APPLICATION NOTE
PURCHASE AND DESIGN DECISIONS

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SUMMARY

Many decisions have to be made during the design or before the purchase of assets. Some organizations look only at the basic functions and the initial investment when they install new assets. This is short term thinking that is ultimately very costly. Many assets and products are either intended to be used many years or simply wind up that way. The financial impact of these decisions can easily be—and quite often is—a hundred times or more larger than the original investment. Moreover, safety and the environment are strongly influenced by the decisions that are made during the engineering stage. To properly balance the importance of all these aspects against each other, the involvement of all stakeholders in the design or acquisition of the new asset is necessary.

This Application Note discusses a practical approach to achieve this involvement. This methodology is called Early Equipment Management (EEM) and was originally was developed by the Japanese automotive industry. The intent was to reduce the total costs of production of cars and components and to assure a start-up without problems related to new equipment.

One of the most important ideas of the underlying philosophy of EEM is that all knowledge within the organization for working with similar assets should be incorporated into the design of a new asset.

Two important points, among others, are that: 1) all information about the new design should be transferred to the people who work with the asset before putting it into place and 2) operators and technicians must be trained well in advance. A key characteristic of EEM is that it puts significant emphasis on comprehensive prior testing procedures and consideration of the actual use to which the asset is to be put rather than just theory. EEM is a concrete approach that describes what an organization should do during each step of the design, construction and or acquisition stages to ensure the organization ends up with an asset that performs optimally throughout its entire life.

This Application Note goes deeper into four subjects that need to be considered during the design process:

1. Financial costs
2. Reliability
3. Energy consumption
4. Environmental impact

For financial costs, methodologies will be discussed to calculate the Net Present Value (NPV) of investment decisions.

A number of approaches are discussed regarding assessment of information dealing with the type and frequency of failures that could occur with a certain design.

The consumption of energy is influenced by three factors:

1. The energy-efficiency of the individual components
2. The energy-efficiency of the system as a whole
3. The efficient use of the system

The chapter on energy discusses a number of standards and learning points to help arrive at an energy efficient system.

The environmental impact of a design is a complex matter. It can be comprehensively analyzed by a Life-Cycle Assessment (LCA). This takes into consideration all relevant flows of matter and energy, from its source in nature until it is back again in nature.

TERMS AND DEFINITIONS

There are a great number of definitions used for all maintenance and related subjects topics in standards and the literature. The terms and definition in this chapter are primarily based on ISO13306 (2010): Maintenance Terminology (ISO13306:2010, 2010), ISO55000 (2014): Asset Management (ISO55000:2014, 2014)and ISO14040 (2006): environmental management—Life Cycle Assessment—Principles and Framework (ISO14040:2006, 2006).

Asset

An asset is any item, thing or entity that has potential or actual value to an organization (ISO55000). Per ISO 13306, it is a formally accountable item.

Asset life

This is the period from asset creation to asset end-of-life.

Asset register

An asset register should list all assets and include all relevant technical and financial data.

Asset system

This is defined as a set of assets that interact or are interrelated. (ISO55000)

Cradle-to-Cradle

This framework seeks to create production techniques that are not just efficient but are as waste-free as it is possible to make them.

Capital expenditure (CAPEX)

CAPEX is defined as the funds used by a company to acquire or upgrade physical assets (investment).

Energy efficiency index (EEI)

The EEI is a measure of the energy efficiency of electrical devices. It indicates the percentage of input energy that is transferred into useful output energy.

Failure

Asset failure is reached when an item can no longer perform a required function. (ISO 13306)

Rate of occurrence of failures

This is the number of failures of an item in a given period or interval divided by the time interval.

Failure mode

Failure mode is the method by which the inability of an item to perform a required function is established. Note: This term was officially replaced by Fault Mode in ISO13306. Nevertheless, it is still widely used.

Fault Mode

Fault mode is the method by which the inability of an item to perform a required function is established. See also Failure Mode immediately above.

Failure Mode and Effect Analysis (FMEA)

This is a systematic technique to analyze all potential failures of a system or process, as well as their causes, effects and consequences.

Hazards and Operability Analysis (HAZOP)

HAZOP is a systematic technique to analyze all potential hazards of an asset system. It is primarily used in the analysis of processes.

Life cycle cost (LCC)

LCC includes all of the costs generated during the life cycle of the item.

Life cycle assessment (LCA)

LCA is the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

Life cycle impact assessment (LCIA)

This is the phase of the life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system throughout its life cycle.

Mean Time to Repair (MTTR)

MTTR is the total repair time of all failures of an asset system during a certain period, divided by the number of failures over this period.

Net Present Value (NPV)

Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows.

Maintenance

Maintenance is the combination of all technical, administrative and managerial actions during the life cycle of an item that are intended to retain it in or restore it to a state in which it can perform the required function.

Operational Expenditure (OPEX)

OPEX is the ongoing cost for running a product, business or system.

Organization

This term includes any type of organization, ranging from a single person to a multinational corporation or a government or non-governmental institution. In this Application Note we use this term for any organization that wishes to implement the standards. (ISO55000)

Process and Instrumentation Diagram (P&ID)

This is a diagram which shows the interconnection of process equipment and the instrumentation used to control the process.

Preventive Maintenance

This includes all maintenance carried out at predetermined intervals or according to prescribed criteria. Such maintenance is intended to reduce the probability of failure or a material degradation in the functioning of an item. (ISO13306)

Reliability

This is the term for the ability of an item to perform a required function under given conditions for a given time interval.

Reliability Centered Maintenance (RCM)

RCM is a method to identify and select failure management policies to efficiently and effectively achieve the required safety, availability and economy of operation.

Total Cost of Ownership (TCO)

This item includes all financial costs and benefits over the life cycle of an asset.

INTRODUCTION

The design and construction quality of a technical system is of the utmost importance for its functioning throughout its entire lifespan. This being the case, why is it that so many assets are built and bought that are of such inferior quality that they will cost much more over their entire life span than assets of higher quality? The latter may require a higher initial investment, but this will—with very few exceptions—pay itself back many times over during the life of the asset. Engineers and their management are too often satisfied if a project merely manages to be finished on time and within budget with a result that at least initially performs the basic function that was required.

To install an asset with enough attention for minimal life cycle costs, it is necessary to analyze the financial and other impact of different alternatives over the entire life span. Often it does not necessarily take more investment in money, only a reasonable investment in time to achieve higher quality assets.

