Climbing the Commercialization Hill

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You've worked hard to build the first working breadboard. That first spark of insight that burst of innovation is paying off and your idea is coming to life. You have something to show to others, a crude package, yes, but it sweeps them along in a wave of excitement. You did it. You're finished. Now it's just a matter of building a bunch of them. Right?

Not quite. It's often frustrating to the uninitiated to find out just how much work is ahead of them to commercialize a new idea. Generally at this point in the process, less than 10 to 50% of the overall work needed to bring a new product to market has been completed. And, although we are constantly looking for ways to shorten this cycle, the fact is that to manufacture a product repeatedly, with predictable delivery, quality, cost and performance, takes a great deal of planning and orchestration beyond the breakthroughs necessary to build the first working prototype. Looking at some examples of product development will clarify the standard steps in that process for a product that is a mixture of hardware and software.

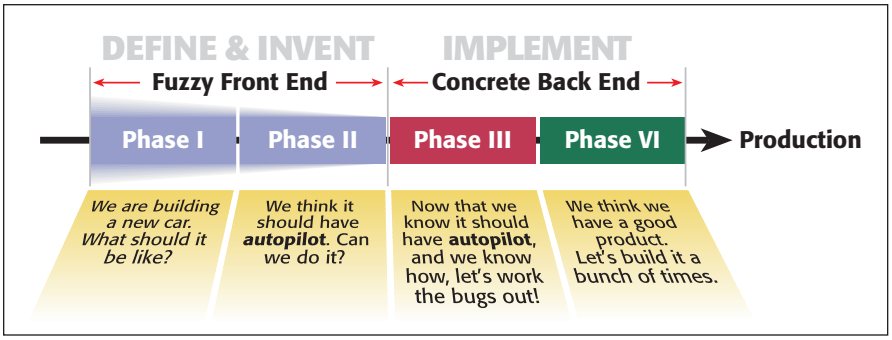

Figure 1: Typical phase/gate process

Phase-Gate or Stage-Gate Processes

The most commonly used process for introduction of new products into manufacturing is the phase-gate or stage-gate process. The name refers to the separation of the project timeline into various phases or stages, separated by "gates" through which a project must pass to proceed to the next phase. This gives a common terminology for use across the organization for preparation and readiness to participate, as well as some level of oversight and control to those in the organization that are ultimately responsible for the project success.

The typical phase-gate process is shown in ***Figure 1***. Although there are many variations of this process, and the details may vary greatly from one company to the next, we should be able to introduce the major concepts through this framework. The diagram uses as an example the evolution of a single element of a product definition; autopilot for a new car.

Although the names of the stages will vary from company to company, the general process is usually the same. Examples of names used for these phases are Concept for Phase 1, Investigation or Definition for Phase 2, Development for Phase 3 and Pilot for Phase 4.

A Line in the Sand: Definition & Invention vs. Implementation

Isaac Asimov said, "The most exciting phrase to hear in science, the one that heralds the most discoveries, is not 'Eureka!' (I found it!) but, 'That's funny.'"[1] In the beginning stages of a new discovery or invention, we tend to hear "That's funny" a great deal.

One cannot plan to *discover* something new. One can only plan to implement a discovery. The planning can only really start in earnest once the issues requiring "miracles" have been solved. At some point, we know what we want to build, and exactly how to build it. For this reason, there is a big difference between what people call the "fuzzy front end" (as shown in ***Figure 1***) and the more "concrete back end." And there is almost always a dividing line in the process that begins at the point in time at which we are sure of the definition of the product we

1 www.quotationspage.com/quote/470.html

wish to commercialize in complete detail and we are fairly sure we have no invention left, and that the high risk areas of cost and performance have all been sufficiently worked.

In ***Figure 1***, this line is at the start of the "Phase 3" stage. Beyond this point, we believe we know how to plan a project and we will be implementing this plan. Previous to this, we are refining the product definition and project goals and inventing our way out of technical issues.

