The business of rapid prototyping

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Abstract

Rapid prototypes will gain acceptance in business only to the extent that they provide bottom-line business value. Thus, this paper guides engineers wishing to "sell" rapid prototyping in helping them to operate from a business perspective. Presuming that the relative value of rapid prototypes is in their speed, I show how to identify, quantify and exploit timesaving opportunities by using rapid prototypes to greatly shorten product development cycles. The article first illustrates how to calculate the cost of delay for a development project so that we have a means of measuring the business value of the time saved. Then I show where to look for leveraged time-savings that will yield greater benefit than just the time saved directly in building the prototype faster. By addressing associated process and cultural change issues, the paper guides the rapid prototyper in setting up an environment in which the identified business advantage will actually be realized after the new system is installed.

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Rapid prototyping remains expensive on a per-part-produced basis. Therefore, most rapid prototypes are made in a carefully controlled business environment where such expense fits. On the other hand, most of the people making rapid prototypes are technologists whose primary focus is on the technology and how it can be improved, not on justifying the expense involved. Rapid prototyping might gain acceptance and grow more quickly if the technologists took on more of a business view so that they could demonstrate to management—in management's terms—that rapid prototypes offer real business value that outweighs their expense.

A common scenario is that the technologists evaluate the available rapid prototyping options and present management with a proposal for adopting a certain rapid prototyping technology. Often, in such cases, both the technologists and management lose because the discussion focuses on the considerable investment involved and ignores the corresponding business benefit. The attention is on the investment and the technology because the benefit cannot be verbalized compellingly or quantified. Instead, if both parties work in the common area of improvements to the product development process, both management and technologists could see the benefit and move forward confidently toward a common goal. This paper will develop such a business-value perspective for rapid prototyping.

Most rapid prototyping technologies have substantial financial implications beyond their initial purchase price. These include materials, additional staff, training, and facilities and systems changes. Clearly, management should be thinking about the connection between these expenses and profitability. However, all too often, management is presented with a yes/no decision on one prototyping option, and the proposal is made in relatively narrow technical terms.

However, the benefits depend on topics that go beyond the initial procurement. Even if the developer is successful in obtaining a certain rapid prototyping capability, for instance, ultimate success will depend not only on the developer's skill in applying the technology but also in management's genuine acceptance of the technology and its implications for running the business. For example, it is all to common for a developer to make a rapid prototype and show it to

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management to obtain approval for a design concept. Management, not recognizing that the real benefit of the rapid prototype comes out of its associated process change, says to the developer, "This plastic toy is interesting. Now make me a real part out of metal and I will decide on your concept." In such situations, not only is management forfeiting the benefit involved, but the developer is also frustrated by not being able to use the technology to its full potential.

Most rapid prototyping technologies offer benefit through savings in time, even if they may cost more than traditional methods. Therefore, to put the cost and benefits in perspective, we must be able to relate time savings to profit, just as we relate the technology's cost to profit. The next section shows how to calculate this "cost of delay."

Quantifying the cost of delay

Thinking of time as a trade-off

Product development projects normally have four objectives:

(1) develop a product with a certain set of features and with certain performance levels, as listed in a product specification (performance objective);
(2) satisfy a target unit manufacturing cost for the resulting product (cost objective);
(3) do this within a certain development budget for the project (expense objective); and
(4) compete the project within a given time (schedule objective).

As managers, we are taught to manage each of these objectives—performance, cost, expense, and schedule—to its target and to control variances of each one. In doing this, we lose sight of the fact that some of these objectives may be far more important than others. If we could cut a week out of the schedule, we would probably be pleased to pay $100 for it. But if the cost of saving a week rises to $1,000,000, we might decide that the week is not that important. Just how important is a week of schedule compared to development expense? How much schedule time would I be willing to give up to cut unit manufacturing cost of the product by $1.00? How much delay should I accept to regain a loss of 10 percent in product performance?

