Design for Multi-Lifecycle and Its Role in Enhancing Environmental Protection in the Agri-Industrial Sector

Israel Dunmade*
*Department of Environmental Science, Mount Royal University, Calgary, Alberta, Canada

ABSTRACT

The purpose of this paper is to present design for multi-lifecycle as a green design paradigm and to explain how it contributes to environmental protection in the agri-industrial sector of the economy.

The development of this design concept resulted from intensive literature survey and several years of personal experience in developing machinery for agri-industrial applications. The design concept incorporated DfX paradigms such as design for modularity; cost; assemblability; manufacturability; disassemblability; maintainability; reusability, and remanufacturability. The concept has been used to design and develop a peanut shelling machine. In addition to the comparability of the technical performance tests on the machine with the imported ones, the machine designed on the basis of this concept resulted in resource use optimization, pollution prevention and cost minimization. All these are essential to environmental protection. Application of this design concept in the industrial and agricultural sectors will go a long way in complementing various efforts aimed at reducing total environmental impact of our industrial activities.

Keywords - Design for Environment, Sustainable Design, Design for Multi-lifecycle, Eco-design, Environmental protection

I. INTRODUCTION

The current trend in consumer demands and legislative requirements have spurred manufacturers to take proactive steps towards greening their products and processes. However, manufacturing just like any other business endeavour exist mainly to make profit. The quest to combine profitability and environmental consideration in the design and manufacturing of products has resulted in the development of eco-efficiency concept. Furthermore, the push for corporate social responsibility in incorporating socio-cultural factor in to their business operations is extending the frontiers of extended producer responsibilities into making the products sustainable.

However, making viable changes to “habit/ culture” of resource consumption, wastage and environmental pollution that has caused resource depletion and lots of environmental damages that has existed for generations is challenging. Furthermore, transformations from such habits to sustainable systems that are environmentally benign, economically sound and socio-culturally acceptable require fundamental and persistent effort. It would also necessitate redesigning those manufacturing systems that have for so long caused damages to our environment.

Making design changes is particularly important because the lifecycle characteristics of a product is determined at the design stage and only little changes could be effected at the later stages of the product lifecycle to improve their environmental friendliness. Many scholars have made several efforts at correcting the design mistakes of the past by introducing a number of design paradigms that seek to achieve close cycling of the material loop through better end of life management of engineering products. Among such design paradigms include design for assembly; design for manufacturability; design for disassembly; design for recycling; design for use/reuse; design for remanufacturing, and others [1- 6]. One of these design paradigms is the new sustainable design concept called design for multi-lifecycle. It was a concept developed with the aim of solving the problems of the peasant agri-industrial sectors in the developing countries in getting agri-processing machinery that are environmentally responsible, economically affordable and socio-culturally suitable. Ascertaining the effectiveness of this design paradigm in closing the material cycle and in achieving the much desired environmental friendliness is considered essential to preserving our environment. The purpose and contribution of this paper is in showcasing how the principles of design for multi-lifecycle can be applied in the agricultural sector, and how application of that design principles enhances the achievement of environmental protection.

II. PHILOSOPHY AND GOALS OF INDUSTRIAL ECOLOGY IN RELATION TO ENVIRONMENTAL PROTECTION

Since the advent of industrial ecology as a concept and discipline, several authors and practitioners have come up with what industrial ecology is, its goals and principles, and how to achieve the goals. For instance, some authors saw industrial ecology as a holistic approach to redesigning industrial activities. They opined that it is a concept that provides an integrated systems approach to managing the environmental effects of using energy, materials, and capital in industrial ecosystems. Furthermore they explained that to optimize resource use and to minimize waste flows back to the environment; managers need a better understanding of the metabolism (i.e. use and transformation) of materials and energy in industrial ecosystems, better information about potential waste sources and uses, and improved mechanisms (markets, incentives, and regulatory structures) that encourage systems optimization of materials and energy use [7-10].

Similarly, Allenby and Richards in their works pictured industrial ecology as "the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution". They opined that the concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in context with them. And that by taking systems view, industrial ecology seeks to optimize the total materials cycle from virgin material, to finished material, to component, to obsolete product, and to ultimate disposal. Such holistic view will result in facilitate the achievement of environmental protection as it will encourage the stakeholders to optimize the use of resources, energy, and capital [11-13].

Moreover, Ehrenfeld described industrial ecology as a new way of thinking that meets the sustainable development goal of achieving a state of development that takes into account the needs of the future generations. He reiterated that industrial ecology as a concept tries to move the social activities towards the reality and limits of the natural system that we live within [14-15].

