

Agile Hardware Product Realization

Mastering the Journey from Concept to Scale

Michael Keer

Co-author: David Eden

Agile Hardware Product Realization

Mastering the Journey from
Concept to Scale

Michael Keer

Founder and Managing Partner,
Product Realization Group

Illustrations and co-author:

David Eden, COO, Product Realization Group

Agile Hardware Product Realization.

Version 2

Copyright © 2023 Michael Keer

All rights reserved.

No part of this publication may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, without the prior written permission of the author, except in the case of brief quotations embodied in critical reviews and certain other noncommercial uses permitted by copyright law.

All trademarks are trademarks of their respective owners. Rather than put a trademark after every occurrence, we use names in an editorial fashion only and to the benefit of the trademark owner, with no intention of infringement of the trademark. Where such designations appear in this book, they have been printed with initial caps.

This book is a work of nonfiction. Although the author has made every effort to ensure the accuracy and completeness of the information contained in this book, the author assumes no responsibility for errors, inaccuracies, omissions, or any inconsistency herein. Any perceived slights of specific people or organizations are unintentional.

This work is provided "as is" without any express or implied warranties. While the author has made every effort to provide accurate and up-to-date information, the author makes no representations or warranties of any kind, express or implied, about the completeness, accuracy, reliability, suitability, or availability with respect to the information, products, or services contained in this book for any purpose. The reader assumes full responsibility for the use of the information provided herein and agrees that the author is not responsible or liable for any claim, loss, or damage resulting from its use.

"This book deeply resonates with my experience. The NPDI processes contained within are of tremendous value to hardware development teams. It is a must read for design and manufacturing professionals!"

Robert Bisailon, VP Operations, Synopsys Inc.

"Michael's insights, methods, and tools provide for an extensive roadmap to successful product realization. From resource management to MVP and beyond, Agile Hardware Product Realization packs decades of experience and understanding of the product development process into easy understandable methods and processes that any aspiring startup team can utilize in a straightforward manner. In particular the areas of scale, manufacturing, and supply chain take the reader through some of the most important areas that are usually neglected or oversimplified by leaders who focus too much on the design and specs of a new product. I recommend a thorough reading of this book and its principles by any team regardless of its experience as a key step to help assure the success of their new venture."

Martin Lynch, Chief Operating Officer, Freewire Technologies

"It's a well-known adage that launching a new hardware product is hard, but this book will help smooth the way. With a clearly defined process distilled from industry veteran's best practices, it offers a guide to help you navigate new projects from concept to launch. As a testament to its effectiveness, we followed this process to successfully launch Roost's first product in under a year, thanks to the early identification of hidden roadblocks. The invaluable lessons in this book are now deeply ingrained in our product development process, paving the way for another 10 successful product launches and beyond."

James Blackwell, CTO & Cofounder, Roost Inc.

I dedicate this book to my father, Leon M. Keer. A loving father and devoted university professor, he has been a source of inspiration for both me and the countless others whose lives he interacted with throughout his lifetime. His spirit lives on through this work, and I hope to honor his memory by sharing the knowledge he instilled in me.

Michael Keer, April 2023

Foreword

In November of 1805, the famed explorers Lewis and Clark arrived at the western edge of North America and looked out over the Pacific Ocean. Their journey had taken almost a year and a half and was filled with stories they captured in their detailed diaries and hand drawn maps. Many Americans waited with anticipation for Lewis and Clark's return - hoping to read the accounts of their expedition, and to imagine taking the journey themselves.

Their journals and maps were published in 1814 and quickly sold out. Adventurous traders and optimistic settlers bought the books hoping they could retrace Lewis and Clarks route to find a new life. Today, these rare first edition journals can be found in private collections and university libraries around the world. But one thing that's even more rare, is an original edition still containing the fold out maps. Anyone that attempted the journey didn't pack the heavy book, instead they cut out the map and folded it into their pocket. For them, it was the most valuable part of the book.

Today, the western edge of the United States is filled with established tech companies and countless startups, hoping to develop products that will change the world. And in every case, there's an adventure that's taken place as that product was brought to market. A daring journey from the first optimistic idea to the product release. And sadly, many products never make it into the market. Michael Keer has carefully mapped and journaled his countless routes along the New Product Introduction (NPI) process. And he's provided it to each of us, so that we might prepare appropriately for our own adventures.