There are many methods to analyze aspects such asset costs, reliability, energy efficiency and ecological impact of assets during their entire life time. This Application Note describes an integrated approach to the designing, building and implementation of a new asset; namely Early Equipment Management (EEM). It was first developed by the Japanese automotive industry. The automotive companies realized that a large percentage of their production losses involved new equipment. The initial period after such equipment had been put into use, often saw a high number of breakdowns and other problems. It was often only after a significant period of time before these problems were solved and the equipment was running without major problems. They also realized that 90% of the operational costs of equipment were determined by the design of the equipment.

EEM focusses on combining the input and knowledge of all relevant departments in an organization to build the best asset possible. In many organizations only the Engineering Department is involved in the design of equipment. EEM emphasizes the important of input from departments such as Operations, Maintenance and Quality in the design of equipment.

The first question an organization should ask is which assets it really needs and what will be the optimal moment to replace the assets it already has functioning. The most effective way to save costs on an asset may be not to procure the asset in the first place. Depending on the type of organization, this analysis may be carried out months or even a few years in advance or over a much longer period such as twenty years. Such long terms are often necessary for very large infrastructure networks. This topic is discussed in another Application Note: Replacement Decisions.

Next, when a decision has been made to install a certain asset system, the correct assets must be designed or bought to achieve the optimal life cycle costs. With ***costs,*** we do not only mean financial costs, but also impact on the environment, loss of customer satisfaction, frustration because of malfunctioning equipment and all other negative impacts of the assets.

This Application Note also describes different types of such impacts, each of which requires its own type of analysis:

1. Financial costs
2. Reliability
3. Energy consumption
4. Environmental impact

The initial investment occurs at the moment the assets are installed, but the savings of a higher investment may come years later. Because of inflation, a Net Present Value (NPV) calculation is necessary to make an informed comparison between alternatives.

CONTEXT: WHY DOES IT MATTER?

The ecological impact of a system, the quality of its products, its energy efficiency and the reliability it can achieve are mainly determined by the design and construction quality. The design of an asset—more than anything else—goes a long way towards determining the costs over the entire life cycle of an asset.

A focus on the investment price tag instead of the life cycle costs is simply a case of "penny wise, pound foolish".

Maintenance and operations can only keep reliability as high and energy consumption as low as optimally determined by the design. In other words: "You can make a system function only as well as it was designed. You can't make it function better without alterations."

In many companies, the highest operational cost is that of raw materials. In process industries, number two is energy and in manufacturing industries number two is personnel costs. Maintenance ranks number three in both types of industry. It is obvious that the design of an asset system will have a major impact on all these costs.

The price of an electrical motor, for example, is only 0.1% to 0.2% of the energy cost of this motor over a life time of 100,000 hours. An 11 KW motor with a life of 100,000 hours will use 1,100,000 KWh over its lifetime. This will cost something on the order of € 250,000. The motor itself costs € 500, which is 0.2% of the total cost. A 110 KW motor uses ten times more energy, but costs only five times more in purchase price.

Roughly 25,000,000 electrical motors are sold every year in the European Union.

Implementing better systems worldwide, would lead to an estimated energy saving by 2030 of 322 TWh, saving about 206 Mt of CO_2 emissions (Waide & Brunner).

On the level of the individual company, possible savings on maintenance costs have been shown to be on the order of 20%.The costs of maintenance of assets in the European Union is roughly 800 billion Euros per year. It is difficult to get exact figures and it depends on what types of maintenance is taken into account, but it is clear that any saving on this amount will have a major impact on the economy.

STRATEGIC APPROACH TO PURCHASING DECISIONS

The only way organizations can optimize their life cycle costs is by making a thorough analysis of all impacts of decisions during the design stage of an asset. Often engineers do not have enough time or expertise for this. They are far too often put under pressure to deliver their project on time and within budget as well as being overloaded with projects.

The only way to assure that the necessary analyses are made is to make them mandatory by company policies. Senior management must be aware of the impact of purchase and design decisions and demand thorough analyses before authorizing any major purchase. For the installation of smaller projects, a less formal approach can be used, without getting into conflict with the basic principles of EEM. In practice, a short discussion with employees from Operations or Maintenance departments can often suffice in these cases.

In many organizations, senior management tends to challenge every project budget estimate that is made by its Engineering department. So if the engineers estimate that an investment of one million Euros is necessary for a project, management tells them—perhaps out of habit—that they must build the system for € 900,000. Companies often cut expenses by:

- Buying lower quality components that are less reliable and consume more energy
- Buying non-standard components, which means the organization in a later stage needs to procure more spare parts and employees are unfamiliar with the replacement components
- Leaving out automated systems and transport systems, which leads to extra work for operators
- Leaving out redundancy, so the system has to operate without backup systems
- Saving money by cutting back on training, analysis tools, manuals, et cetera

The result is a system that will in principle perform its basic functions, but will cost a lot more in energy, maintenance and operational costs during its life time.

The entire organization must have a sharp focus on Life Cycle Costing (LCC) and the Cradle-to-Cradle (C2C) principle.

LCC is a methodology that calculates the total costs of an asset system over its life time and calculates it back to present day value. It is a methodology that is mainly focused on the Euro. Cradle-to-Cradle (McDonough & Braungart, 2002) is a philosophy that strives to achieve the full recycling of all materials. So instead of designing assets in such a way that they can be discarded at the end of their useful life with little or no harm to the environment, Cradle-to-Cradle wants to design assets in such a way that all their materials can be reused. In conventional design, products that are made from recycled materials are of lower quality than in their first use. C2C wants to design in such a way that recycled products are of the same or even higher quality than their originals.

CONCRETE APPROACH

In classical project management, engineers are strongly focused on building an asset that performs just its basic function, on time and within budget. Engineers, unless told otherwise, tend to focus on the technical demands of the asset. However, such demands are not written with consultation of all the stakeholders. The result is a rather narrow approach that leads to sub-optimization. The problem with this approach is that it will lead to assets that do exactly what is described in a certain specification, but this doesn't mean that costs and trouble are minimized at the level of the entire plant. In other words, the specification describes only a function such as: the machine must produce 10,000 cookies per hour, but says nothing about e.g., the maintainability, energy efficiency or how easily the machine can be operated.

This problem has been recognized by many people for as long as assets have been constructed. Through the years, many methodologies have been developed to overcome this problem. They include:

- Holistic design
- Integrated design
- Systems engineering
- RAMS (Reliability, Availability, Maintainability and Safety analysis)
- Early Equipment Management

All of these approaches to design have a number of things in common. First of all they focus not only on the building of the asset, but on its entire life span. Secondly, they do not focus primary on the function of the asset, but include all relevant demands, such as energy consumption, noise production or user friendliness. Thirdly, they take into account the function of the asset within the system of which it is only a part. For example lowering the temperature of liquid stored raw materials may lead to savings in energy costs for the storage tanks on the tank park of a company. The company should however consider the total cost of energy. How much more energy is needed to pump the colder, more viscous, raw materials and to heat them up later in the process?