In the same vein, Indigo defined industrial ecology as "an interdisciplinary framework for designing and operating industrial systems as living systems interdependent with natural systems with the aim of striking a balance between environmental and economic performance within emerging understanding of local and global ecological constraints" [16].

On the whole, authors and practitioners agreed that industrial ecology is a body of knowledge and practices that seek to ensure the symbiotic relationship between industrial systems and natural systems. And that the main concepts of industrial ecology include modelling industrial systems on ecological principles, closing the material cycles, waste exchanges, and design for environment [17]. Close examination of all these concepts reveals that the attainment of the first three concepts depends on innovative sustainable systems design. Although many design for environment paradigms have attempted to achieve the goals of sustainable design, it is believed that none has been able to achieve the same fit as the concept of designing for multi-lifecycle..

III. PRINCIPLES OF DESIGN FOR MULTI-LIFECYCLE (DFML)

Design for multi-lifecycle is a design approach that maximizes the utility of resources used in developing a technology by incorporating at the design stage, features that enable the elongation of the techno-economic service life of that technology [18]. The goal of design for multi-lifecycle is 'indefinite' use of the resources invested/embodied in a technology without compromising its economic reasonableness, technological soundness and social-cultural acceptability.

IV. EVOLUTION OF DFML CONCEPT AND ITS APPLICATION

The idea of Designing for Multi-lifecycle evolved as an offshoot of a great desire and attempts to help small scale agri-industrial business owners and farmers in alleviating a number of problems plaguing the sub-sector of the economy. It has been observed that many of the agricultural produce from farmers are often in abundance and cheap around the harvest seasons but a large proportion of them are lost due to inadequate storage and the inability of the small scale agri-processing firms to process them for preservation and for other industrial use. One of the major factors responsible for this is that many of the farmers and agri-processors in the developing West African economies cannot afford the machinery needed. For those that could afford them, the technologies are either not locally available or obsolete. In addition, most of the imported technologies are often characterized by unavailability of spare parts and they are locally unserviceable. Consequently, the maintenance and repairs of these technologies require employment of expatriate to reduce downtime. As a result, the total cost of ownership/lifecycle cost is beyond what average agri-industrial business owners in this region could afford.

Design Considerations

The need to find solution to the precarious situation of small scale agri-industrial business owners necessitated the development of a design approach that could simultaneously result in lifecycle cost reduction; improvement in the technology's service life and its availability; enhanced reparability and proliferation by local technicians; socio-cultural acceptability to the users, and environmental friendliness. This is further illustrated in Figure 1.

Environmental Consideration

One of the goals of DFML concept is to take account of the different environmental issues and concerns at different stages in the product development process considering anticipated environmental issues that may arise at various stages of the product's lifecycle, not only in the first life of the product but also in the subsequent "lifecycles". The idea is to minimize losses of parts and material constituents of the product. Only few and small faulty parts are to be replaced after long period of use and reuse, thus the design should enable the recycling of majority of the parts of the product assembly over and over again. The intent is to cut down on resource consumption and waste releases that are the main contributors to the environmental impact of our industrial activities. Repeated use of parts over a long time period is to be facilitated by selecting durable and abundantly available materials, easy accessibility to various product parts with minimal disassembly, and robustness of the main product structure/framework. Many of the methodologies and metrics for assessing the environmental profile of products, especially lifecycle assessment, can be used to compare the environmental benefits of designing for multi-lifecycle with one-lifecycle design methodologies.

Economic consideration

Economic factor is another main consideration in designing for multi-lifecycle. The focus is the net economic benefit of using the product for multi-lifecycle. The net benefit/savings is the difference between the total lifecycle costs of the number of machines designed for single lifecycles and the total multi-lifecycle cost of the same machine designed for multi-lifecycles for the same number of years' horizon. Typical components of lifecycle cost and savings illustrated in Fig. 2 include various avoided costs. It also include the cost of acquiring and processing the resources (i.e. materials, energy, water, etc.) that is used in developing the technology, not only as part of the hardware but also in manufacturing the hardware; transporting and installing the technology. Other cost components considered are the cost of operating and maintaining the technology. In addition, reverse logistics cost associated with managing the end-of-life of that technology are to be accounted for. Elements of end of life management costs include decommissioning, cascading, remanufacturing, upgrading, incinerating and/or landfilling costs. The total cost assessment will also need to account for remediation and reclamation cost, potential accident claim, and compensation for ecosystem losses especially if landfilling and incineration options are included in the end-of-life management strategies.

