Mechanisms and Machine Science

Jörg Niemann
Adrian Pisla

Life-Cycle Management of Machines and Mechanisms

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Jörg Niemann · Adrian Pisla

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Jörg Niemann
Department of Mechanical
and Process Engineering
Fachhochschule Düsseldorf
Düsseldorf, Nordrhein-Westfalen, Germany

Adrian Pisla
Design Engineering and Robotics
Department
Technical University of Cluj-Napoca
Cluj-Napoca, Romania

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Contents

Acronyms/Terms and Abbreviations

A&D	A&D Industry, Aerospace & Defense Industry
AAM	Application Activity Model
ABV	Added Business Value
AEC	Aided Engineering in Construction
AGV	Automated guided vehicle
AI	Artificial intelligence
AICAPA	American Institute of Certified Public Accountants
AIM	Application interpreted model
ANSI	American National Standards Institute
AOV	Average order value
AP	Application protocol
APPTR	Axial piston pump test rig
APUID	Acquisition Program Unique Identification
AR	Augmented reality, to the physical (real) components are added data for connecting characteristics to an image
ARIS	Architecture of Integrated Information Systems
ARM	Application Reference Model
ASCII	American Standard Code for Information Interchange is a character encoding standard for electronic communication. ASCII codes represent text in computers, telecommunications equipment, and other devices (labeling, bar codes, etc.)
ASG	Alternative scenarios generation
ASRS	Automated storage and retrieval systems
AT&T Inc.	American multinational conglomerate holding company headquartered at Whitacre Tower in Downtown Dallas, Texas
ATA	Air Transport Association
ATO	Assemble-to-order
AVM	Architecture virtual machine
BC	Best in the class
BCFTR	Bearing cage friction test rig

BFTM	Bending fatigue testing machine
BMC	Business Model Canvas
BO Model	Business object model
BOM	Bill of materials
BSC	Balanced scorecard
BTO	Build to order
BVC	Best value chain
C	Cheap, not expensive
CAC	Computer-aided control
CAD	Computer-aided design
CAE	Computer-aided engineering
CAM	Computer-aided manufacturing
CAPA	Corrective and preventive action
CAPP	Computer-aided processes planning
CAPP	Computer-aided production planning
CAQ	Computer-aided quality assurance
CAX	Computer aided for X applications
CCSDS	Consultative Committee for Space Data Systems, founded in 1982 for governmental and quasi-governmental space agencies to discuss and develop standards for space data and information systems
CE	Concurrent engineering
CEO	Chief Executive Officer
CHP	Combined heat and power plants (cogeneration plants)
CIL	Correlation with insurance companies and social dedicated legislation
CIM	Computer-integrated manufacturing
CM	Condition monitoring
CM	Configuration management
CMP	Change management profile
CNC	Computer numerical control
COS	Computer operating system
COTS	Commercial items including services
CPG	Consumer packaged goods
CPP	Conventional power plant
CPPS	Cyber-Physical Production System
CPR	Contract provided resources
CPU	Central processing units
CRISP-DA	Cross-industry standard process for data mining
CRM	Customer relationship management
CSI	Customer Satisfaction Index
CSR	Corporate social responsibility
CTC	Company technological culture
CTO	Chief Technical Officer
CUS	Conversions–upgrading–shutdown

D&M	Design and manufacturing
DAC	Digital Age Context
DAG	Directed acyclic graph
DAM	Digital assets management
DAO	Data access objects
DB	Databases
DC	Designated community
DF	Digital factory
DFE	Design for the Environment
DFEA	Design for Environment Alternatives
DHD	Documents handling department
DITA	Darwin Information Typing Architecture
DKP	Direct kinematic problem
DL	Deep learning
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DMS	Data management solution
DMSS	Digital mobile security systems
DMU	Digital mockup
DNC	Direct numerical control
DoD	Department of Defense
DPI	Dots per inch
DPM	Direct part marking
DPS	Digital preservation system/digital preservation strategy
DRP	Disaster recovery plan
DRS	Distributed Resource Scheduler
DSN	Data source name
DSPD	Data sources, processing, and distribution
DT	Digital tool/digital twin
DTO	Data transfer object
DTT	Digital twin technology
EAM	Enterprise asset management
EAS	Engineering analysis and simulation
EBIT	Earnings before interest and taxes
EBITDA	Earnings before interest, taxes, depreciation, and amortization
ECC	Error correcting code memory
ECM	Engineering change management
EDGE	Enhanced Data Rates for Global Evolution network
EDM	Engineering Data Management
EDMS	Electronic data management system
EH&S	Environment, health and safety
EHD	Elastohydrodynamic
EID	Enterprise Identifier
EK	Engineering knowledge
EMD	Electromechanical design
EMK	Engineering and management knowledge

