alfredo Lambiase, Salvatore Miranda: Sustainable Maintenance: a Periodic Preventive Model with Sustainable spare Parts Management, ScienceDirect PapersOnline 50-1

Module_5

Maintenance Management

Géza CS. NAGY

Sustainable engineering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