Approach on Lifecycles on Research Environment and Analysis Based on Systems Engineering (SE)

Marja Lintala, Jivka Ovtcharova, Pierre Bonnal

Approach on Lifecycles on Research Environment and Analysis Based on Systems Engineering (SE)

Marja Lintala[1], Jivka Ovtcharova[1] and Pierre Bonnal[2]

[1]Karlsruhe Institute of Technology, Institute for Information Management in Engineering, Karlsruhe, Germany
{marja.lintala,jivka.ovtcharova}@kit.edu
[2]CERN, European Organization for Nuclear Research, Genève, Switzerland
pierre.bonnal@cern.ch

Abstract. In recent years, researchers and industrial communities have been increasingly interested in Product Lifecycle Management (PLM); hence the product lifecycles have received considerable attention. The general features of the lifecycles are well known, however the special character of the equipment in research environment: the particularly long life, experimental character, complexity and interdisciplinary, are still not completely understood. The paper analyses the specific requirements and describes a common approach to lifecycle of equipment in research environment such as large-scale scientific facilities generating ionizing radiation. Based on the key findings a lifecycle model is developed. In order to develop this model, research includes a case study carried out in CERN (Geneva, Switzerland), analysis based on PLM, SE product development framework and discussion on the basis of the results. The research was done within the PURESAFE research project, which is funded under the European Commission's Seventh Framework Programme Marie Curie Actions.

Keywords: Product Lifecycle, Product Lifecycle Management (PLM), Research Facilities, Particle accelerators, Systems Engineering (SE)

1 Introduction

A considerable amount of research has been conducted related to lifecycles. For example [3] estimated that before 1980's the lifecycle's were more marketing oriented stating the stages of development, growth, maturity and decline. After the 1980's models present a life of a product from conception, design, production, sale, usage/service to decommissioning [3], which suggest the process view of the lifecycle.

In previous research [17], [19] it is indicated that the lifecycle model and the phases depend on the product type or a project. In [17] it is stated that, if the lifecycle is tailored to match the needs of a project, it will reduce the development risk. Hence, it is of interest to fill this gap for the research equipment such as large-scale scientific facilities generating ionizing radiation.

In this study we use the [11] determination of the lifecycle, which determines lifecycle as the evolution from conception through retirement. In [11] the term lifecy-

adfa, p. 1, 2011.

cle model is determined to provide a framework of processes and activities. On the other hand we consider the definition from [19], where it is indicated, that term lifecycle generally express the set on phases or stages that are performed during the physical life of a product.

1.1 Product Lifecycle Management (PLM)

The essence of Product Lifecycle Management (PLM) according to [19] is sharing and managing product data, information and knowledge. Many times PLM is associated to information and communication technology (ICT) -solutions. In fact, [16] defines PLM is a 'holistic business activity' with many components for example products, methods, processes, people, information and ICT systems. The generic PLM models, methods and tools include the whole lifecycle of a product [1]. Therefore it is easy to agree with [19], when they indicate that PLM is an integrator of tools and technologies in the information flow of product lifecycle or lifecycle-oriented business model that is supported by ICT.

The common view in PLM field is information and knowledge in the product lifecycle. The approach is the common need for use of product data in different business functions and in different activities [16]. According to [16] PLM manages the whole range from individual parts, to products and to the entire product portfolio of the company, where the products may be unique or a batch of thousands and they may be successor or derivative of another product.

1.2 Systems Engineering (SE)

In addition to PLM also Systems Engineering (SE) addresses lifecycles. In [12] it is defined as a guide to the engineering of complex systems. In [14] it is pointed out that the objective of SE is to see that the design, building and operating of the system is accomplished most cost-effective way possible and in a safe manner. In turn [17] imply that SE is about creating effective solutions to problems and managing the complexity of developments.

System elements are hardware, software, facilities, people and data [10], [14]. In [12] a complex engineered system is defined as multiplicity of intricately interrelated diverse elements. Most complex systems have a long life, during which they undergo multiple major and minor upgrades [12]. In majority cases there are also predecessor systems that will impact the development of a new system [12].

Noteworthy is, that ISO/IEC 15288 standard does not describe specific system lifecycle model, but states that "A life cycle can be described using an abstract functional model that represents the conceptualization of a need for the system, its realization, utilization, evolution and disposal" (see Fig. 4) [11].