EMS	Energy management system
EOF	End-of-life, management
EOL	End-of-life
EPP	Electronic prototyping platform
ER	Enhanced reality
ERP	Enterprise resource planning
ETO	Engineering to order
FAR	Federal Acquisition Regulation
FASB	Financial Accounting Standards Board
FBS	Function–behavior–structure
FDA	Food and Drug Administration
FGI	Finished goods inventory
FMECA	Failure mode effects and criticality analysis
FMS	Flexible manufacturing systems
FPGA	Field-programmable gate array
FSA	Flexible Spending Account, also known as flexible spending arrangement
FTO	Freedom to Operate
FWTR	Fretting wear test rig
G	Good
GD&T	Geometric dimensioning and tolerancing
GHG	Greenhouse Gas protocol
GRA	Golden Robot Award
GSM/EDGE	The technology Enhanced Data for Global Evolution (EDGE) is a high-speed mobile data standard, intended to enable second-generation Global System for Mobile communication (GSM) and time-division multiple access (TDMA) networks to transmit data at up to 384 kilobits per second (Kbps)
GTO	Game theory optimal
HMI	Human–machine interfaces
Homo Faber	In Latin, means "Man the Smith," "Man the Maker," or "Man the Toolmaker." As used by Max Frisch, it refers to a man who controls his environment through his abilities and tools, to be a maker of things. Including the Internet of things (IoT) or the industrial Internet of things (IIoT)
HVAC	Heating ventilation/air conditioning
I/O	Input/output
I4.0	The Fourth Industrial Revolution, rise from the activities digitalization
ICAM	Integrated Computer-Aided Manufacturing
ICT	Information and Communications Technology
IDEF0	Integration definition for function modeling
IEC	International Electrotechnical Commission

IEEE	Institute of Electrical and Electronics Engineers, a professional association for electronic engineering and electrical engineering with its corporate office in New York City
IFIP	International Federation for Information Processing
IIC	Information item contents, lifecycle management documents
IIoT	Industrial Internet of things
IKP	Inverse kinematic problem
ILS	Integrated logistic support
IMPS	Integrated manufacturing process systems
IoT	Internet of things
IPR	Intellectual property rights
IQ	An intelligence quotient is a total score derived from a set of standardized tests designed to assess human intelligence
IRR	Internal rate of return
ISO	International Standardization Organization
ISV	Independent software vendors
IT	Information Technology
ITAR	International Traffic in Arms Regulations
ITT	Invitation to tender
IUID	Item Unique Identification
JBP	Joint Business Planning
JEDEC	Joint Electron Device Engineering Council, a solid-state technology association independent semiconductor engineering trade organization and standardization body
JTC	Joint Technical Committee
JT™	Data format, for viewing and sharing lightweight 3D product data
KADS	Knowledge analysis and design support
KBS	Knowledge-based systems
KDE SC	K Desktop Environment Software Compilation, founded in 1996 by Matthias Ettrich, a student at the University of Tübingen, troubled at the time by certain aspects of the Unix desktop. Among his qualms was that none of the applications looked, felt, or worked alike. He proposed the formation of not only a set of applications, but, rather, a desktop environment, in which users could expect things to look, feel, and work consistently. He also wanted to make this desktop easy to use; one of his complaints with desktop applications of the time was that his girlfriend could not use them. His initial Usenet post spurred a lot of interest, and the KDE project was born
KPI	Key performance indicators
LAN	Local area network
LCA	Life cycle assessment (or life cycle analysis)
LCC	Life cycle cost
LCM	Lifecycle management
LCP	Life cycle planning