To be wise shoppers for time compression, we need answers to such questions. It is not good enough to manage each of the four objectives to its target independently, being blind to the fact that one target may be a thousand times more important to profitability than another. In fact, the typical project manager manages project expense very carefully but is usually less concerned with schedule slippage, which usually has a far larger profit impact.

Effective developers and project managers do not manage their projects blindly to the four targets. Instead, they regard the four objectives as a balancing act. They are actively looking for opportunities to trade off one against the other, gaining net advantage. They can always find more expense money to buy some time at a bargain price. And they will refuse to delay a project to add another product feature if the price (in time) is too dear.

There are six possible trade-offs among the four objectives listed above. To trade off any of the objectives against any of the others, we need six trade-off values for the project. These six values prepare us to be better shoppers for development time. Although all six values have their applications, one of them is especially useful to the person shopping for rapid prototyping technologies: the trade-off between schedule time and development expense. We call this trade-off the cost of delay. The cost of delay usually varies greatly between projects, even within the same company, but for major projects in a large company, this value can exceed US$1,000,000 in lost profit per day. Although the expense of a rapid prototype may seem quite high in absolute terms, in comparison with the cost of delay, it can be very smart purchase indeed!

If values of the cost of delay are this large, and if they vary greatly from project to project, we need a way to calculate them. This is the topic of the next section.

Calculating the cost of delay

These calculations are described in detail in Smith and Reinertsen (1998, Chap. 2), so I provide just an overview here. The first step is to build a baseline profit-and-loss model for the project for its entire development and sales period. This model, which is usually created as a spreadsheet and fills just one sheet of paper, covers all of the expense and cost of developing, manufacturing, and selling the product over its life. The key result of this

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model is the pre-tax profit earned by the product over its lifetime.

"Baseline" in the previous paragraph means that everything goes as planned for the project: it is on time, on budget for expenses and unit cost, and the product's performance meets its specification. The next step is to create scenarios for variations of the four objectives. For example, the high-cost scenario might have the initial manufacturing cost being 10 percent high for the first two years of production, after which we apply value-engineering methods to bring the cost back down to its target value. The lateness scenario might suppose a six-month delay in introduction, due to engineers not being available to work on the project as planned.

Next, we express these verbal scenarios quantitatively as variations of the baseline spreadsheet. For example, to create the high-cost spreadsheet, we would increase the unit manufacturing cost by 10 percent for the first two years after introduction, and we would increase the engineering expense during these two years to reflect our estimate of the additional engineering hours needed to cost-reduce the product.

Expressing the lateness scenario quantitatively usually requires the most judgement, but it is also provides the most useful results. To construct it, we ask ourselves which customers might not buy the product at all if it were six months late, which would defer their purchase, and what might be the long-term effect on the product's market share, for example because of lost referrals from early customers. Often, people assume that if the product is late to market, the major financial effect is extra engineering labor consumed during the delay period, but this labor expense is usually the smallest effect. Lost initial sales and permanent loss of market share are usually far more disastrous.

Clearly, these variation spreadsheets are not very accurate, but it is important to recognize that they do not have to be. They are far better than just guessing as to the financial effect of lateness or, as usually happens, ignoring it altogether. Often, the opportunities to "buy time" using the cost of delay are so clear-cut that even an inaccurate model is good enough.

At this point we have five spreadsheets, the baseline and its four variations. The last step is to construct decision rules, such as the cost of delay. To calculate the cost of delay, we subtract to life-cycle profit of the six-month-late spreadsheet from the baseline life-cycle profit, and divide by, say 26, if we wish to express to cost of delay as a weekly value.

Many development teams post their cost of delay prominently in the team area or distribute it on laminated wallet cards. They use this value to assess the opportunities that arise every day to "buy time." For example, they may consider shipping parts by air freight, paying higher weekend rates for toolmakers, sending out testing work when the internal test lab's lead time is too long, or buying extra parts to have them available if the team is not sure just which parts it will need. More pertinent to this paper, they use the cost of delay to make decisions on procuring rapid prototyping services or equipment or employing rapid tooling.

Again, for more information on calculating the cost of delay, checking your calculations, or extending them to more complex cases, see Smith and Reinertsen (1998, Chap. 2).