1.3 Product Development models

We also take into a consideration two different product development models for the lifecycle development: Stage-Gate model [8] and product development model from

[20]. Stage-Gate system or process is conceptual and operational map for project manager to reach the desired destination of a well-thought-out and carefully executed new product [7-8]. Stage-Gate consists of stages, where the work is done, and in between are gates, where the go/kill/hold/recycle decisions of the continuance of the project are done [8]. Usually Stage-Gate systems have from four to seven stages and gates, which are dependable of the company [8]. In [7] it is pointed out, that the system is built for speed with stages that are cross functional and activities that are parallel. It is also emphasized, that a Stage-Gate is not a substitute for project management methods; on the contrary, they are complement each other [7].

In [8] Stage-Gate model after the idea there are five stages (idea + 5 stages) and consequently in between five gates. The Stage-Gate system suggests the best practices, recommended activities, and likely deliverables [7]. The activities in the stages may over-lap each other, often are parallel and related [8].

Even though the Stage-Gate systems are for New Product Development, they have quite a lot of similarities with PLM and especially with SE. For example the decision points between the phases are really important in SE (e. g. [14]).

Other model that is taken into consideration is the six phase product development process from [20]. The purpose of the process is to transform set of inputs into set of outputs, with sequence of steps [20]. Product development is a process that can be divided into phases. As the project is an important phase in the lifecycle model proposed in this paper, the phases presented in [20] have been included too the analysis.

1.4 Approach and organization of the paper

PLM and SE concepts are linked to each other as in the system's breakdown structure, also products are found. In SE lifecycle is seen from the perspective of a complex system that is created and manufactured in a few instances. On the other hand Product Development processes such as Stage-Gate system is concentrated on project handling methods especially in the front-end. Therefore they are briefly compared. It is important to remember, that in [8] Stage-Gate model, between each stage, there is a gate to go through, even though they are not seen in Fig. 4. It was decided to use all mentioned methodologies in the analysis for the interdisciplinary purposes.

The purpose of this paper is to provide a model with common lifecycle phases. On the other hand, each phase is characterized by not only the inputs or outputs, but also the activities [9]. Hence, this paper also presents some activities those phases include.

The following of this paper is structured as follows. In the second chapter we describe the background of the case used in this paper, and the research problem at hand. The next two chapters describe research methodology (chapter 3) and development process (chapter 4). On chapter 5 results, analysis and discussion based on the results are presented. We end the paper with conclusions at chapter 6.

2 Background

2.1 Research Facility

CERN, the European Organization for Nuclear Research, is one of the world's largest and most respected centers for scientific research. Its business is fundamental physics: to find out what the Universe is made of and how it works. At CERN, for the studying the basic constituents of matter — the fundamental particles, the world's largest and most complex scientific instruments are used. By studying what happens when these particles collide, physicists learn about the laws of Nature. The instruments used at CERN are particle accelerators and detectors. Accelerators boost beams of particles to high energies. The particles are made to collide with each other or with stationary targets and these collisions are observed and the results recorded in Detectors. [4].

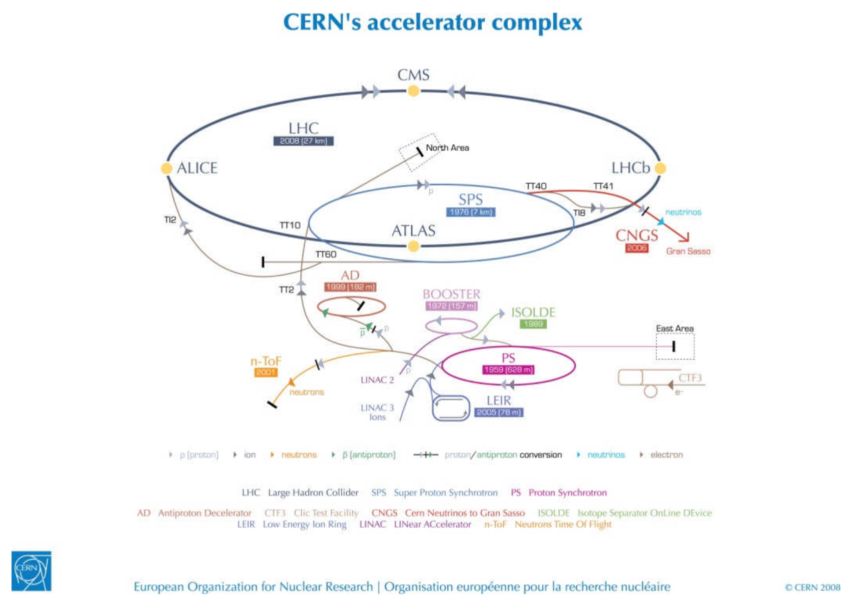

Fig. 1. The CERN accelerator complex [5]. © 2008 CERN.

