PHYSICALLY-BASED RENDERING REVOLUTIONIZES PRODUCT DEVELOPMENT

NVIDIA IRAY HELPS REDUCE DEVELOPMENT COST & TIME-TO-MARKET BY ENSURING CONCEPT MODELS MATCH THE REAL-WORLD PRODUCT

EXECUTIVE SUMMARY

During the creation of a physical product, digital assistance in the form of computer automated design software (CAD) enables fast and cost effective development. Such tools allow designers to comprehend correct form and function throughout product development. Concept drawings or renderings provide the earliest insight into the product and set overall expectations. Any difference between product concept and product reality can create problems. When real-world appearance differs from expectations, products require iteration and start life under a cloud of disappointment. Differences can result from the limited ability of tools to truly model actual behavior, the lack of complete detail captured in the digital representation, or the creation of a synthetic environment that unintentionally suspends the laws of physics. Iteration adds expense and delays revenue realization.

NVIDIA, a longtime leader in the advanced graphic engine industry, seeks to address these problems through the NVIDIA IRAY system. IRAY is a physically-based rendering (PBR) solution that creates a photorealistic representation of models. It is designed to ensure that renderings conform to the laws of physics in both appearance and actual behavior by accurately modeling the materials.

This paper uses IRAY as an example to explore the advancement and advantage of physically-based rendering, and it provides a model to characterize potential business impact when “concepts match reality”.

THE VALUE OF PHYSICALLY-BASED RENDERING

This section includes two real-world examples showing the value of PBR. The first example is a set-top box (Figure 1), showing light bars running along the edge of two top skewed surfaces. Upon close inspection, the intersection of these two planes inadvertently produces “shadow” or dark line.

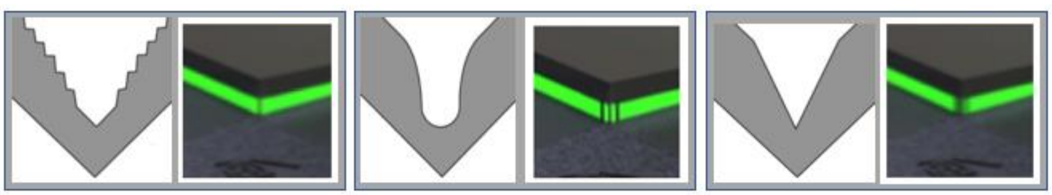
FIGURE 1: UNACCEPTABLE DISTORTION EXAMPLE

(Source: NVIDIA)

In this design, the unacceptable distortion was found after prototypes arrived and were resolved by the design team using other means. By retrospectively applying IRAY, designers ensured that PBR did expose this flaw and further allowed designers to experiment with various notch types and shapes, verifying their solution.

Figure 2 shows different notch types and shapes and the resulting physical renderings IRAY produced. This capability highlights PBR's value, not just in defect detection but also for use during actual design.

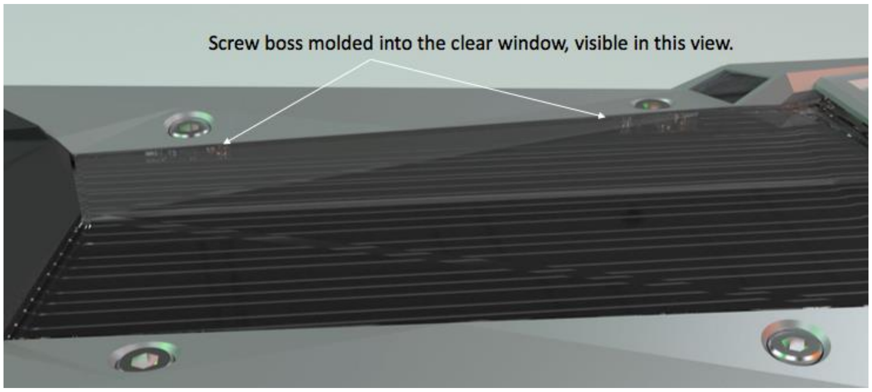
FIGURE 2: NOTCH EXPERIMENTATION



(Source: NVIDIA)

The second example is the design of an NVIDIA GPU card. A "screw boss" molded into the transparent front of the card exposes undesirable visible detail (Figure 3).

