An investigation into the early and retirement life-cycle stages: tools, requirements

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Abstract: This publication discusses the integration of the conceptual design and the end-of-life stages in the management of a product. This is done by pointing out the influences of the end-of-life of a product on the cost of a product and investigating links between these two stages. Then, both stages and their interrelations are examined for possible needs in terms of their management. This knowledge is then used to evaluate the status quo of product life-cycle management. In particular, the gap between the "as-is" and "should be" functionality of PLM solutions with respect to these two stages is examined for two most popular PLM solutions.

Keyword: conceptual design, end-of-life, PLM, product life-cycle management

1 Introduction

Product life-cycle management (PLM) -- as considered in this publication -- is a holistic approach concerned with product data, the associated business processes governing it, as well as people involved in the various stages of the life of the product as defined in [1]. PLM by this definition can be looked upon as being the sum of three aspects:

Product data, which comprises all data related to the product: CAD/CAM models, bills of material, and so on, including documents such as governmental regulations and costumer feed back.

Extended enterprise consists of strategic partners of a company and other product stake holders (for example, materials suppliers, sub-contractors, and customers). Thus, the extended enterprise possibly includes multi-national companies and may extend beyond geographical and company boundaries.

People, processes, information and business systems comprises everybody and everything that is part of the workflow. Processes include program and project management processes as well as processes required to manufacture the product or plant, the processes to distribute, operate, dispose, or decommission the product at the end of its useful life. Business systems encompass, among others, CRM, SCM, and ERP systems.

Although alternative definitions of PLM exist, the authors feel that this definition is closest to their understanding of PLM and because it is independent of any organisation (in particular their strategic interest) or PLM implementation.

1.1 Motivation

The primary reason for the industry using PLM systems is the need for improving the management of PLM in order to provide sustainable products at lowest cost and to capture the market the soonest possible due to an improved management of the three aspects of PLM [2]. The improvement in communication within a company and the extended enterprise is perhaps the most important single benefit from a functional product lifecycle management system [3]. Currently, PLM solutions and their actual implementation in companies are most prevalent for the detailed design and manufacturing stages, but are rather scarce if not absent in other stages. It can be expected that if PLM is extended to other stages in a product’s life-cycle, a company’s competitiveness can be further improved. This publication therefore focuses on the needs of other life-cycle stages, in particular on the conceptual design and product end-of-life for reasons further discussed in the following.

The conceptual design stage is rather crucial in determining the overall direction of the product development process [4, 5]. A good product concept can reduce the number of design iterations and therefore benefit the timeliness of the product launch. When a new product is launched, the first two companies control about 80% of market share within that particular product category [6]. Furthermore, compared with the later stages of product development, product conceptualization commits more than 70% of total cost incurred during the entire product life cycle. In other words, even the highest quality of manufacturing and production cannot compensate for a poor design concept released from the product conceptualization stage. Decisions made at the conceptual design stage have significant influence on factors such as costs, performance, reliability, safety and environmental impact of a product [7]. It is estimated that around 60% of the resources needed to manufacture a product are committed once the conceptual design is completed [8]. As the conceptual design itself accounts for a relatively small percentage of the total development cost, investing in this stage has pivotal effects with respect to product costs [9].

At the same time, the influence of a product's end-of-life on (conceptual) design becomes stronger for several reasons:

- The consumer is the dominant stake holder in the end-of-life of a product and has growing demands in terms of ecological impact, customisability, functionality, energy consumption, and so on.
- Ecological constraints on products become stricter: standards and regulations constrain the use of materials and the way they are disposed or recycled, enforce systematic collection of products for recycling, or disallow the use of certain substances [10, 11].

