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# Resolving the Conflict between Design and Manufacturing: Integrated Rapid Prototyping and Rapid Tooling (IRPRT)

By James E. Folkestad, Ph.D. and Russell L. Johnson, Ph.D.

## Introduction

Rapid advancements in computer technology have given life to an explosion of computer-aided design (CAD) related technologies, which by their mere speed and automation, are used to produce rapid prototypes (RP) and rapid tools (RT) quickly and at low cost. Although each of these technologies have shortened the time it takes to produce a physical prototype or tool, RP or RT used in isolation may provide only modest reductions in the overall product development life cycle. In other words, it's not just one thing that cuts design time; it's the combination thereof. A company has to integrate RP & RT technologies within their organization to rapidly bring product to market (Smith & Reinertsen, 1998; Swanstrom, 1999; Hewson, 1998).

The intent of this paper is to highlight a growing problem the authors have observed in the application of these technologies from a management perspective. A technical review of the available rapid prototyping (RP) and rapid tooling (RT) technologies has not been included in this paper. Numerous professional presentations and articles elucidate on the advantages of the various RP and RT technologies to reduce the time and/or cost of producing prototypes and tooling. Others expound on the superiority of one technology over the other or present detailed cost justification models. Few, however, seem to address the need to integrate these technologies into an overall rapid-to-market strategy, identify the potential

positive outcomes of doing so, and provide suggestions on policy or practice to avoid the potential negatives while enhancing the positives.

## Why rapid-to-market?

The winners in today's competitive marketplace are those companies that can bring innovative high value products and services to the customer ahead of their competition (Murray, 1998). Reaching the marketplace with innovation before the competition has several critical benefits. These benefits include:

- The product's sales life is lengthened,
- The rapid-to-market company gains a pricing advantage,
- The rapid-to-market company can start product development later and therefore can use more up-to-date technology to develop that product,
- The rapid-to-market company has a marketplace advantage by gaining customers that potentially become loyal customers (Smith & Reinertsen, 1998).

Figure 1 illustrates these benefits. In this figure, Company A used traditional product development techniques and reached the market last; while Company B used rapid-to-market (accelerated) product development techniques (i.e., rapid prototyping, rapid tooling), therefore reaching their target market prior to Company A. By reaching the market first in this scenario, Company B's product has an

extended sales life and generates more sales than Company A. This advantage is more significant than it may appear as it is not the sum of the vertical gap of increased sales and the horizontal gap of extended product life, but rather the product of the two as represented by the increased area of Company B's curve in contrast to Company A's.

Furthermore, reductions in product introduction time (point *a* minus point *b* for Company B versus point *a* minus point *c* for Company A) gives Company B several advantages. These advantages include:

- Reduction of fixed cost for product development through early release and reduction of project overhead related to personnel as well as facilities and equipment;
- Ability to delay design commitments resulting in the opportunity to respond to changes in customer demand, or if in a high risk or volatile market environment, to abandon the project with little/no development costs.
- Ability to incorporate improved technology or design resulting in a superior product while still matching the competitors' introduction date (Smith & Reinertsen, 1998).

All of these issues result in significant cost savings and/or market advantages that are not mutually exclusive. In other words, the organization can realize all of the financial benefits simultaneously. Furthermore, these financial benefits not only impact new product costs, but they can also be distributed across all products lines—even those not using rapid-to-market technology—thereby giving the company a price and/or a level of service advantage in all markets (Hundal, 1997).

**Controlled change: Focus on time and accuracy.**

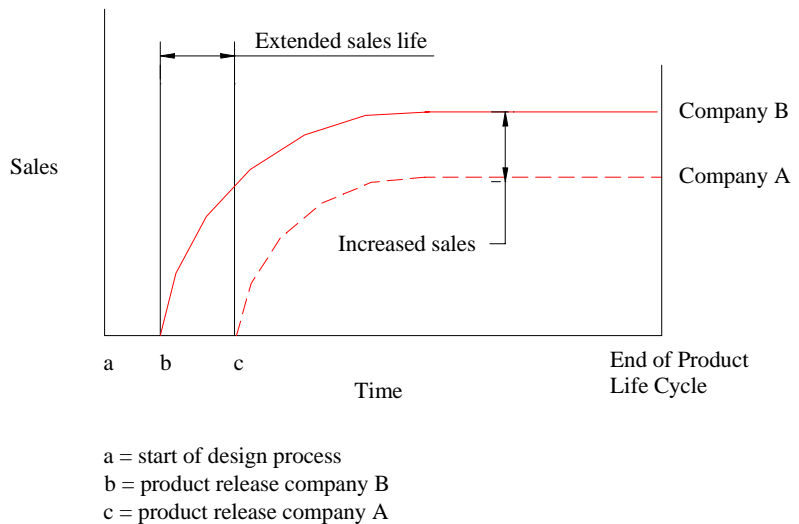
Engineers from both design and manufacturing are using RP & RT technologies to control change (Ferrara, 1998). As a development project progresses, the design of the product

