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ENVIRONMENTAL EVALUATION OF TECHNICAL OBJECTS – FRAMES

Increasing interest of different organizations in the environmental evaluation of products has caused the need of tools for its realization. Due to the great number of machines and devices in use and their total significant influence on environment, special concern should be focused on this group of technical objects. In this series of paper the main task is to present the methodology of encompassing the whole life cycle of the object valuation of machines and devices with the special attention on environmental issues and its application to evaluation of real objects. At the beginning, the general overview of environmental problems in global scale is outlined. Special attention is concentrated on issues which are of concern for designers of technical objects. Broad spectrum of factors, which should be considered during the anticipation of environmental burdens done by technical objects, is discussed. General approaches dedicated to evaluating negative environmental impact of different scale are identified. Since the life cycle approach seems to be the most promising it is chosen for further development.

Keywords: evaluation, technical objects, environmental issues

1. INTRODUCTION

The directions of the world development, as many cases have shown, should be forestalledly assessed. It deals also to the technology and it means that the whole development process should be monitored and deeply considered. The problem has the complex nature.

One of the key messages conveyed by a study published by the European Commision is either we accept a substantial fall in our living standards in the years to come or the countries of Europe must invest more in innovation and research [Caracostas, Muldur 1997]. The recent evolution research and innovation policies

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are now directed towards socio-economic issues such as health, job creation and environmental problems. The main idea developed currently is that, in order to tackle the challenges of unemployment and ageing, Europe must intensify its efforts in knowledge-based activities (research, innovation, education-training) and use the means at its disposal more effectively.

In majority of industrialized countries research and innovation policies have emerged, integrating societal objectives with governmental support of innovation systems. This is the idea of a "knowledge-based economy" which is integrated in the slogan – society, the endless frontier, expressing idea that research, innovation and skills are no longer ends in themselves but have to meet individual and social needs and develop in close interaction with various socio-economic activities. "Endless frontier" means that these interactions will always be pushed further, that in fact one understand little of them and research on them must henceforth be an integral part of the process of innovation itself [Caracostas, Muldur 1997].

Research, development and the use of new technologies are key elements in innovation, but they are not the only ones. Incorporating them means that the organization must make an effort by adapting its methods of production, management and distribution. The factor of key importance is the possession of accumulated knowledge as the basis for innovation. In OECD documents one can find that the knowledge in all its forms plays today a crucial role in economic processes. Intangible investment is growing much more rapidly than physical investment [Soete 1996].

Growth theory has traditionally recognized the key role of knowledge accumulation in the growth process. Without technological change, capital accumulation cannot be sustained, its marginal productivity declines and the equilibrium growth of the economy will inexorably tend towards zero. It is the invention of new machines and intermediate goods which provides opportunities for new investments.

Whereas the embodiment of technology in physical capital has long been recognized, the increasing importance of the embodiment of technology in people has been expressed much more recently. Yet there is little doubt that the way to use a particular technology is fully part of that technology. Human skills are essential complementary assets, an essential part of implementing, maintaining, adapting and using new physically embodied technologies. The accumulation of human capital can involve both an improvement in the knowledge embodied in skilled workers and an increase in the number of skilled workers [Soete 1996].

By its nature industrial innovation requires change in management practices and in production processes as well as in products. Adaptive organizations have become a prerequisite for innovation. At the basis of innovative organizations lie multi-skilled employees, decentralization of responsibility, considerable recourse to team work and the integration of different functions within the firm from research, engineering, production to marketing and distribution around joint projects. Innovative activity is often the result of dynamic relations between actors rather than the simple transfer of information or technology. Feedback loops between different actors are very important in the innovation process. This should be kept in mind when considering the sources of innovation [The competitiveness of European industry. EC Luxembourg 1997].

Case studies of innovation systems have identified three important characteristics:

– innovation systems are rooted within a given set of national and sub-national institutions,

– continental innovation systems are characterized by a high degree of diversity,

– the role of supporting institutions, both private and public, formal and informal, is of crucial importance; successful innovation requires more than basic research and research and development expenditures [Nelson 1993].

Used in the right way, different requirements (e.g. environmental ones) can lead to the development of innovation, resulting in new products. It is now based on the integration of environmental responsibility in wider international context in various sectors, in the pursuit of sustainable development.

Sustainability is a term that is used so often that its users do not bother to define it. But the concept of sustainable development has long tradition in Bruntland Commission activities. It was there defined as development which meets the needs of the present without compromising the ability of future generations to meet their own needs [Caracostas, Muldur 1997]. Some years ago a number of environmentalists have begun to develop a new framework, moving beyond cost-benefit thinking and taking into account the fact that many environmental costs and benefits accrue over a long period of time. Sustainable development is about the coordination of our actions across companies, geographies, and political entities to adopt many proper treaties and thus to solve our environmental problems [Stoner, Freeman, Gilbert 1995, Calkins et al 1989].

The list of environmental problems is long. Individuals, as well as organizations, contribute to these problems and can have an impact on their resolution. It begins with the consumption of renewable and nonrenewable resources. Renewable resources are capable of being replenished quickly enough to meet near-term demand.