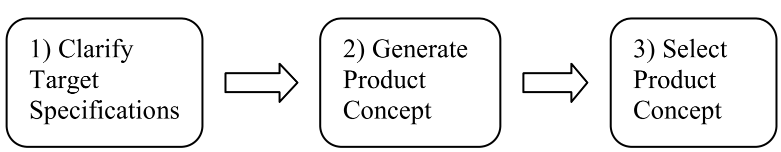
This strengthening of influences of constraints originating from a product's end-of-life on design implies that one should not be considered without the other. It is not inconceivable that in the near future a design will only be successful if it complies with constraints imposed by its end-of-life. In consequence of this observation and to better understand how today's PLM solutions support these two life-cycle stages in terms of data, processes and benefits to stakeholders, this paper

- discusses the characteristics of these two stages,
- tries to identify the needs of these two stages, and
- examines dominant PLM solutions – those offered by UGS and Autodesk – with respect to their proposed management of the two stages in question. It is *not* the intention of the authors to compare the solutions on the basis of their efficiency, usability, and so on.

2 Conceptual design

During this stage, the company's strategic partners and customers align their needs and requirements. Then, the company's product designers develop a design concept, which is subsequently developed in the embodiment design stage. Although many highly detailed methodologies for the conceptual design exist (see for example [12-15]), this paper is based on the simplified model presented in figure 1, which captures the essence of all these more elaborate models while highlighting the essential activities.

Figure 1: essential steps of the conceptual design stage



The three steps are:

1) *Clarify target specifications*: the engineering design specification embodies information on customer and company requirements, which fall into three groups:

- **Functional performance**: motion/kinematics, forces/torque, energy conversion/usage, control.

- **Operating environment**: air temperature, pressure, humidity, contaminants, shock, and vibration.
- **Product factors safety**: economic, geometric limitation, maintenance, repair, retirement, reliability, robustness, pollution, human factors, and appearance.

The customer requirements and the preliminary product specifications are inputs to this stage, although often this information is still refined after the concept generation is initiated. The three main outcomes are:

- An activity analysis list
- A function decomposition diagram.
- A technical specification list
- A product modular decomposition diagram

2) *Generate product concepts*: the design team determines the approximate description of the technology, the working principles, the form of the product, as well as many ideas and concepts as possible so to ensure that the design space is thoroughly explored [9]. A concept is usually expressed as a set of sketches or rough three-dimensional models accompanied by brief textual descriptions. Designers critically examine its feasibility and possibilities for further improvement. Idea generation requires creativity and imagination as well as logic and reasoning to analyze and ascertain the feasibility of the concepts and ideas. Though the proficiency of designing and idea generation may seem to depend highly on individual skill and expertise, the process can also be improved through the use of rational and systematic design methods. There are many steps in the concept generation stage and they serve different functions. The steps and tools used are summarized in table 1.

Table 1: Steps in concept generation

Step		Tools
Search Externally	Aimed at finding existing solutions to satisfy the specifications identified in the previous stage. The external search is essentially an information gathering process.	1. Interviews 2. Consult experts 3. Search patents 4. Search published literature 5. Benchmarking
Search Internally	Internal search uses personal and team knowledge and creativity to generate solution concepts.	1.Individual discussion 2.Group discussion 3.Review of relevant past cases
Explore	A systematic exploration alternative solutions results in a synthesis of solutions fragments.	1. Classification tree 2. Morphological chart 3. Concept combination table

2.1 Current practices of conceptual design

Each team member usually maintains a project notebook containing information such as product ideas and sketches that may be used for patent disclosures as well as trademark and/or copyright registrations [16, 17]. The team establishes a central repository. Sketching is preferred as compared to CAD as they can quickly communicate form and function. Design review meeting minutes are maintained to record the team's findings as well as its reasoning. Subsequent design teams may tighten the design process arising from the minutes to avoid past mistakes [18]. During activities related to the concept design stage, a host of information and documents is produced and processed:

Photocopies of archival matter	Printouts from the internet
Vendor catalogues and data sheets	Preliminary test results
Approximate calculations	Patent abstracts
Minutes of meetings	Concept sketches
Concept screening sheets	Concept evaluation matrices
Expert interview notes	Standards, laws, etc.