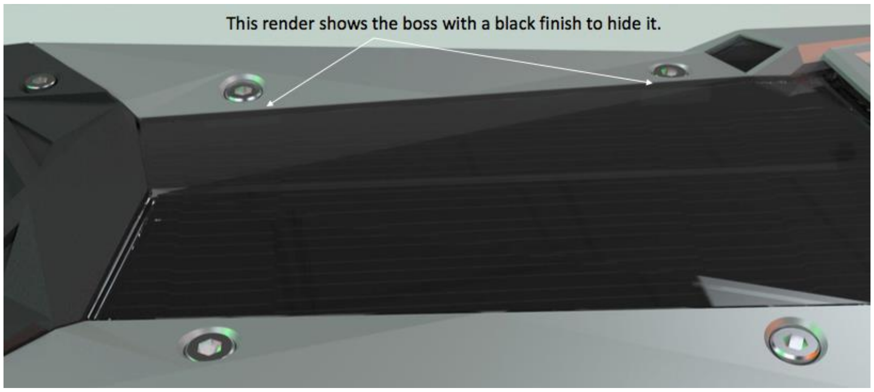
FIGURE 3: UNDESIRABLE VISIBLE DETAIL



(Source: NVIDIA)

By using IRAY and experimenting with both geometry and finish, designers determined the undesirable visible details could be hidden. The solution introduced a black finish inside the cylinder of the boss (Figure 4).

FIGURE 4: DETAIL CORRECTION



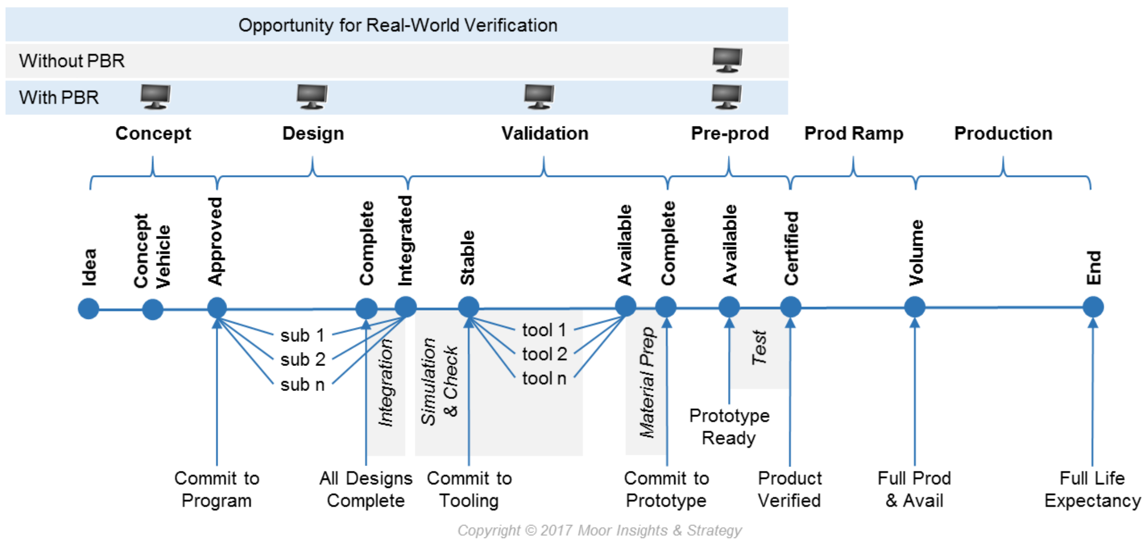
(Source: NVIDIA)

These examples show the potential value of IRAY, its accuracy, and the timesaving it can provide. Not only can IRAY be a useful design service for development, but it also eliminates physical inaccuracies to help limit design iteration.

PRODUCT DEVELOPMENT & FINANCIAL IMPLICATIONS

The actual process and time for developing a physical product can vary widely by industry, a company's capability, and product complexity. Figure 5 shows a general overview, including critical development stages and decision points. Product development has many facets and is usually built around an idea that quickly requires a concept drawing or artifact. Early in a product cycle, research based on this idea will determine requirements, target market, expected timeframe, development cost, and economic expectations. These are captured in the supporting business plan.

FIGURE 5: GENERALIZED DEVELOPMENT PROCESS



(Source: Moor Insights & Strategy)

In the case of a physical product (where physical appearance and behavior is an important part of customer acceptance), concept drawings or models are a crucial part of this research, and their accuracy is pivotal to success. Accuracy is not only required for size and dimension but also appearance and, importantly, customer perception.

Duration can vary from a few weeks to many months. In most ongoing concerns, market and product research is a continuous process that includes regular refresh of product concepts. The ability to render these concepts quickly and photorealistically can do as much to verify appearance as CAD software has done to check physical design. Renderings that conform to physical laws and behavior—without requiring enormous time ensuring that they do reflect reality—are an advantage.

After concept and product plans are approved, design begins. Depending on size and complexity, programs are broken into subassemblies (“sub 1”, *etc*.) which progress independently and are integrated as each completes. As design progresses, decision points with varying criteria are reached until each design is deemed complete or has sufficient stability to commit to tooling. Additional validation may continue.