may go through many changes or modifications. It is common knowledge that changes should be managed and made when they are inexpensive. However, a common mistake is to focus on how fast changes can be made (i.e., how fast we can make another prototype or another tool) (Field, 1999). To gain rapid-to-market advantage the focus should be on timing (when changes are made), and accuracy (making well-informed changes) (Teaque, 1998; Cunagin, 1999).

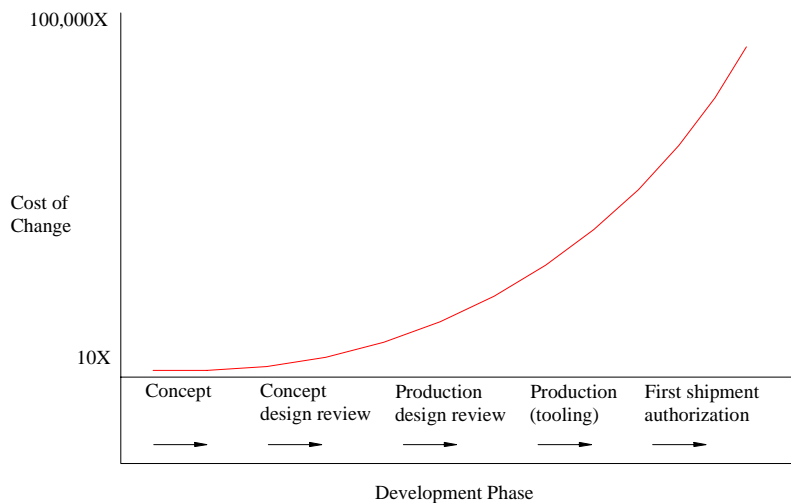
**Timing**

The cost of changes associated with an engineering change order (ECO) fluctuates with time. An ECO issued early in the development process will cost less than the same one issued late in the process. ECO costs increase over time as a design becomes solidified due to product documentation (i.e., CAD drawings and/or product specifications) and through product artifacts, such as prototypes and production tooling. Changes that occur late in the

**Figure 1. Benefits of reaching the marketplace faster than the competition (Huthwaite, 1996).**



**Figure 2. Cost of Design Changes in relation to product development phase (traditional development).**



development of a product affectedly involve changing more product documentation and artifacts and can have significant economic impact on manufacturing, distribution, or packaging, for example.

This economic concept is typically illustrated using a generic product development cycle and cost of ECO curve. A generic cycle may include the following phases: concept, concept design review, production design review, production (tooling), and first shipment authorization (Hanson, 1998; Hewson, 1998). As a product progresses through these phases, the costs associated with ECOs increases rapidly (see figure 2).

For example, if an ECO issued in the conceptual phase has an associated cost of 10X, the same change issued in the production phase (late in the process) may cost more than 50,000X. Making decisions early in the product life cycle has proven to be a viable strategy for avoiding costly late phase changes (Teague, 1999). Adele Hars (1998) stated that a "... strong focus on minimizing manufacturing costs has significant benefits because they are eight to ten times higher than design costs."

**Accuracy:**

Typically, the number of product design changes increase just prior to the tool production and again just before product release (see figure 3). These changes are triggered by two major project milestones, which include 1) manufacturing of production tooling, and 2) the scheduled product release deadline. The pressure of these milestones has had a major impact on the development process often causing engineers to make forced / uninformed decisions and subsequently ship low quality or poorly configured product.

Specifically, tooling costs place pressure on team members to commit to a product's design. This pressure often forces engineers to make decisions without fully understanding the design problem. Traditionally, this has led to the production of poorly designed and inaccurate production tooling, thus putting the project in a

significant position of loss in either time and/or money.

Rapid prototypes are used frequently to increase accuracy of decisions. It is not difficult to find examples of how RP parts were used by product development professionals to identify design elements that had been previously overlooked or under defined. Anecdotal stories of this type are enough evidence for most to come to agreement that RP parts help to improve design. However, despite widespread use of RP, inaccurate decisions continue to occur slowing the pace at which product is released to the marketplace.