2.2 The needs of the concept design

In the past, concept design activities relied on documents written on paper distributed and passed on according to a business process defined by a company. An absence or presence of a document triggered an action. In a digital environment, digital documents replace paper documents, yet the same or similar business processes are adopted.

To improve the product development process, new products are created by combining or modifying existing designs [19]. It is well-known that the reuse of existing design information is much more cost effective and time saving as compared to designing a product from scratch [20]. Thus, the ease of retrieving this data, determines to a considerable extent the efficiency of the design process. A globalisation of design, marketing, manufacturing and support is a major factor for companies to remain competitive [2]. Consequently, there is a need for the concept design team to communicate efficiently over large distances. Product conceptualization must also take into account the marketing perspective [21]. Based on this understanding, an integration of the three perspectives, namely functional, commercial and marketing, becomes imperative in product conceptualization. Criteria based on these factors can help the designer to select the best concept more comprehensively and appropriately.

Overall, the conceptual as well as other design stages hinge very much on an efficient collaboration and communication, possibly over large distances. This suggests the use of a virtual PLM room in which the team can work and exchange information. In this room, visualization tools and access to the same data as used in a conventional design process are very important. Table 2 shows some of the activities that the authors feel a virtual PLM room should accommodate.

Table 2: Design activities and tools

Activities	Tools/methods
Search	Data vault (past designs and related information) Design pattern recognition and analysis Online catalogue Web-browser
Write	Word processor
Sketch and Design	Sketching tools, CAD Recalled existing design patterns and modules with modification tools
Analyze	Spreadsheets Flow charts Quality function deployment (QFD) tables Engineering design specification tools
Discussion, Decision making, and review	Voice and video recording and playback Minutes Digital whiteboard Vote scoring matrices Progress charts Presentation tools

3 Product end-of-life

Most considerations made with respect to a product's end-of-life concern directly or indirectly its environmental impact. However, companies do not directly judge the environmental impact of a design, including those from manufacturing, use and retirement, but base their judgment on governmental or international regulations or directives, industrial standards, and possibly recommendations from various sources or self-imposed rules (in the following, these documents are referred to as regulations). These considerations fall into two groups:

- The first group is most relevant to the conceptual or detailed design stage. Considerations in this group are implemented as a compliance of the product to regulations.
- The second group of considerations is related to use and retirement of the product (for example: detailed product information or contacts of remanufacturers).

Some of the information pertinent to a product can not be completely managed by a system installed in a company or in a group of companies, as an explicit (contractual) agreement or an explicit communication channel between their respective PLM systems is inconceivable. Examples for such situations are:

- The unavailability of a (comprehensive) PLM system due to technological or economical constraints.
- An end-user can not be expected to own or even access such a system (including, say, an online WWW interface to a PLM system).
- Numerous companies are potential partners for the collection, transport, repair, maintenance, recycling, treatment (including hazardous materials), or disposal of products. However, their number prevents the manufacturer from establishing individual agreements on end-of-life management all of them.

3.1 Current practices of end-of-life management

It is worth noting that a considerable amount of PLM is implicit in what may be called "best practices". For example, the industry standardizes materials, parts, labels, and so on, which considerably reduces the need for the exchange of product specifications and requirements. In other words, the bodies issuing industrial standards implicitly manage the life-cycle of a product or ease issues related to their management.

Designers and manufacturers check relevant regulations as comprehensively as possible and integrate them into product design and manufacturing processes, and so on. This practice excludes

- the compliance of manufacturing processes and related business activities,
- the generation of related reports or manuals and their distribution to concerned stakeholders, and
- the management of new or changes to existing regulations.

Stakeholders most concerned with these documents (though the relevance of these documents depends on the individual stakeholder) are designers (conceptual and detail), end-users, regulating bodies, as well as companies taking care of collection, remanufacturing, disposal, recycling, and so on of used products. The large number of stakeholders and types of documents implies that a workflow or a peer-to-peer communication is impossible and some sort of mass-communication is more suitable (WWW pages, mass-emailing, and similar).