LSF	Logistic storing facilities
LTE	Long-Term Evolution, a 4G communication standard for wireless broadband communication for mobile devices and data terminals, based on the GSM/EDGE and UMTS/HSPA technologies
LTO	Limited time offer
M2M	Machine to machine
MANK	Management knowledge
MBSE	Model-based systems engineering
MDA	Model-driven approach
MDE	Multiple Discipline Engineering
MK	Marketing knowledge
ML	Machine learning
MLM	Machines and mechanisms lifecycle management
MM	Machines and mechanisms
MoU	Memorandum of understanding
MPR	Micro-pitting rig
MR	Mixed reality
MRO	Maintenance, repair, and overhaul
MTO	Made to order/Make to order/Manufacture to order
NC	Numerical control
NDA	Net Digital Age
NEN	Nederlands Normalisatie-instituut
NOPAT	Net operating profit after taxes
NPV	Net present value
OAIS	Open Archival Information System
OASIS	Open standards opens source
OEM	Original Equipment Manufacturer
OMG	Object Management Group
ORC	Organic Rankine cycle is a steam generator that uses an organic, high molecular mass fluid with a liquid–vapor phase change, or boiling point, occurring at a lower temperature than the water–steam phase change
OSLC	Open Services for Lifecycle Collaboration
PAS	Publicly Available Specification
PASM	Product accompanying service model
PBM	Policy-based management
PC	Personal computer
PCB	Printed circuit boards
PCH	Project change histories
PCPR	Previous contract provided resources
PD	Product data
PDM	Product data management
PESTEL	Political, economic, social, technology, environmental, legal
PiP	Picture in picture
PIV	Particle image velocimetry

PLC	Programmable logic controllers
PLCS	Application Protocol for Product Life Cycle Support
PLM	Product lifecycle management
PLMP	Product lifecycle management platform
PM	Parts management
PMBOK	Product management book of knowledge
PMT	Project management triangle
POD	Pin on disk
POF	Problem optimization formulation
POS	Point of sale
PP	Product process
PPC	Production planning and control
PROSA	Product sustainability assessment
ProSeCo	Product and service co-design
PSH	Process Simulate Human
PSM	Product structure management
PSS	Product-service system
PTAB	Primary Trustworthy Digital Repository Authorisation Body
PTO	Paid time off
PTR	Pump test rig
PVM	Process virtual machine
R&D	Research and development
RACI	Responsible, Accountable, Consulted, Informed
RCF	Relative centrifugal force
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals, an European Union regulation dating from 18 December 2006
RFID	Radio-frequency identification
RGB	Red Green Blue, is an additive color model in which red, green, and blue light are added together in various ways to reproduce a broad array of colors. The name of the model comes from the initials of the three additive primary colors
RIO	CompactRIO is a real-time embedded industrial controller made by National Instruments for industrial control systems. The CompactRIO is a combination of a real-time controller, reconfigurable IO modules, FPGA module, and an Ethernet expansion chassis
RMA	Records Management Applications
RMMD	Refined mechanism-machine design
RMT	Reliable Memory Technology
ROCE	Return on capital employed
RoHS	Restriction of Hazardous Substances Directive 2002/95/EC
ROI	Return on investment
RPA	Robotics process automation
RPM	Rotations per minute

RPUID	Real Property Unique Identification
RQ	Robotics quotient is a scoring way of a company or individual's about the ability to work effectively with robots
RTO	Recovery Time Objective
RTPV	Real-time project visibility
S	Swift
SADT	Structured analysis and design technique
SCM	Supply chain management
SE	Sale Engineer
SEC	Securities and Exchange Commission, an independent agency of the United States federal government
SEM	Systems engineering methodologies
SEO	Systems Engineering Organization
SHRM	Society for Human Resource Management
SIPOC	Suppliers, inputs, process, outputs, customers
SLM	Simulation lifecycle management/service lifecycle management
SMBO	Sequential model-based optimization
SME	Small and medium-sized enterprises
SMRL	Semantic Markup Rule Language
SOP	Standard operating procedure
SPDM	Simulation and Process Data Management
SSCC	Serial Shipping Containers Code
ST	Synchronous technology
STEP	Standard for the Exchange of Product Model Data
STEP	Is an open-source two-dimensional physics simulation engine that is included in the KDE SC
SVM	System virtual machine/support vector machine, a supervised machine learning model that uses classification algorithms for two-group classification problems.
SWOT	Strengths, weaknesses, opportunities, threats
SysML	Systems Modeling Language
TaT	Turnaround time
TCD	Total customer demand
TCO	Total cost of ownership
TCP	Tool Center Point
TLCM	Total Life Cycle Management
TOC	Total ownership cost
TPM	Trusted Platform Module
TRL	Technology readiness level
TTM	Time to market
TTR	Tiltrotor test rig
TTR	Turbocharger test rig
TWTR	Thrust washer test rig
UA	User agent
UI	User interface