Using the cost of delay to make business decisions

The cost of delay is a very helpful tool, but it must be used in the proper context. It only applies to activities that are on the critical path [1], for example. Also, even though an isolated decision may be justified by the cost of delay, there may be other opportunities that are much better buys. For these reasons, one must understand the overall development process and schedule before just applying the cost of delay to an isolated decision, for instance, to purchasing a rapid prototyping machine.

Now we describe a process for finding the cycle-time opportunities in your development process that represent the best bargains for the funds you have to invest in rapid prototyping or other time-compression technologies.

Understand the business drivers

First, understand the role of new products and their development on the success of the company. Management needs a certain number of new products to maintain sales momentum, and if these products could be developed for nearly nothing, management would be happy. In some companies, this is

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the extent of management's interest in new products. Rather than being primarily concerned with new products, the company's strategy may be more oriented toward controlling the distribution channel or servicing and supplying consumables for products that have been in the field for years. It will be difficult to get management's interest in time compression technologies for product development if management does not believe that new products are critical to the success of the company.

Next, understand the company's strategy for developing new products. Does your company want to be a leader or a fast follower, letting others take the larger risk in pioneering? Does it want to be known primarily as a leader in innovation, in cost, or in reliability and quality? Does it want to get to market as fast as possible, or does it really want to meet a specific launch date, such as product availability for a trade show?

All of these choices will determine the kinds of rapid prototyping tools you should be considering. For example, to improve schedule predictability, you will take certain steps to minimize schedule risk, and you will procure time-compression technologies toward this end. However, because these steps will add time to the schedule in most cases, they are not wise for those who want to get to market as fast as possible, so this choice suggests different technology tools. As this example illustrates, if you cannot make the kinds of distinctions mentioned in the previous paragraph, you will be limited to buying generic technologies and obtaining mediocre benefits.

Finally, know the relative importance of the four project objectives discussed earlier. These will vary by project, but you will probably be able to lump your projects into two or three categories. For instance, one company found that they had some products that were new offerings for them. Time to market was the most important driver for these projects. Other projects developed improved models to replace models they were already manufacturing. For these, unit cost was more important, because they could continue to sell the old model if the new one was late.

Know where the time slips away

Some rapid prototyping technologies offer remarkable degrees of time compression. For example, a rapid prototype might be built in a day, where it took two weeks to build it with the previous method, an impressive 90 percent reduction. However, there might be an opportunity to save three months out of the fuzzy front end of the project (Smith and Reinertsen, 1998, Chap. 3) for less than the rapid prototype's cost. Or, for the cost of the rapid prototype, you might be able to modify a database to cut one day from each engineering change approval, which, for the hundreds of engineering changes in a typical product, could contribute far greater time savings than the rapid prototype would provide.

There is no substitute for analysis here. Analyze several completed projects to see where the time went. Were there typically delays waiting for a decision? What would have helped to make the decision faster? Was time wasted redesigning parts? Did the designs have to be redone because they were done poorly the first time, which might suggest better engineering design tools or more training in using existing methods? Or did redesigning occur because marketing kept changing its interpretation of what the market wanted? This might suggest other capabilities, such as the ability to make concept models to clarify concept distinctions in customers' (and marketing's) minds early.

Unfortunately, many companies are slow to market simply because management tries to work on too many development projects at once, which dilutes the resources of all types on every project and stretches all projects out proportionately. Advanced technologies to compress time are likely to offer little benefit here. For instance, you might be able to make a prototype part in one day instead of ten, but if the manufacturing engineer, who is supposed to take the this part to a supplier, is tied up on another project for the next ten days, the rapid prototype will provide no advantage.

This analysis of your projects provides an understanding of where the major opportunities are to save time in your schedule. Armed with this information, you become a far savvier shopper for rapid prototyping technologies. Rather than being overly influenced by the technical wizardry being sold, you will know which solutions are likely to yield benefit and which will not in your current situation.