My hope for you, as you read this book, is that you will find yourself embarking on the adventure of a lifetime. I did just that 7 years ago, and Michael was my guide for much of the journey. If your NPI adventure is like mine, it will be filled with some ups, some downs, moments of contemplation and lots of realizations. And ultimately, if well plotted, your expedition will be filled with much success as you look out over the market and observe the fruition of your efforts.

So, with that I'll give you some advice: Dream big. Work hard. Imagine success. And most importantly - don't start your journey without the map.

Mark Frederick,

Chief Technology Officer and Co-founder, MäkuSafe Corp.

Agile Hardware Product Realization

Contents

1	Introduction.....	17
2	Product Realization Overview	19
2.1	Defining Product Realization.....	19
2.2	Product Realization Flow.....	19
2.3	Phase-Gate Process	21
3	Understanding Your Markets	25
3.1	Impact of Shipping on Your Development and Deployment Plans	25
3.2	Aligning Your Business with Your Product Realization Strategy	26
4	Distinguishing Agile Hardware from Agile Software.....	29
4.1	Key Elements of Agile Software.....	30
4.2	Key Elements of Agile Hardware	31
5	Agile Hardware Product Realization	33
5.1	Impact of Following the “Bad Old” Ways	33
5.2	Difficulties in Bringing the Right Team Together.....	34
5.3	Missing Interactions in the “Ideal” Project Plan.....	35
5.4	Challenges in Aligning Resources to the Project Schedule	35
5.5	Benefits of Agile Hardware Product Realization	37
6	Preparing for Agile Hardware Implementation	39
6.1	10 Critical Warning Signs of a Broken Process	40
6.2	Marketing’s Role in the Product Realization Cycle.....	42
6.3	Defining the Product.....	46
6.4	Tradeoffs among Cost, Performance, and Time	56
6.5	Accounting for “Total Cost of Ownership”	57
6.6	Impact of Cost Escalation throughout the Product Lifecycle.....	59
6.7	Flexibility Versus Control through the Hardware NPDI Process	60
7	The 10 Best Practices of Agile Hardware Product Realization	63
7.1	Employ Agile Hardware Development	65
7.2	Leverage Simulation Tools and Rapid Prototyping.....	73
7.3	Develop an MVP	79
7.4	Understand and Mitigate Risks Early	83
7.5	Apply DfX.....	88
7.6	Incorporate Product Reliability, Validation, and Testing.....	100

Agile Hardware Product Realization

7.7	Meet Agency and Environmental Compliance Requirements	117
7.8	Deploy Scalable Business Systems and Processes.....	123
7.9	Develop a Resilient Supply Chain	131
7.10	Verify Readiness for Volume Manufacturing	141
8	Managing the Agile Hardware Lifecycle	143
8.1	Documenting Your Product	143
8.2	Project Management.....	150
8.3	Managing Change	151
8.4	Key Performance Indicators: Measuring and Monitoring Success....	152
9	What Success Looks Like.....	157
9.1	Startup Company – Freewire Technologies.....	157
9.2	Established Company – Leading EDA Business, USA.....	159
10	Putting It All Together.....	161
11	Are You Ready for Scale?.....	163

Agile Hardware Product Realization

List of figures

Figure 2.1: Product Realization Flow.....	19
Figure 2.2: Typical phase gate process.....	22
Figure 2.3: Phase gates showing cross-functional dependencies.....	24
Figure 3.1: Geographical shipping considerations.	25
Figure 4.1: Traditional waterfall and agile methodologies (conceptual).....	30
Figure 4.2: Standard Agile sprints.....	30
Figure 4.3: Agile hardware iterations.....	31
Figure 4.4: Realistic journey of agile hardware iterations.	32
Figure 5.1: Typical product development cost–profit curve.....	34
Figure 5.2: Example of the ideal plan.	34
Figure 5.3: Example of the ideal plan including interactions.	36
Figure 5.4: Minimizing costs and extending profits with agile hardware.....	37
Figure 6.1: Marketing’s role in the product realization cycle.	42
Figure 6.2: Requirements for marketing clarity.....	43
Figure 6.3: Example relationships between MRD and PRD requirements.....	45
Figure 6.4: Example of a product tree diagram.....	46
Figure 6.5: Example of a product tree augmentation diagram.	47
Figure 6.6: Example of a typical BOM for a laptop computer (partial).	49
Figure 6.7: Elements of the item master: BOM part "DNA."	52
Figure 6.8: Effects over time on the locked-in costs of a product.	54
Figure 6.9: Performance triangle.....	56
Figure 6.10: Elements of total cost.	58
Figure 6.11: Cost escalation through the product lifecycle.	59
Figure 6.12: Moving from flexibility to control during the hardware lifecycle. ...	61
Figure 7.1: The 10 best practices of agile hardware product realization.....	63
Figure 7.2: Example of NPDI product schedule.....	69
Figure 7.3: Computer simulation and modeling of complex parts.	73
Figure 7.4: Example of 3D printed prototype parts.....	77
Figure 7.5: Definition of MVP.....	79
Figure 7.6: The MVP process	80
Figure 7.7: Successful hardware MVP: iPhone.	81
Figure 7.8: Examples of DfX categories.....	88
Figure 7.9: Applying DfX through the NPDI process.....	89
Figure 7.10: Impact of DfM throughout the product lifecycle.	90
Figure 7.11: DfM applied to the design of a mechanical part.	92
Figure 7.12: Practical examples of the application of poka-yoke.	93
Figure 7.13: DfT applied to a complex PCBA.....	94
Figure 7.14: Tradeoffs between cost and time for a product.	100
Figure 7.15: Example of what can go wrong with reliability.	102