This Application Note briefly describes the first four approaches to engineering. The fifth, Early Equipment Management, will be discussed in more detail. It is a concrete step-by-step approach of project management that demonstrates clearly how projects can be engineered and executed taking into consideration all relevant interests over the entire life cycle of the system.

Holistic design

Holistic design is a design methodology which emphasizes the role of the asset in a larger system. Holistic design is used not only for mechanical and electrical assets, but also for buildings or work places for organizations. Holistic design also pays great attention to the impact of the design on the environment.

Integrated design

Integrated design is a methodology that considers the concept, design, building, implementation installation, use, maintenance and reuse of products, services and processes.

Systems engineering

Systems engineering is an engineering approach that was developed to manage complex projects over the life cycle of assets. Several topics are part of systems engineering, including reliability, logistics, testing, maintainability, et cetera. Systems engineering also describes methodologies that can be applied for performing risk analysis, managing teams, reporting, et cetera.

RAMS

RAMS stands for Reliability, Availability, Maintainability and Safety. It is a project approach that was developed for complex projects. As the name suggests, RAMS focuses on mitigating many different kinds of risks. It uses a wide array of analytical methods for optimizing a design in order to minimize all kinds of risks and improve maintainability.

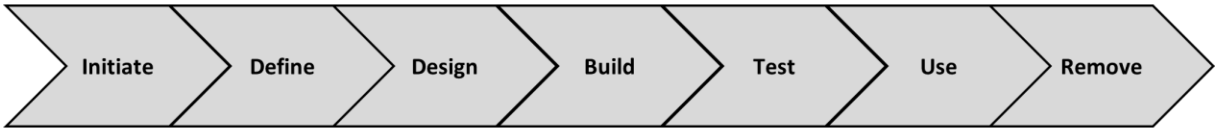
Early Equipment Management

As noted earlier, Early Equipment Management (EEM) originated in Japanese automobile production, where it is was part of Total Productive Maintenance (TPM). EEM has a structure of communication and reviewing each step in a design process with all involved stakeholders. EEM is sometimes described as: “making sure that all past experience of the shop floor is taken into account in the new design and that all knowhow of the project team is brought back to the shop floor”. EEM will be further discussed in the next paragraph.

Phasing of projects

One thing all design methods mentioned in the previous paragraph have in common is that they introduce deliberate steps to analyze and improve the design in each phase of a project.

A classical project management structure usually looks something like this:



During the initiation phase, a decision is made as to whether project should be started. This should be done by a business case based on a rough estimate of the costs and benefits of the project. In the definition phase a specification is written of the assets and asset systems that should be delivered at the end of the project. These specifications are often made by engineers that mainly focus on technical and productivity demands, such as the size and capacity of a system. Next a design is made that should be able to meet the demands in the specification. Then the system is built, tested, commissioned and put into production.

In principle this classical project management approach can be quite effective, provided it is executed as it should be. This means:

1. Each following step can only start after the previous step is finished. So a design stage should not start as long as the specifications are not clear and the building stage should not start while the design is not finished
2. The input and approval of all stakeholders should be requested in each step

In the real world these two demands are often forgotten and projects run over time and budget, because of all the changes that have to be made to get a working system. The only way to make sure that both demands are met is to describe them in a formal project management methodology and to structure them in a more concrete way. In principle this is what the methodologies described in the previous paragraph do. The next paragraph goes deeper into one of them: Early Equipment Management.

Early Equipment Management

While only a part of Total Productive Maintenance (TPM), EEM nevertheless became an important focus point of TPM. Companies had discovered that much of their production losses occurred in the initial period after a new system had been put into use.

EEM is an integrated approach to project management. It involves many aspects. The most important points of EEM are:

1. A project is a co-operation between all involved departments and employees in an organization. It is not a “one department show” starring the engineering department
2. In a project, a company should try to use all of its knowledge of the existing system, especially on the shop floor, in its new designs
3. All knowledge of the new design should be transferred back to all relevant people in the company

In many classical approaches of project management, an engineering department makes a specification and a design independently, without consulting other departments. It delivers a design and starts to build it. In EEM, the specification is first discussed with all stakeholders. Often a production department adds wishes such as user friendliness of systems or extra quality control measures. Maintenance may have demands such as the use of standard equipment, accessibility of components or clear failure messages on control panels.

An example of this is a production company where the engineering department wanted to replace forty year old compressors with the same type. This would be the easiest course to follow. Before the implementation of EEM in the company, Engineering would have simply installed them. Now, during the review of the design, Production demanded lower energy consumption. A solution was found that reduced the energy use by tens of percent.

EEM works with a step-by-step approach. **Error! Reference source not found.** shows the main outline of the EEM design and implementation process.