**The design versus manufacturing conflict**

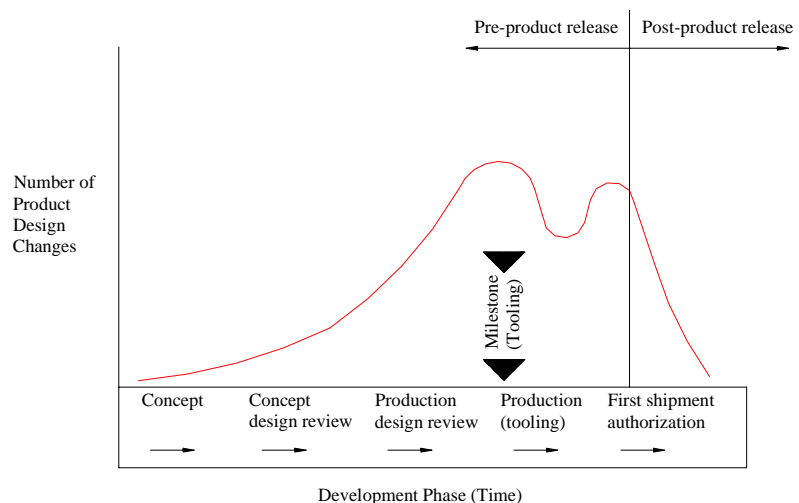
If the advantages of using RP and RT to deliver a quality product to the market ahead of the competition are so obvious, what makes it so difficult to accomplish. The difficulty is in large part due to an inherent conflict resulting from the way in which we measure and evaluate employees' performance in design versus those who work in manufacturing. Those responsible for design are held accountable for meeting or exceeding the customer needs with substantial penalties in the marketplace for failure. There is considerable pressure to ensure that the product specifications, at the minimum, match or lead market requirements. With increased levels of uncertainty in

the market and reduced time to gather the needed information - due to rapid-to-market timelines - designers feel pressure to delay commitment to design specifications as long as possible. On the other hand, those responsible for manufacturing of the product are held accountable for exceeding acceptable cost and/or missing market release dates. The lead-time to identify materials and suppliers; identify, purchase and install production equipment; and hire and train production personnel is considerable. As a result, those responsible for manufacturing are constantly pushing for the earliest possible identification of product specifications.

With the time available for product development decreasing, the unavoidable result is a constantly escalating battle between the two groups, as each group struggles to perform to the incongruent measurements. As was stated before, when the product introduction process requires significant investment in production tooling such as molds, the battle may become an all out war. This tooling milestone does not represent a solution but a compromise or management induced truce to the conflict, and often causes escalating pressures between groups as they work to meet the requirements.

Application of rapid prototyping (RP) in isolation fails to break the design versus manufacturing conflict.

**Figure 3. Typical number and timing of product design changes in the traditional development process.**



Companies have traditionally justified the purchase of RP technologies based on cost savings associated with the quick production of prototypes. However, astute employees are quick to find other uses for these models. For example, employees at Teledyne Water Pik have experienced tremendous dividends using RP to communicate between functional departments. Employees reported reducing the concept-design-phase time by 50%. The concept-design phase was reduced from 6-14 months prior to using RP to three - seven months after incorporating RP models into the process cycle (Hanson, 1998).

Companies using RP parts in this fashion have seen a shift in the number of product design changes from the late phase to early phase (Teaque, 1998; Wohlers, 1998; Cunagin, 1999). The use of prototype parts to identify design requirements has always had limitations, leaving conflicts unresolved and resulting in late phase changes. Similar to traditional prototyping processes, rapid prototyping does not produce parts that have identical characteristics to a manufactured part. These differences in physical characteristics prevent engineers from identifying all product specifications. Material-of-choice and process-of-choice changes continue to occur late in the product development cycle. These are typically manufacturability parameters that are only realized after a production tool has generated parts under production conditions (i.e., injection pressure, cycle time, etc.) and in the production material (material of choice). The result of this application of RP in isolation is significant potential for improved performance on the design side of the conflict with minimal impact on the manufacturing side.

For example, HACH Company produces water-analysis equipment. To obtain certification many of its products must remain airtight during water submersion. RP parts allow HACH to identify typical customer driven design modifications such as product aesthetics. However, RP parts cannot be used for full-product certification and

testing, this type of verification can only be done after a part has been produced using both the material and process of choice (Hewson, 1998).