Agile Hardware Product Realization

Figure 7.16: Example of a production test station.....	107
Figure 7.17: Traditional V-model.	110
Figure 7.18: V-Model modified to include agile techniques.....	114
Figure 7.19: Examples of compliance requirements.....	117
Figure 7.20: Example of compliance certification requirements and costing... ..	121
Figure 7.21: Examples of business systems.	123
Figure 7.22: Example of data flows between business systems.	128
Figure 7.23: Example of data mapping across business systems.	129
Figure 7.24: Typical elements of a resilient supply chain.....	131
Figure 7.25: Elements that make up total product cost.....	132
Figure 7.26: Proportions of total cost between prototype and volume.....	133
Figure 7.27: Order fulfillment flow.	136
Figure 7.28: Typical customer journey including returns flow.	137
Figure 7.29: Typical logistics management cycle.	138
Figure 8.1: Product requirements hierarchy example	145
Figure 8.2: Diagram of documents in lifecycle.....	149
Figure 8.3: Example KPI dashboard.....	155
Figure 11.1: Agile hardware product realization: benchmarking areas.	163

Preface

After \$300 hundred million dollars and three years into my first Silicon Valley startup, Raynet Corporation, this innovative optical telecommunications startup got hit with a serious blow from Bellcore, the telecommunications regulatory body, who rejected its “fiber in the loop” architecture that was the basis of its competitive advantage. Unfortunately, this meant that the product, as designed, could not be shipped to customers.

To fully comply with Bellcore, it took three more years and an additional \$300 million dollars. Making matters worse, this new architecture eliminated the product’s fiber bending competitive advantage. After the new product was revised to comply with Bellcore’s requirements, growing sales were not forthcoming, and the primary investors became increasingly concerned. Sadly, after more than six years of development and \$600 million in funding, the business was sold to Ericsson for roughly \$30 million – a catastrophic return on investment. One upside was that over 800 innovative technologists quickly dispersed to companies such as Cisco, Finisar, Ascend Communications, Google, Apple, and many others. These colleagues and friends became strong network connections for future endeavors, fulfilling the Silicon Valley adage that company names may change, but the names of the talented people supporting them remain.

As a young, idealistic engineer, this experience opened my eyes to the unanticipated risks (and costs) that high-tech companies face in bringing innovative new products to market. Several years later, I was Senior Director of Operations at Paramit Corporation, a Silicon Valley electronic manufacturing services provider. Over the eight years I worked there, I saw an increasing gap between our clients’ need to ship versus their ability to create, communicate, and manage changes for the sets of documentation needed to build their products at scale. It struck me that few involved in the product realization process seemed to care about bridging this gap, and so I formed the Product Realization Group (PRG) to help companies bridge the gap between concept and full market scale.

The intent of this book is to share the many years of “hands-on” experience and wisdom from the members of PRG in combination with outside industry experts into a book that will increase the awareness of what it really takes to get a hardware-based product to market at scale. By sharing these experiences, wisdom, and expertise, my desire is to demystify the process of bringing new hardware-based products to market in an agile way as well as help businesses avoid common unintentional and costly mistakes.