The facility consists of a chain of accelerators (see fig. 1). Particles are produced in linear accelerators: Linac3 for heavy ions and Linac2 for protons. Particles are then accelerated in the PS Booster (built in the late 1960s), then the Proton-Synchotron (PS, built in the 1950s), then the Super-Proton-Synchotron (SPS, built in the 1970s), and finally in the Large Hadron Collider (LHC, commissioned in 2008). Particles can hint fixed targets (e.g. in the East and North Experimental Areas) or collide as it occurs in the LHC, at the center of one of its four big detector.

The LHC is emblematic of the complexity of such scientific facility projects. The history of this equipment started early 1980 with an idea of re-using the Large Electron Positron Collider (LEP) 27 kilometer ring for more powerful machine. The starting point was at Symposium organized at 1984. The construction got approved by CERN Council 1994, civil engineering work began at 1998, construction had many phases and the scheduled start was at 2008. [6]. Even the time between the idea to the start of the construction took more than 10 years and the construction of the equipment took a decade. Concerning its operation life, it is expected to last at least 20 years. But an upgrade program is already on-going, and it is very likely that its operation last over 30 years. The CERN's Proton-Synchotron is a key component of the CERN's accelerator chain, and is in operation for more than 50 years and should be kept in operation for the next 30 years of operation of the LHC. So it is reasonable to say that the lifecycle is particularly long.

The LHC accelerator project cost more than 6 billion Swiss francs. The cost of its four big detectors and three smaller ones is to be added to this figure. Finally, from a technical point of view, it embeds many technologies pushed at their limits: 8.7 T superconducting magnets operating at 1.8 K, ultra high vacuum.

The project itself can be associated to a large-scale industrial project like a petroleum refinery for instance. But it embeds construction sub-projects (400 million Swiss francs underground civil engineering sub-projects that shall be managed according to state-of-the-art construction projects). It also embeds new product development sub-projects that aim at manufacturing components in series. It also consists of a few IT projects that could only succeed if state-of-the-art IT project management approaches were implemented. All this contributes to the complexity of this project that makes it difficult to associate to it a unique lifecycle scheme.

2.2 Research Problem

In thorough literature review [3] it is noted, that the product lifecycle concept has a different meaning to different researchers. Hence, it is easy to say that also the lifecycle model differs in different use cases. The lifecycle of the case study has the special characters as mentioned in chapter 2.1. This paper addresses the lifecycle phases of the equipment in research environment and some of the activities in the phases.

3 Research Methodology – Case study

The study is made in a context of research project called PURESAFE – "Preventing hUman intervention for increased SAfety in inFrastructures Emitting ionizing radiation". PURESAFE is an Initial Training Network (ITN) for the training of young researchers, funded under the European Commission's Seventh Framework Programme Marie Curie Actions. The program aims at career development of Researchers on Systems Engineering (SE) for radiation protection and lifecycle management of facilities generating ionizing radiation. In the PURESAFE CERN is serving as case study for project based learning. The long-term goal in PURESAFE is to protect humans from radiation and to increase machine experimental time with reduced lifecycle expenses [15].

For the basis of the data collection for this paper, research was done in the framework of the CERN A&T (Accelerators and Technology) Sector Maintenance Management Project (MMP). The data for this paper was collected in late 2011 and in early 2012. The MMP will continue forward after this paper is finished.

The most commonly used case study sources according to [21] are documentation, archival records, interviews, direct observations, participant-observations and physical artifacts. It is highly complementary for a good case study to use as many sources as possible [21]. For this paper the chosen sources were observations, informal discussions and by going through the documentation and written material of MMP -Project at CERN.

In this paper there are two different approaches for case study: quantity and quality. For assuring the quantity approach, wide band of documents in the mentioned project were reviewed. As for the quality, in depth discussions were held, but fewer amount. The informal discussions were chosen over more formal interviews for the flexibility and for the non-intimidating and non-time-consuming character. For the informal discussion there was no need to set up the time in advance, and because there was no formal interview template the interviewee didn't know what the interviewer wanted and this didn't influent the answers as reflections. Interactions took place with multiple members of the CERN MMP -Project team.