Increasing consumption of nonsustainable resources seems more obviously self limiting. Energy, now derived primarily from fossil fuels, is one of the most critical needs of industrialized society and also prime example of human reliance on nonrenewable resources. The world depends now on fossil fuels mainly.

Industrial processes consume round 40 percent of energy demand. Energy seems relatively abundant in the short term, but our heavy reliance on nonrenewable fossil sources and the continued exponential increase in demand as developing countries become more industrialized suggest that future sources and patterns of use must change substantially [Keoleian, Menerey 1994].

One of the largest environmental problems is pollution, in many different forms. Some substances are a major concern as contaminants to air, some to drinking water. Pesticides accumulate in the soil over time. Many applied earlier constructional materials, as lead or asbestos, are toxic. Other substances, being hazardous wastes, e.g. nuclear wastes or toxic chemicals, must be safely stored. A form of air pollution that damages also soil, water and vegetation are acid rains.

In addition to problems created by depletion, resource and energy use ultimately produce residuals that create significant environmental impacts. Many residuals are temporarily concentrated in landfills, while others are immediately dispersed throughout the ecosphere. A comparison of anthropogenic and natural fluxes of toxic metals on a global scale provides one example of the environmental problems created by human activity, causing dramatic increase of the dispersion of toxic metals. The implication for toxic metal production – substantial reduction in mining virgin ores, and virtual elimination of their releases as residuals, applies to other hazardous and toxic materials if humans are to achieve sustainable society.

Dispersing pollutants into the environment may cause irreparable damage and lead to human-induced climate change such as global warming. Some scientists have suggested that global warming poses a severe threat to life. Greenhouse gases which are emitted from the burning of carbon-based fuels such as gasoline, serve to trap warmth in the atmosphere, and some scientists predict a global average temperature increase of 1,5 to 4,5 degrees centigrade over the next century unless current trends abate [Simon, De Fries 1990].

The degradation of the ozone layer surrounding the earth, when CFCs are released into atmosphere and break down is another problem. If the earth's protective ozone layer gets to thin, then damaging ultraviolet radiation will lead to increasing of skin cancer cases.

Production and consumption of many materials is increasing. The annual production data are the metal content of the ore mined for main raw materials. Annual consumption of metal refers to the domestic use of refined metals, which include metals refined from either primary (raw) or secondary (recovered) materials. The world reserve life index is expressed in years remaining [World Resources 1994-95 1994].

Finally, there are some more large global issues such as protection of biodiversity. Now, renewable resources such as water, forests and soil are heavily exploited, resulting in a significant loss of biodiversity. The manner, in which these resources are used and managed also determines the level of their sustainability. Overuse can damage ecosystem structure and function, thereby lowering future sustainable yields. Thus, although a resource can appear renewable at current usage, exploitation at the same rate may not be possible for long due to impacts that affect both resource itself and related ecosystem elements.

Once designers recognize that environmental problems need to be addressed in their work, establishing priorities can help concentrate eforts on the most critical areas. The following priorities for environmental impacts set by EPA provide an example of such a global ranking:

1) relatively high-risk problems:
    - global climate change,

   - habitat alteration and destruction,
   - species extinction and overall loss of biodiversity,
   - stratospheric ozone depletion,
2) relatively medium-risk problems:
   - acid deposition,
   - airborne toxics,
   - herbicides/ pesticides,
   - toxics, nutrients, biochemical oxygen demand, and turbidity in surface waters,
3) relatively low-risk problems:
   - acid runoff to surface waters,
   - groundwater pollution,
   - oil spills,
   - radionuclides,
   - thermal pollution [Keoleian, Menerey 1994].

Items within the three groups are ranked alphabetically, not by priority. In developing hierarchy EPA considered reducing ecological risk as important as reducing human health risk. Of course, many human actions are interrelated and produce multiple consequences, so assigning environmental priority to specific actions will be complex.

There are a growing awareness that the traditional focus on production processes may no longer be appropriate in environmental policy and regulation. While industrial and energy production remains an important source of pollution and waste, the relative importance of consumption-related emissions and wastes has been rising over the last decades. Transition towards product-oriented policies faces diverse practical, political and legal obstacles:

1) it implies a transition from intervening directly in the frequently local environmental impacts of single sites with well-known technological environmental characteristics operated by single industrial enterprises, to influencing indirectly the imprecisely understood and frequently regional and global environmental impacts of globally-spread product systems involving many stakeholders distributed across many countries,

2) the recognition of products as a key focus for environmental policy is far from pervasive in international policy making circles; there is a great need for a clear framework for an integrated product-oriented environmental policy which can be widely communicated and applied,

3) the global scope of product systems and environmental impacts raises the issue of the trade-off between promoting the internal market and securing high levels of environmental protection; a balance needs to be struck between allowing market forces to help foster innovative product development in the context of continuing economic growth, and taking targeted action to ensure that any such growth is sustainable in environmental terms.

The fundamental goal of product life cycle design is to promote sustainable development at the global, regional, and local levels. Principles for achieving sustainable development should include:

- sustainable resource use,
- maintenance of ecosystem structure and function,
- environmental equity [Keoleian, Menerey 1994].

