ESD. 71 Application Portfolio:

Flexibility in the Product Design Process

Alison Olechowski

Department of Mechanical Engineering
Massachusetts Institute of Technology

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ABSTRACT

In this paper,we model fixed and flexible engineering design and perform a Monte Carlo simulationto explore differences inoutcomes. The typical point-based design process consists of deciding at the project start on which specific design concept to pursue, based solely on first forecasts of uncertain customer requirement and technology performance. The alternative flexible set-based design method uses parallel exploration and the delaying of decisions to achieve an improved pay-off based on what is learned about both uncertainties through the development time. Results from the simulation reveal that the flexible design process results in a significantly higher expected net present value than the fixed process. Thus, the higher sales revenue resulting from the better design outweighs the high cost of carrying additional designs forward. Further simulation revealed that the set-based design process is more valuable on a high-risk project, such as an evolutionary product with new technology. On a low risk project, the marginally better resulting design is not worth the extra development cost.

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1.0 INTRODUCTION

Many of today's products are made up of mechanical, electrical and software components. The design of these new products can be a complex and costly process; there is interaction between components and modules, there are multipleengineering teams working on various facets of the product, there are a number of management decisions that need to be made throughout the process, and there aresignificant uncertainties affecting the design. New product design is influenced by uncertainties in technology, market/competition and customer requirement, just to name a few. These uncertainties are especially important to consider when designing revolutionary/radical (as opposed to evolutionary/incremental) products.

Given the above characteristics, the system of product design was chosen for analysis in this application portfolio.

2.0 SYSTEM DESCRIPTION

The product design decision-maker is faced with a number of uncertainties throughout the life of the project. He/she will learn more information about technical performance and customer requirement as time goes on, when tests are run, prototypes are built, etc. but he/she must make decisions before that information is created.

Consider the design of a product with multiple distinct features, for example, an isolator with ventilation, containment, and decontamination sub-systems. This model will consider the design of one feature, from the point of view of one design team. As the team designs, they are receiving information about requirements from the other teams, since all features interact. At the same time, it's possible that the customer has changing needs. Thus the performance requirement will change over the timeline of the project. The model presented will explore one specific feature requirement, for example, the required flow rate through the ventilation system. This is a measurable quantity that is very much dependent on the design of the other sub-systems.

A typical design process is made up of four phases, as shown in Figure 1. Consider a set of design review meetings occurring at the end of each phase, at which point there is the opportunity for design teams and management to communicate. It is at these design review meetings that decisions are made about abandoning designs, based on the estimate of the current level of technical requirement and performance level.

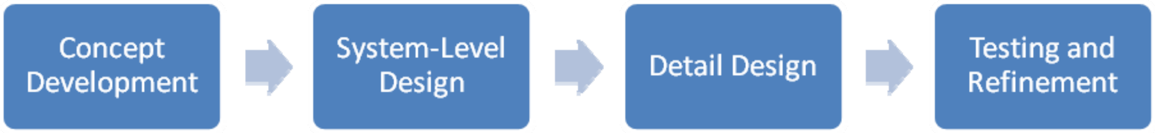

Figure 1: The four phases of product design.

In product development there is a balance between freezing a design early so that teams can focus their resources (point-based design), and carrying a number of possible designs forward in order to learn more about which is the best solution (set-based design).

In the case of point-based design, an initial set of designs is considered. Forecasts for these designs are evaluated, and based on estimates of technical performance and requirement, the best design is chosen and pursued to completion, without alteration of the original design concept.

Set-based design is a term coined by Allen Ward to describe a design process where instead of deciding on one design idea to pursue through the design process, sets of designs are carried ahead and are slowly abandoned until a final design is selected. It is described as a process where “Upon evaluating the initial range of alternatives,rather than selecting the apparently best alternative, PD teamsdevelop the set of viable alternatives from multiple perspectives” [1].

Two principles of set-based design are parallel exploration and delaying of decisions. Parallel exploration allows for full exploration of the design space,with hopes that keeping the additional designs increases the probability that the eventual chosen design is a success. Delaying of decisions is essentially giving flexibility to the program in that designs aren’t ruled out at the start based on estimates of final design performance. More information is gained about the performance of each design before a design is abandoned.

As taught in product development textbooks, “It is clear that new-product development requires a major commitment of resources and that most funds are at risk in the final testing and introduction phases. Managerially, this suggests that (1) the time when many creative ideas are to be encouraged is early in the design of the product when less investment is at risk, and (2) it is important to eliminate failures early before they lead to major loss in investment.” [2]

Some see a balance between set-based design, where resources are “wasted” on the designs that are worked on but don’t end up being chosen, and point-based design where it is possible to “lock-in” to the wrong design, leading toa lower quality final product, or rework when changes must propagate through the entire engineering team.