Observations were made during the meetings, during a tour at the premises and during a short stay at CERN. The documentation reviewed were concerned the MMP -Project at CERN. The weakness of the document review is the selectivity of the documentation as they were related to maintenance issues.

4 Development Process

This paper addresses the application domain of equipment in research environment at the context of CERN accelerator complex, which characteristics have been discussed in chapter 2.1. The facility is large, which creates complexity and is harder to handle. But the deeper in the breakdown structure, more like products are found. Some equipment is specifically designed and some are off the shelf, hence the origin of the products varies.

For defining a suitable lifecycle we took the following steps. Firstly we identified the phases that were repeatedly used not only in the documents, material and presentations reviewed, but also in the discussions held. We took these phases as a starting point for the development. The lifecycle was in most cases presented as in fig. 2. Next we determined the level on which we wanted to proceed and lastly we modified the lifecycle model to our findings.

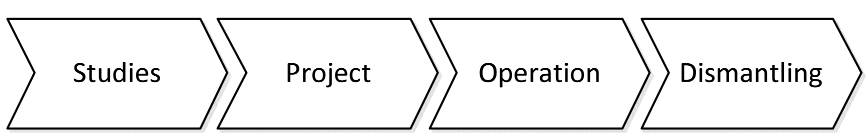

Fig. 2. Original Lifecycle Phases.

It was recognized, that even thought studies is the first phase that is similar to a process; there are activities to be carried out even before. Consequently, it was desirable to define a phase before the studies. Since the target for the lifecycle model was research facility and its equipment the reason why to create the equipment is to study and do research on scientific problems (see chapter 2.1). Conclusively, 'Scientific Problem' is suggested to be added in the beginning of the lifecycle. No other additions were thought to be needed at this level.

As the phases are quite general, research was done on some of the activities, which the phases encompass. Activities describe what needs to be done (the needed outputs, and also inputs) in the phase. According to [18] all processes and activities in product lifecycle are varied. In [16] it is said, that activities vary from industry to industry. They also point out that there are some differences in the activities and priorities with hardware and software products [9]. Activities are presented with many lifecycle models in the literature e.g. [8], [10], [12-14], [16-17], although they are called with different names.

In the activities there weren't such a unity to be found in the case study as with the phases. Through the discussions and documentation following eight activities were recognized to recur: conceptual design, design, engineering, procurement, construction, manufacturing, installation and commissioning. Noticeable is, that these activities belong to study and project phases, but neither in the latter operation and dismantling phases nor the newly proposed 'Scientific Problem' phase. One possible explanation to this is that there is a lot of research done for industrial projects for example [2] and product development projects for example [20].

For the latter phases: operation and dismantling, activities were not as easy to determine. In MMP -Project (see chapter 3) one of the goals is to harmonize the maintenance activities in the accelerator complex. Because the project will continue after this paper is finished, the maintenance activities are not described here. But for all that, it is desirable to emphasize, that the operating is not possible without some maintaining efforts such as support, maintenance and upgrading (upgrades also mentioned in [12]). Hence, we propose change of the phase name to 'Operate and Maintain'.

For dismantling a full accelerator, there is only one record in the history: the dismantling of LEP (Large Electron Positron Collider) that ran from 1989-2000 [6]. Due to tight regulations at facilities generating ionizing radiation for the impact on the environment, recycling point of view wanted to be added in the end of the life. Hence the name proposal 'Dispose and Recycle'.

According to [12] in the evolutionary characteristics of the development process of engineering a new system the predecessor systems do exist and will impact the development. Two views to the issue are considered in [18]; firstly the product lifecycle and secondly product evolution chain, where the evolution chain takes also the origin of the product into consideration. In case study the evolution and integration of different experiments are also factors that have to be taken into account. Each change needs to go through the same activities (e.g. design and construction) as developing a new system. The evolution with modifications to the existing equipment is a reason for presenting the lifecycle as a circle (Fig. 3). New ideas or Scientific Problems add something new (for example a new detector) to the existing system and adequately decommissioning experiments leave equipment and/or infrastructure behind, that can be, and if possible, should be used for other purposes. For example the 27 km ring of Large Electron Positron Collider (LEP) that Large Hadron Collider (LHC) inherited.