Depending on the product, tooling can take various forms—molding, forming, cutting and various combinations ("tool 1", *etc*.)—and take a few weeks to several months. Once ready, a small number of units for test and inspection is usually manufactured in a limited production environment.

Experience overwhelmingly supports the idea that the earlier errors are found in the design process, the smaller their impact. Without some form of photorealistic, physically-based rendering, first article inspection can be the first time real-world appearance and characteristics are seen and can expose unfortunate surprises.

Impacts

Earlier, two examples were given where the actual physical product was not accurately depicted during the design process until the physical product was in hand. Recapping briefly, they are:

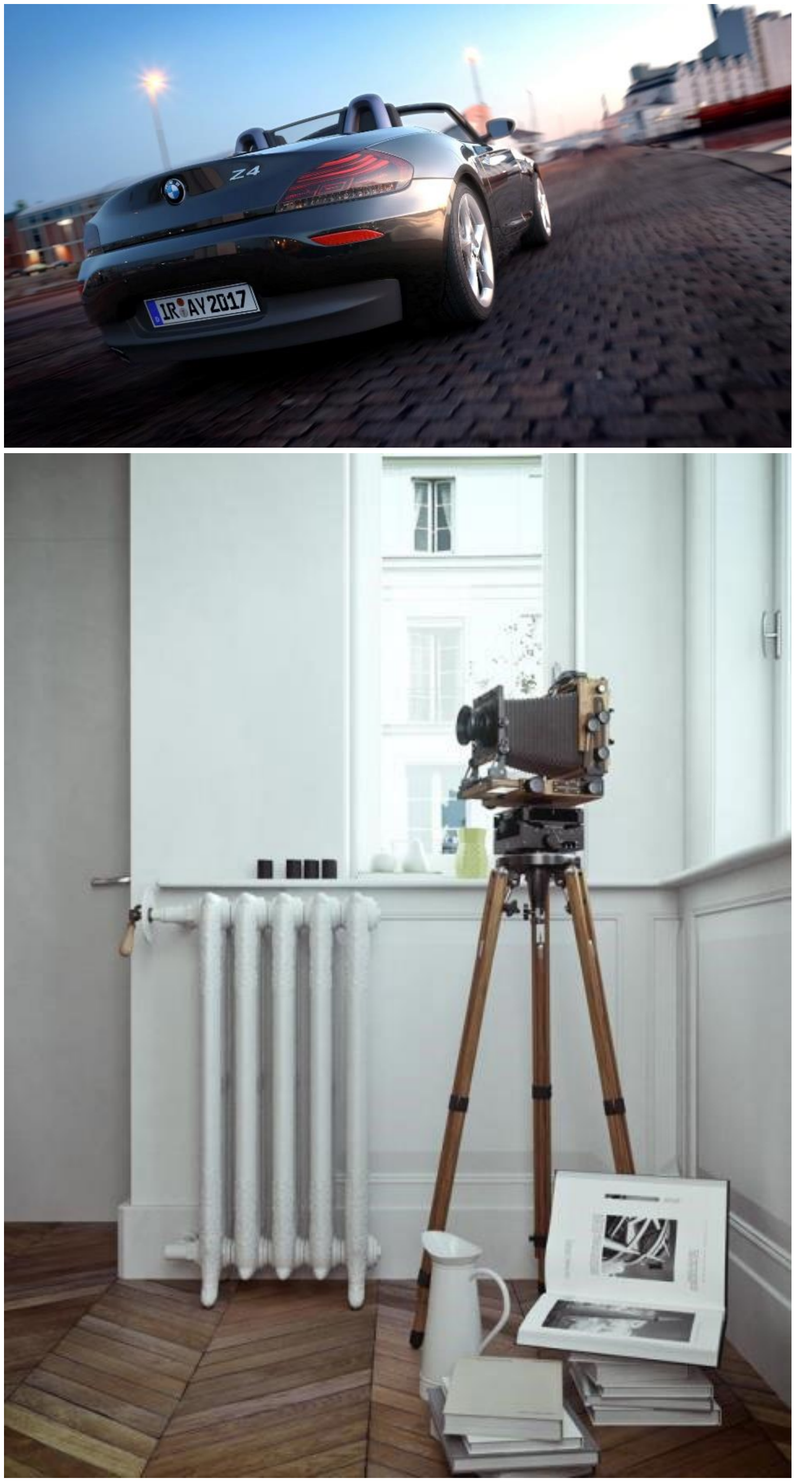
- **Unacceptable Image Distortion**: The impact is about 2 weeks of mechanical prototyping and around $10K in parts and labor, plus about 3 weeks of tooling fabrication and an additional $20K. The resulting total impact is about 5 weeks to the schedule and approximately $30K in total cost, just considering development.
- **Undesirable Visible Detail**: The impact from discovery of undesirable visible details required tooling modification to effect correction. The impact is about 1 week of mechanical prototyping and around $10K in parts and labor, plus about 3 weeks of tooling fabrication and an additional $25K. The resulting total impact is about 4 weeks to the schedule and approximately $35K in total cost, again just considering development.