**Application of Rapid Tooling (RT) in isolation fails to break the design versus manufacturing conflict**

Similar to RP, rapid tooling (RT) in isolation provides a tremendous poten-

tial for increase in speed and reduction in cost on a per tool basis. RT fundamentally alters the ECO cost curve during the tooling phase as is illustrated in figure 4. The altered ECO cost curve reduces the risk associated with the production-tooling milestone. The flattening of the ECO curve allows the engineering team to first produce an inexpensive tool and subsequently produce material and process of choice

Figure 4. Effect of rapid-prototype tooling on cost of change curve.

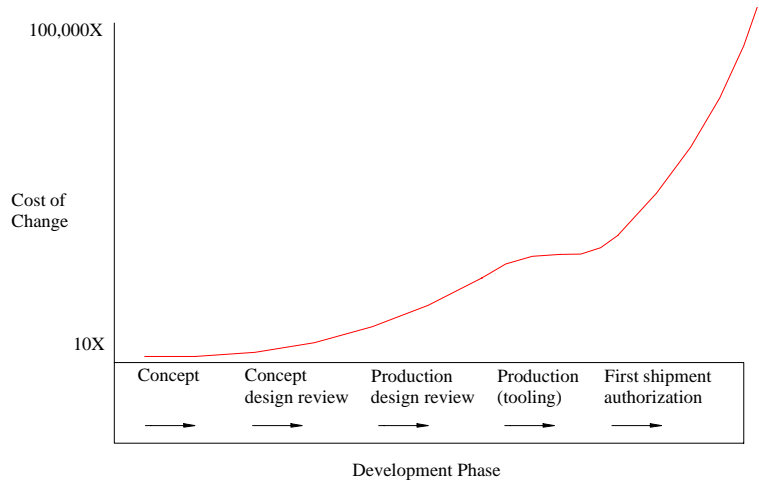
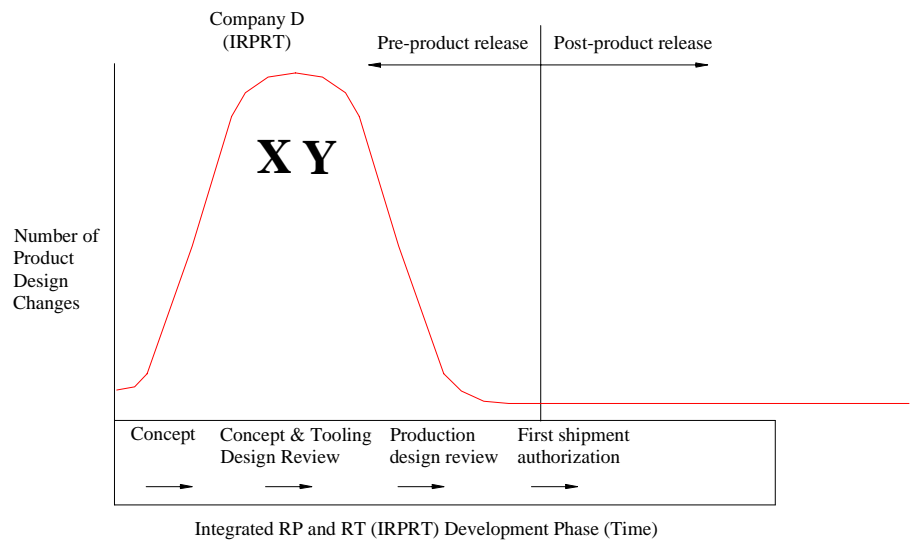


Figure 5. Effects of integrated rapid prototyping and rapid tooling (IRPRT) on the number and timing of product design changes.



Company D = Integrated Rapid prototyping and rapid tooling.

X = Customer / Design Changes

Y = Material / Process of Choice Changes

parts. Using these parts engineers can identify critical manufacturing criteria earlier in the development cycle before committing to expensive production (high volume) tooling.

RT-generated parts are used to move the material / process of choice design requirements forward and spread them over time. Engineers are able to move design changes associated with material-of-choice and process-of-choice away from the product release deadline. However, knowing that a tool can be produced quickly, the design engineer can use the faster technology to increase the window of time for further deliberation and/or solidification of the final design. If this tactic is used, and changes are required, the manufacturing side of the conflict still exists and may even be exacerbated.

### ***Strategically Integrating RP and RT (IRPRT) technologies to break the design versus manufacturing conflict***

The strategic integration of RP and RT (IRPRT) must be the next step toward leveraging and sustaining the gains offered by and expected of RP and RT technologies and breaking the design versus manufacturing conflict. As mentioned prior, tooling technologies are being developed that can produce tooling that is considered to be virtually "disposable" compared to traditional tooling. These "disposable" tooling technologies allow the engineer the opportunity to integrate the tool design and the concept design phases, as is illustrated in figure 5.