Technical consideration

The number of times the life of a technology can be technically cycled depends on its material properties, system architecture, and service environment. The material properties affect the durability of the component parts and consequently the frequency of breakdown and replacement.

System architecture, as used in this paper, refers to how the component parts are designed to fit together, the types of joints/liaisons used, fabrication process specifications, and geometry of the component parts. System architecture affects the longevity of service life of a product. In regard to the relative motion between component parts, it affects not only the wear and tear of mating parts but also the operation efficiency of the product. Continued use of a product assembly or its component parts in the next lifecycle depend on the service requirement of the assembly and the allowable wear that doesn't compromise the functionality/safety of the unit.

Socio-political consideration

The design considers the indigenous technological development, maintenance culture, and the general way of life of the stakeholders with the aim of adapting the new technology to their way of life thereby enabling them to maintain and improve on the technology at a later date. Generally, culture is dynamic. The extent and rate of cultural changes are mainly influenced by education, exposure to other cultures and demographic factors. Design for multi-lifecycles anticipates socio-cultural dynamics by considering the trends in cultural changes and how these changes will affect the subsequent life of the product.

V. THE LINK BETWEEN ENVIRONMENTAL PROTECTION AND DFML

Design for multi-lifecycle is a design for environment principle that seeks the attainment of industrial ecology goals of reducing the ecological footprint of our industrial activities on the environment by promoting resource use optimization through product design in such a way that components can be reused several times thereby preserving the materials, energy and other resources used in its first lifecycle. This reduces material, energy and other resources that would be needed to produce a new one thereby conserving all these resources and making them available for future generations. Furthermore, because there is reduction in material, energy and other resource requirement, all the wastes and emissions that are associated with the extraction, production and refinement/treatment of these resources will also be reduced thereby reducing the environmental pollution and other impacts of our industrial activities on the environment. Since attainment of these goals would result in environmental protection, design for multi-lifecycle can be seen as a design paradigm that enhances environmental protection.

VI. Design of a shelling machine for multi-lifecycle

Each of the design features for multi-lifecycle concept was highlighted in a peanut shelling machine shown in Figure 3 as follows:

Environmental consideration

Incorporation of the environmental consideration was achieved in design for multi-lifecycle by designing the shelling machine for assemblability and disassemblability. Designing for disassemblability makes the reuse of components and subassemblies of the machine possible. This would in turn eliminate the need to exploit resources to produce those new components and subassemblies. Consequently, this would result in resource conservation, reduction in waste generation and energy consumption, and environmental protection.

Economic consideration

The economic consideration in design of the shelling machine for multi-lifecycle involved the use of locally available materials and the use of standard parts that could be purchased off-shelf. Assemblability and disassemblability of the component parts facilitates reusability of parts, reduction in total lifecycle cost of the machine and improves the economic sustainability of the machine.

Socio-political consideration

Ergonomic consideration was incorporated into the design by carefully choosing the machine height, hopper size, and safety features that protect the user from any foreseeable harm. The machine was also designed for simplicity to foster maintainability by local technician. Current applicable regulations, foreseeable regulatory changes, and cultural lifestyles of the locality and intended users of the machine were also considered in the choice of materials and fabrication process used to produce the machine.

These sustainability considerations were made to achieve the industrial ecology goals of resource use optimization and reduction in overall ecological footprints of the machine.

VII. Conclusion

A sustainable design methodology is presented. Results showed that application of design for multi-lifecycle (DFML) concept to an Agri-industrial project resulted in material and energy cost savings, waste reduction, an innovative product design and a considerable reduction in costs. DFML design concept presents 'a win-win' situation in which there are benefits for both the agri-industrial business sector and the environment. If the design concept is applied to any technology design, resource use optimization will be achieved and the overall environmental liabilities of wasteful design procedures will be avoided. Consequently, the design methodology enhances the achievement of environmental protection in whatever sector of the economy that the principle is applied. This work served as a foundation for future case studies on the application of DFML concept in various areas of agriculture and other industrial sectors.

References

[1] J. Sun, B. Han, S. Ekware-Osire, and H-C. Zhang, Design for Environment: Methodologies, Tools, and Implementation, *Transactions of the SDPS, 7(1)*, 2003, 59 – 75.