Changing of the Guard: Relative Resources in Each Stage

Figure 2 shows how resources from each functional area will contribute to the overall successful introduction of a product. The relative levels of resources shown are normalized for a given functional area and may vary from company to company based on roles and responsibilities. The color for each phase and the color of the line graph for a specific functional area's resources are shown as the same, for clarity. Marketing has a significant role in the beginning of the project in the product definition. R&D will have a growing role, and the staffing of R&D personnel on the project is typically greatest upon the movement out of the "fuzzy front end" into Phase 3. Manufacturing, Service, Applications, and Commercial Marketing will have stronger roles toward the end of the project. This is not to say that they have no involvement in the beginning stages. In fact, without early involvement, the risks to the successful launch of the product grow significantly. However, relative to the total involvement in the end stages, their role is generally much smaller in the beginning stages.

The Product Development Funnel

The Chinese philosopher Lyn Yutang said, "Sometimes it is more important to discover what one cannot do, than what one can do."[2] It's easy to generate ideas. Most healthy R&D organizations have far more ideas than they can successfully execute. What is hard is finding the right sorting, selection, and prioritization process, one that takes into account financial payback, current competencies, risk, corporate strategy, and portfolio balancing. One of the purposes of the "fuzzy front end," the first 2 phases, is to weed out as quickly as possible the projects that will not be pursued in this time frame. By Phase 3, we are ready to invest a significant number of resources into the project and we need to make sure we are "backing the right horse" from the point of view of the market, the technology risks, and other internal business and logistic issues. One must choose projects to optimize payback and minimize the opportunity cost of leaving others behind.

We would expect then that in a healthy organization there would be many projects that fall away early in their lifecycle, to be set aside for another day, or maybe cancelled completely. In ***Figure 3***, we show the typical product development funnel. In this diagram, we have assumed that for every ten ideas, one is commercialized. The exact fallout will vary greatly from one organization to another, and probably over time.

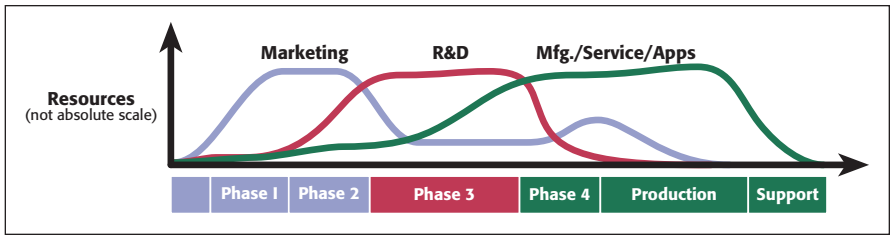

Figure 2: Typical resource balancing throughout the phase/gate process

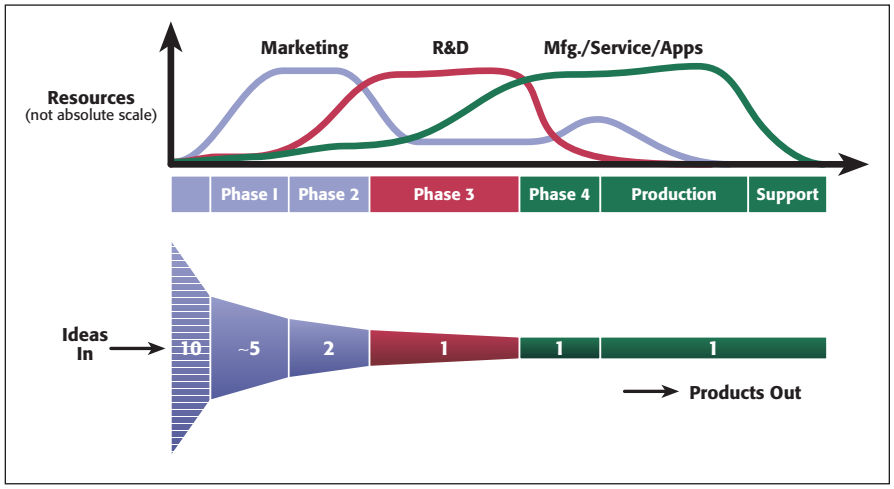

Figure 3: The product development funnel

The Cart before the Horse

A common problem in bringing an invention to an established company for sale or inclusion into the portfolio is that you may feel you are much farther ahead in the process than the company does. Even though you have a working prototype and have done some market research, the company will undoubtedly wish to do their own research as well.