Because this book spans the entire product realization process, it covers each practice at a fairly high level. If you desire more details about a specific area (e.g., development or supply chain), there are many books available that focus on these areas in detail. The unique value added of this book is its holistic view of the entire product realization process, with practical tips provided for each of the practices described.

We’ve grouped this knowledge and wisdom into 10 best practices of agile hardware product realization. These practices are geared for those directly involved in the new product introduction process of hardware-based (or system-based) high-tech products. If these practices are implemented properly, they will help reduce your risk for bringing new products to market and increase your chances of success in the market with a byproduct of scalable business processes to support the introduction of future products.

If you are involved in the process, or are just curious about how the process works, then this book is for you. It assumes that you have already done the heavy lifting of marketing discovery to the point where your product definition is clear and documented properly via a Marketing Requirements Document (MRD) and a Product Requirements Document (PRD) as robust inputs to the process. It is worth noting that both of these documents can be considered as “living” throughout the life of the product; that is, they will change as new challenges present themselves or new ways of achieving results are found.

Agile Hardware Product Realization

I would like to thank all the seasoned consultants, clients, and dedicated service providers who contribute actively to the hardware product realization process on a daily basis. Many of these contributors fly under the radar of high-profile high-tech startups and established corporations. These “unsung heroes” have dedication and passion for bringing new products to market and are adept at getting things done in the background to help these businesses mitigate risk and enable them to wow the market with innovative new products.

Michael Keer

Acknowledgments

I am incredibly grateful to the brilliant team who has helped bring this book on hardware product realization to life. Their expertise, dedication, and passion for the subject matter have shaped this work into what it is today.

First, I must express my sincere appreciation for my co-author, editor, and outstanding graphic artist, David Eden. His creativity and attention to detail have elevated both the content and visuals throughout this book. My genuine gratitude also goes to our contributing editors, Jane Nevins and David Couzens, whose keen eyes and expert insights have significantly improved the quality of this manuscript.

I would be remiss if I didn't acknowledge the invaluable contributions of our expert reviewers, who generously shared their time and knowledge. A heartfelt thank you to Allen Adolph, Howard Edelman, Jay Feldis, Wayne Firsty, Michael Freier, Shirish Joshi, Ken Kapur, George Lewis, Sunil Maulik, Wayne Miller, Feroze Motafram, Sheila Walsh-Pickering, Jeffery Rosen, and Fred Schenkelberg. Your feedback and wisdom have undoubtedly made this book better.

On a personal note, I must express my deepest gratitude to my wife, Cindy. Her unwavering patience, understanding, and support have made this remarkable journey possible. I am truly blessed to have her as my partner in life.

1 Introduction

By reading this book, you will gain the wisdom from knowledgeable experts that span hundreds of years of experience and substantially increase your ability to meet new product time-to-market goals, lower costs, reduce risk, and set a solid foundation for future growth. This book applies agile hardware development concepts combined with best practices for scaling into volume manufacturing to the entire product realization process.

This book is intended as a practical guide for those engaged in the technology-based hardware product realization process, from conception to full market scale, and for all sizes of business and product complexity, from startups to Fortune 50 companies. An agile and robust New Product Introduction process is important for all hardware companies independent of their size and lifecycle status.

As you explore the book, an important element of your New Product Development and Introduction process to consider is the type of product that you intend to move from concept to volume production. Less complex and higher volume products involve very different development and operational strategies than more complex and lower volume products.

If you are short on time, then you may want to skip to Section 6.1 to help you gain quick insights into the areas where your business is at the greatest risk.

For companies bringing their first product to market, there will be a great opportunity to implement best practices from the start and to “get it right the first time.” For companies with established processes and systems, there is an opportunity to revisit, retool, and optimize your existing process. As you likely already know, actively changing established business processes and systems will require strong management support, a desire for cultural change, and companywide dedication to achieve sustainable results.

Agile Hardware Product Realization

I recommend reading the whole book to demystify the process and gain the full value offered. By doing this, you will learn about areas you may not typically become involved with and understand the importance of how these practices reinforce each other to help you get better products to market faster with less risk.

2 Product Realization Overview

2.1 Defining Product Realization

Product realization is a term used by the International Organization for Standardization (ISO) 9001:2015 and refers to the basic design and realization of a product provided to customers that are measurable by quality control. It provides clear, certifiable standards for the process of bringing a product to market. Because this book encompasses multiple elements throughout the product lifecycle, you may see terms such as New Product Development (NPD) and New Product Introduction (NPI), as well as New Product Development and Introduction (NPDI). Regardless of the three- or four-letter acronym used, the intent of this book is to share a framework that combines agile hardware development concepts along with best practices for scaling into volume production to increase your chances of success and reduce your risk in bringing new products to market.