UID	Unique Identification
UII	Unique item identifier
UML	Unified Modeling Language
UMTS/HSPA	Technologies, where UMTS provides a clear evolutionary path to high-speed packet access (HSPA). HSPA refers to the combination of high-speed downlink packet access (HSDPA) and high-speed uplink packet access (HSUPA) that allows data rates up to 14.4 Mbit/s in the downlink
VC	Variant configurator
VM	Virtual machine
VMC	Virtual machine controls
VMM	Virtual machine monitor (hypervisor)
VMT	Virtual machine templates
VP	Vice President
VR	Virtual reality
VSM	Viable system model
VSOE	Vendor-specific objective evidence
VTR	Valve test rig
W3C	World Wide Web Consortium
WACC	Weighted average cost of capital
WAN	Wide area network
WBS	Work breakdown structure
WEEE	Waste Electrical and Electronic Equipment Directive (2002/96/EC)
WIPO	World Intellectual Property Organization
WPDM	Web-based PDM
XML	Extensible Markup Language

Part I
Life Cycle System Modeling: Factors of PLM Design

Chapter 1
Product Life Cycle and Services Management

1.1 The New Paradigm

Industrial manufacturing and the consumption of technical products have led to a dramatic depletion of natural resources and an increasing strain on the environment due to emissions. Society's heightened ecological awareness is taking effect, with the result that more and more companies are publicly committing themselves to environmental protection. In the process, laws and requirements are bringing about a change in the management of resources. Many companies now recognise the fact that they can make cost savings by encapsulating critical technical processes and handling problem materials more frugally. Today, this development is leading to a rediscovery of the product life cycle. In consequence, this development is also strengthening the sustainability sought by politics and society with regard to responsible commercial trading. Commercial sustainability means that all trade should be orientated towards maintaining all resources. The question at the core of manufacturing is how to achieve overall value creation with one product over its entire lifetime by taking life cycle management into account. Consequently, a change in strategies has taken place which not only takes economical aims but also ecological and societal aspects into consideration in the design and utilisation of technical products (Fig. 1.1).

Manufacturers have to accept more and more responsibility for the usability of their technical products and for the consequences of usage. However, many companies only follow statutory general conditions in pre-sales and after-sales in order to avoid losing their markets. There is a general impression that the cost-benefit ratio, especially in after-sales business, is insufficient. This also applies to industrial recycling.One main factor is the availability of actual information about the products and a lack of synergy between final assembly and after-sales operations [1].

The development of modern products is being decisively influenced by the application of technologies contributing towards increased efficiency. Products are becoming complex highly-integrated systems with internal technical intelligence enabling the user to implement them reliably, economically and successfully even in the fringe

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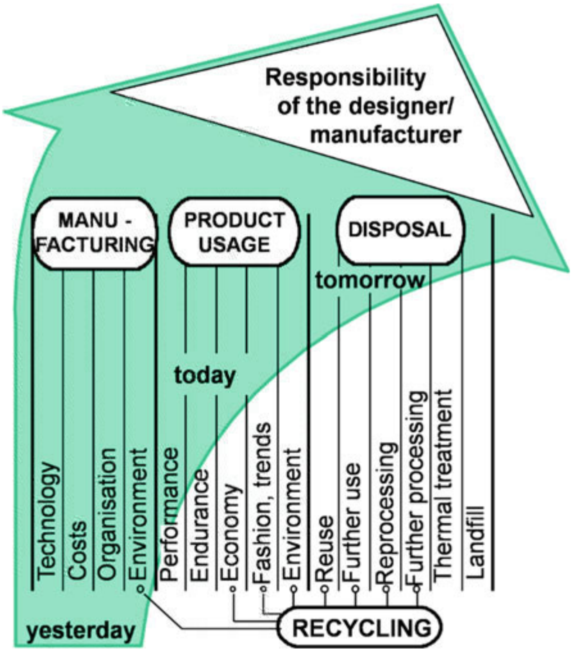

Fig. 1.1 Increased responsibility over the entire product life cycle

ranges of technology. As a result, business strategies are aiming more and more at perfecting technical systems, optimising product usage and maximising added value over the entire lifetime of a product. In this context, the total management of product life cycles coupled with the integration of information and communications systems is becoming a key success factor for industrial companies.