In other cases, market research will regularly result in modifications of the product definitions, to which the designer will have to respond. This iterative work can seldom be avoided. At this point, your prototype is likely the result of what the company will call either the "Phase 1" or the "Phase 2" stages. And there is a great deal more work to do before it is ready for market.

Next, we discuss what the typical company needs to accomplish in each stage in order to introduce that new product right the first time.

Phase 1 – Concept

During this phase, we are refining the product concept. In a mature organization, the largest investment in resources in this stage is probably from the marketing organization, though there is by necessity some involvement from R&D to evaluate possibilities and contribute technology understanding to the choices being made. In this and the following stage, we have by necessity a very iterative process. Market and customer knowledge feeds into technology efforts

2 www.quotationspage.com/quote/14559.html

and technology understanding feeds into the product possibilities. All of this work is moving us toward a tighter definition of the product to be built. It is likely that a working breadboard will not be seen until the following stage, though bits and pieces of the most critical blocks will be tested and tried. The hope is that by the end of this stage, we will know what needs to be done in the following stage, Phase 2, and we will know what market and customer assumptions must be validated.

Figure 4 shows the high-level tasks necessary in this Phase. ***Table 1*** expounds on this by detailing the purpose for these activities and the risk of circumventing the activity. If the activities in this phase are executed well, gathering solid information and reading between the lines of customer input, one is able to introduce a product that satisfies the customer's needs.

Recently, Keithley introduced the Model 2602 Source Measure Unit (SMU) with features that are clearly in the center of previously unidentified customer need (***Figure 5***). Through careful understanding of the competitive offerings and customer applications, through complete technology assessment and significant breakthroughs, we produced a product that has exceeded expectations of our customers in rack density, extendibility to many channels, testing speed (through elements such as our Test Script Processor—TSP™) and cost per SMU channel. This was a perfect example of what can happen through healthy iteration of customer application understanding and technology assessment and development.

Figure 4: Activities in Phase 1

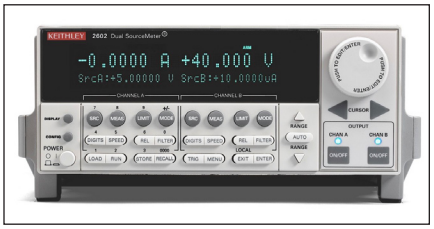

Figure 5: Keithley Model 2602 2-Channel Source Measure Unit

Table 1: Phase 1 Activities, Purpose, and Risk

Tasks to complete	Typical Owner	Purpose	Risk with Deletion
Understand competitive offerings, customer applications, critical requirements, core contribution; Positioning in market	Strategic Mktg	Aid in positioning with respect to competition and defining product that will solve customer needs	Miss key definitional elements; Competitive offering may overshadow new product; May not be prepared to aid customers pre or post sales
Strategic fit with goals and capabilities; Market potential; Preliminary financials	Strategic Mktg	Maintain synergy with other plans; Assure this is financially the right investment	Disjoint product plans create inefficiencies; Without solid financials, may over or underestimate payback
Preliminary key customer/partner list	Strategic Mktg	Customer to aid in making the right product	May engage key customers too late in development to influence design
Technology assessment; List of high risk areas, major decisions and major milestones	R&D	Assess technical risk, prepare for major tasks to be completed in next phase	May enter into development with too much technology development on main path; Schedule slippage
List of potential development partnerships	R&D	Early recognition of risk or cycle time benefit; make/buy decisions the need to be made	May pass up opportunity for significant development benefit
Preliminary schedule, resource plan, other goals (such as DFx)	R&D	Aid in financial analysis, organizational awareness and commitment	Poor information input to financials; Resources not available when needed; Need goal/direction for team
Key issues Preliminary material sourcing plan	Manufacturing	Early recognition of major efforts	Schedule slippage due to surprises
List of key issues	Cust. Service/ Apps Support & Commercial Marketing	Early recognition of major efforts	Schedule slippage due to surprises