[2] G. Boothroyd and L. Alting, Design for assembly and disassembly, *Annals of CIRP, 41(2)*, 1992.

[3] T.-C. Kuo, S.H. Huang, H.-C. Zhang, Design for manufacture and design for 'X': concepts, applications, and perspectives, *Computers & Industrial Engineering 41(3)*, 2001, 241–260.

[4] I.S. Dunmade, *Development of Systems Model for the Selection of Industrial Processes with regard Product Lifecycle Extension* (Berlin: Logos Verlag, 2001).

[5] K. Ishii, C. Juengel, C.F. Eubanks, Design for Product Variety: Key to Product Line Structuring. ASME Design Engineering Technical Conference Proceedings, Boston, MA, 1995, 2, 499-506.

[6] I.S. Dunmade, Collaborative lifecycle design: A viable approach to sustainable rural technology development, *International Journal of Technology Management & Sustainable Development, 9(2)*, 2010, 149-158.

[7] A. Eik, K. Røine, and H. Brattebø, Promoting industrial ecology by extended producer responsibility – principles and practices. *Presented at ATHENS Intensive Seminar "Solid Waste Management and Recycling Technologies", NTNU*, March 1998.

[8] D. O'Rourke, L. Connelly and C.P. Koshland, Industrial ecology: a critical review, *Int. J. Environment and Pollution, 6(213)*, 1996, 89-112.

[9] J. Korhonen, Industrial ecology in the strategic development model: strategic applications of industrial ecology, *Journal of Cleaner Production, 12*, 2004, 809–823.

[10] J. Korhonen, Theory of industrial ecology, *Progress in Industrial Ecology, 1(1–3)*, 2004, 61–88.

[11] B.R. Allenby, *Design for environment: implementing industrial ecology*, PhD Dissertation, Rutgers University, New Brunswick, NJ. 1992.

[12] B.R. Allenby, *Industrial Ecology: Policy Framework and Implementation*, (Upper Saddle River, NJ: Prentice-Hall, 1999).

[13] B.R. Allenby and D.J. Richards (Eds.), *The Greening of Industrial Ecosystems*, (Washington, DC: National Academy Press, 1994).

[14] J. Ehrenfeld, Industrial ecology: A strategic framework for Product Policy and Other Sustainable Practices, *Speech at Green Goods: The second international conference and workshop on product oriented policy*, Stockholm, 1994.

[15] J. Ehrenfeld, Industrial ecology: a new field or only a metaphor? *Journal of Cleaner Production, 12*, 2004, 825–831.

[16] Indigo, Industrial Ecology. Accessed on August 20, 2006 at http://www.indigodev.com/IE.html.

[17] R. Isenmann, Further efforts to clarify industrial ecology's hidden philosophy of nature, *Journal of Industrial Ecology, 6(3-4)*, 2002, 27– 48.

[18] I.S. Dunmade, Design for Multi-lifecycle: A sustainable design concept applied to an Agro-industrial development project. *Presented at the 2006 Annual International meeting of the American Society of Agricultural and Biological Engineers*.