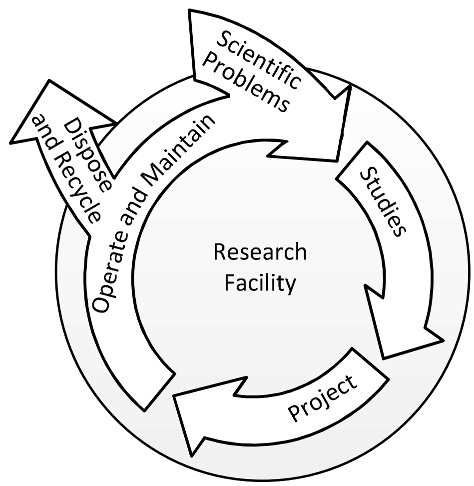

Fig. 3. New Lifecycle Phases

5 Results, Analysis and Discussion

A problem encountered, when comparing lifecycle phases in literature: different terminology is used in different models to describe the same lifecycle phase. Another problem was to be able to separate the phases from the activities. For example the lifecycle model of [13], with phases: life beginning-of-life (BOL), middle-of-life (MOL) and end-of-life (EOL) is described in more detailed in the activities. The BOL phase includes design and production activities, the MOL phase includes usage, service and maintenance activities and the EOL phase includes various scenarios for reuse activities and finally disposal activity. [13].

To avoid the possible confusion and interoperability problems with the terminology, only the proposed phases are shown in fig. 4 on vertical lanes. On horizontal lanes models adapted from Systems Engineering (SE), from Product Lifecycle Management (PLM) and from product development, are separated. Also colors are used in fig. 4 to separate lifecycle phases (gray) from what we consider activities (white). Some simplifications had to be done with the coloring: only one color per step is used.

There is some diversity found in the lifecycle models presented in fig. 4; for instance at the beginning and at the phase that we consider a project. We conclude that together with the activities, the lifecycle phases in fig. 3 are well aligned with the other models. Only two significant differences can be found. Firstly in [1] and in [8] models the sales point-of view is raised. And secondly in [20] the production ramp-up is brought-up. However, in case study neither is needed, as the equipment as a whole is unique and it is not the purpose to produce goods for sale.

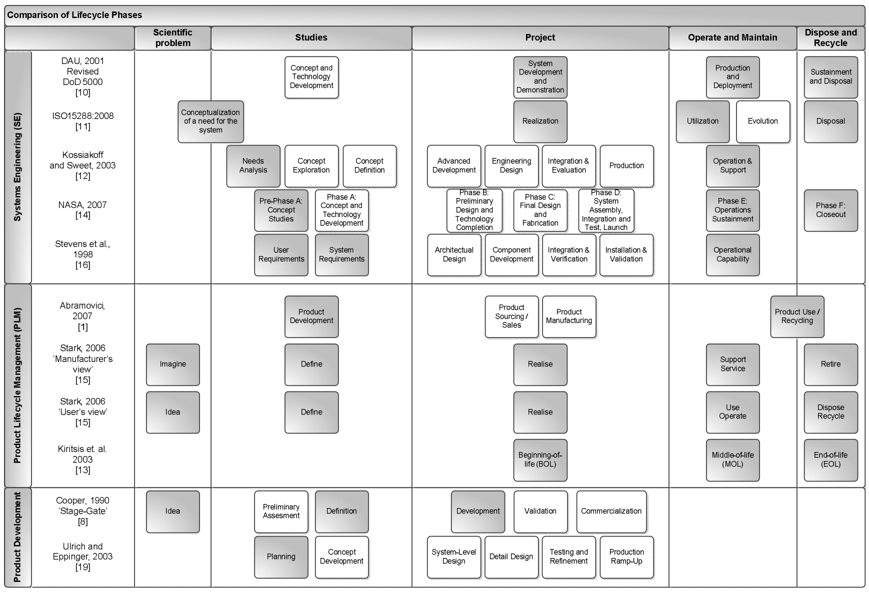

Fig. 4. Comparison of lifecycle phases.

6 Conclusions

In this paper, we start by describing contexts of lifecycles in Product Lifecycle Management (PLM), Systems Engineering (SE) and product development. We also provided the overview of the case study object in CERN. The needs and problems that have occurred in CERN in the past, sooner or later might come to other industries. For example Global collaboration tool WWW (the World Wide Web) was conceived in CERN for sharing information between scientist working all over the world. Hence, it was significant to keep the model adaptable for other environments.