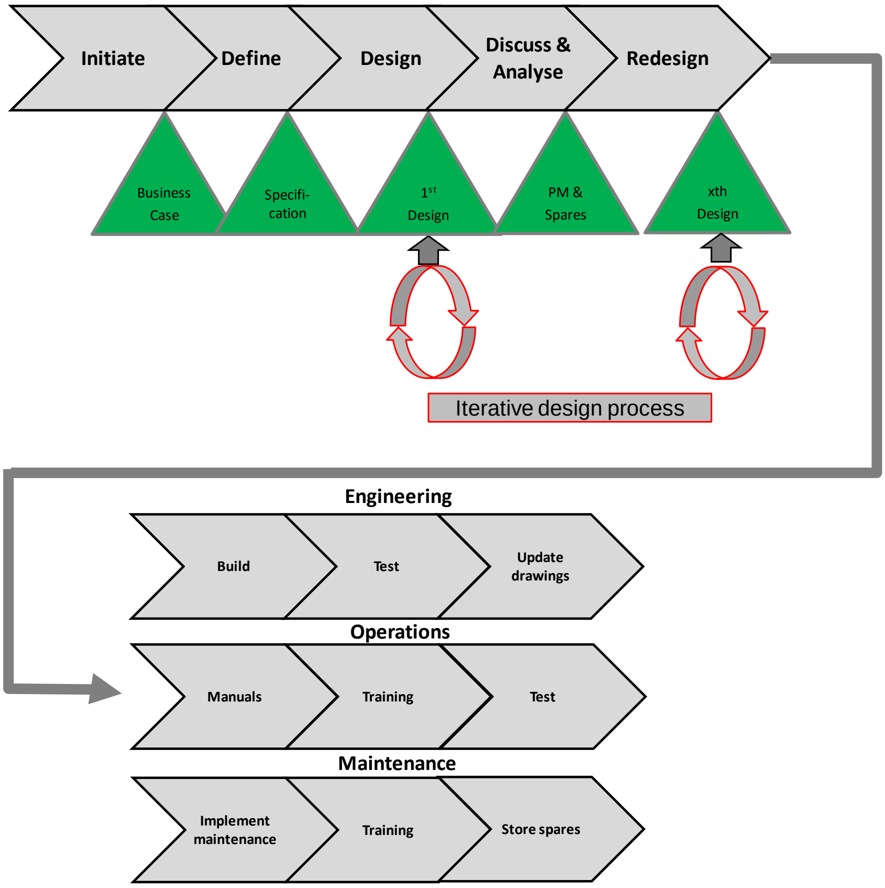


Figure 1

Many aspects have to be taken into consideration when designing or purchasing an asset. One of the first questions is to ask if the organization genuinely needs a new asset. In many cases assets are bought to replace existing assets, because they have reached the end of their useful life. The problem here is to predict when this moment will arrive. This question was discussed previously in the Replacement Decisions Application Note. Other reasons to replace assets that are currently in use or to invest in new assets are:

1. The introduction of new laws and regulations
2. New technical possibilities
3. New demands from the market

Before a decision can be made if new assets should be installed and what kind of assets these should be, the organizational strategy must be clear. It has direct consequences for the asset management strategy. The asset management strategy describes how an organization manages its asset through all stages of their life, from the investment decision right through to the moment they are removed from service.

During the Initiation Stage of the project, a general scope of the project is made. The goals of the project are determined and based on rough estimates of costs and benefits. A feasibility study is made to determine if the project should be executed. In this stage, one or more meetings are held with all involved departments to gather their input on this matter.

In the Definition Stage, a specification is written for the project. In this stage there is a lot of attention paid to the needs of the users (Operators) and maintenance personnel. Depending on the size of the project, this can be accomplished in several ways. In smaller projects it may consist of just a discussion with an operator and a maintenance technician. Larger projects may call for a few maintenance engineers and production engineers to be added to the project team. They will focus on demands such as:

1. User friendliness
2. Standardization
3. Availability of manuals
4. Lay out of the equipment

Also demands will be set for other aspect such as:

- Quality: What product(s) or service(s) should the asset system deliver and with what quality? Is it a big problem if the system delivers products or services that are a little or severely below standard?
- Capacity and speed: What volume of products or services can the system deliver?
- Flexibility: How easily can different products be made with the asset? This is especially important if the organization's strategy is to deliver a range of different products or to be the first to introduce new products on the market.
- Personnel: Number and level of operators required. Energy: an amount of energy needed per day or per product.
- CO2 footprint: How much carbon dioxide, or other greenhouse gas, emissions are produced in the manufacturing and use of the asset?
- Sustainability: What natural resources are used for the production or use of the asset? What is the amount of recyclable materials?
- Social responsibility: Does buying or making this asset have an impact on social issues, such as the relations with the organizations own employees, child labor, working with oppressive regimes, corruption and much more.
- Reliability: What are the chances of failures during the use of the assets?
- Maintenance: What will the costs for preventive maintenance be?
- Maintainability: How easy is it to repair or maintain the asset? What is the maximum downtime that can be permitted for a single breakdown?
- Availability: What percentage of time will the asset be out of use for maintenance, cleaning, change over, breakdowns, et cetera?
- Safety: Are there risks for personal safety involved in using the asset?
- Consumer safety and product safety: Can the asset have a negative impact on the safety of the user of the product that is produced by the asset?
- Security: Can security of the asset be guaranteed? This issue is getting more and more attention from asset owners, because many assets are now connected to the internet and could be vulnerable to cyber-attacks, user mistakes, et cetera.
- Environmental impact: What impact does the asset have on the environment?
- Health and labor circumstances: Does the asset produce noise, smell, vibrations, vapors, et cetera? Does it require heavy lifting?
- Corporate image: What will the general public, employees, neighbors and shareholders think about this purchase?
- Politics: Does this purchase influence relationships with authorities?
- Aesthetics: Does it look good? Does it fit into the environment? Does it have company colors, look and feel?

The list above covers the most common aspects that need to be judged in purchase or design decisions. It is long, but can never be complete. There may be other aspects that need to be taken into consideration for every industry or organization.

The design is discussed in a similar way as the specification. The Engineering Department will start by making a basis design. It will explain this design to all stake holders: how it works, what the consequences are for day-to-day operations and other relevant topics. Usually this is done in a work team with representatives of each department, such as Operations, Maintenance, Quality and Sales. In production facilities, these departments are not only represented by engineers or managers, but also by operators and technicians. They are usually far better informed as to what the actual problems are with the current systems and have hands-on experience regarding the possibilities to improve. In larger projects, production and maintenance employees are sometimes dedicated full time to a project in its design stage.

Many changes are usually made during the reviews of a design. This is the reason why only a basic design is made at first. Details are filled in later. An example is a chemical company where the engineering department had designed a system where operators had to transport 200 kg batches manually in mobile containers. After discussion it was decided to install fixed piping for the transport of the product.

One of the main goals of EEM is to get the support and cooperation of all employees in the realization of the project. A practical example of how to achieve this is to invite production and maintenance employees to accompany engineers on visits to suppliers. This way the new systems feel like their own design, not like something somebody else forced upon them. The psychological impact of this has proven to be quite remarkable. In companies where operators and technicians are not involved in the design, solving start-up problems takes a lot of time. If there is a problem, operators might say: “Hey, I don’t know this system. It is not my problem. Call somebody to fix it.” In companies that have involved their operators, they will roll up their sleeves and say: “Let’s see what the problem is.”

The reliability and maintenance needs of the system are also analyzed in the design stage by formal methods such as RCM, HAZOP or FMEA. Many of these methodologies involve teams of stakeholders from all departments.

After the design is finalized, all involved departments keep working on the project:

- The Operations department writes procedures and manuals. Operators are trained and a test protocol is written.
- Engineering is involved in testing and makes all documentation as built
- Maintenance sets up a preventive maintenance schedule, signs maintenance contracts, writes working instructions and trains its employees. It also buys spare parts and makes sure they are available during start up.