With respect to remanufacturing and recycling, the manufacturer has to provide fairly detailed specifications of the product (or even give instructions for remanufacturing or recycling procedures). On the other hand, information on the ease of remanufacturing or recycling a certain product (possibly with suggestions for changes to the product) can help to improve the products and increase the competitiveness of the product. As remanufacturers, recyclers, and end-users are not necessarily in close contact (bound by an explicit contract or agreement), their integration in a PLM process requires communication channels that are accessible to everybody. Similar arguments apply to repair and maintenance of consumer products and low-cost products. The disposal of the product is rather different in this aspect: direct communication between the manufacturer, the end-user, and the company disposing of the product is likely not necessary.

3.2 The needs of end-of-life

With respect to the compliance of a product, its production, and its end-of-life treatment with regulations, a PLM system should provide tools to support the activities related to supervising its compliance. This tool is likely data driven (that is a process checking a product's compliance is triggered by a change to regulations or product data) and knowledge based (the regulations will have to be "translated" into a knowledge base which checks the compliance).

Effective communication between the designer or manufacturer and many end-of-life stakeholders is difficult to achieve within a dedicated PLM system. Therefore, a PLM system must support alternative information channels. These information channels could be:

- WWW pages with product information for end-users, recyclers, and so on.
- An electronic mail system alerting end-of-life stakeholders of product changes or other urgent issues.
- An integration of an analysis of costumer feedback obtained through email or a feedback WWW page.
- An online forum where companies announce their capabilities to handle a certain product.

Consequently, a PLM system should support these or interface with them.

4 Conceptual design and end-of-life

The link between conceptual design and end-of-life originates mostly from considerations of environmental aspects. Designers are required to reduce and avoid pollution caused by a product over the whole life-cycle. Some of these activities include choosing the materials for construction and auxiliary purposes, production processes and the disposal of waste materials. Table 1 summarizes important environmental factors a design team should consider.

Table 1: Environmental factors linked concept design

Material and part selection	The material or by-products of an (improper) disposal may pollute the environment or change the cost of product retirement.
Mechanical equipments and processes	Thermal pollution occurs when the ambient temperature increases at the work area. Apart from contributing waste energy, this effect causes discomfort and health problems.
	Noise pollution due to emission of sound from operating equipment or processes.
	Vibration of machines weakens structures and might result in failures and can be harmful for humans.
	Pollution by by-products of the manufacturing process.
Energy	Some of the energy used in machines can be recovered and reused (*e.g.* heat from combustion or air conditioning) or energy losses reduced (*e.g.* those from friction in bearings).

It is worth noting that the factors in table 1 often pertain to regulations. This means they are not handled differently compared to those concerned with safety issues or industrial standards.

End-of-life management requires (in particular remanufacturing, recycling, and disposal) information on the product that are not necessarily contained in a design.

In conclusion, the conceptual design stage raises the following challenges with respect to PLM:

- PLM has to establish links between multidisciplinary knowledge sources, possibly overlapping or conflicting with one another. This includes in particular parallel and periodically coordinated work by specialists with different backgrounds at geographically distant locations.
- This stage requires a systematic selection process of the best concepts based on factors like functionality and marketability, as well as the end-of-life.
- The reuse of design information in both semantics and implementation levels.
- An understanding and thorough documentation of customer needs, with an emphasis on end-of-life requirements, and linking them to technical specifications.

5 PLM solutions for conceptual design and end-of-life

5.1 Conceptual design

Autodesk [22] Alias Studio[1] and NX[2] by UGS [23] provide both industrial design and styling tools to support the concept design stage. Both solutions allow designers to sketch 2D or 3D models in a digital environment in various ways. Both systems claim to improve communications within the development team (attributed by the respective solution providers to the graphical representation of design concepts and the ease of creating them). Neither of the solutions integrates business processes or the extended enterprise applications as a PLM systems should.