There could be no product development or economic activity of any kind without available resources. Except for solar energy, the supply of resources is finite. Efficient designs conserve resources while also reducing impacts caused by material extraction and related activities.

Depletion of nonrenewable resources and overuse of otherwise renewable resources limit their availability to future generations. In past two hundred years, human activity in certain regions depleted economically exploitable reserves of several natural resources with critical applications at the time, such as certain woods for ship building, charcoal for steelmaking, and whale oil for lighting [Keoleian, Menerey 1994]. When this happened, substitutes were found that often proved both cheaper and more suitable for advancing industries. However, it would be unwise to assume that infinite abundance will be characteristic of the future. It may be true that widespread, critical shortages have not yet developed in the brief history of intensive human resource use, but the amount and availability of resources are ultimately determined by geological and energetic constraints, not human ingenuity.

Maintaining healthy ecosystem structure and function is a principle element of sustainability. Because it is difficult to imagine how human health can be maintained in a degraded, unhealthy natural world, the issue of ecosystem health should be a more fundamental concern.

The issue of environmental equity is a complex as the subject of sustainable development. A major challenge in sustainable development is achieving both intergenerational and intersocietal environmental equity. Over-consuming resources and polluting the earth in such a way that it enjoins future generations from access to reasonable comforts irresponsibly transfers problems to the future in exchange for short-term gain. Beyond this intergenerational conflict, enormous inequities in the distribution of resources continue to exist between developed and developing countries. Inequities also occur within national boundaries. Pollution and other impacts from production are also unevenly distributed [Kłos, Kurczewski, Laskowski 2000].

Life cycle design applies sustainable development principles at the product system level. The environmental goal for life cycle design is to minimize the aggregated life cycle environmental burden associated with meeting societal demands for goods and services.

2. STRUCTURE OF FACTORS FOR ENVIRONMENTAL VALUATION

2.1. Introductory remarks

The potential rewards from developing successfully new products are high, but the risks are correspondingly high. While some large organizations may be able to survive by trying to introduce one product after another in the market until success is achieved, most organizations cannot afford these efforts. Even large organizations are now more profit conscious and concerned about the costs of development.

One of the basic strategic decisions is whether to be reactive or proactive. A reactive product strategy is based on dealing with the initiating pressures as they occur while a proactive strategy would explicitly allocate resources to preempt undesirable future events and achieve goals. A reactive view of the competition is to wait until the competition introduces a product and copy it if it is successful, while a proactive strategy would be based on preempting competition by being first on the market with a product competitors would find difficult to match or improve.

One of the product aspects that concentrates the attention of many organization is its complex influence on environment. Some companies have invested heavily in new processes, systems, production technologies and design methods in search for substantial reductions in the environmental impact of their products and production. They have decided to invest this way because they:

- want to position as market leaders or innovators,
- don’t want future surprises (they want to anticipate the changing regulatory
- market context rather than react to changes as they are upon them),
- recognize the emergence of a new business paradigm and a new competitive terrain,
- desire to act responsibly,
- desire to influence direction of regulations/legislation in partnership with government and to secure their investment,
- desire to strengthen technical competence and develop new areas of technical competency (“handling environment”),
- want to change or improve the market image of whole company [Ryan 1996].

To reach the above mentioned goals the different methods and techniques have been developed, gathered in environmentally conscious engineering. The common thread linking all environmentally conscious engineering effects is the reducing the negative environmental impact of product during its entire life cycle.

The general goal of environmentally conscious approaches is the reduction of the impact of a product throughout its life cycle. Two general approaches exist:

- the first approach takes this goal to its logical, albeit impossible, extreme; if the environmental impact of a product life cycle can be reduced to zero, the cycle would be absolutely sustainable, and the product could be designed, manufactured, used, and disposed of without affecting the environment. (with the Second

Law of thermodynamics indicating the unfeasibility of achieving this, the emphasis in this approach is in creating a product cycle which is as sustainable as possible),

– the second approach notes that there is a certain amount of negative impact from a current cycle, and measures success based on the reactive reduction of this impact or the "cleaning" of the product cycle.

Several general approaches to reducing negative environmental impact were identified through literature search, where one define an approach as a guiding philosophy. These are: environmental engineering, pollution prevention, environmentally conscious design and manufacturing, design for the environment, life cycle design, green engineering, industrial ecology, and sustainable technology [Coulter, Bras, Foley 1995].

One have used two basic factors to distinguish the approaches, namely:

– scope of environmental concern: what impact is considered by each approach? The impact being considered may be as narrow as the impact of the emissions from a single manufacturing plant, or as broad as the total impact from all material extraction, processing, use, and disposal operations of all industries in the world,

– scope of temporal concern: what is the time scale over which the impact mentioned above is considered? Possible considerations range from the im-pact during only the manufacturing process to the impact until the earth crashes into the sun.