In the EEM philosophy, a project is not finished until the asset is running smoothly. This means it puts a lot of focus on the development of a good start up plan, enough time for testing, and support by all departments during the first period of use.

The next paragraphs describe four of the aspects mentioned above in more detail:

1. Financial costs over the life cycle of the asset
2. Energy consumption
3. Reliability and costs of breakdowns
4. Environmental impact

Financial cost and reliability are important considerations in every investment. Reducing the energy consumption and the environmental impact are core goals of Leonardo ENERGY, the Global Community for Sustainable Energy Professionals.

LIFE CYCLE COSTS

In the procurement of an asset, the costs over its entire life time are a crucial decision factor; even more so than the initial investment cost. Both the Life Cycle Costs (LCC) and the Total Cost of Ownership (TCO) are important. There are different definitions for LCC and TCO in different literature. This Application Note uses the following definitions:

- Life Cycle Costs (LCC) are all costs necessary to keep the asset operational during its entire life cycle. It includes the CAPEX of the investment and the OPEX over its life span.
- Total Cost of Ownership (TCO) involves all costs and benefits related to an asset

So for a typical machine, LCC will involve the investment, operational costs, energy costs, et cetera. TCO involves all these costs but also takes the amount of products produced and their sales price into account. Take for instance, a stretch of motorway. The LCC does not include the economic losses due to traffic jams; the TCO does include these losses.

We will explain the method of comparison of alternative assets by explaining the LCC of an asset. Other costs and benefits involved can be dealt with in a similar manner.

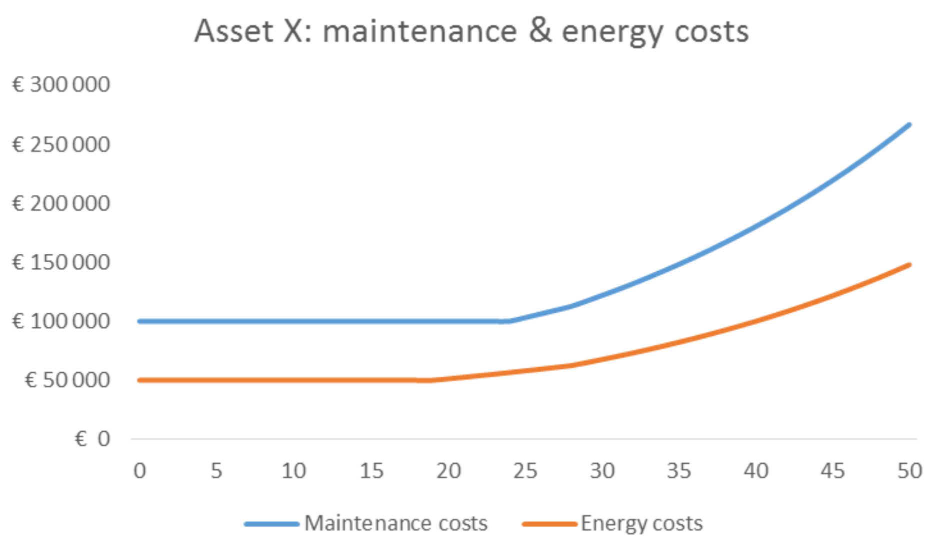


Figure 3

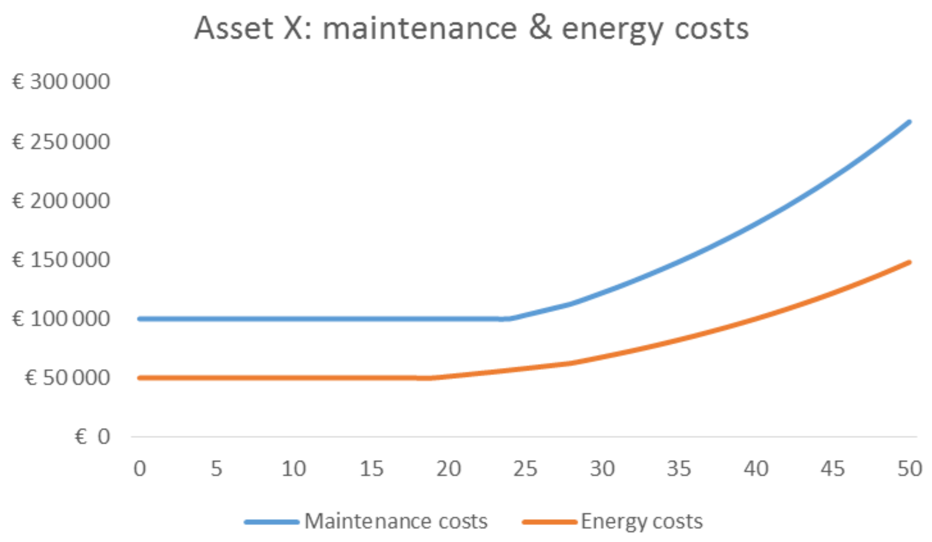


Figure 3

Generally, after about twenty years of use, asset deterioration sets in, causing the costs of maintenance and energy to rise. For the purpose of simplicity, for this example, we presume that all other operational expenditures (OPEX) such as labor costs are stable over the years.

The most important costs that are generated by the initial investment are the costs of capital, namely depreciation and interest. For Asset X, we presume it is depreciated over a period of 10 years. Figure 4 shows the annual costs of capital for Asset X.

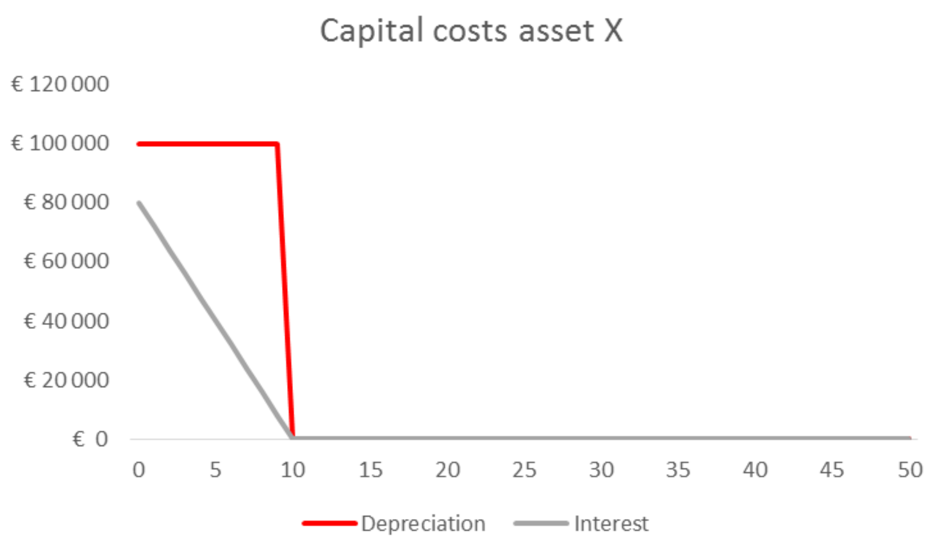


Figure 4

Figure 5 shows the sum of all costs per year.