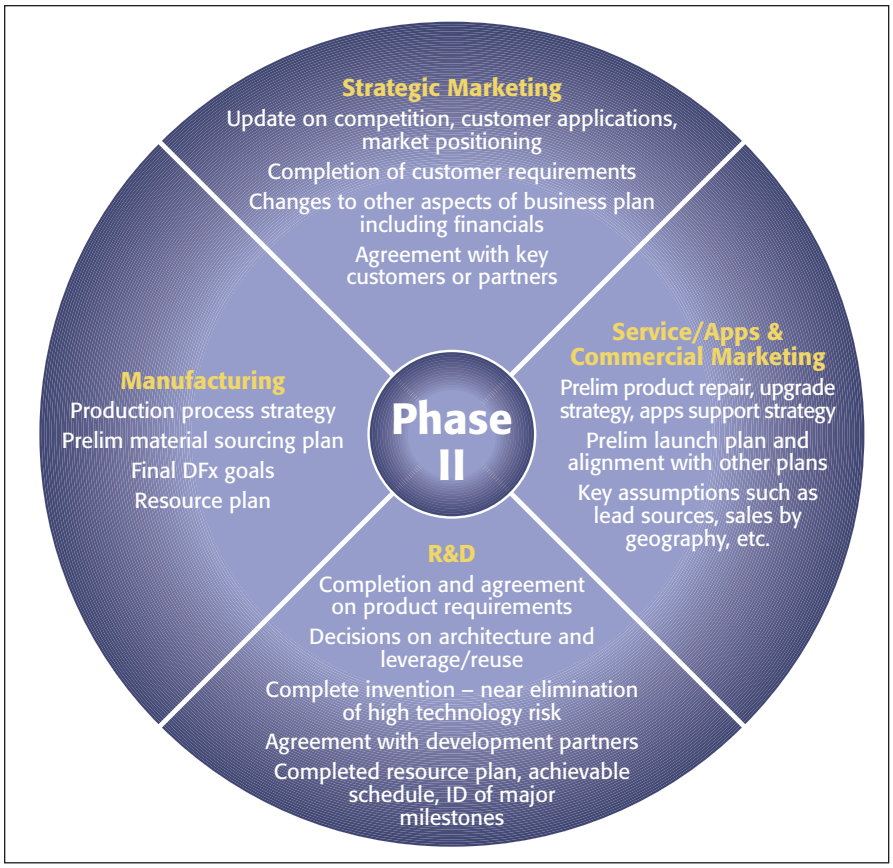

Figure 6: Activities in Phase 2

Phase 2 – Investigation

By the time we leave Phase 2, we would like to have eliminated most or all major risks. This includes market, technology, and internal logistic risks. In some cases, this stage may require the completion of a crude, working breadboard. But frequently, testing out the major risky elements, sub-units of a system may be all that is required. If the major risks can only be examined through a full integration of the system (such as heat dissipation, power budget, EMI, EMC, etc.), a full working system may be necessary before the major risks are reduced significantly.

At the end of this phase, we would like to have a solid plan for resources and project cost. We would also like to see a complete product definition that will change little in its key elements in the coming phases. In short, we are ready by the end of this phase to implement, rather than invent.

The calendar time spent in Phase 1 and 2 taken together tends to be about 50% of the project. This is not necessarily ideal. But unless there is a concerted effort to reduce the time spent in this "fuzzy front end", this will be the sad truth. It is well known that