APPENDIX

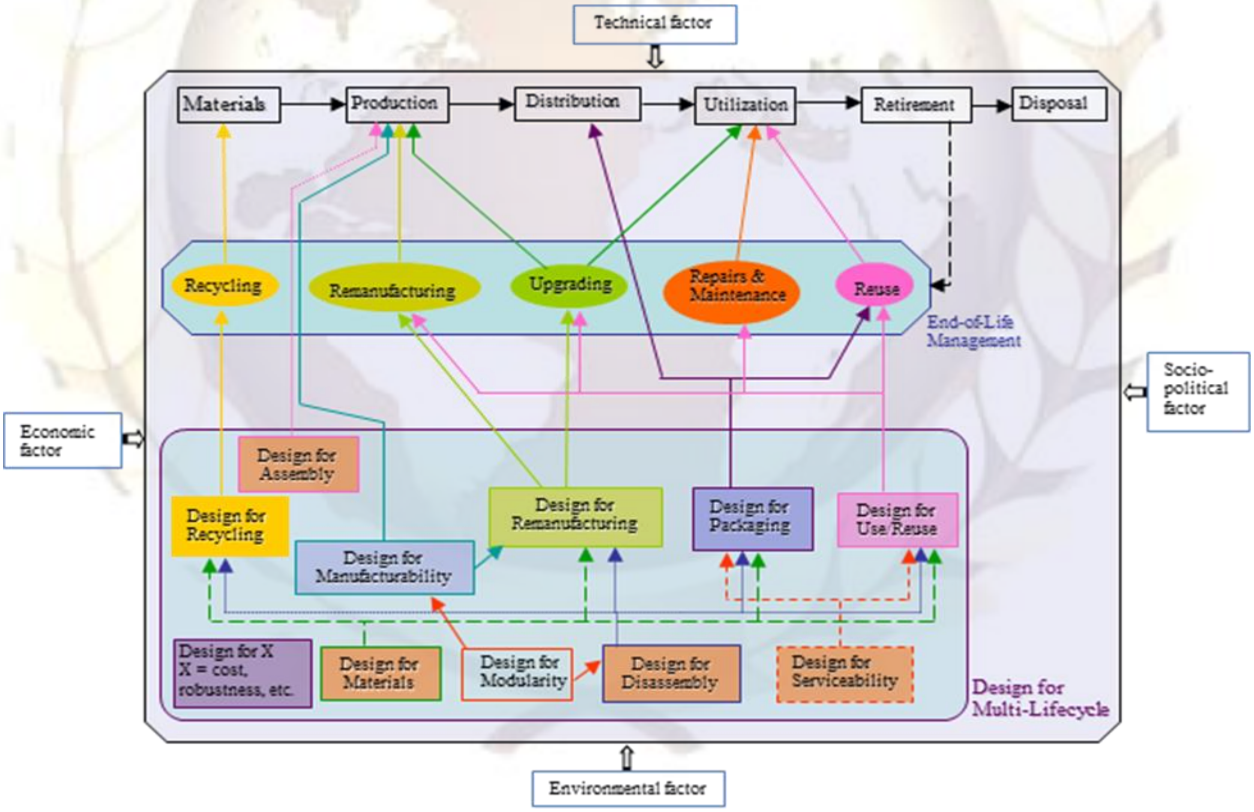

Figure 1 Correlation between Lifecycles stages, End-of-life Management, Design Concepts and Influencing Factors