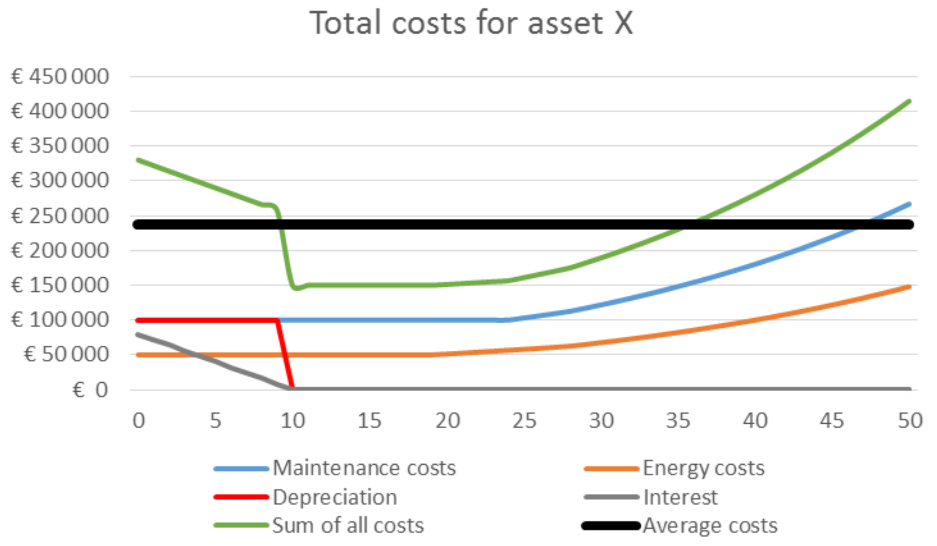


Figure 5

The green line in this figure shows the total of all costs. The thick black horizontal line shows the average total costs per year during the period under consideration. This therefore is the cost level that results if all costs are added up over the life of the asset and divided by its age (in years). It is these total average costs per year that need to be minimized.

If all costs, now and in the future, are known, it is possible to judge exactly which alternative is best from a cost point of view.

Of course, we can never know exactly the future maintenance costs of an asset, but there are methods available to make a prediction with high confidence that include the following:

1. Using standard tables with historical data of components. This is not very accurate, because the rate of occurrence of failure of a component strongly depends on its quality, its application, and the operational circumstances in which it is being used. However if an organization has many similar assets, this method can be effective.
2. Using historical data of the actual component on site. Weibull analysis can be used to extrapolate historical data and apply it to the future. This method needs very little data to still be able to make a quite reliable prediction of future failure behavior of an asset.
3. Using expert opinions.

To make a detailed judgment of the alternatives, inflation and interest will have to be taken into account. An organization prefers to have one thousand euros today to having one thousand euros a year from now or ten years from now. The investment in new assets is done at a certain moment and should pay itself back over many years. To make a good calculation, future costs and benefits have to be calculated back to present day value.

The Net present value (NPV) formula is used to accomplish this:

$$NPV = CF / (1+R)^{\wedge y}$$

With:

CF = Cash Flow

R = Interest

Y = Year (1, 2, 3, …)

The Cash Flow is the difference between money spent and money earned in a certain year. This can, for example, include costs of maintenance, personnel or energy five years or ten years from now.

Suppose the calculation is made to calculate the NPV of a cash flow of € 100,000—ten years from now. The company has an interest rate of 8%. In that event, the formula yields the following:

$$€\ 100{,}000.\text{--}\ /\ (1+0.08)^{10} = €\ 46{,}319.35$$

So at an interest rate of 8%, it is not inconsequential for the organization whether it possesses €46,319.35 now or € 100,000—ten years from now. This calculation must be made for the cash flows in every separate year in the future during the expected asset life time.

To calculate the real NPV for an investment, the sum of all the NPVs for every year over the life cycle of the asset system must be calculated, minus the initial investment amount.

The NPV can be used to calculate the Equivalent Annual Cost (EAC). The EAC is the actual cost per year, calculated back to the value of money in the present year. The EAC is calculated by dividing the NPV of an asset by the “present value of annuity factor”.

$$EAC = NPV / A(t,R)$$

With:

$$A(t,R) = (1-1/(1+R)^{t}) / R$$

This formula can be used to calculate the EAC for different scenarios, such as keeping the present asset in use for another five years versus keeping the present asset in use for another ten years before installing a new asset. This formula can also be used if the different options for new assets have different life expectancies.

The most difficult part in these assessments is collecting the correct data for the calculations. Therefore, it is important to set up an effective enterprise asset management database to collect all the relevant technical and financial data regarding the assets in question. Many organizations do not have an effective system or they only installed it recently and therefore lack sufficient historical data.

In case there are not enough data to make a plausible calculation, it is possible to estimate data based on expert opinion. There are some software tools that can create future cost patterns based on wizards that ask concrete questions to the people using or maintaining the system. Often the help of a consultant will be needed to assure the validity of the data.

Reliability

One of the most important aspects to be taken into consideration when making purchase or design decisions is reliability. Reliability is defined as the ability of an item to perform a required function under given conditions for a given time interval. It can be written as a probability. This means that if the reliability of an asset is low, it will often fail to fulfill its functions. This can lead to production losses, wasted materials, accidents and environmental disasters. There are a number of methods readily available to analyze the reliability of an asset before it is purchased or built. They differ slightly in detail from case to case, but the main outline is usually the same.

Criticality ranking

To determine how reliable a design is, it is necessary to gain an insight into what type of failures might occur when the asset is put in use and how often they are likely to occur. A thorough analysis of an asset to establish all of its failure modes is very time consuming. Usually this analysis is only done when an asset is critical. Therefore the first step in a reliability analysis is to establish which assets are critical. This is done by a criticality ranking.

To be able to perform an appropriate criticality ranking, it must be clear which risks an organization is willing to accept. This can be described in a risk matrix as shown in Figure 6.