For example, in order to integrate RPRT, tool designers at HACH Company are working with a consortium to develop the Rapid Solidification Process (RSP). The RSP spray-forming process uses a hot, inert gas to atomize molten alloy and apply this alloy using a specialized spray gun. Using this process, Hach's Bob Hewson is working to produce fully densified P20-steel production tools within one-week lead-times. These spray metal tool inserts have identical characteristics to machined P20 tools and will allow HACH

Company to achieve cost reductions of 50-60% over current tool making process (Hewson, 1998).

Hewson acknowledges that the real benefit of the RSP process will be realized when HACH fully integrates parts injected from this rapid production tool into its early development phases. "If the price of the production tool gets low enough, and we make a major change late in the game, we can just throw the tool away," Hewson (1998) stated.

Engineers can produce material-of-choice / process-of-choice, parts in the concept/design phase for testing and evaluation. If these material-of-choice / process-of-choice parts are accepted, the tool has already been qualified by manufacturing and production can begin immediately. On the other hand, if parts are rejected, the design can be changed and a new rapid tool can be made within time and budget constraints due to the improved speed and cost benefits of the technology (Hewson, 1998).

Combining these two phases and moving them to the earliest time possible does much to resolve the ongoing conflict between design and manufacturing. Disposable tooling allows the design engineer to release product specifications early, as there is no tooling milestone at which the design must be fully solidified. The manufacturing engineer can produce parts to determine material-of-choice, process-of-choice, and production-tooling issues early and subsequently is not dependent on final design specification to verify for manufacturability. And, if updated design specifications require retooling, a new tool can be produced without putting the project in jeopardy. Furthermore, these design iterations, which include input from both design and manufacturing, improve the final product early when changes are inexpensive. The removal of the conflict eliminates the internal battle over time placing, the focus on the product's overall quality in production.

### ***Concluding remarks – thoughts for the future***

In conclusion, the use of both RP and RT in isolation has provided a burst of speed in localized processes (i.e., prototype and tool production) and as such has allowed many companies to realize a significant advantage by bringing their products and services to the market before their competitors. The application of RP in the concept phase, to shift changes forward, has paid great dividends to not only the companies discussed in this paper but organizations worldwide.

The companies identified in this paper have recognized both the opportunities and limitations of implementing RP and RT technologies in isolation. They are working collaboratively to take the next step to fully integrate both RP and RT into the concept design phase and to minimize market-driven and manufacturing-driven changes that occur late in the development life cycle.

An integrated RP and RT (IRPRT) strategy offers the opportunity to achieve sustainable reductions in both time and cost to market and significantly reduce or even eliminate many of the inherent conflicts between design and manufacturing. Rapid tooling processes have matured to a level where tooling can be considered to be "disposable." Disposable tooling allows the product development life cycle to fundamentally change, incorporating the concept and tooling design review phase into one milestone; eliminating an entire step from a project and its associated hand-offs and opportunities for error. This strategic application / integration of RP and RT allows the design and manufacturing engineers to identify both the customer design requirements (X changes - see figure 5) and the manufacturing design changes (Y changes - see figure 5) during this phase. Again, these changes are made at a fraction of the cost incurred using traditional tooling and product release milestones, and allow the product to be released based on strategic market demands.

While the integration of RP and RT offers the possibility of significant reductions in both time and cost, relative to product design and introduction, the true value of these technologies will vary from company to company for two basic reasons. First, the shape of the cost of change and number of changes curves presented in this paper will vary by company and selected technologies. These curves were selected to generically represent concepts to a broad audience and may be different for specific companies. The potential impact of time compression and/or cost reducing technologies on an individual organization's efforts to deliver a product to the market will obviously vary with the increased or decreased severity of their specific situation. As such, these curves should be evaluated with these differences in mind and should be modified as needed to represent individual company change and costing trends.

Integrating both RP and RT to fundamentally change the development life cycle can be a major advantage. However, this presents a risk if new milestones and decision criteria, specifically performance measures, are not established for the movement of the product from phase-to-phase within the project. Without this clear criteria, the ability to make last minutes changes may tend to drive last minute "tweak-

ing" delaying phase hand-offs and, therefore, the overall project. The success of IRPRT depends on a company's ability to integrate work processes and align performance measures to overall organizational goals to avoid these problems.

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