Rather than indicate years, the temporal concern gradations were based on life spans of products, people and civilizations. The scale as shown is not linear but instead used to indicate important distinctions between the approaches. Within a product life cycle an additional set of distinctions were made, indicating manufacturing, use, and disposal as possible lengths of temporal concerns. It is recognized that a product life cycle could be as short as 1-2 years for consumer electronics or longer than 30 years for an airplane or ship, and that the application of a given approach might change accordingly [Coulter, Bras, Foley 1995].

Similarly, the scale of environmental concerns was chosen to indicate distinctions. These gradations are fairly self-explanatory; although it is worth noting that "X products" refers to the negative environmental impact of some number of products X, and that a scope equivalent to "one manufacturer" would indicate concern about all the activities of a single manufacturing firm.

Environmental engineering is concerned with managing the fate, transport, and control of contaminants in water supplies and discharges, air emissions, and solid wastes. In the manufacturing context, the focus of environmental engineering effort is after pollutants have been generated, or at the "end of the pipe". As environmental policy expanded from clean water to clean air to cradle-to-grave solid and hazardous waste management, environmental engineering research helped us better understand how pollutants migrate through soil, groundwater, and the air, and developed treatment technologies to minimize their impact on the natural and human environments. Over the past 30 years, treatment and disposal technologies (stack scrubbers, clarifiers, incinerators, synthetic landfill liners, etc.) were codified in technology-based policies and incorporated into manufacturing processes. One problem with traditional environmental engineering approaches is intermedia transfers. Pollutants removed from the air using stack scrubbers are transferred to wastewater, which is then treated. The end result is a solid or hazardous waste sludge that may still contain the original air pollutants. The sludges require further treatment, either dewatering or incineration, prior to disposal in a regulated landfill. An effective NIMBY (Not In My Back Yard) response to the rising demand for landfill space brought industry and policy makers to their senses. The long term approach to reducing environmental impacts should focus on changes in the products and processes themselves before the end of the pipe.

As the hazardous waste regulations were implemented in the early 1980s, the concept of pollution prevention, as an alternative to treatment and disposal, was embraced by pioneering corporations and region level industry assistance programs. Subsequent amendments to the regulations established a hierarchy of preferred waste management approaches: source reduction, closed-loop or in-process recycling, out-of-process recycling, treatment, and disposal. As practiced in industry, pollution prevention usually focuses on elimination of pollutants from existing products and process technologies. The transition from pollution control to prevention has been hampered by limited information, technologies and capital, as well as by impediments in existing regulatory policies [Treeman, Harten, Springer, Randall, Curran, Stone 1992].

Perhaps the most recent approach to emerge is that of environmentally conscious design and manufacturing (ECDM). It can be divided into environmentally conscious product design and environmentally conscious process design, or environmentally conscious manufacturing. Rather than designing for the environment, the philosophy of ECDM recognizes that there will be negative environmental effects from the product life cycle, but that the designers are conscious of this during the design. An overview of this work can be found in [Matysiak 1993], which notes that it is important to include "every operating constraint into the initial design phase of the product or process life cycle".

ECDM is quite similar to the next few approaches discussed. In each of these approaches, the scope of considerations, both in terms of time and environment, is the life cycle of one product. Environmental concerns include all phrases of this life cycle, extending beyond the scope of pollution prevention to include the negative impact resulting from the use and disposal of this product. Similarly, the time scale considered is that of the product life cycle, from design and manufacturing through use and final disposal or recycling of the materials in the product.

Design for the environment (DFE) is somewhat of a misnomer, since true DFE would be to reduce the impact to zero by not designing it at all. The idea of DFE is instead that the environment be considered during the design process.

In papers [Ashley 1993, Olsen, Keldman 1993] a general overview of Design for the Environment can be found. The work of Olesen and Keldmann is particularly interesting as a general overview of design methods considered to be part of DFE. Navin-Chandra mentions DFE in a similar context, however, he immediately proceeds to use the term green engineering throughout the paper, an indication of the change of terminology mentioned elsewhere [Navin–Chandra 1991]. The survey of Van der Horst and Zweers is presented within the framework of DFE. The scope of this approach is virtually identical to that of ECDM, with the span of environmental concern again being the entire product life cycle [Von der Horst, Zweers 1993].

A life cycle approach is described as a systematic "cradle to grave" approach and provides the most complete environmental profile of goods and services [Keoleian, Menerey 1994]. The argument is that consideration of the entire life cycle helps designers ensure that the environmental impact of their products are discovered and reduced, not merely shifted to other places. As such, the scope of this approach is again one product life cycle, both temporally and environmentally.

As stated in the Life Cycle Design Guidance Manual, the primary objective of life design is "to reduce the total impacts and health risks caused by product development and use"[Keoleian, Menerey 1993]. This is accomplished by examining the environmental impact of the activities related to each stage of the product life cycle, from material acquisition to disposal. This makes it possible for designers to recognize that a slight reduction in waste during production may result in greatly increased waste at disposal. Since the total impact is to be minimized, each stage must be examined. Alting and Jørgensen present life cycle design as a basis for sustainable production, relating this approach to goals mentioned above. Alting and Jørgensen also provide references to other work in their paper [Alting, Joergenson 1993].