Severity	Economics	Safety	Quality	< 1 time/ 50 years	< 1 time/ 10 years	< 1 time/ year	< 1 time/ month	> 1 time/ month
1	<€ 1,000	No impact	No impact					
2	<€ 5,000	First aid	Minor complaint					
3	<€ 50,000	Lost time incident	Customer return					
4	<€ 500,000	Permanently disabled						
5	>€ 500,000	Death	Product recall					

Figure 6

Organizations use the risk matrix also for:

- Decisions on replacement investments
- Decisions on counter measures after incidents
- Setting up preventive maintenance schedules

The first column of this matrix gives a ranking of 1 to 5 for the impact severity of incidents. The next three columns define the severity categories; in this case by the impact on cost, safety and quality. The following columns indicate which frequency of failure an organization is willing to accept. A green block means the failure is acceptable. Red means the failure is unacceptable.

In a criticality ranking for purchase and design decisions, a list of all relevant assets to be installed must be made. This can be a high level list, without too much detail. This list is called an asset register. In this stage of the project, it may just contain the assets shown on a factory lay out drawing or on a P&ID (Process & Instrumentation Diagram).

For the creation of a criticality ranking, a team of people should be formed who know the impact of failures on all relevant aspects. These people can be experienced staff members of departments such as Operations, Maintenance, Engineering or Quality and of course Marketing and Sales. The team assesses the assets one by one to determine in which category of severity the impact of a failure of an asset may rank. So in this example each asset is judged for its impact on economics, safety and quality. At this stage the frequency of occurrence of such a failure is not taken into consideration, because this depends very strongly on the design, maintenance and operation of the future asset. That is simply not known yet. The only purpose of this criticality ranking is to assess if failure of an asset may have critical impact. So a company can decide that if an asset scores 4 or 5 points, it is critical. If the asset is critical, a more thorough process for design and risk analysis is necessary. Techniques for this are described in the next paragraph. If an asset is judged to be non-critical, the engineers can buy or build standard equipment from a trusted supplier, without further analysis.

Reliability analysis

A risk analysis is necessary for the more critical assets. There are a variety of analytical methods to carry out this analysis. Which one is best, depends on the type of assets and their application. A number of these analyses are described below.

Qualitative methods

- Expert analysis: Expert(s) with knowledge and experience give their opinion about the design, strengths, weaknesses, opportunities and threats.
- Failure Mode, Effects (& Criticality) Analysis (FME(C)A): A systematic analysis per component to determine all possible failures, causes, effects, severity, frequency of occurrence and how soon it will be detected in practice.
- HAZard & OPerability (HAZOP): A systematic analysis of all possible failure modes. It resembles FMEA, but is more applicable to processes with flow of liquids or powders.
- Human Reliability Analysis (HRA): An analysis of possible human failures in the total system

Quantitative methods

- Parts Count Analysis: Determines per component or subsystem the frequency of failure and adds them. This gives an indication of the rate of occurrence of failure of the system as a whole.
- Reliability Block Diagrams (RBD): Builds a model of the system that shows how reliability of the system as a whole depends on the reliability of its components and shows the impact of redundancy.
- Fault Tree Analysis (FTA): Determines the combination of causes of a possible failure, such as failure of the system as a whole. It starts out by defining the failure that will be analyzed.
- Event Tree Analysis (ETA): Analyses the probability of certain consequences of a system failure.
- Markov-Analysis: A statistical analysis of systems where random failure can occur. It is an advanced and complicated technique.

Research by Professor Tinga (Tinga, 2013) shows that the life expectancy of components very strongly depends upon circumstances and load. For instance, the strength of the electrical field has a huge impact on the life of polyethylene insulation of cables. An electrical field that is twice as strong decreases the life 500 times. This is only one of many examples where a small change in load has a major impact on life-expectancy.

Professor Brombacher (Brombacher, 1992)has shown that the use of different handbooks leads to different failure frequencies and that these frequencies do not match the failure frequencies measured in reality.

This means that quantitative techniques are useful to compare reliability of two alternative designs, but care has to be taken to rely on their exact outcome to calculate failure rates or budgets.

ENERGY EFFICIENCY

Energy consumption has a major impact on the life cycle costs of an asset and of course on its carbon footprint. On average, 95% of an electric motor's LCC comes from energy consumption, versus just 5% for purchase, installation and maintenance.

When judging the energy efficiency of a design several factors have to be taken into account:

1. The energy-efficiency of the individual components
2. The energy-efficiency of the system as a whole
3. The efficient use of the system

The Ecodesign Directive (Directive 2009/125/EC) has set a framework for energy consuming products and other products like transformers and power cables. It covers more than 40 product groups, both industrial and consumer products. For many types of components there are energy standards, which make it possible to judge the energy efficiency of that component, as well as other environmental parameters, such as water consumption or noise production. Some examples:

1. For electrical motors these are the IE standards, ranging from IE1 to IE4. They are described in standard IEC60034. IE stands for International Efficiency. Since 16 June 2011, only motors with class IE2 or higher are allowed to be brought onto the European market. Since January 2015, motors in the range of 7.5—375 kW must be category IE2 in combination with a variable speed drive or IE3. From January 2017 this obligation will be extended to motors as small as 0.75kW. A new proposal also foresees higher efficiency requirements from 2018 for motors up to 1,000 kW and for ATEX motors in the range of 0.75—375 kW. The categories are given standard names:
    - IE1 = Standard Efficiency
    - IE2 = High Efficiency
    - IE3 = Premium Efficiency
    - IE4 = Super Premium Efficiency
2. For lighting, the categories range from A++ through E. For a directional lamp of category A++, the energy efficiency index (EEI) is lower than 0.13, while the EEI for a lamp in category E can be higher than 1.75. This means that the second lamp is consuming more than 13 times more energy than the first. When evaluating lighting options, it is important to focus on the efficiency of the entire system, i.e. the combination of lamp and fixture. After all, the most efficient lamp will not realize its full potential in an old, inefficient fixture. The intelligent user is interested in a certain amount of light (lumens, or lm), not in the lamp or fixture that produces it. Therefore, when evaluating lighting options, one should focus on total lighting system efficiency in lm/w.

The list of components that are covered by the Ecodesign Directive is much longer. It covers components such as:

- Air conditioning and ventilation systems
- Heating systems
- Pumps for waste water
- Network, data processing and data storing equipment
- Ovens
- Ventilation fans
- Transformers

- Machine tools
- Refrigerating and freezing equipment

Even if there is no standard, it is still necessary to calculate the energy consumption with care. For electrical wires, it is often prudent to choose a larger diameter rather than the required minimum. With the same current, voltage and cable length, a 6mm2 cable may cause 2.7% of power loss, while a 10mm2 cable only has 1.53% power loss. This can mean that the investment in a cable with a larger diameter will pay itself back in a few weeks.