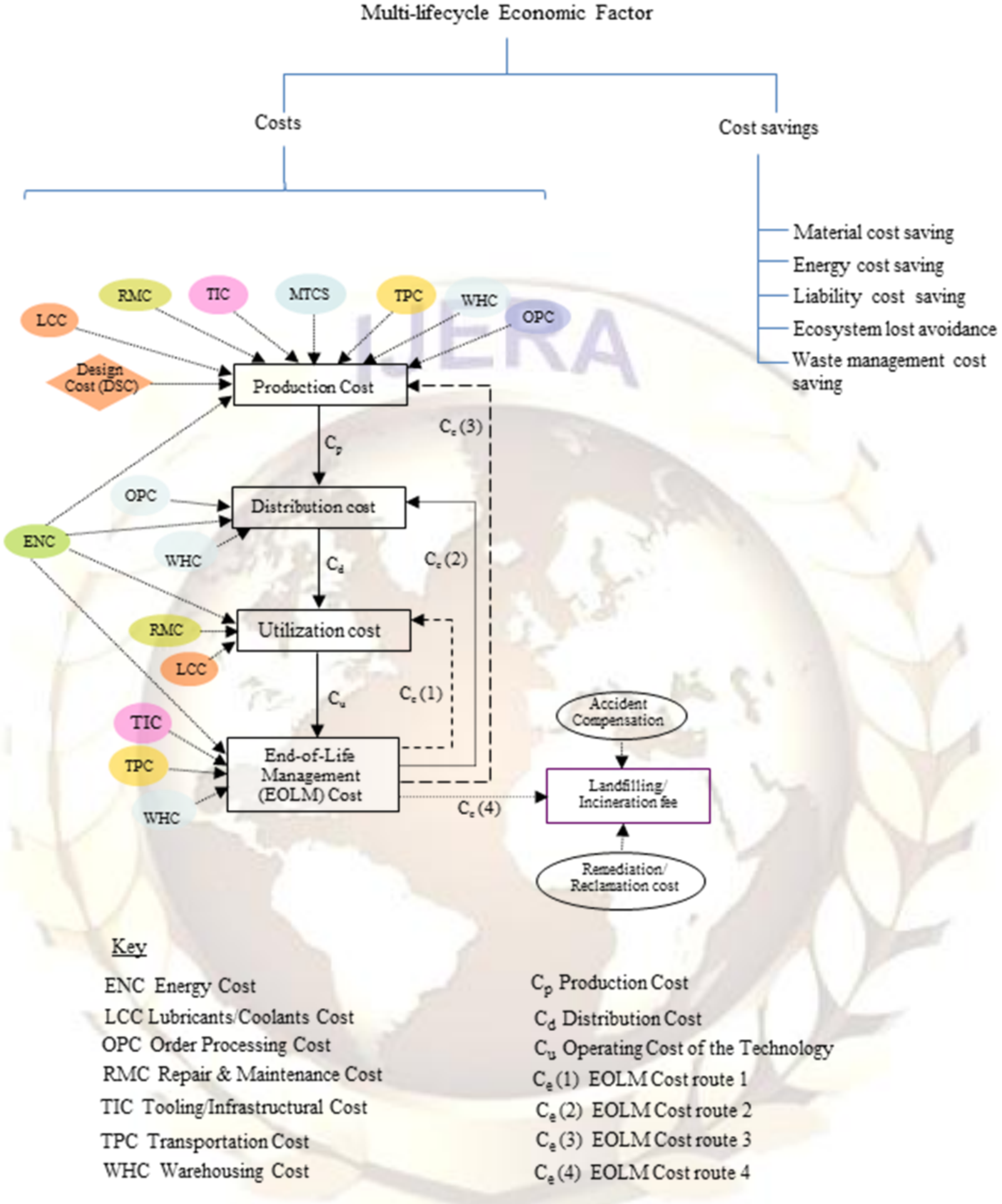

Figure 2 Multi-lifecycle cost and cost saving components

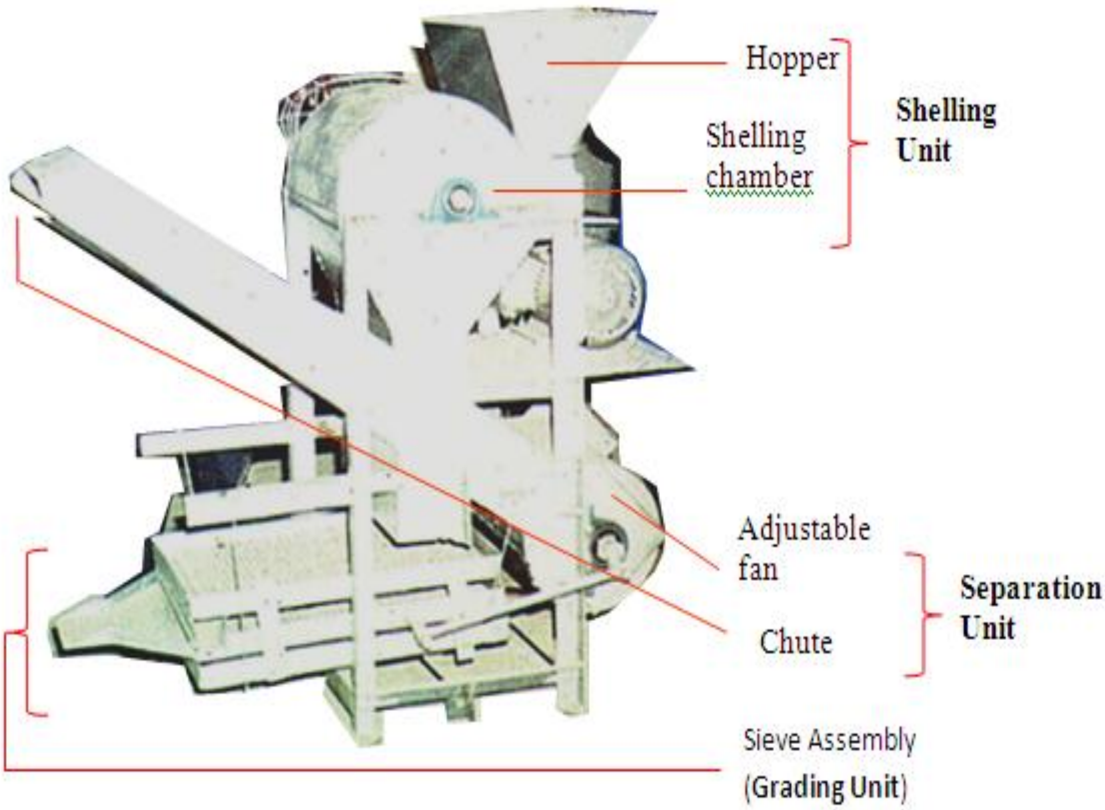

Figure 3 A Peanut Shelling Machine designed for Multi-Lifecycle