John Morris John Wagner Gregory Mocko

PRODUCT LIFECYCLE MANAGEMENT

Processes for a Modern Industry

CLEMSON

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PRODUCT LIFECYCLE MANAGEMENT CENTER
AT CLEMSON UNIVERSITY

This book was produced in support of the Product Lifecycle Management Center at Clemson University and its teaching mission. Queries on usage can be addressed to plmcenter@clemson.edu. More information on the PLMC can be found at its website: https://www.clemson.edu/centers-institutes/plm/

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Contents

About this Book

This text was written to accompany a university course teaching students about Product Lifecycle Management (PLM). PLM is high-level subject, building off concepts such as product design, manufacturing processes, and modeling skills. For this reason, a course teaching students about PLM is best targeted towards engineering professionals, graduate students, and perhaps undergraduate students who have completed most of their undergraduate coursework.

Software While PLM may be a software agnostic subject, its implementations certainly are not. With its focus on digital definitions and data management, PLM can quickly reduce down to technical advice on software management. This book attempts to refrain from using software-specific references, keeping its advice general. Though it is impossible (and not useful) to refrain from referencing applications that are used to perform the discussed tasks, the reader should note that they do not need access to any specific software to enjoy the presented concepts. The book does not attempt to be a technical guide for any PLM software.

Many exercises within the book require software to be completed, though efforts have been made to make completion of exercises broad for a number of applications. Though the demonstrations provided in the book are performed in proprietary software packages such as Siemens NX, and Teamcenter, the communicated concepts should be applicable to many other applications. In some instances the authors have tried to mitigate this by providing examples in many different software packwages or open-source solutions. Programming examples are provided in Python for this reason.

All models, scripts, and other electronic media referenced in the text can be found at the textbook's GitHub repository: https://github.com/Clemson-PLMC/PLM-Textbook

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Chapter Arrangement As this book is meant to accompany a class, the chapters are arranged to encourage practical learning of the material, rather than by being grouped together by common subject matter.

While this makes it convenient for classroom use, the authors are aware of the issues this approach brings to other uses. For readers studying a single subject or using the book as a reference, we have regrouped the topics below (in Table 1) by subject. We hope this reordering helps alleviate some of the organizational dysfunction associated with our chosen ordering.

Course Project

Motivation Concepts as technically based as PLM benefit from being taught through applied activities, such as design projects. The authors have accordingly sought to integrate a hands-on activity to supplement this textbook. The primary problem is the scope of any PLM project, which by definition should cover a product over its entire lifecycle. This raises an complicated point of consideration: any project that demonstrates PLM should start at a product's conception and end at the product's retirement–a lengthy time frame.

One solution to providing an acceptable accompanying project might be to string together several short projects that focus on various products at different stages in their lifecycle. However, though this allows for decent compression of the project, the discontinuity between the projects prevents students from realizing the holistic nature of PLM.

In this light, the authors decided that it was more acceptable to include a project that simulated taking a single product all the way through its lifecycle. In order for such a project to fit into a traditional course semester (16 weeks), and also teach valid PLM, we have sought to create a project with the following attributes:

- It does not require significant time to design.
- The project is group based, since much of PLM is focused on collaboration.
- The project involves a product with multiple parts, to demonstrate part relationships and configurations.
- It has sufficient complexity to yield insights from various simulations.
- The product produced within the project should be interesting to the students, with the idea

Table 1: Chapters grouped by subject matter

of encouraging creative work.

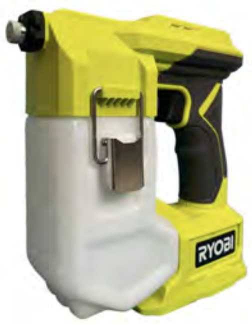

Figure 1: Cordless Handheld Sprayer from Ryobi, as part of their 18V ONE+ product line.

RYOBI 18V ONE+ CORDLESS HANDHELD SPRAYER **Purpose:** Develop and manage the sprayer across a simulated lifecycle, using PLM tools and processes learned throughout this book.

Framework: This project is designed to be completed in groups of 4-5 students. It is expected to take about 16 weeks to complete the 13 activities shown in Table 2

Outline:

Resources: Supporting files and guides can be found at the course project's GitHub at https://github.com/Cle PLMC/PLM-Textbook/tree/main/Course-Project.. Note that the project exercises are broken up by chapter, but a single combined guide is provided on the GitHub repository.