Alias Studio entirely delegates PLM-related functionality other than rudimentary product data management to other solutions, *e.g.* Autodesk Data Management. Compared to this, NX provides similar functionalities as Alias Studio but implicitly integrates some PLM functionality as it includes CAD, CAM, and other modules. Whether this difference is significant is open to debate: Autodesk offers other solutions, which in sum provide similar functionality.

NX requires an additional PLM solution - Teamcenter or UGS Velocity - in order to cover the three aspects of PLM mentioned in the introduction. UGS's solution provides the following functionality relevant to conceptual design and end-of-life:

- Teamcenter Community, which can be configured to define a workflow and therefore communication channels with the extended enterprise (which seems to exclude the end-users and companies with no explicit alliance with the manufacturing company).
- Environmental and regulatory compliance management to address overall compliance objectives while enabling producers to comply with specific directives, as well manage and report on environmental compliance and material content [10, 11].

Both solutions support most of the identified needs of the conceptual design stage, but neglect the integration of functional, commercial and marketing concerns during product concept development beyond a simple inclusion of the respective stakeholders into the workflow.

Neither tool provides an integration of something close to the suggested virtual PLM room.

5.2 End-of-life and links to conceptual design

Neither Autodesk nor UGS provide explicit end-of-life management modules concerned with regulation compliance. Little support is given to the communication with end-of-life stakeholders without a close relation to the company. For example, if a redefinition of the workflow (integrating end-of-life stakeholders in the business processes at the end-of-life of a product or into designing a product for end-of-life) in the respective PLM solution (Teamcenter community and Autodesk Data Management) is acceptable, the integration of a re-manufacturer is possible. Information concerned with the end-of-life of a product is not explicitly handled during conceptual or detailed design in either solution; at least, no explicit access to it is given.

It is not clear whether the Teamcenter compliance solution can be used for purposes other than evaluating a product's design with respect to a given set of regulations; in particular, whether it could be used to ensure that a certain recycling or disposal process is adopted. Furthermore, UGS offers two modules called NX Check-Mate and NX Quick Check; both modules are in principle capable of supporting a design analysis with respect to arbitrary criteria. This could be used for an evaluation of end-of-life processes, yet an appropriate knowledgebase is not provided.

Another issue concerns the communication channels offered by the PLM systems. Particular to the end-of-life are two types of communication:

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[1] Autodesk Alias Studio, Autodesk Streamline, Autodesk Data Management are trademarks by Autodesk Inc.

[2] NX, Teamcenter, UGS Velocity, Teamcenter Community, NX Check-Mate, and NX Quick Check are trademarks by UGS Corp.

- Communication between close (commercial) partners (typically two companies with an explicit agreement) with dedicated PLM systems and the possibility of establishing a dedicated communication channel through which data is transferred reliably in both ways.
- The other type of communication is rather loose, short in time, often unidirectional (typically between a company and an end-user), and does not follow a particular protocol (*i.e.* through emails or WWW pages). This also includes the communication between companies concerned with recycling or disposal and the manufacturer, with whom they often do not have a close relationship.

The latter type of communication is somewhat addressed by Autodesk Streamline, yet the solution seems short on collecting or analysing feedback from clients. Consequently, industry uses *ad hoc* methods to communicate with end-users, recyclers, and similar stakeholders.

On a general note, both PLM solutions often have overlapping functions which are relevant to the conceptual design and end-of-life stages of a product. For example, UGS offers three modules concerned with design validation, Autodesk attributes conceptual design facilities to AutoCAD and Alias Studio.

6 Concluding remarks

This publication examines links between conceptual design and end-of-life of a product and enumerates the most important relationships between stakeholders, business processes, and associated data. Some of these relationships are compared with industrial practice. For example, conceptual designs are evaluated for compliance with laws, regulations and standards, but much less with respect to aspects like the cost of maintenance, remanufacturing, disposal, etc. Overall, considerations of end-of-life processes enjoy little attention by PLM systems during the conceptual design stage. No explicit support for the integration of the numerous end-of-life stakeholders, business processes, and so on concerned with the ultimate retirement of the product is given by either of the evaluated PLM systems.