The Appendix provides a hypothetical business case, including development, sales, product life, and full lifecycle financial impact.

NVIDIA Physically-Based Rendering

NVIDIA designed IRAY to provide designers and visual effects artists with tools to generate photorealistic imagery using physically-based rendering techniques. These methods incorporate properties of the actual materials into the rendered image to help ensure they match the real world.

FIGURE 6: PHYSICALLY-BASED RENDERING EXAMPLES



(Source: NVIDIA)

NVIDIA intends for IRAY to change the workflow of concept development. Through speed and ease of use, IRAY is designed to help the creator develop ideas interactively. Each alteration or variation can be rendered with nearly immediate results. Accurate, physically-based rendering of the target product allows for great effectiveness and creativity, including assurance that the concept is valid.

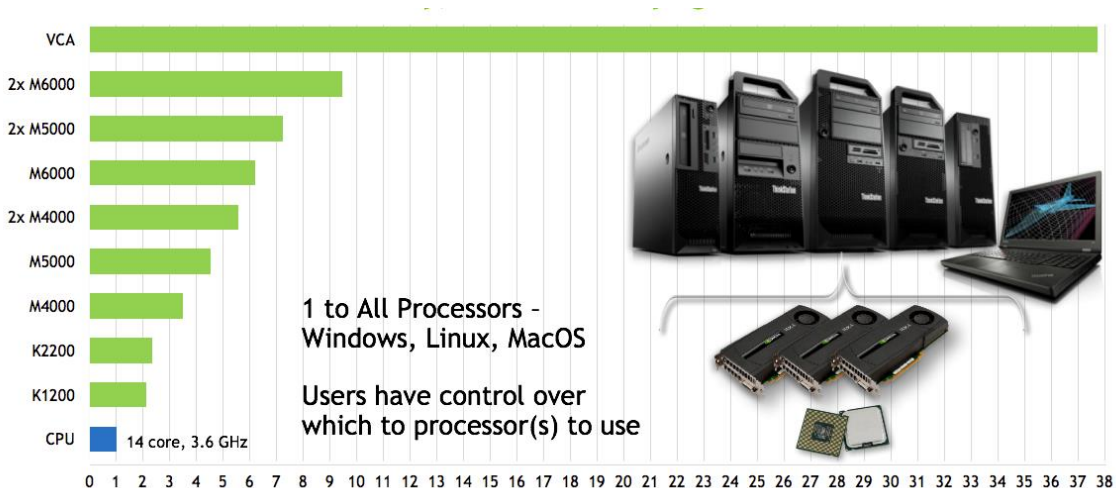
The NVIDIA IRAY system consists of the IRAY software suite, NVIDIA drivers, and NVIDIA hardware. It works with most major, widely accessible rendering programs including 3DS Max, Cinema 4D, MAYA, and Rhinoceros.

Figure 7: NVIDIA IRAY Landscape

(Source: NVIDIA)

Each IRAY plugin is designed to enable artists and designers to render images easily and quickly as photorealistically as possible. Features include physically-based lighting and materials, motion blur, subsurface scattering, depth of field, volumetrics, instancing, and others. By combining physics-based features, IRAY helps create real-world representations of designs and products. This is thanks to NVIDIA's ability to do physical calculations quickly and efficiently using GPU compute capabilities. Combining NVIDIA's IRAY plugin and physically-based rendering capabilities with its CUDA library allows IRAY to work on virtually any NVIDIA professional GPU and to achieve extreme scale utilizing available GPU horsepower.

FIGURE 8: NVIDIA IRAY SCALABILITY



(Source: NVIDIA)

NVIDIA provides single-GPU solutions ranging from the Quadro M2000 to the (six times faster) Quadro M6000. NVIDIA also offers multi-GPU solutions that enable a double-digit increase over a single M2000 GPU. Additionally, to improve rendering times, NVIDIA provides a distributed computing solution that can be combined with an organization's compute resource. IRAY server's distributed GPU computing can be done locally, networked, or on a remote cluster. Finally, NVIDIA offers a VCA (visual computing appliance)—a self-contained, rack-mountable GPU server that also can be combined in a clustered solution—for high performance GPU rendering tasks.