2.2 Product Realization Flow

Transforming a product from concept to volume manufacturing requires a journey through a series of stages or phases of activity increasing the details of knowledge about it and reducing the uncertainties. The standard sequence of phases is depicted in Figure 2.1 below.

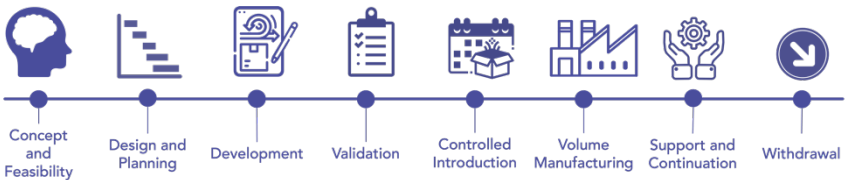


Figure 2.1: Product Realization Flow

The phases of the product realization flow are described below:

- **Concept and Feasibility:** This initial stage is where ideas for product development are generated, market viability is assessed, technical feasibility is determined, and essential product features are identified.
- **Design and Planning:** In this phase, high-level ideas and concepts for the product are translated into concrete plans, with cost estimations, timeline and resource requirements being established.
- **Development:** This phase encompasses all engineering design and development work, including prototype creation and risk reduction efforts associated with product requirements. Agile hardware development may involve multiple rapid prototyping cycles within this phase.
- **Validation:** This phase involves formal product testing to verify that all the requirements have been met before transferring the design to manufacturing.
- **Controlled Introduction:** During this phase, volume manufacturing set up is performed to ensure cost-effective production. Concurrently, customers are provided with the first complete products to experience, including all the packaging, documentation, training as well as the support and returns processes.
- **Volume Manufacturing:** In this phase, products are manufactured in quantities sufficient to meet sales demand, guided by sales projections and customer needs to guarantee product availability when desired by customers.
- **Support and Continuation:** As the product matures in the market, customer support for issues and upgrades become necessary. Manufacturing may require replacement or upgrades due to unavailability of parts.
- **Withdrawal:** Eventually, the product will need to be withdrawn from the market. This decision may stem from the introduction of a newer model, because low sales numbers have made it unprofitable, or because it is no longer viable to manufacture.

2.3 Phase-Gate Process

As you begin your product realization journey, implementing a phase-gate process (see Figure 2.2) will enable you to assess the viability of the project as it progresses through the product lifecycle.

At the end of each phase, a formal team-based review is held to evaluate the project viability relative to a specified exit criterion. During the review process, the team will assess the progress of the plan, resource allocations, risks, costs, and potential pivots required for the project to move forward. If the project fails the gate review, then it will either be restructured to pass in the future or cancelled altogether (embracing the concept of “fail fast”) to avoid increasing sunk costs for a nonviable project. If the project passes successfully through the gate, then it will move forward to the next phase, as shown in Figure 2.2.

This type of phase-gate process may seem to be at odds with the traditional ideal of an agile process, however, but for hardware, owing to the increasing cost of change during the latter phases of this flow, it is important to maintain regular check points on progress. Later sections of this document show how agile repetitions can be built into several of the phases described above as part of agile hardware product realization.