It should be noted that the roots for Life-Cycle Design can be traced to the early seventies when the Defense Advanced Research Program Agency initiated investigations in so-called Unified Life-Cycle Engineering [Navin–Chandra 1991], followed by research in Concurrent Engineering (CE) and, more recently Integrated Product and Process Development (IPPD). CE is defined as "a systematic approach to the integrated concurrent design of products and their related processes, including manufacturing and support. It is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements" [Navin–Chandra 1991]. Some consider the more recent IPPD to be an expansion of CE because it focuses on the integration of products and business processes. Experience tells that this may be another phrase incorporating the same ideas as CE. Keoleian and Menercy discuss the use of CE in life cycle design and note that CE is usually used to improve product quality and manufacturability [Keoleian, Menerey 1993]. CE and IPPD can be viewed as the roots for the U.S. EPA's life-cycle design approach, though the U.S. EPA places higher emphasis on environmental issues than traditional CE and IPPD.

From the Congress Office of Technology Assessment "green design involves two general goals: waste prevention and better materials management" [U.S. Congress 1992]. This is one of the more limited definitions. For instance Navin-Chandra defines green engineering as "the study of, and an approach to, product/process evaluation and design for environmental compatibility that does not compromise product quality or function" [Navin–Chandra 1991]. It is presented as the successor to DFE, encompassing many of the same tools. Navin-Chandra remarks that highly focused approach such as design for recyclability may be too narrow, noting that while thermoplastic are easier to recycle that thermosets, thermoplastics are not as strong and an increased volume must be used possibly negating environmental benefit from increased recyclability.

In industrial ecology, a much larger scope of concerns is applicable. While the previously discussed approaches were limited to a single product from a single manufacturer, the concern of industrial ecology ranges over man products from multiple manufacturers. In addition, this approach is not limited to a single product life cycle instead considering the interactions of several product life cycles (of possibly different lengths) over a larger time scale.

This term was popularized by a work of Frosch and Gallopoulos [Frosch, Gallopoules 1989]. Here, the idea of a industrial ecosystem is introduced to take advantage of the analogs to biological ecosystems. They note that the ecosystem would ideally be closed: "a chuck of steel could potentially show up one year in a tin can, the next year in an automobile, and 10 years later in the skeleton of a building." For this closed system to exist, and waste from one part of the ecosystem must be used as input to another part of the system. Using this idea waste from one manufacturing process does not have a negative impact on the environment if it can be used as an input to another process [Frosch, Gallopoules 1989].

Industrial ecology serves as a general paradigm for "improving the environmental performance of industrial processes and the environmental attributes of products." Within this paradigm, a variety of techniques for accomplishing this improvement can be found. As chronicled in [Richards, Fullerton 1994], areas of concern include energy use, material consumption, impact evaluation, design for environment, and recycling.

The most general approach noted in terms of scope is sustainable development and technology. The most common definition is taken from the United Nation's World Commission on Environment and Development, and specifically from their report [World Resources 1994-95 1994]. Sustainable development is defined as "development that meets the needs of the present generation without compromising the needs of future generations." In a similar vein, Georgia Technology Center of Sustainable Technology uses the definition: "sustainable technology is the finding of practical solutions to achieve economic growth in harmony with the environment."

The concern of sustainable technology is the impact of all human activity, and the time span considered is essentially the life of the planet. This approach is remarkable for its inclusion of economic growth within the stated goal, and for the sheer scope of the concerns.

2.2. Life cycle stages in product development

Defining the system is fundamental to any design activity. The definition of the product system begins with a clear statement of the basic societal needs being met by the design. In the project initiation stage, design teams determine the scope of their activity but frequently do not explicitly state the spatial and temporal boundaries of the proposed design. In life cycle design, boundaries should usually be determined by the full environmental consequences arising from a product system. The physical dimensions of the system encompass the material and energy flows and transformations associated with an entire product life cycle. In the process of defining boundaries for a design project, the various groups potentially impacted by the design should also be identified.

The product life cycle provides a logical framework for sustainable design because it considers the full range of environmental consequences and other stakeholder interests associated with a product. By addressing a life cycle system, designers can help prevent shifting impacts between media (air, water, land) and between other life cycle stages. This framework also includes stakeholders (e.g., suppliers, manufacturers, consumers/users, resource recovery and waste managers), whose involvement is critical to successful design improvement. The life cycle system is complex due to its dynamic nature and its geographic scope. Life cycle activities may be widely distributed over the planet, and they may also create environmental consequences on global, regional, and local levels.

Several diagrams have been proposed to represent the product life cycle [Alting, Joergenson 1993, Keoleian, Menerey 1993]. Material and energy flows through a product life cycle are of circular nature. On an elementary level, every product requires that resources be consumed and wastes generated which accumulate in the earth and biosphere. A product life cycle can be organized into the following stages:

– raw material acquisition,
– bulk material processing,
– engineered and specialty materials production,
– manufacturing and assembly,
– use and service,
– retirement,
– disposal.