The NVIDIA Material Definition Language (MDL) is a crucial part of the IRAY rendering solution and is the language describing the material and properties that govern physically-based rendering. IRAY includes an extensive library of material, making easier to design using real-world materials. These materials can be used as is, modified, or extended with information provided by the designer.

FIGURE 9: NVIDIA MDL RENDERING EXAMPLE

(Source: NVIDIA)

CONCLUSION

When considering development of a physical product and maximizing economic returns, physically-based rendering provides a useful path to ensure that concepts match the actual product being developed. Product iterations may be required if article inspection is the first opportunity for verification of appearance and perception. Iteration can be both expensive and severely impact the development organization. Physically-based rendering helps reduce iteration, allowing designers to deliver the business benefits when "concepts match reality". Physically-based rendering systems help ensure that concepts conform to the laws of physics in appearance and behavior by accurately modeling the materials.

NVIDIA designed its IRAY physically-based rendering system to make it easy to embed true physical behavior into product concepts. Moor Insights & Strategy suggests that designers, conceptual artists, and others involved in product development investigate physically-based rendering and IRAY.

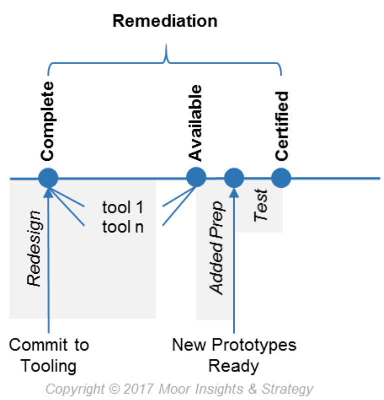
APPENDIX: HYPOTHETICAL CASE

This hypothetical case is based on insights and information derived from the industry. Similarity to any company or actual event is purely coincidental.

An equipment manufacturer is developing a system for outdoor use. The operator's instrument panel is filled with monitors and indicators. During the concept and design phase, developers are concerned about the effect of sunlight on instrument readability and use. Principal features are safety, ease-of-use, and appearance. However, operation after dark is not carefully considered. Once assembled, testers discover the combination of materials used on the instrument panel itself, the reflectiveness of the nearly transparent covering, and the placement of panel lighting creates enough glare to be a safety hazard for nighttime operation. The product must be redesigned. The redesign will use a different covering material. Unfortunately, a material with the correct finish and required tensile strength is unavailable in the same thickness. Further, the complete solution requires repositioning panel lighting, so two tools must be recreated.

The problem exposed here—composition elements and light path expression—is what photorealistic, physically-based rendering is designed to help prevent.

FIGURE A1: REMEDIATION



(Source: Moor Insights & Strategy)

Remediation (Figure A1) is an extension of time and cost required to correct the design, create new tooling, and manufacture new prototypes. It is added to the overall development during the prototype testing period and represents at least a partial testing restart. In this hypothetical case, the two tools are reasonably complex and require eight additional weeks to complete. (Few experienced executives would develop a program expecting a "first pass success" and would include some allowance for iteration.)

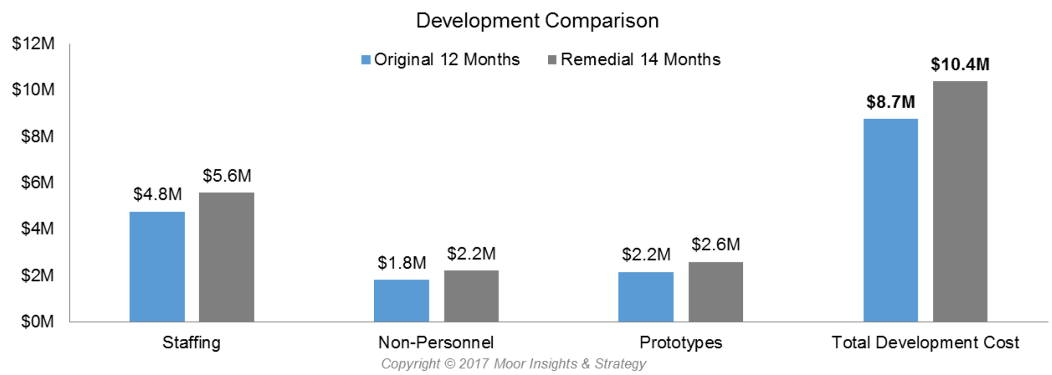
DEVELOPMENT COST & ECONOMIC IMPACT

The development cost and overall economic impact from a physically-based rendering system can be substantial. Program managers must account for not only the direct cost for remediation but also the opportunity cost of delayed introduction. Tools like those used in the hypothetical case can range from $20,000 to $250,000 (based on complexity, size, expected useful life, *etc*.), and a redesign can be expensive.