Table 2: Phase 2 Activities, Purpose, and Risk

Tasks to complete	Typical Owner	Purpose	Risk with Deletion
Update on competition, customer apps, market positioning	Strategic Mkts	Update definition of product and key reasons customer would chose your product	May have obsolete product before introduction
Completion of customer requirements documentation	Strategic Mktg	Solidify agreement with R&D on deliverable as seen by customer	Without completion, stand good chance of product rework and project delays
Changes to other aspects of business plan including financials	Strategic Mktg	Update organization on changes	May miss a key decision point if conditions changed
Agreement with key customers/partners	Strategic Mktg	Identify customers who will aid in key elements of product definition	Will not have in-depth analysis by one who uses equipment; May miss the mark in key parameters
Completion and agreement on product requirements	R&D	Turn customer requirements into product requirements – translation of customer needs into methods for achieving	May not have understanding with marketing on the need and method of taking the "need" to the "solution"; Wrong product
Decisions on architecture and leverage/ reuse; Complete invention - near elimination of high technology risks	R&D	Lock in on high level decisions that affect technology risk; Get to point where you can plan for implementation	Uncertainty in technology employed and likely schedule slippage
Agreement with development partners	R&D	Understanding with all parties on who will do what development	Uncertainty in roles and responsibilities; Schedule slippage
Completed resource plan, achievable schedule; ID of major milestones	R&D	Financial analysis, organizational awareness and commitment	Poor information input to financials; Resources not available when needed; intermediate goals for team not clear
Production process strategy Preliminary material sourcing plan Final DFx goals	Manufacturing	Define major elements of manufacturing process; Influence design for manufacturing	Chance of major process change in direction late in project; Miss opportunity to influence product; Potential for schedule slippage
Resource Plan	Manufacturing	Financial analysis, organizational awareness and commitment	Poor information input to financials; Resources not available when needed
Prelim product service and support strategy	Cust. Service/ Apps Support	Estimate required budget, identify design-for-serviceability issues; identify customers' service requirements	Unexpected expenses; difficulties in servicing product; service strategy not accepted by customers
Prelim launch plan & alignment w/ other plans; Key assumptions such as lead sources, sales by geography, etc.	Commercial Marketing	Estimate scope and cost of promotion; set preliminary lead and opportunity objectives	Inadequate lead and opportunity generation; excessive promotional costs

reducing this front end, in the first 2 phases, is perhaps the quickest way to reduce overall cycle time.

Figure 6 shows the tasks typically performed in Phase 2, and ***Table 2*** shows greater detail on the purpose and the risks.

This ideal of having a completed product definition at the end of this phase is not always possible. This is especially true in cases where one is working on cutting edge technology, such as MEMS and nanotechnology, and the product needs are being defined interactively while a key customer is completing their technology investigation (***Figure 7***). For emerging measurement needs for instance, a key area of pursuit for Keithley, we often find ourselves working tightly with a customer and altering the product definition more deeply into the project cycle than the ideal.

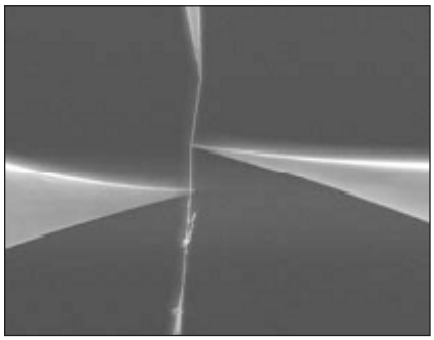

Figure 7: Measurement of carbon nanotube using Keithley Model 4200-SCS Semiconductor Characterization System and Zyvex S100 Nanomanipulator

For instance, with the recently introduced Model 6220 Current Source (***Figure 8***), used by customers in the nanotechnology field, we learned progressively more about the customer needs, as their applications were refined. It was necessary in this case to live with a greater level of uncertainty in the product definition going into Phase 3. This uncertainty did, of course, produce a longer cycle time for the product owing to some level of rework on the product design. However, this cycle time was well worth the effort in this case to produce the kind of product that could make the necessary measurement for this cutting edge technology.

On the other extreme, a company will at times find significant opportunities that begin with a special product for a key customer. In these cases, the definition for the special product will usually be clear from the beginning. For a one-of-a-kind product, many of the activities to set up for long-term manufacturing can be ignored.

Figure 8: Keithley Model 6220 Current Source

In later full "commercializing" of a special product into a general product, there may exist an opportunity to alter the definition. Many of the items listed below for Phase 3 and 4 will not be done for a special, one-of-a-kind system, but must be done for a product that will be continually generated out of manufacturing.