When manufacturing technical products, industrial companies generally direct their strategies towards economic targets. Their main business lies in developing, producing and operating products either for individual customers or for complete sectors of the market. Service and maintenance are considered by many companies to be necessary in order to achieve lasting business relationships with customers.

Several studies indicate that the role of these services will change from being a product-accompanying service to becoming the main *revenue driver*. This means that the original product itself will turn into a vehicle (platform) to sell such services as *main business* [1].

Consequently, industrial manufacturing companies are increasingly concentrating their businesses on engineering, assembly and services. They are following new paradigms in order to add value through customer orientation, system management and services during the lifetime of their products. The machine manufacturing industry and other industrial fields such as the automobile industry have reduced their own capacities down to the main or core technologies and final assembly. Parts and components are manufactured by suppliers or specialised companies. Profit is increasingly becoming a result of business operations in design, engineering, final assembly and service. These phases of production are the core competencies of companies which produce strong market or customer-orientated products and add value during a product's life cycle [2].

The functionalities of products are defined in the processes of design and engineering. The functionality of products and their specific or characteristic properties for usage are determined (as built) or altered by assembling, maintaining and disassembling real configurations. In the usage phase, special know-how regarding design and characteristic properties is required, such as specific process knowledge for optimising utilisation and performance. Increasing technical complexity is promoting product-near services and manufacturer assistance. This brings about new business models for marketing only the functionality of capital-intensive products rather than selling the products themselves.

There is a new paradigm behind these tendencies: in order to add value and maximise utilisation, products are linked in the manufacturer's network from the beginning right up to the end (Fig. 1.2). In order to realise this paradigm, manufacturers need life cycle management (LCM) systems, tools and technologies. The concentration of all processes into the total life cycle of a product and the optimisation of usage of each single technical product can be described as a new paradigm. Seen from a global point or macro-economical point of view, this is only logical. Seen from an operational or micro-economical point of view, it is proving difficult to initiate such strategies. This is because fundamental structural changes are required in products as well as in organisations and production technologies and also that the economic benefits involved are either uncertain or associated with risks [1].

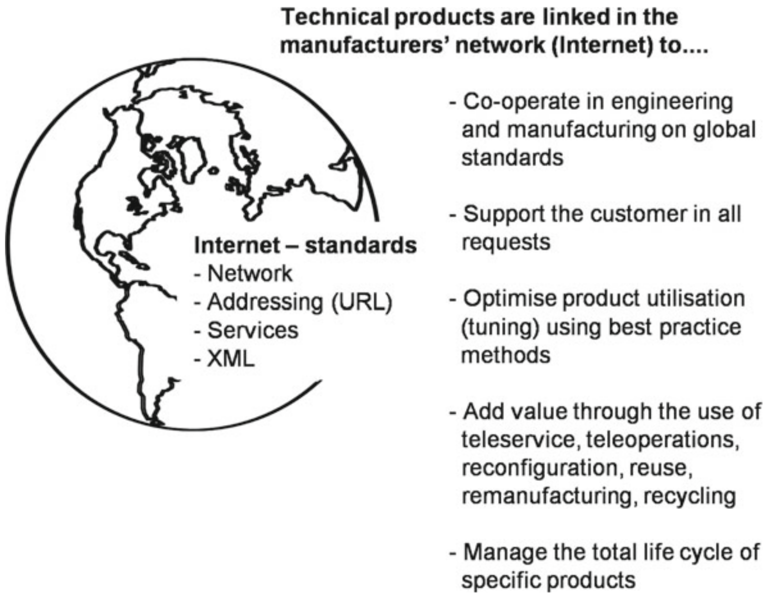

Fig. 1.2 The vision of life cycle management

Additionally, locally optimised product life cycles (i.e. optimisation of individual processes) may not exhibit superior performance globally from multi-objective perspectives. Therefore, the performance of product life cycles needs to be evaluated from holistic and multi-objective perspectives.