For this hypothetical case, the development period is 12 months with an expected sales lifecycle following introduction of 36 months. It is further known, that a key competitor plans to introduce a competing product (based on a large new technology investment) in the later part of year three, which is expected to "tank" sales volumes.

Development costs for two versions of the hypothetical program, including staffing, materials, and prototypes are shown in Figure A2. The two versions are the 12-month $8.7M plan (Original) and the 14-month $10.4M plan (Remedial).

FIGURE A2: SIDE-BY-SIDE DEVELOPMENT COMPARISON

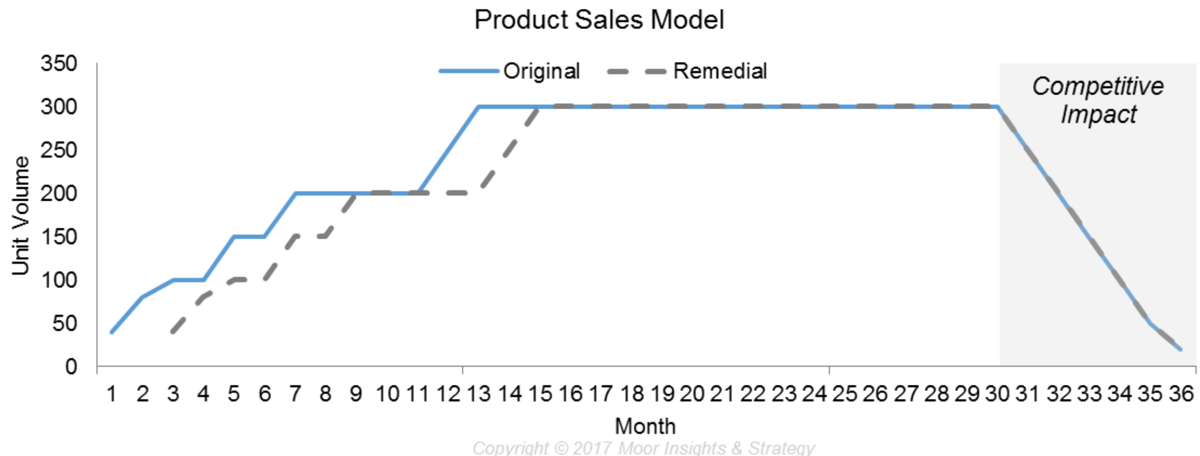


(Source: Moor Insights & Strategy)

In the Remediation plan, two of the six tools must be redesigned, adding $350,000 of tooling cost and delaying introduction by eight weeks. Remediation further adds $431,160 in a limited prototyping run to assure safety and quality issues are resolved. Remediation extends staffing by two months and costs $400,000 (not including the lost productivity from staff's inability to move to another critical program for two months).

Comparative three-year sale volumes are shown in Figure A3 (with details in Figure A6). Both the Original and Remedial plans have the same shape and volumes, but the Remedial sales begin two months later. Competitive pressure causes the same volume decline for both in year three. Financial outcomes are shown in Table A1.

FIGURE A3: COMPARATIVE THREE-YEAR SALES VOLUME



(Source: Moor Insights & Strategy)

TABLE A1: ECONOMIC OUTCOME

	Original Plan	Remedial Plan	Difference	Delta
Total Unit Volume	8,040	7,440	-600	-7.5%
Total Sales	$86,663,160	$80,195,760	-$6,467,400	-7.5%
Total Margin	$38,998,422	$36,088,092	-$2,910,330	-7.5%
Development Cost	$8,740,800	$10,371,960	+$1,631,160	+18.7%
Return on Invest	$30,257,622	$25,716,132	-$4,541,490	-15.0%

(Source: Moor Insights & Strategy)

The plans generate revenue of $86.6M and $80.2M respectively and total gross margin of $38.9M and $36.1M. However, the Original plan generates a total lifetime profit of $30.3M, while the Remedial plan only generates $25.7M, 15% less due to development cost increase and delay. Figure A7 shows the Original plan is profitable after first year by $329,000, while the Remedial plan is still over $3.4M in the red.

The case presented here is purely hypothetical and highlights the potential business impact when “concepts match reality”. The model can serve as a guide to help you understand your business and assess the impact of physically-based rendering.