We sometimes find that some of our best ideas come from working with customers and understanding their application to such a degree that we are able to give significant help in critical measurements. This often takes the place of writing customer specific software, or integrating various instruments to produce a full solution. The Model 4200-SCS (***Figure 9***) with PIV solution sprang from our customer application efforts and a set of critical new algorithms written by Keithley to solve a specific semiconductor device problem. The recent commercialization of this product was largely the process of integrating a pulse card and an o-scope into the Model 4200-SCS Parameter Analyzer, and wrapping critical applications software around it. Although the solution had been proven with an external pulse instrument, one of the key risks in the project was to create and integrate a voltage pulse card into the Model 4200-SCS. Reduction of this key risk, clearly on the critical path of the schedule, could be accomplished through creation of a working circuit on the bench. This was necessary before we left the "fuzzy front end".

Phase 3 – Development

The purpose of Phase 3 is to implement the design plan, to complete the design of the product, processes, and services. The product should be brought to the point of readiness so as to enter Phase 4 (sometimes known as the "Pilot" phase) at which point

Figure 9: Keithley Model 4200-SCS, now with Pulsed I-V

the product and process will be tested for cost, yield, performance, etc. It is in Phase 3 that we will prove that we can build a small sample of the product (non-shippable) that meets the critical specifications. This is the stage where the greatest investment in R&D resources will typically take place. It is also the stage, along with Phase 4, through which we would like to move as quickly as possible. Upon entry into Phase 3, the market need is known, the product is defined, and the major technological issues are solved. We need to shoot through this stage rapidly, before the customer needs change, and before the competitive landscape changes.

At Keithley, we learn from our successes and our struggles with smooth transitions of products into manufacturing. Recently we tried to develop a new core competency in our R&D operation. The calendar time spent in Phases 1 and 2 was relatively short, and yet the time spent in Phases 3 and 4 was over 90% of the total project timeline. The primary reason for this long duration was an underestimation by R&D of the effort and time needed to develop this new core competency within the company. This underestimation caused significant increases in development time. As the development time stretched out, the customer needs changed, requiring a continuous redefinition of the product.

This vicious cycle is a trap that can occur whenever the project cycle time to commercialize the idea is long compared to the speed with which the market changes. Once we are in Phase 3, it is critical that we sprint for the finish line.

Figure 10 and ***Table 3*** show the tasks typically performed in Phase 3.

Phase 4 – Pilot

Phase 4 is designed to test the product for cost and yield to performance specs and

to test the manufacturing processes such as material ordering, assembly, and test. It is expected that these tests would be run on a representative sample of products that are essentially the same as the upcoming production products. Plus, any circuit modifications that result from these tests would be minor and not material to altering the conclusions as listed above. This phase is usually owned by manufacturing, since it is they who will live with the result, though R&D must be at the ready to help wherever necessary.