Week	Activity	Chapter	Page
1	Setup	1	1
2	Requirements	2	34
3	Project Management	3	63
4	Systems Modeling	4	94
5	Form Design	5	132
6	PDM Integration	6	193
7	Initial Project Report	*N/A*	*N/A*
8	Technical Drawings	8	
9	Change Management	9	
10	Simulation	10	
11	Additive Manufacturing	11	
12	Data Manipulation	12	
13	Final Report	*N/A*	*N/A*

Table 2: Outline for Course Project by week.

CHAPTER 1

Introduction to PLM

1.1 Concepts and Definitions

Product Lifecycle Management, more commonly abbreviated as PLM, is a concept without a stable definition. Once a buzzword fancied by industry professionals, it has slowly migrated from a fringe concept to a more normalized usage, morphing in its terminology as it has been employed by more diverse stakeholders. As part of modern, digital industry, the concept of PLM has suffered the same fate of other modern buzzwords: when it was first defined PLM was perceived as new and exciting, characterizing innovation and progress. But over several decades–a massive amount of time in fast-paced technological development–it has become somewhat regarded as more of a relic than a useful tool.

This gradual disenchantment with PLM is not due to a lack of efficacy: PLM is more than just software and its underlying concepts are ageless. Instead, the definition of PLM has begun to shift, losing its association with some of its core concepts. In many cases concepts once central to PLM have been designated as "new" technology and given new labels. Examples of this include the digital thread and digital twins, important new concepts that can be misrepresented as replacing PLM rather than occupying key functionalities of the PLM domain.

The inevitable shifting of definitions is a feature of the accelerated digital growth, where new technology is considered superior to old paradigms. In the case of PLM, it has led to some confusion

CHAPTER 2

PLM in Practice

Chapter 1 provided a working definition of PLM and offered examples of activities in various stages of a product's lifecycle. This introduction to PLM was supplemented by summarizing its origins and evolution through modern times, providing a conceptual foundation that should demystify how PLM is understood.

This chapter adds to that conceptual outlining a skeleton of technical concepts and examples, with the purpose of communicating not just what PLM is, but also how it is used. The primary objective of this chapter is to demonstrate the utility of PLM within an organization: first by deconstructing the tools of PLM, then showing how those tools support specific activities common to PLM systems. Next, the chapter discusses the functional break down of PLM into distinct user groups, and the ways that these various users operate within the PLM paradigm.

2.1 Common Tools

The term tool has been used liberally without offering a technical definition. To aid in understanding the context of this chapter, it is appropriate to rectify this usage by defining a tool within the genre of PLM. In general, a tool provides some added functionality that is useful for accomplishing some task. A hammer has the functionality of amplifying the impulse of an operator's blows to some object; this function is useful for driving nails, breaking apart structures, or cracking brittle

CHAPTER 3

Project Management

Imagine an ideal product that is perfectly simple. It has one working part made from a single, cheap, and abundant material. It is made by a single person in a short amount of time, and fulfills a small role. Such an ideal product likely doesn't exist, though tools made by animals and early hominids–such as rock hammers or sticks for poking things–may come closest to encapsulating this idea of perfect simplicity. An ideally simple product would take no effort to design or produce. While there are competing factors that have to be weighed with which shoes to wear, phone to use, or bus to take, there would be no complications with this idealized product.

In reality, no product can achieve such simplicity, because such simplicity implies a lack of information. Instead, all products exist across an infinite spectrum of complexity. This complexity must be managed to produce the product, hence the focus on product lifecycle management. But that inherent complexity also speaks to the level of work required to do the production: while a rock hammer is simple to pick up off the ground, an offshore oil rig requires considerably more labor to build. Consequently, in addition to the tasks associated with managing a product's complex information there is a need to manage the associated complex production of that product. This work falls under a branch of theory known as project management.

At first the connection between project management and PLM may seem contrived. Project management is often considered a business concept for executives and managers, while PLM is traditionally engineering-focused. Yet, as has been said before, limiting PLM solely to engineering precludes the insights and value-adding practices that come from connecting all managers of product

CHAPTER 4

Systems Engineering

Much of what has been said about the maturation of PLM can be similarly said about Systems Engineering. Though humans have been engineering systems since the earliest rock hammers, Systems Engineering (SE) has evolved dramatically over the past decades in response to the same stimulus advancing PLM. As a discipline focused on managing complex, interconnected information, SE shares more than just a history with PLM. The perception of the two domains in modern industry has waxed and waned along with the tides of technology acceptance, not to mention the proximity of their respective definitions [1].