A closer examination of end-of-life and conceptualisation with respect to their special needs resulted in a set of requirements. These were then used to evaluate the abilities of two major PLM solutions.

Overall, it can be stated that PLM solutions cater rather well to the conceptual design stage with respect of the product functionality expected by the authors. However, the solutions of the two major PLM solution providers have little to offer for the end-of-life management. The only contributions come from the generic communication framework of both solutions with two exceptions: UGS proposes support for managing products' compliance with regulations and standards, thus addressing implicitly environmental issues, while Autodesk proposes a solution that manages information given to stakeholders outside the range of close business partners.

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References

1. CIMdata, *Product Lifecycle Management - Empowering the Future of Business*. 2002.
2. Stark, J., *Product Lifecycle management- 21st Century Paradigm for Product Realisation*. 2005: Springer.
3. Saaksvuori, A. and A. Immonen, *Product Lifecycle Management*. 2005: Springer.
4. Hales, C. and S. Gooch, *Managing Engineering Design*. 2004.
5. Ulrich, K.T. and S.D. Eppinger, *Product Design and Development*. 2000.
6. Ameri, F. and D. Dutta. *PLM-TR3-2004 PLM: Needs, Concepts and Components*. Accessed 2004 via http://plm.engin.umich.edu/PDFs/PLMA-TR3-2004.pdf.
7. Hsu, W. and I.M.Y. Woon, 'Current research in the conceptual design of mechanical

products.' *Computer-Aided Design*, 1998. **30**(5): p. 377-389.

8. Alisantoso, D., et al., 'A rough set approach to design concept analysis in a design chain.' *International Journal of Advanced Manufacturing Technology*, 2004. **26**(5-6): p. 427-435.
9. Rehman, S. and M.D. Guenov, 'A methodology for modelling manufacturing cost at conceptual design.' *Computers and Industrial Engineering*, 1998. **35**(3-4): p. 623-626.
10. MEP. *Introduction to the RoHS and WEEE European Union Directives*. Accessed 2006 via http://www.mep.nist.gov/RoHS-WEEEIntro-MEPpw-Aug06.pdf.
11. Electronic Industries Alliance. *EIATRACK*. Accessed 2006 via http://www.eiatrack.org/.
12. Dieter, G.E., 'Engineering Design - A material and processing approach.' *Research in Engineering Design*, 2000. **15**(2): p. 122-137.
13. Eggert, R.J., *Engineering Design*. 2005.
14. Pahl, G. and W. Beitz, *Engineering Design*. 1996.
15. Dixon, J.R. and C. Poli, *Engineering design and design for manufacturing*. 1995: Field stone publisher.
16. Parameswaran, M.A., *An introduction to design engineering*. 2006: Alpha Science International Ltd.
17. Kurakawa, K., 'A scenario-driven conceptual design information model and its formation.' *Research in Engineering Design*, 2004. **15**(2): p. 122-137.
18. Duffy, A.H.B., *The design productivity debate*. 1999.
19. Salter, A. and R. Torbett, 'Innovation and performance in engineering design.' *Construction Management and Economics*, 2003. **21**: p. 572-580.
20. Rao, Z.M. and C.-H. Chen, *A CBR-based Design Evolution Approach for New Product Development*, in *Proc. of the International Design Congress – IASDR 2005*. 2005. p. 1-4.
21. Chen, C.-H., L.P. Khoo, and W. Yan, 'A strategy for acquiring customer requirement patterns using laddering technique and ART2 neural network.' *Advanced Engineering Informatics*, 2002. **16**(3): p. 229-240.
22. Autodesk. *Company web page*. Accessed 2007 via http://autodesk.com.
23. UGS Corp. *Company web page*. Accessed 2007 via http://www.ugs.com/.