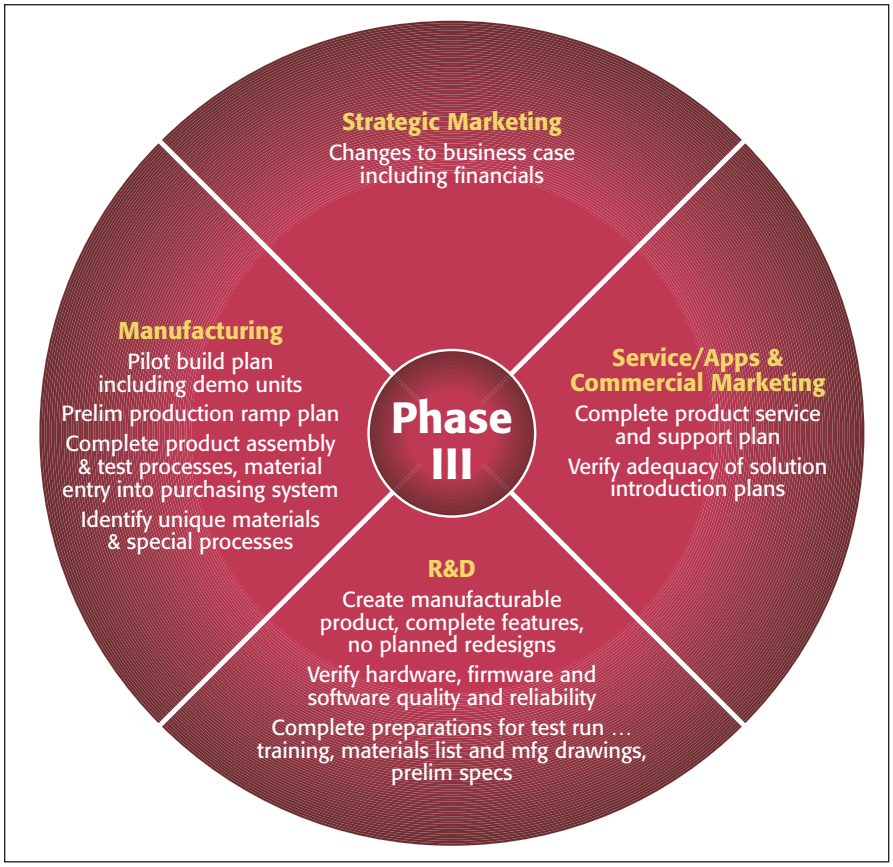

Figure 10: Activities in Phase 3

Figure 11 shows the primary activities in Phase 4. Further detail is shown in ***Table 4***.

At Keithley, we have found that Phase 4 is critical to the smooth transfer of product into manufacturing and to the ability to deliver a quality product on time to our customers from the beginning of the shipment cycle. There have been times in the past where we have tried to shortcut this phase. This is desirable when time to market is of the greatest concern. You may get a product out the door and into the market place sooner. But without a complete Phase 4, the struggles will be taken in the first production runs, with orders on the books and customer waiting, and with possible exposure to the customer of quality and delivery problems.

Table 3: Phase 3 Activities, Purpose, and Risk

Tasks to complete	Typical Owner	Purpose	Risk with Deletion
Changes to business case including financials	Strategic Mktg	Update organization on changes	Miss a key decision point if conditions change
Create manufacturable product, completed features, no planned redesigns	R&D	Complete the design	Potential schedule slippage from reworking units in following stage; potential for not meeting quality, cost, yield goals
Verify hardware, firmware and software quality and reliability	R&D	Tests to assure a quality product released to desired performance	Potential schedule slippage; potential for not meeting quality goals
Complete preparations for test run… training, materials list and mfg drawings, prelim specs	R&D	Training of technicians, assemblers, testers, engineers; Readiness for manufacturing processes	May have untrained people, material shortages for next phase; schedule slippage
Test run (pilot) build plan including demo units	Manufacturing	Number of units to demonstrate yield, etc during next phase	May not have good sampling for statistics
Prelim production ramp plan	Manufacturing	Plan for first production run; stage material, etc.	May not be ready with material for first production run
Complete product assembly and test processes, material entry into purchasing systems	Manufacturing	Readiness for processes to build samples during next phase	May not be representative test of production processes
Identify unique materials - set up special processes	Manufacturing	Special handling identified	Quality, cost, production cycle times or performance may suffer
Complete product service and support plan	Cust. Service/ Apps Support	Prepare plans to procure spares; identify required training	Inability to service product due to unavailability of spares or trained personnel
Verify adequacy of solution introduction plans	Commercial Marketing	Verify optimal solution rollout into marketplace	Confused or inadequate market introduction