Due to their similarities some pedagogues and subject-matter experts specializing in SE and PLM have actively discounted the other topic. Though there are many methods and reasons (some of them excessively pedantic) for classifying these areas, this text takes the position that neither SE nor PLM subsumes the other, nor are they mutually exclusive. Instead, their relationship should be thought of a hyper-dimensional Venn diagram. In this viewpoint various subdomains of SE and PLM overlap at times, each providing specific tools and perspectives. Other parts of PLM are entirely non-existent in SE, and vice versa. Considering the two of them together will inevitably result in some overlap, but this overlap supports a robust understanding of how product information moves throughout its lifecycle.

One clear difference between SE and PLM is the amount of attention given to SE by universities and professionals. While PLM seemingly remains solely as a product of industry, many Universities offer System Engineering programs, complimented by many textbooks and studies on the discipline.

CHAPTER 5

Computer-Aided Design

Any comprehensive discussion on PLM must include a reference to Computer-Aided Design (CAD), which should be considered the heart of the PLM ecosystem.. Few other topics are as critical to the implementation of PLM as a CAD platform, a fact attested to by its exceptionally high usage rates across all levels of industry worldwide [1]. The goal of this chapter is not only to review what CAD entails, but also to discuss how to reap greater benefits of information though the correct usage and integration of CAD applications into a product's lifecycle.

5.1 Form

For all its ubiquity (or perhaps because of it), CAD lacks a singular task that it is used for. Instead, what differentiates CAD applications from other software applications is its focus on establishing form for an arbitrary object.

Definition

Form: The tangible properties of an object, especially its shape.

An alternative way to understand form is to consider all the attributes of a object that are possible to interact with. The word object is employed because CAD is exclusively used for the examination

CHAPTER 6

Product Data Management

Product Data Management (PDM) has already been mentioned dozens of times in this textbook. Chapter 1 discussed how PDM is commonly (mis)interpreted as PLM, while other chapters have routinely mentioned how PDM is necessary for Project Management, Systems Engineering, or CAD. Chapter 5 described CAD as the heart of PLM. Considering the role PDM plays in every aspect of PLM, this analogy can be extended to compare PDM to the skeleton of PLM: providing essential structure to every PLM activity.

PDM is not the only tool focusing on managing data. Different development domains such as software, media, and Big Data use other tools to accomplish similar tasks. Indeed, most of the actual practices of data management are not unique to PDM and are subsequently not discussed in this chapter.[1] This chapter focuses on providing a greater understanding of what PDM is, its functionalities, why it is used, and how best to integrate it within the PLM ecosystem.

6.1 Introduction to PDM

Chapter 1 described how the development of PDM mirrored that of CAD applications. The consideration of a separate application for managing product data developed as the use of digital engineering tools (such as CAD) ballooned from the late 1990's into the Dot-com era. These early PDM

[1] More insight on data preservation, security, and analytics can be found in Chapters **??** and **??**.

CHAPTER 7

Modeling and Simulation

Literature on technological frameworks (including this one) are replete with various phrases emulating or referencing the famous quote by statistician George Box, "all models are wrong, some are useful" [1]. Models have formed an important discussion throughout this book, including their introduction in Chapter 4. This discussion is elaborated in this chapter in describing how to make models useful through simulation.

A simulation is the virtual behavior of a real entity as predicted by a set of associated models. This informal definition (which will be supplanted by a more robust one later) establishes the context of this chapter. The previously treated acts of creating, implementing, and linking models sets the foundation for the production of useful insight. The first section introduces Computer-Aided Engineering, followed by a discussion on how models and simulations are executed using digital tools. The remainder of the chapter focuses on specific simulation and optimization methods, and how they can be integrated into the PLM ecosystem.

7.1 Introduction to Simulation

The idea of simulation as tool for engineers has a long established history. When viewed as a way of predicting something's behavior based on reasonable estimates (models), simulations must have been used to predict the material volume and labor necessary to build such structures as the Great

Index