Lifecycle model organizes the phases during the life as a continuous process. The research carried out in this paper found out the phases for the lifecycle of case study environment and as a solution, a lifecycle model is proposed (Fig. 3). The proposed model provides simplified, but suitable view on the processes during the life of the cases study. The proposed lifecycle not only enjoy the advantage of low complexity and ease of implementation, but also is generalized for other research facility than just the case study. The paper found out only some of the activities in lifecycle phases. Therefore additional research is needed on the activities.

7 References

1. Abramovici M., Future Trends in Product Lifecycle Management (PLM), The Future of Product Development 2007, Part 12, Pages 665-674 (2007), DOI: 10.1007/978-3-540-69820-3_64.
2. Bonnal P., Gourc D., Lacoste G., The life cycle of technical projects, Project Management Journal 2002, Volume: 33, Issue: 1, Publisher: Project Management Insitute, Pages: 11–19, (2002), ISSN: 87569728
3. Cao H. and Folan P., Product life cycle: the evolution of a paradigm and literature review from 1950-2009, Production Planning & Control: The Management of Operations, (2011) DOI: 10.1080/09537287.2011.577460
4. CERN (2008) CERN public website http://public.web.cern.ch/public/ Accessed 30 January 2012
5. CERN (2008) The CERN accelerator complex https://cdsweb.cern.ch/record/1260465 Accessed 30 January 2012
6. CERN (2008) LHC Milestones http://lhc-milestones.web.cern.ch/LHC-Milestones/. Accessed 30 January 2012
7. Cooper R. G., Perspective: The Stage-Gate® Idea-to-Launch Process—Update, What's New, and NexGen Systems, Journal of Product Innovation Management, Volume 25, Issue 3, pages 213–232, (2008), DOI: 10.1111/j.1540-5885.2008.00296.x
8. Cooper R. G., Stage-Gate systems: A new tool for managing new products, Business Horizons, Volume 33, Issue 3, (1990), Pages 44–54, DOI: 10.1016/0007-6813(90)90040-I
9. Crnkovic I., Asklund U., Persson Dahlqvist A., Implementing and Integrating Product Data Management and Software Configuration Management, Artec House Inc., 685 Canton Street Norwood, MA02062. (2003)
10. Systems Engineering Fundamentals, Defense Acquisition University (DAU) Press, Fort Belvoir, VA 22060-5565. (2001)
11. International Standard ISO/IEC 15288, IEEE Std 15288:2008 Systems and software engineering — System life cycle processes (2008)
12. Kossiakoff A. and Sweet W.N., Systems Engineering Principles and Practice, John Wiley & Sons Inc., New Jersey (2003)
13. Kiritsis D., Bufardi A. and Xirouchakis P., Research issues on product lifecycle management and information tracking using smart embedded systems, Advanced Engineering Informatics, Volume 17, Issues 3–4, Pages 189–202, (2003) DOI: 10.1016/j.aei.2004.09.005
14. NASA Systems Engineering Handbook, NASA/SP-2007-6105, Rev1. (2007)
15. PURESAFE (2012), PURESAFE – Marie Curie Initial Training Network Homepage http://webhotel2.tut.fi/iha/puresafe/ Accessed 30 January 2012
16. Stark J., Product Lifecycle Management: 21st century Paradigm for Product Realisation, Springer-Verlag London Limited, 3rd printing (2006)
17. Stevens R., Brook P., Jackson K., Arnold S., Systems Engineering – Coping with Complexity, Pearson Education (1998)
18. Tang X. and Yun H., Data model for quality in product lifecycle, Computers in Industry Volume 59, Issues 2–3, Pages 167–179, (2008) DOI: 10.1016/j.compind.2007.06.011
19. Terzi S., Bouras A., Dutta D., Garetti M. and Kiritsis D., Product lifecycle management – from its history to its new role, International Journal of Product Lifecycle Management, Volume 4, Number 4/2010, Pages 360-389, (2010) DOI: 10.1504/IJPLM.2010.036489
20. Ulrich K.T. and Eppinger S.D., Product Design and Development, International Edition (3^{rd} edition), McGraw Hill, Singapore (2003)
21. Yin R.K., Case Study Research - Design and Methods,4th Edition, Sage Inc., USA (2009)