Raw materials acquisition includes mining nonrenewable material and harvesting biomass. These bulk materials are processed into base materials by separation and purification. Some base materials are combined through physical and chemical means into engineered specialty materials. Examples include polymerization of ethylene into polyethylene pellets and the production of high-strength steel. Base and engineered materials are then manufactured through various fabrication steps, and parts are assembled into a final product.

Products sold to customers are consumed or used for one or more functions. Throughout their use, products and processing equipment may be serviced to repair defects or maintain performance. Users eventually decide to retire a product. After retirement, a product can be reused or re-manufactured. Material and energy can also be recovered through recycling, composting, incineration, or pyrolysis.

Some residuals generated in all stages are released directly into the environment. Emissions from automobiles, wastewater discharges from some processes, and oil spills are examples of direct releases. Residuals may also undergo physical, chemical or biological treatment. Treatment processes are usually designed to reduce volume and toxicity of waste. The remaining residuals, including those resulting from treatment, are then typically disposed in landfills. The ultimate form of residuals depends on how they degrade after release.

The life cycle design framework introduced in Life Cycle Design Guidance Manual provides the template used for reviewing major concepts and approaches to LCD [Simon C, De Fries 1990]. Several connections demonstrate the complexity of integrating environmental issues into design. The goal of sustainable development is located at the top to indicate its fundamental importance. Both internal and external forces shape the creation, synthesis, and evaluation of a design.

External factors include government regulations and policy, market demand, infrastructure, state of the economy, state of the environment, scientific understanding of environmental risks, and public perception of these risks. Within a company, both organizational and operational changes must take place to effectively implement life cycle design.

Of the internal factors, management exerts a major influence on all phases of development. Both concurrent design and total quality management provide models for life cycle design. In addition, appropriate corporate policy, goals, performance measures, and resources are needed to support LCD projects.

Research and technology development uncover new approaches for reducing environmental impacts, while increased understanding of the state of the environment by the scientific community and the general public provides global, regional, and local priorities for environmental problems that can be addressed by design. In this way, current and future environmental needs are translated into appropriate designs.

A typical design project begins with a needs analysis, then proceeds through formulating requirements, conceptual design, preliminary design, detailed design, and implementation. During the needs analysis or initiation phase, the purpose and scope of the project are defined, and customer needs are clearly identified.

Needs are then expanded into a full set of design criteria that includes environmental requirements. Various strategies are explored to meet these requirements, which act as a lens for focusing knowledge and new ideas into a feasible solution. The development team continuously evaluates alternatives throughout the design process. Environmental analysis tools ranging from single environmental metrics to comprehensive life cycle assessments (LCA) may be used in addition to other analysis tools. Successful designs must ultimately balance environmental, performance, cost, cultural, and legal requirements.

This issue, in relation to the small and medium size enterprises, was investigated to answer the question of whether environmental LCA is a good management tool for this type of business [Witczak, Kasprzak, Kłos, Kurczewski, Lewandowska, Lewicki 2014].

Ideas that lead to design projects come from many sources, including customer focus groups and research and development. In addition, environmental assessment of existing product systems may uncover opportunities for design improvement. In any case, the need which a design intends to fulfill must be clearly defined and the current options for meeting this need must be assessed. The basic needs of society have not changed; but the means for satisfying them have evolved, frequently in an unsustainable manner. Life cycle design projects should contribute to sustainable economies by pursuing the most sustainable pathways for addressing needs.

Survey reveal a high degree of public awareness and concern for the environment [US Environmental Protection Agency 1991].

Although there seems to be a positive correlation between informing the public of a discrete environmental problem and encouraging some from of appropriate behavior, there may be less correlation between environmental concern and specific actions. Human behavioral response to potentially large-scale environmental changes, such as global warming or ozone depletion, still remains largely unknown, due in part to the uncertainty of scientific predictions concerning the magnitude and impact of such changes. In light of this, companies must make difficult choices about the types of needs they will address and how willing their customers are to purchase environmentally responsible products. Product development managers should first recognize that environmental burdens can be substantially reduced by ending production of environmentally harmful product lines for which more benign alternatives are available.

In addition to defining the project timeline and budget, the development team should define system boundaries. The ideal framework for design considers the full life cycle from raw material acquisition to the ultimate fate of residuals, but more restricted system boundaries may be justified by the development team in order to meet the demands of a particular product development cycle.

Beginning with the most comprehensive system, design and analysis can focus on the full life cycle, partial life cycle, or individual stages or activities. Choice of the full life cycle system generally provides the greatest opportunities for achieving the goals of sustainable development. In some cases, the development team may confine analysis to a partial life cycle consisting of several stages, or even a single stage. Stages can be omitted if they are static or not affected by a new design. As long as designers working on a more limited scale are sensitive to potential upstream and downstream effects, environmental goals can still be reached. Even so, a more restricted scope will reduce possibilities for design improvement.