However, there is a futuristic vision in the life cycle management of optimising the total exploitation of each product and reducing environmental impact to a minimum. In reality, the different types of products need to be taken into account individually. For some products, it makes economic sense to link them to the manufacturer's network. If the futuristic vision is followed that all machines and high-quality technical products remain in the manufacturer's information network, the Internet will attain a central importance in total life cycle management [3–5].

The strategies followed by companies are significantly dependent upon the type of product involved. In a preliminary classification, three categories with varying time scales and strategies may be defined. The first category is goods with a short lifetime and a low product value or complexity. Such non-durable technical consumer goods are usually mass-produced and manufactured in large series. Here the main emphasis of life cycle management is placed on the rational organisation of services, marketing and product recycling techniques. Robust techniques can be used for recycling due to the fact that the added value profit is low in relation to the value of the product. The second category is assigned to series products with a limited number of variants. Life cycle management for these products includes services and maintenance as well as industrial recycling and the partial reuse of parts and components. The third category is reserved for high-quality capital goods. The main emphases here are on maximum utilisation strategies, maintaining performance and additional added value in the field of after-sales. Industrial recycling only plays a minor economic role in this category of products.

A forward-looking life cycle plan for the product is one example of a maximum utilisation strategy. On completion of the usage phase, the owner faces the alternatives of either scrapping/recycling the product or of upgrading it. Through upgrading, the product is transformed so that it obtains a new operational status reflected in new product functions. Specific software or hardware modifications are carried out on the product to equip it with advanced, extended or new functional features in comparison with its original condition. Consequently, the product can be improved, extended or utilised to perform completely new tasks. Through upgrading, a product almost starts a new life (Fig. 1.3).

However, upgrading is not always possible due to either technical or economic circumstances. In order to be able to upgrade at a later point in time, far-sighted product planning is required which commences in the product engineering stage. In this early phase of development, the fundamental product features—including later modification possibilities—are fixed. Numerous technical and organisational measures decide whether a product can be successfully transformed to attain another level.

From a technical point of view, the modular design of a product's construction is of particular importance. Modular product design in accordance with the laws of system technology enables the variable and economically-viable re-design of a