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Find tools that address specific needs

Finally, we are ready to go shopping! With today's technology explosion, you will encounter a superstore full of opportunities. Just in rapid prototyping, there are many alternatives, because each technology can influence different parts of the development cycle quite differently. Simple concept models can resolve design intent issues with marketing and customers early, so that specification changes are far less likely later. Working parts made of strong materials can be used to test certain design assumptions, while other design assumptions must be checked using tooled parts, which might be made using rapid tooling techniques. Still other rapid tooling methods might be appropriate for initial production, setting up an opportunity at the production stage for a major time-versus-money trade-off. The opportunities that arise from analysis of your projects will tell you where to place your rapid prototyping/tooling investments.

Besides rapid prototyping, there are many other technologies that might offer timesaving opportunities on their own or synergistically with rapid prototyping tools. These include CAD and CAE, product data management (PDM), finite-element modeling, simulation modelers and a host of others. Don't ignore these other tools, because your rapid prototyping solution may not reach its potential without some of the other tools. For example, you may need enhanced data transfer technologies to get your CAD data to the rapid prototyping machine quickly and reliably.

This is not a comprehensive discussion of the technologies available, but it should serve to illustrate that:

- a wide array of technology tools exist to compress time; and
- to be most beneficial, these tools must be closely tied to a specific process opportunity.

By doing your analysis before you start looking at technologies, you will be able to find the one you need more quickly and ask very pointed questions about how it will fit your process needs.

Match the process and the tools

As you consider various tools, you will have to adapt the tools to fit your process, and you will also have to change your process to really gain the benefit that the tools promise. Plan to work this matchmaking from both sides. Most important, do not just assume that the match will work itself out; actively identify and adjust on both sides to gain an effective marriage.

In linking the development process with rapid prototyping tools effectively, it is helpful to keep in mind how schedules get compressed in development projects. The most obvious mechanism is direct shortening of an activity. For example, stereolithography might be ten times as fast as CNC machining, thus cutting that much time out of a prototyping cycle. Chrysler built an automated test track that enables it to run a brutal automobile durability test in two weeks rather than the six weeks formerly required.

However, the greatest savings are likely to be the ones that go beyond such direct reductions, so look for opportunities to leverage the power of a rapid prototype. Communication and decision making between groups is a fertile place to look, because often decisions get delayed at these interfaces. Could a rapid prototype crystallize design intent or design direction among several alternative approaches so that you can get on with the next stage of development more quickly? Could you reach a decision on styling or ergonomics more quickly by building an evaluating a few rapid prototypes? Some designers and buyers show suppliers rapid prototypes instead of drawings to get quotations, because they have learned that suppliers can grasp the design intent and offer cost-saving suggestions both better and faster through this medium than with drawings. These types of time savings are likely to be much greater than you will gain from just the reduced fabrication time of a rapid prototype.

Another place to look for time savings is in redesign and rework. Such rework can occur because the worker lacked certain needed skills, because the worker had been given inadequate information, or because of the normal learning process that occurs in innovation. Although learning will always be a part of innovation, we can eliminate much rework that does not have to be relearned each time. For instance, Cummins Engine Company analyzed their product, diesel engines, and found some parts, the flywheel for example, didn't have to be a learning experience on every project. Although a flywheel is complex, it can be designed completely analytically by specifying a few dozen values that determine its design—no creativity required. Cummins has thus automated flywheel design by writing high-level software that drives their computer-aided design (CAD) system and stress analysis software, producing drawings and machining tapes from the input values.

Redesign and other types of rework waste time and money, often late in the project, where they are most destructive. Any technology tools that reduce redesign or shift it earlier in the cycle will help here. For example, contemporary mechanical CAD systems with 3D capability can detect interferences, thus allowing these design mistakes to be corrected while they are much easier and less disruptive to resolve. Rapid prototyping and rapid tooling could play similar roles if you look for where and how rework occurs.