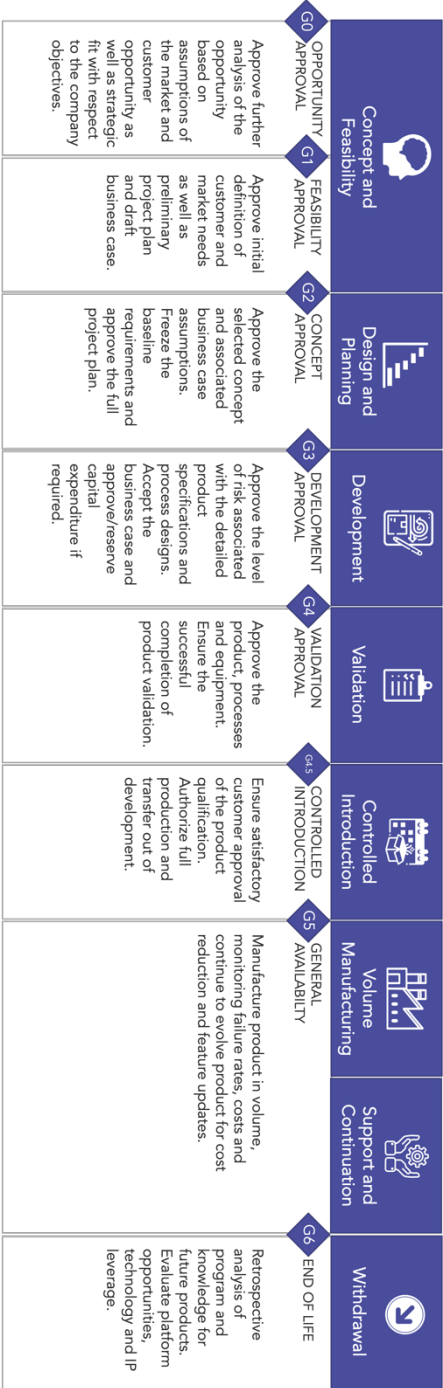


Figure 2.2: Typical phase gate process.

As your product progresses through each key gate in the process, you will want to ensure that all team members are aligned and in agreement before moving to the next gate. Figure 2.3 illustrates, at a high level, some of the key activities and dependencies that are required to support the product realization process.

The combination of multiple disciplines that must be organized and applied in the proper order through each gate along with the need to meet outside regulatory requirements makes developing physical products more expensive, time consuming, and risky than developing pure software application products. Many hardware products fail because of a lack of understanding of what is truly required to navigate the product realization process.

Agile Hardware Product Realization

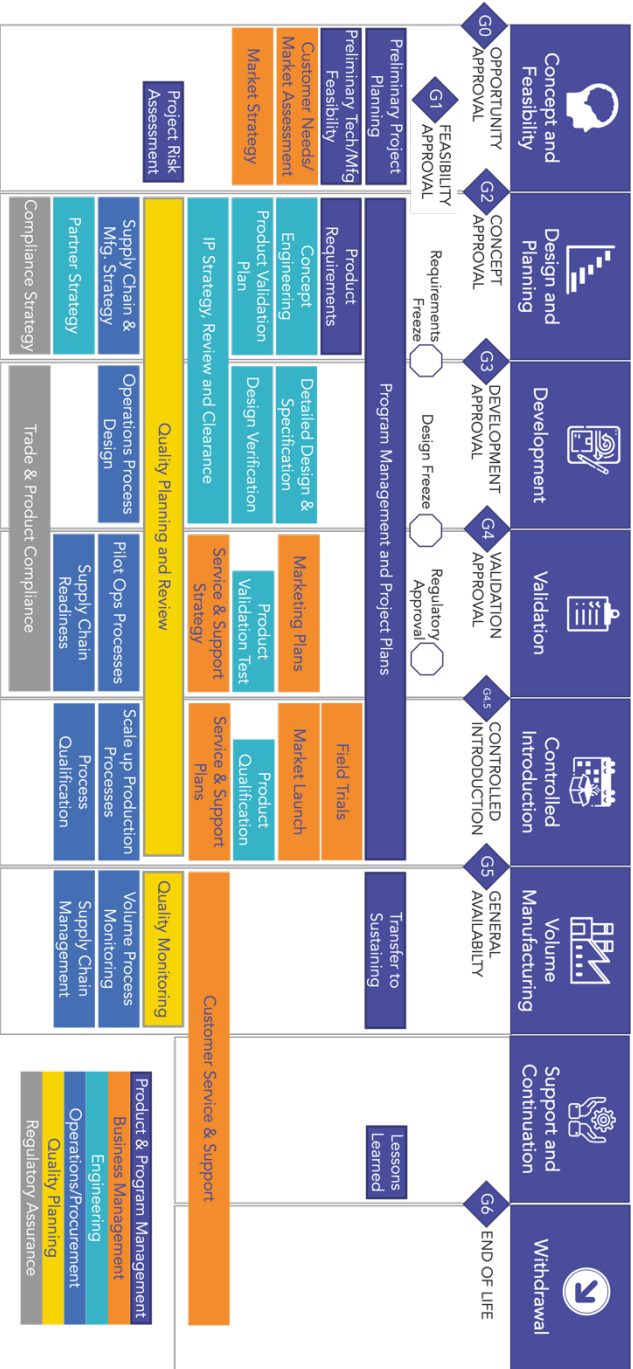


Figure 2.3: Phase gates showing cross-functional dependencies.