FIGURE A4: ORIGINAL DEVELOPMENT PROGRAM COSTS

As Planned Development Schedule																							
Month of Development			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Totals		
			Concept			Design						Validation			Preprod		Ramp		Full Production		Staff	Cost	Non-Personal
Concept / PM		Staffing	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	$ 420,000.00	
Matket Study			$ 80,000			Sales Compaign and Materials Cost						$ 100,000			Sales Training				$ 250,000				$ 430,000
SUBSYSTEM	1	Staffing				5	5	5	5	5	5	5	5	5	2	2	1	1	0.25	0.25	51.5	$ 1,030,000	
Overhd / Lab supplies						$ 50,000						$ 5,000			$ 5,000		$ 5,000		$ 5,000				$ 70,000
Tooling												$ 250,000											$ 250,000
SUBSYSTEM	2	Staffing				4	4	4	4	4	4	4	4	4	2	2	1	1	0.25	0.25	42.5	$ 850,000	
Overhd / Lab supplies						$ 50,000						$ 5,000			$ 5,000		$ 5,000		$ 5,000				$ 70,000
Tooling												$ 250,000										$ -	$ 250,000
SUBSYSTEM	3	Staffing				4	4	4	4	4	4	4	4	4	2	2	1	1	0.25	0.25	42.5	$ 850,000	
Overhd / Lab supplies						$ 50,000						$ 5,000			$ 5,000		$ 5,000		$ 5,000			$ -	$ 70,000
Tooling												$ 150,000											$ 150,000
SUBSYSTEM	4	Staffing				3	3	3	3	3	3	3	3	3	2	2	1	1	0.25	0.25	33.5	$ 670,000	
Overhd / Lab supplies						$ 50,000						$ 5,000			$ 5,000		$ 5,000		$ 5,000				$ 70,000
Tooling												$ 150,000										$ -	$ 150,000
SUBSYSTEM	5	Staffing				2	2	2	2	2	2	2	2	2	2	2	1	1	0.25	0.25	24.5	$ 490,000	
Overhd / Lab supplies						$ 50,000						$ 5,000			$ 5,000		$ 5,000		$ 5,000				$ 70,000
Tooling												$ 100,000											$ 100,000
SUBSYSTEM	6	Staffing				2	2	2	2	2	2	2	2	2	1	1	1	1	0.25	0.25	22.5	$ 450,000	
Overhd / Lab supplies						$ 50,000						$ 5,000			$ 5,000		$ 5,000		$ 5,000				$ 70,000
Tooling												$ 75,000											$ 75,000
															Non Personel Cost								**$ 1,825,000**
											Materials	**100**	**prototypes**		**$ 2,155,800.00**								**$ 2,155,800**
															Total Personel						**238**	**$ 4,760,000**	
															Total Non-Personel								**$ 3,980,800**
															Total Develooment Cost						**$**		**8,740,800**

Assumptions		
Person Cost per Month	$	20,000
Prototype Cost (each)	$	21,558

Original Development Summary		
Staffing Cost	$	4,760,000
Non-Personel Cost	$	1,825,000
Prototypes	$	2,155,800
Total	$	8,740,800

(Source: Moor Insights & Strategy)

FIGURE A5: REMEDIAL DEVELOPMENT PROGRAM COSTS

Remedial Development Schedule																									
Month of Development			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Totals		
			Concept			Design						Validation			Preprod		Remediation		Ramp		Full Production		Staff	Cost	Non-Personal
Concept / PM		Staffing	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	$ 460,000	
Matket Study			$ 80,000			Sales Compaign and Materials Cost						$ 100,000			Sales Training						$ 250,000				$ 430,000
SUBSYSTEM	1	Staffing				5	5	5	5	5	5	5	5	5	5	5	2	2	1	1	0.25	0.25	61.5	$ 1,230,000	
Overhd / Lab supplies						$ 50,000						$ 5,000			$ 5,000		$ 5,000		$ 5,000		$ 5,000				$ 75,000
Tooling												$ 250,000					$ 250,000								$ 500,000
SUBSYSTEM	2	Staffing				4	4	4	4	4	4	4	4	4	4	4	2	2	1	1	0.25	0.25	50.5	$ 1,010,000	
Overhd / Lab supplies						$ 50,000						$ 5,000			$ 5,000		$ 5,000		$ 5,000		$ 5,000				$ 75,000
Tooling												$ 250,000												$ -	$ 250,000
SUBSYSTEM	3	Staffing				4	4	4	4	4	4	4	4	4	4	4	2	2	1	1	0.25	0.25	50.5	$ 1,010,000	
Overhd / Lab supplies						$ 50,000						$ 5,000			$ 5,000		$ 5,000		$ 5,000		$ 5,000			$ -	$ 75,000
Tooling												$ 150,000													$ 150,000
SUBSYSTEM	4	Staffing				3	3	3	3	3	3	3	3	3	3	2	2	2	1	1	0.25	0.25	38.5	$ 770,000	
Overhd / Lab supplies						$ 50,000						$ 5,000			$ 5,000		$ 5,000		$ 5,000		$ 5,000				$ 75,000
Tooling												$ 150,000												$ -	$ 150,000
SUBSYSTEM	5	Staffing				2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	0.25	0.25	28.5	$ 570,000	
Overhd / Lab supplies						$ 50,000						$ 5,000			$ 5,000		$ 5,000		$ 5,000		$ 5,000				$ 75,000
Tooling												$ 100,000					$ 100,000								$ 200,000
SUBSYSTEM	6	Staffing				2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	0.25	0.25	26.5	$ 530,000	
Overhd / Lab supplies						$ 50,000						$ 5,000			$ 5,000		$ 5,000		$ 5,000		$ 5,000				$ 75,000
Tooling												$ 75,000													$ 75,000
																						Non Personel Cost			$ 2,205,000
											Materials	100	Prototypes		$ 2,155,800		20	Protytopes			$ 431,160				$ 2,586,960
																						Total Personel	279	$ 5,580,000	
																						Total Non-Personel			$ 4,791,960
																						Total Develooment Cost	$		10,371,960