As you consider a technology tool, ask yourself some questions to check whether the tool is well matched to your time compression opportunities:

(1) What cycle-time mechanism is involved here? Will this tool shift redesign issues earlier in the cycle, or will it cut decision delay in the fuzzy front end, or just what will it do?
(2) Does the tool address an activity that is often on our critical path?
(3) How large is the opportunity involved (how much time might be saved)?
(4) Does this situation occur frequently or seldom?
(5) What will it take to implement the solution?
    - Purchase price?
    - Training?
    - Process change?
    - Cultural change?

Think about these last four questions carefully. Often, the purchase price is the main consideration, but some of the others can be a greater burden and have a vital effect on the outcome. Consider, as an analogy, changing to a new word-processing technology in your office. The purchase price of the software is likely to be small in comparison with the training expense and the time lost while learning the new word-processing system. Changes in the documentation process required to realize the benefit may be larger still, and the cultural change for people to become accustomed to the new documentation process may be an even greater issue. Without addressing the questions all the way to the cultural issues, the anticipated benefit is unlikely to result.

Once you have chosen a tool or tools using this methodology, test your decision by running a pilot application on a small scale. For instance, if you find that a desktop modeler could have a great impact on cycle time, do not just go out and buy one. Instead, use a local service to make some models using the same technology to test the proposed new process. The value and approach for doing a pilot, relative to a full-scale rollout, is explained in Chapter 15 of Smith and Reinertsen (1998).

Balancing the tools for maximum impact

As just suggested, these high-tech rapid prototyping tools often need a strong dose of old-fashioned management fundamentals to yield their potential benefit. The most effective companies rely on neither technology tools nor management approaches alone, but look for ways to use one to leverage the other, all to fit their own unique way of doing business.

Two opposite philosophies are arising for viewing many of the technology tools. Many tools, such as CAD and finite element analysis, are what could be called analyze-first tools, because they allow you to do most of the work by analyzing the design in the computer before any parts are made. Because computers are fast and physical artifacts cost money, advocates of this approach argue that it employs technology to save both time and money.

The alternative is make first, whereby physical artifacts are produced early, and then the design goes back to the computer for further refinement, depending on what is learned from the artifacts. Rapid prototyping technologies fit with this approach.

From a time-compression standpoint, the question is, which approach gets you to a final design faster? To some extent, the answer depends on the nature of the product. When designing an integrated circuit, for example, the design is analytically determined (except for some manufacturability issues), and the main issue is eliminating mistakes while

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combining millions of components. In this case, the analyze-first approach is best.

However, when designing a computer mouse, the design issues are far more subjective. Eliminating functional mistakes is not nearly as important as arriving at a shape and click sound that customers will enjoy. In this case, the fastest route is to make some first, even if they are not fully functional. The initial models will help to sort out the critical design issues in conjunction with customers and marketing people.

Most products are in the middle, with important functional and subjective factors. Examples are automobiles and electric saws. Companies that do best at these products use a creative blend of the two approaches. For portions of the product where function dominates, such the gearbox in an automobile, analyze-first predominates, but when subjective factors dominate, as with an automobile's instrument panel, they make first.

When time to market is important, our bias is toward make first, simply because this style exposes the big issues faster. For example, I once sat through a gate review of an electronic product employing sophisticated digital signal processing technology and housed in a small plastic case. The go/no-go decision was basically up to the director of marketing, and she reached her decision based not on how well the device could detect signals but on how it looked and felt. That organization was wise to get a physical model into her hands as early as possible. Tom Peters (Peters and Austin, 1985) calls this "getting the chicken test out of the way," referring to a standard test in the jet-engine business in which developers check the integrity of their design by inserting a live chicken into the engine at full power, as might occur on takeoff.

This is an important time-compression point, because politically wise engineers would rather not have their designs exposed to a chicken test without further analysis. Thus, it is management's job to encourage early chicken tests when the engineers would rather hide behind their computers. The companies that employ rapid prototyping most effectively are those that continually watch how the technology is used to further management's objectives for the business.

Note

1 An activity is on the project's critical path if a slip of one hour in that activity moves the completion date of the project out by one hour. Unless an activity is on the critical path, it will have no direct impact on the project completion date.

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