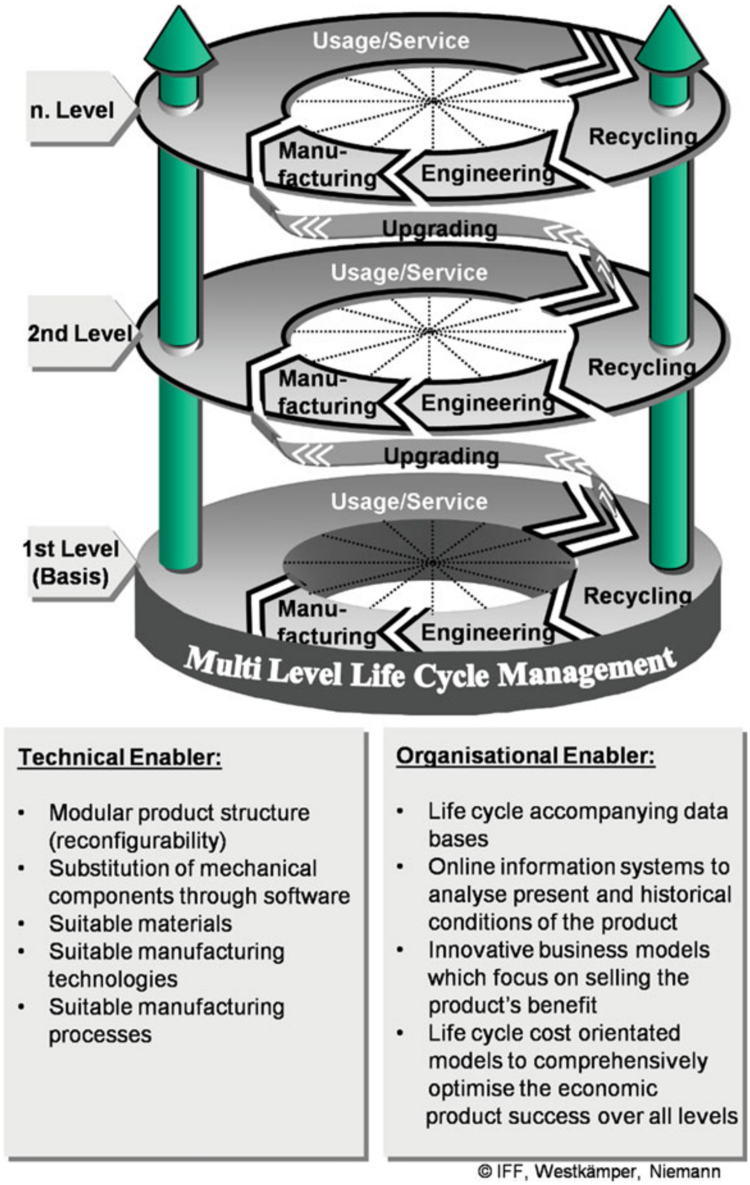

Fig. 1.3 Products have several lives [2]

product throughout its entire lifetime. If the fact is taken into consideration that a product may be modified many times over or even altered completely during its lifetime, such product constructions not only bring about advantages for product maintenance but also create enormous potentials. The increasing substitution of mechanical components with software also supports the short-term usage of a product for variable task assignments. Retrofitting times can be shortened due to the fact that modified software can be installed much faster than hardware components can be exchanged [1].

From a technical point of view, product optimisation can be supported using lifelong data acquisition. Data-logging enables the behaviour of a product to be statistically analysed or products and processes to be monitoring online. The data obtained using this method is evaluated according to specific criteria and discloses optimisation potentials. This permits machines to be completely controlled with the result that, in the future, not only will it be possible to perform technical optimisation but also to take economical factors into consideration and to carry out far-sighted planning thanks to the availability of "real" machine data. Life cycle simulation techniques also enable us to predict product behaviour even in the early phases of the design process. Such real machine data dynamically improve the life cycle model used in life cycle simulation. Up till now, conventional manufacturing paradigms have focused on profit aspects associated with manufacturing and selling products to the end-customer. The new paradigm takes into account the life cycle of technical products and the optimisation of value and benefits during the phases of engineering, assembly, service, maintenance and disassembly. The objective is to reduce environmental losses and to fulfil public or governmental restrictions over the life cycle [5, 6].

Following the new paradigm of optimisation and added value over the total life of products, a structural change in the relationship between the manufacturer and the user will take place. Both have different views regarding the same business processes in the life of products, as shown in Fig. 1.4.

Different views held about the same product are the result of industrial developments in the twenty-first century. In the future, the holistic view will offer new ages of manufacturing.

1.2 Manufacturer's Viewpoint

In general, the life cycle of products can be divided into the phases of design and engineering, manufacturing, assembly, usage, service, disassembly and recycling.

The main objective is to fulfil markets and customer requirements to ensure the efficient utilisation of manufacturing resources. The new view adds value in the usage and recycling phases as a result of customer-related services including maintenance and disassembly for reconfiguration, reuse and recycling. More than ever before, this view of the usage and recycling phases makes it indispensable to take into account

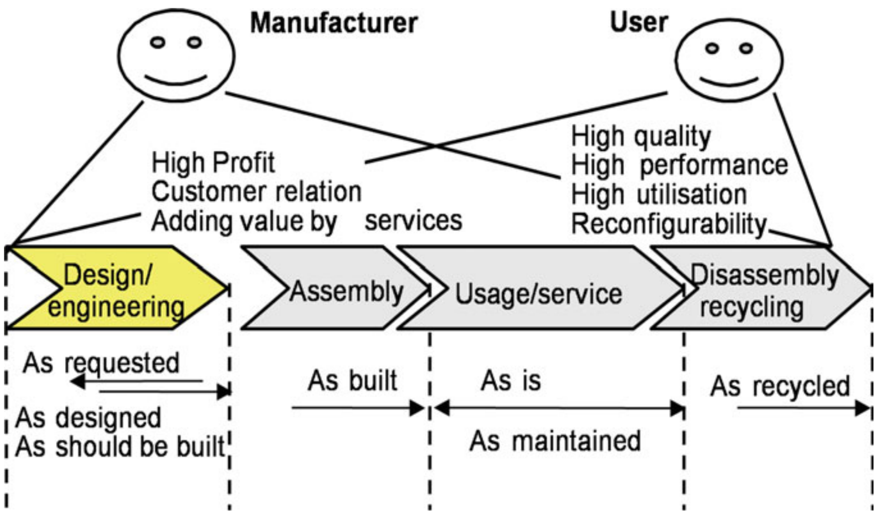

Fig. 1.4 Views of manufacturers and users on the life cycle of technical products