Similar calculations can be made for energy losses for flows of fluids through piping.

Efficient use of the system may not seem a design criterion, but in some cases it does depend on the design.

For this purpose we will define:

Energy efficiency = Useful energy output / Total energy input

For electrical motors, maximum energy efficiency is often around 75% of maximum power. If the motor is loaded more than 75%, the efficiency drops slightly, but is it is used below 50%, efficiency drops dramatically.

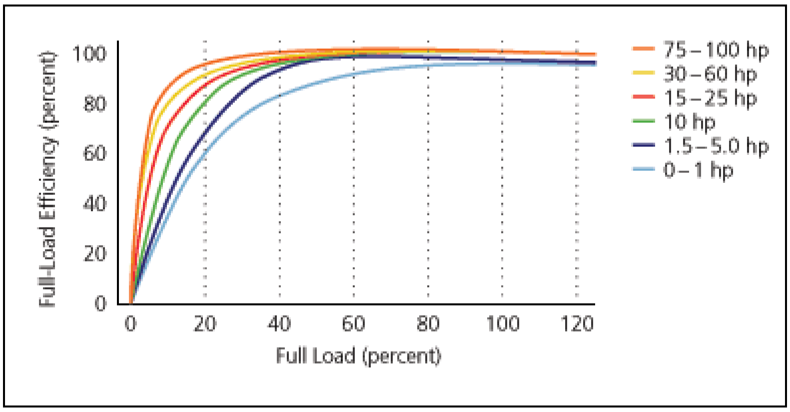


Figure 7—Source: Natural Resources Canada

There are many more such examples. In many cases the flow of gases and liquids through pipes is controlled by valves; this produces energy losses. Alternatively, the use of a variable speed drive can achieve similar or better control over the flow rate, while significantly decreasing energy consumption.

A special case of energy saving is the peak shaving. This means that electrical devices are not switched on at moments when the load of their power grid is already near maximum. This will also described in the Leonardo Application Note about Load Management (coming soon). Many electrical companies charge not only for the energy consumption as such, but also for the maximum peak of the usage of their customer. However peak shaving does not only save the individual company money, it also profoundly effects the environment, because generators and power plants run more efficiently.

The risk of energy price fluctuations and shortage of energy has to be taken into account, especially for assets that are intended to be in use for many years. Systems that consume less energy or produce their own energy are less sensitive to fluctuations in supply and demand of energy.

ENVIRONMENTAL IMPACT

More and more organizations are adopting policies of social responsibility and sustainability. Sustainability is often regarded as mainly an issue of carbon-dioxide emissions, but there are many more aspects to consider, including waste reduction and energy use.

In 2014 a directive from the European Union appeared, prescribing organizations with more than 500 employees to publish an annual report on non-financial information. This report becomes compulsory in 2017.

There are a number of guidelines organizations could use for this report, for example:

- ISO 26000
- UN Global Compact
- OECD Guidelines for Multinational Enterprises

Although there are differences in content and approach between these three documents, they all have a broad perspective on social responsibility. They include topics such as

- Human rights
- Labor practices
- Environment
- Operating practices
- Consumer issues
- Community and development
- Information disclosure
- Corruption

In this paragraph we will mainly focus on purchase and design decisions with impact on the environment.

One of the philosophies giving a more practical approach to the problem of how to select the best alternative from an environmental point of view is Cradle-to-Cradle (C2C).

Cradle-to-Cradle is originally the title of a book by William McDonough and Michael Braungart: Cradle-to-Cradle: Remaking the way we make things (McDonough & Braungart, 2002).

C2C has now developed into a framework that aims at designing systems that produce no waste. This opens a new point of view on re-using materials. In traditional recycling, the recycled materials are often of inferior quality. Recycled plastics may for instance be used to produce simple plastic poles to make a garden fence or to put at the side of a motorway. Because of the inferior quality of the plastic, it will degrade quite fast and pollutants from the plastic will contaminate the soil. C2C strives at reusing materials at a similar or even higher quality than in their first life.

C2C promotes life-cycle assessment (LCA). LCA is a methodology to establish the impact that a product or asset has on the environment in all stages of its life. Therefore, it includes stages such as the mining of raw materials, but also the maintenance of the asset. LCA quantifies all effects an asset has on the environment by inventorying all flows of materials and energy during the life of the asset. The procedures for LCA are also described in ISO14040 (ISO14040:2006, 2006).

LCA consists of four stages.

The first stage is the definition of goal and scope. These must clearly be defined and communicated. In this stage of the process it is also described to whom this information should be communicated. The scope describes:

- The boundaries of the asset system to be studied
- The assumptions and preconditions of the study
- The sorts of environmental impact that will be investigated
- How impacts that are shared by several systems will we divided over the individual systems

The second stage is the Life Cycle Inventory (LCI). During this stage all flows of materials and energy are inventoried. This also includes flows like water, air, fuel, et cetera. The flows are analyzed from their source in nature, through their use in the asset until they are released back into nature again. Often a flow chart is used to describe these flows. The flows must be quantified. One of the problems in this analysis is that a major part of the flows are outside the direct view of the analysts. Topics such as mining and production of raw materials have a significant influence on the environmental impact of a product.

CONCLUSIONS

There are many aspects to take into consideration when making purchase and design decisions. Traditionally in many organizations only the Engineering Department was involved in the design or procurement of new assets. Their primary focus was on the functions of an asset (what should it do?), deliverability and the initial investment needed. Intelligent purchase and design decisions require much more than such a simplistic approach.

The total impact of purchase and design decisions over the entire impact of an asset is much larger than just function and investment. Looking from a strictly financial point of view, aspects like reliability and energy consumption can have an impact that is many times larger than taking only the original investment into consideration. For electrical motors, the price of energy during their life time can be up to a thousand times higher than its original purchase price. Choosing a cable with a diameter one step larger can reduce its energy losses by more than a full percent.

But the impact of purchase and design decisions goes even further than just financials. The decisions of organizations to choose one asset or another can have a huge impact on the environment and on social issues.

Because of the enormous impact of purchase and design decisions of large assets, organizations must incorporate systematic analysis methodologies such as FMEA, RCM and LCA in their project and procurement procedures.

Early Equipment Management is a concrete framework to integrate the input of all departments in an organization into a specification, design and start-up of new equipment. It is a step-by-step approach to specify, design, build and put into use new assets and asset systems.

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