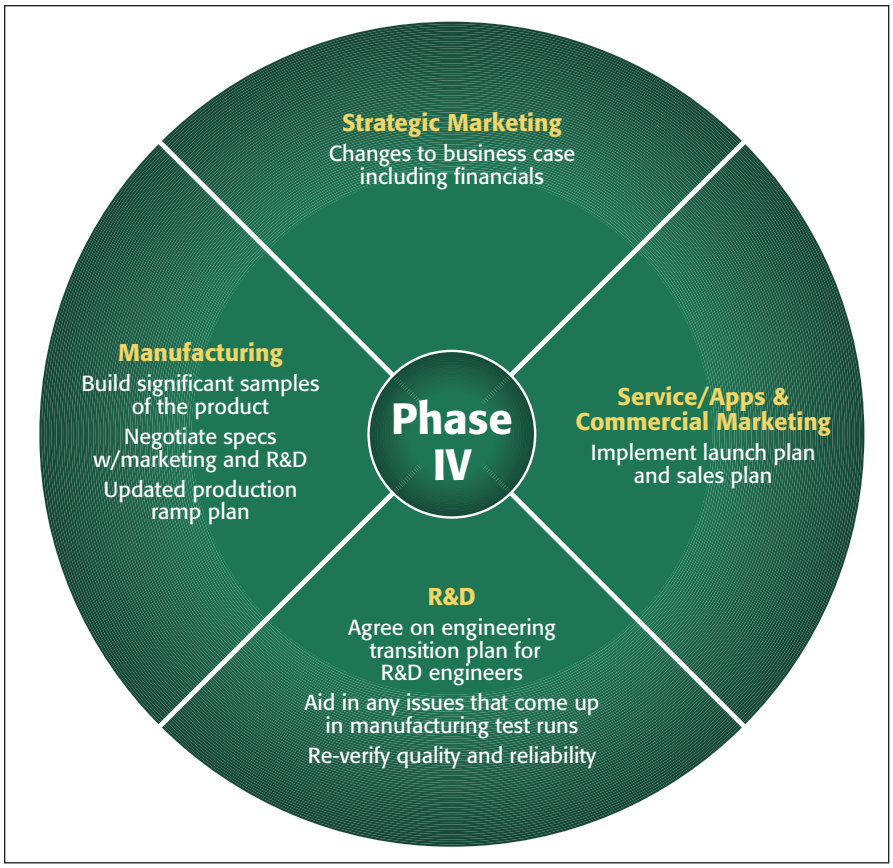

Figure 11: Activities in Phase 4

Conclusion

We have tried here to give some sense of the activities and the amount of work still remaining after the creation of the first working product breadboard. It is estimated that typically only 10 to 50% of the work has been done by the time this first breadboard is done. The rest of the effort will typically require significant cooperation between employees in each functional area. All of these activities are designed to deliver a product that will allow the organization to manufacture the product repeatedly, with predictable delivery, quality, cost, and performance. KEITHLEY

Editor's Note: Keithley's process described here is appropriate for a manufacturer of commercial, medium-volume products. Other companies might optimize in other ways. High-volume manufacturers have more manufacturing involvement in the early phases. Manufacturers of large, complex systems have more invention and innovation during phase 3. Software companies use a number of variations such as spiral development.

Table 4: Phase 4 Activities, Purpose, and Risk

Tasks to complete	Typical Owner	Purpose	Risk with Deletion
Changes to business case including financials	Strategic Mktg	Update organization on changes	Miss a key decision point if conditions change
Agree on engineering transition plan for R&D engineers	R&D	How long or through what goals will R&D support manufacturing during first runs	No commitment from R&D to focus on release product until goals met
Aid in any issues that come up in mfg test runs	R&D	Assure that test runs go smoothly	Manufacturing engineering left to solve all problems, risk to schedule
Re-verify hardware, firmware and software quality and reliability	R&D	Tests on final product to assure a quality product released to desired performance	Possibility that final product w/ recent changes not represented by earlier verification
Build significant sample of product	Manufacturing	Check yields, process, material flow	May have line shutdown later due to inability to build to specs
Spec negotiation with marketing and R&D	Manufacturing	Use results of data taken in Phase 4 to set realistic specs balancing yield risk with market demand for specs	May not have product specs supported by manufacturing results
Updated production ramp plan	Manufacturing	Final check on material flow	May not ramp quickly enough to meet market need
Implement launch plan and sales plan	Commercial Marketing	Ensure optimal solution rollout into marketplace	Suboptimal or inadequate market introduction

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