the various aspects of life cycle design and engineering or the capability of systems to be assembled, disassembled and diagnosed in all phases, especially in that of usage.

It is also necessary to describe the architecture of a product which, in effect, is a mixture of goods and services. Using a model of the integrated architecture, interdependencies between goods and services can be managed more easily because it clarifies how various parts contribute to realising a function. As mentioned before, the early phases of the manufacturing process are mostly outsourced to suppliers. Therefore, it is necessary to consider the relationship between manufacturers and suppliers from an economical and environmental perspective. This creates profitable product-orientated services throughout all operations by supporting the diagnostics of actual features, as well as the partial disassembly and assembly for reconfiguration or upgrading and the final disassembly for recycling [7, 8].

1.3 Customer's Viewpoint

Customers are generally interested in achieving high product utilisation in the usage phase at the lowest cost, even if this demands that manufacturing processes need to be changed. This requires flexible manufacturing systems which provide guaranteed process performance and require minimal set-up times and costs. The high efficiency of the usage of complex technical products depends on specific skills and know-how concerned with the details of machines, mechatronic components, software and process optimisation. These costs can be overcome by using specific skilled services and assistance or support provided by manufacturers. Users prefer buying specialised services to reduce the fixed costs of products as well as the costs of inspection, maintenance and reconfiguration or upgrading.

The economic efficiency of capital-intensive products in industrial manufacturing depends on the demands and profiles of products, technical requirements and capacities. These requirements are constantly changing with the result that manufacturing systems need to be permanently adapted [7].

1.4 Goals of a Sustainable Product Life Cycle Management

The new paradigm of optimising a technical product's cost–benefit is orientated not only towards economic but also towards environmental aspects by applying ecological criteria. It assumes that the concentration on core competencies and specialisation offers new potentials to add value or reduce the cost of usage by industrialising services and disassembly.

A common understanding between manufacturers and users is a prerequisite for activating potentials in order to obtain the maximum benefit from each technical product during its life cycle and to fulfil economic and environmental objectives (Fig. 1.5).

Common sense and active optimisation demand technical solutions that link products at any point in the time of their entire life cycle to the information networks of manufacturers and users. This can be achieved by integrating technical products into global IT networks and electronic services. It is evident today that we have the technologies to do this and also to follow the technical trend for developing intelligent machines connected up to communications systems [9–11].

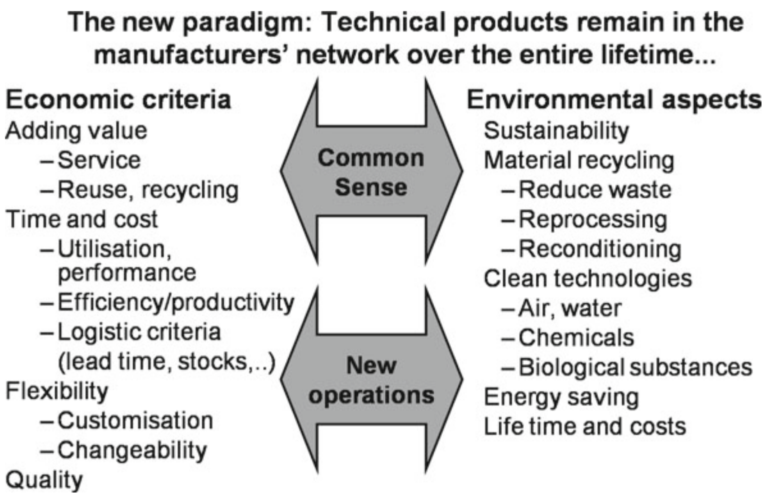

Fig. 1.5 Objectives of life cycle management