Assumptions		
Person Cost per Month	$	20,000
Prototype Cost (each)	$	21,558

Remedial Development Summary		
Staffing Cost	**$**	**5,580,000**
Non-Personel Cost	**$**	**2,205,000**
Prototypes	**$**	**2,586,960**
Total	**$**	**10,371,960**

(Source: Moor Insights & Strategy)

FIGURE A6: SALES VOLUME PLAN

Original

Year 1	1	2	3	4	5	6	7	8	9	10	11	12	Total Units Year 1
Original	40	80	100	100	150	150	200	200	200	200	200	250	1870

Year 2	13	14	15	16	17	18	19	20	21	22	23	24	Total Units Year 2
Original	300	300	300	300	300	300	300	300	300	300	300	300	3600

Year 3	25	26	27	28	29	30	31	32	33	34	35	36	Total Units Year 3
Original	300	300	300	300	300	300	250	200	150	100	50	20	2570

Remedial

Year 1	1	2	3	4	5	6	7	8	9	10	11	12	Total Units Year 1
Remedial			40	80	100	100	150	150	200	200	200	200	1420

Year 2	13	14	15	16	17	18	19	20	21	22	23	24	Total Units Year 2
Remedial	200	250	300	300	300	300	300	300	300	300	300	300	3450

Year 3	25	26	27	28	29	30	31	32	33	34	35	36	Total Units Year 3
Remedial	300	300	300	300	300	300	250	200	150	100	50	20	2570

Competitive Impact (months 31–36)

(Source: Moor Insights & Strategy)

FIGURE A7: FULL PROGRAM ECONOMIC ANALYSIS

Financial Performance when NO Remediation is Required							
Unit Volume Year 1	1870	Unit Volume Year 2	3600	Unit Volume Year 3	2570	Ttotal Volume	8040
Annual Sales	$ 20,156,730	Annual Sales	$ 38,804,400	Annual Sales	$ 27,702,030	Total Sales	$ 86,663,160
Margin	$ 9,070,529	Margin	$ 17,461,980	Margin	$ 12,465,914	Total Margin	$ 38,998,422
Development Cost	$ 8,740,800	Development Cost	$ -	Development Cost	$ -	Development Cost	$ 8,740,800
Return on Invest	$ 329,729	Return on Invest	$ 17,461,980	Return on Invest	$ 12,465,914	Return on Invest	$ 30,257,622

Financial Performance when Remediation IS Required							
Unit Volume Year 1	1420	Unit Volume Year 2	3450	Unit Volume Year 3	2570	Ttotal Volume	7440
Annual Sales	$ 15,306,180	Annual Sales	$ 37,187,550	Annual Sales	$ 27,702,030	Total Sales	$ 80,195,760
Margin	$ 6,887,781	Margin	$ 16,734,398	Margin	$ 12,465,914	Total Margin	$ 36,088,092
Development Cost	$ 10,371,960	Development Cost	$ (3,484,179)	Development Cost	$ -	Development Cost	$ 10,371,960
Return on Invest	$ (3,484,179)	Return on Invest	$ 13,250,219	Return on Invest	$ 12,465,914	Return on Invest	$ 25,716,132

	Original Plan	Remedial Plan	Difference	Delta
Total Unit Volume	8,040	7,440	-600	-7.5%
Total Sales	$86,663,160	$80,195,760	-$6,467,400	-7.5%
Total Margin	$38,998,422	$36,088,092	-$2,910,330	-7.5%
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Return on Invest	$30,257,622	$25,716,132	-$4,541,490	-15.0%

Assumptions	
Average Sale Price	$ 10,779.00
Gross Margin	45%

(Source: Moor Insights & Strategy)

Important Information About This Paper

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