Formulating requirements may well be the most critical phase of design. Design initiatives such as quality function deployment and total quality management recognize the primacy of customer needs, and thus increasingly focus on ensuring quality and value at the earliest stages of development [Gause, Weinberg 1989, Ishikawa 1985]. Through their emphasis on designing quality into products, rather than achieving it through later remediation, these programs prepared the way for LCD's focus on environmental requirements. Requirements define the expected outcome and are crucial for translating needs and environmental goals into an effective design solution. Design usually proceeds more efficiently when the solution is clearly bounded by well-considered requirements. In later phases of design, alternatives are evaluated on how well they meet requirements [Red. Kurczewski, Lewandowska 2008].

Incorporating environmental requirements into the earliest stage of design can reduce the need for later corrective action. This proactive approach enhances the likelihood of developing a lower impact product. Pollution control, liability, and remedial action costs can be greatly reduced by developing environmental requirements that address the full life cycle at the outset of a project. Life cycle design also seeks to integrate environmental requirements with traditional performance, cost, cultural, and legal requirements. All requirements must be properly balanced in a successful product.

Regardless of the project's nature, the expected design outcome should not be overly restricted or too broad. Requirements defined too narrowly eliminate attractive designs from the solution space. On the other hand, vague requirements (such as those arising from corporate environmental policies that are too broad to provide specific guidance), lead to misunderstandings between potential customers and designers while making the search process inefficient.

An estimated 70 percent of product system costs are fixed in the design stage. Activities through the requirements phase typically account for 10 to 15 percent of total product development costs, yet decisions made at this point can determine 50 to 70 percent of costs the entire project [Von der Horst, Zweers 1993].

Environmental requirements should be developed to minimize:

- the use of natural resources (particularly nonrenewables),
- energy consumption,
- waste generation,
- threats to ecological health,
- human health and safety risks.

By translating these goals into clear functions, environmental requirements help identify and subsequently constrain environmental impacts and health risks.

Table 1 lists issues that can help development teams define environmental requirements. Although these lists are not complete, they introduce many important topics. Depending on the project, teams may express these requirements quantitatively or qualitatively. For example, it might be useful to state a requirement that limits solid waste generation for the entire product life cycle to a specific weight.

In addition to criteria discovered in the needs analysis or benchmarking, government policies can also be used to set requirements.

It can also be wise to set environmental requirements that exceed existing government statutes. Designs based on such proactive requirements offer many benefits. Major modifications dictated by regulation can be costly and time consuming. In addition, such changes may not be consistent with a firm's own development cycles, creating even more problems that could have been avoided.

Table 1. Some issues to consider when developing environmental requirements [Keoleian, Menerey 1994]

Materials and Energy

Amount Type	*Character*	*Resource Base*	*Impacts Caused By Extraction and Use*
	Virgin	Location	
Renewable	Reused/recycled	local vs. other	Material /energy use
Nonrenewable	Reusable/recyclable	Scarcity	Residuals
		Quality	Ecosystem health
		Management/ restoration practices	Human health

Residuals

Type	*Characterization*	*Environmental Fate*	
		Containment	
Solid waste	Constituents,	Bioaccumulation	Treatment/Disposal
Air emissions	Amount, concentration, toxicity:	Degradability	Impacts
Waterborne		Mobility/transport	
	Non hazardous		
	Hazardous		
	Radioactive		

Ecological Health

Ecosystem Stressors	*Impact Categories*		*Scale*
Physical	Diversity	System structure and function	Local
Biological	Sustainability, resilience to stressors		Regional
Chemical		Sensitive species	Global

Table 1 cont.

Human Health			
Population at Risk	*Exposure Routes*	*Toxic Character*	*Accidents*
Workers Users Community	Inhalation, skin contact, ingestion *Duration & frequency*	Acute effects Chronic effects Morbidity/mortality	Type & frequency Nuisance Effects Noise, odors, visibility

3. CONCLUSIONS

Ranking and weighting distinguishes between critical and marely desirable requirements. An example of one useful classification scheme follows:

– “must requirements” are conditions that designs have to meet. No design is acceptable unless it satisfies all must requirements. Government regulations are examples of must requirements,

– “want requirements” are desirable traits that are not mandatory. Want requirements help designers seek the best solution, not just the first alternative that satisfies mandatory conditions. These criteria play a critical role in customer acceptance and perceptions of quality,

– “ancillary functions” are low-ranked in terms of relative importance. They are relegated to a wish list. Designers should be aware that such desires exist, but ancillary functions should only be expressed in design when then do not compromise more critical functions. Customers or clients should not expect designs to reflect many ancillary requirements [Frosch, Gallopoules 1989].

Once must requirements are specified, want and ancillary requirements can be assigned priorities. There are no simple rules for weighting requirements. Assigning priority to requirements is always a difficult task, because different classes of requirements are stated and measured in different units. Judgments based on the values of the design team must be used to arrive at priorities.

Requirements can also be strategically organized in a time dimension. Future or anticipated requirements which may not be presently met can be distinguished from other requirements that apply to current designs.

REFERENCES

Alting L., Joergenson J., 1993, The life cycle concept as a basis for sustainable industrial production. Annals of the CIRP, Vol. 42, No. 1.

Ashley S., 1993, Design for the Environment. Mechanical Engineering, Vol. 115, No. 3.

US Environmental Protection Agency, 1991, Assessing the environmental consumer market, Washington DC.

Calkins D.E., Gaevert R.S., Michel F.T., Richter K.J., 1989, Aerospace system unified life cycle engineering: producibility measurement issues. IDA Paper P-2151 Institute for Defeuse Analyses, Alexandria, Virginia.

Caracostas P., Muldur U., 1997, Society, the endles frontier. A European vision of research and innovation policies for the 21st century. EC Studies. Luxembourg.

Coulter S., Bras B., Foley C., 1995, A lexicon of green engineering terms. International Conference on Engineering Design ICED 95, Praha.

Frosch R., Gallopoules N., 1989, Strategies for manufacturing. Scientific American, Vol. 261, No. 3.

Gause D.G., Weinberg G.M., 1989, Reguirements: Quality before design. Dorset House, New York.

Ishikawa K., 1985, What is total quality control. The Japanese way. Prentice Hall, Englewood Cliffs.

Keoleian G., Menerey D., 1994, Sustainable development by design: review of life cycle design and selected approaches. Air & Waste, Vol. 44.

Keoleian G., Menerey D., 1993, Life cycle design guidance monnal. U.S.EPA Office of Research and Development, Washington D.C.

Kłos Z., Kurczewski P., Laskowski G., 2000, Anticipative environmental valuation of technical realizations for machines and appliances. Wyd. PP, Poznań.

Matysiak L.M., 1993, Cost-Benefit Analysis for Design of Environmentally Conscious Manufacturing. Int. J. of Environmentally Conscious Design α Manufacturing, Vol. 2, No. 3.

Navin–Chandra D., 1991, Design for environmentability. Design Theory and Methodology, Vol. DE-31.

Nelson R., 1993, National innovation systems – a comparative analysis. OUP, New York.

Olsen J., Keldman T., 1993, Design for environment a fromework. 9th International Conference on Engineering Design. The Hague.

Richards D., Fullerton A., 1994, Industrial ecology: US-Japan perspectives. National Academy Press, Washington DC.

Ryan C., 1996, Life cycle analysis and design – a productive relationship? Proceedings of First National Conference on LCA. Melbourne.

Simon C., De Fries R., 1990, One earth, one future: our changing global environment. National Academy Press, Washington.

Soete L., 1996, The challenge of innovation. The IPTS Report, No. 7.

Stoner J., 1995, Freeman E., Gilbert D., Management. Prentice Hall, Englewood Cliffs.

The competitiveness of European industry, 1997, EC Luxembourg.

Treeman H., Harten T., Springer J., Randall P., Curran M.A., Stone K., 1992, Industrial pollution prevention: A critical review. J. of the Air and Waste Management Association, Vol. 42, No. 5.

U.S. Congress, Office of Technology Assessment, 1992, Green products by design: choices for a cleaner environment. U.S. Government Printing Office. Washington D.C.

Von der Horst T.J.J., Zweers A., 1993, Environmentally oriented product development; Various approaches to success. 9th International Conference on Engineering Design. The Hague.

Witczak J., Kasprzak J., Kłos Z., Kurczewski P., Lewandowska A., Lewicki R., 2014, Life cycle thinking in small and medium enterprises: the results of reseach on the implementation of life cycle to ols in Polish SMEs – part 2: lCA related aspects. Int. J. Life Cycle Assess, p. 891-900.

World Resources 1994-95, 1994. A report by the World Resources Institute. Oxford University Press, New York Oxford.

Zasady prośrodowiskowego projektowania obiektów technicznych dla potrzeb zarządzania ich cyklem życia. Red. P. Kurczewski, A. Lewandowska. Wyd. PP, Poznań 2008.

ŚRODOWISKOWA OCENA OBIEKTÓW TECHNICZNYCH – RAMY

Streszczenie

Wzrastające zainteresowanie różnych organizacji środowiskową oceną produktów wywołało potrzebę powstania metod w celu jej dokonania. Pewne próby w tym zakresie już podjęto, a dotyczyły one głównie przedmiotów codziennego użytku. Ponieważ w użyciu jest duża liczba maszyn i urządzeń oraz wywierają one sumarycznie znaczny wpływ na środowisko, specjalna uwaga winna być skupiona na tej właśnie grupie obiektów technicznych. W tej serii artykułów głównym zadaniem jest zaprezentowanie metodyki wartościowania maszyn i urządzeń, ze szczególnym uwzględnieniem aspektów środowiskowych. Metodyka ta uwzględnia analizę całego cyklu istnienia. W artykułach przedstawiono jej zastosowanie do oceny rzeczywistych obiektów. Na początku dokonano ogólnego przeglądu problemów środowiskowych w skali globalnej, a uwagę skoncentrowano na zagadnieniach, które są w centrum uwagi projektantów obiektów technicznych. Następnie omówiono szerokie spektrum czynników, które winny być rozważone w trakcie antycypacji obciążeń środowiskowych przez obiekty techniczne. Rozpatrzono różne podejścia do zagadnienia oceniania negatywnego oddziaływania środowiskowego, formułowane dla różnej skali. Do dalszego opracowania wybrano, jako najbardziej obiecujące, podejście cyklu życia.