3.0 SOURCES OF UNCERTAINTY

Two sources of uncertainty are considered in this model: technology uncertainty and customer requirement uncertainty.

3.1 Technology Uncertainty

When initial design ideas are generated, the technical performance of the final product can only be approximated. The initial expected level of performance can be thought of as the mean of the distribution of possible performance levels (represented by the point with bars in Figure 2), based on known information.

As the product design process progresses, the current estimate of technical performance level will change. As the process goes on, the design is refined and thus the standard deviation in the performance level is reduced and the distribution becomes tighter. Testing, prototyping, modeling, analysis, etc. narrows the uncertainty distribution from one phase to the next and betters the current estimate of performance, sometimes with a shift of the distribution. Thus, as shown below in Figure 2, the uncertainty distribution will start off with a high volatility which will lessen over time (assuming tests, etc. are performed).

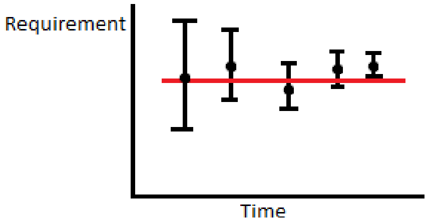

Figure 2: Estimates of one design requirement tracked through various phases of product design. Each circle represents an estimate of the most likely design performance. The red line is a stablecustomer design requirement.Figure adapted from [3].

As an example, a bench level test (very rough test with analogous materials and messy assembly) is effective in eliminating the very end of the downside tail of the performance distribution, since it shows that the design concept under consideration performs as designed in its basic form.As shown in Figure 3, after this test, the mean (expected level of performance) would shift, and the distribution would change from one period to the next:

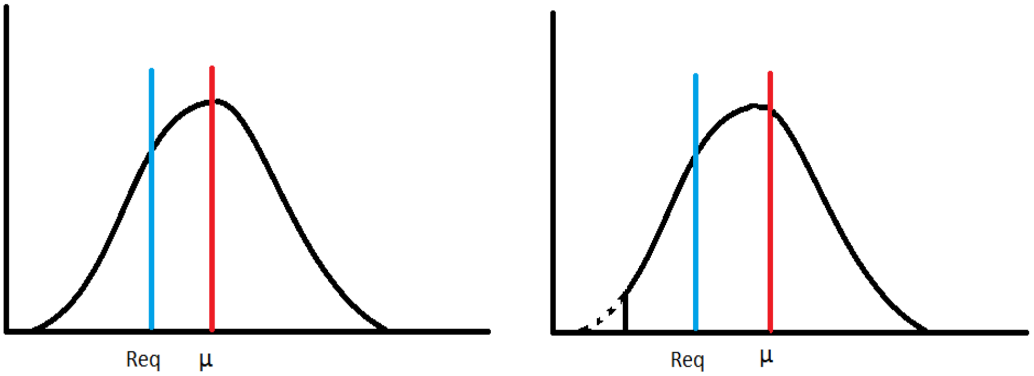

Figure 3: Error bars from Figure 2represented as probability density functions.

On the other hand, you might do testing on your industrial design with a focus group and find that the product is not as ergonomically appealing as analysis had predicted. In this case, the upper extreme of the distribution would beeliminated, shifting the mean down.

3.2 Customer Requirement Uncertainty

Since the product design process takes anywhere from months to years to complete, depending on the product, it's not hard to imagine that the customer requirements would change over time. Changes in customers' taste is identified as a top cause of new product failure, with suggested safeguard being frequent monitoring and updating of customer preferences in the design phase [2].

Therefore in this model, customer requirement has been considered an uncertain value. As above, frequent monitoring and updating of customer requirement will result in a changing customer design requirement, whose distribution narrows as the end of the project nears.

4.0 SYSTEM DESIGN DESCRIPTION

Both a deterministic and a flexible design were analyzed.

The product design system was modeled with cash flow analysis and simulation.Simulation was selected because this method can use a priori conditions for the decision rule for when to use flexibility.

Decision analysis was not used since the uncertainties are continuous and since there will be multiple complex decisions to be made. The curse of dimensionality associated with a decision tree would quickly over-complicate the analysis. Uncertainties were not modeled using a lattice because the modeler wanted the potential to expand the model in future work to include more than one flexibility decision per project, and to introduce rework, which would make the system non-stationary.

4.1 Deterministic Design

In a typical product design process, the designers' first step is to generate a number of concepts spanning the design space. In this case, five designs are conceived and evaluated in Period 0 based on best estimates of future performance and customer requirement. In Period 0, the "best" option – that where the current estimate of performance level is closest to current estimate of customer requirement– is selected to be further developed, as shown below in Figure 4.

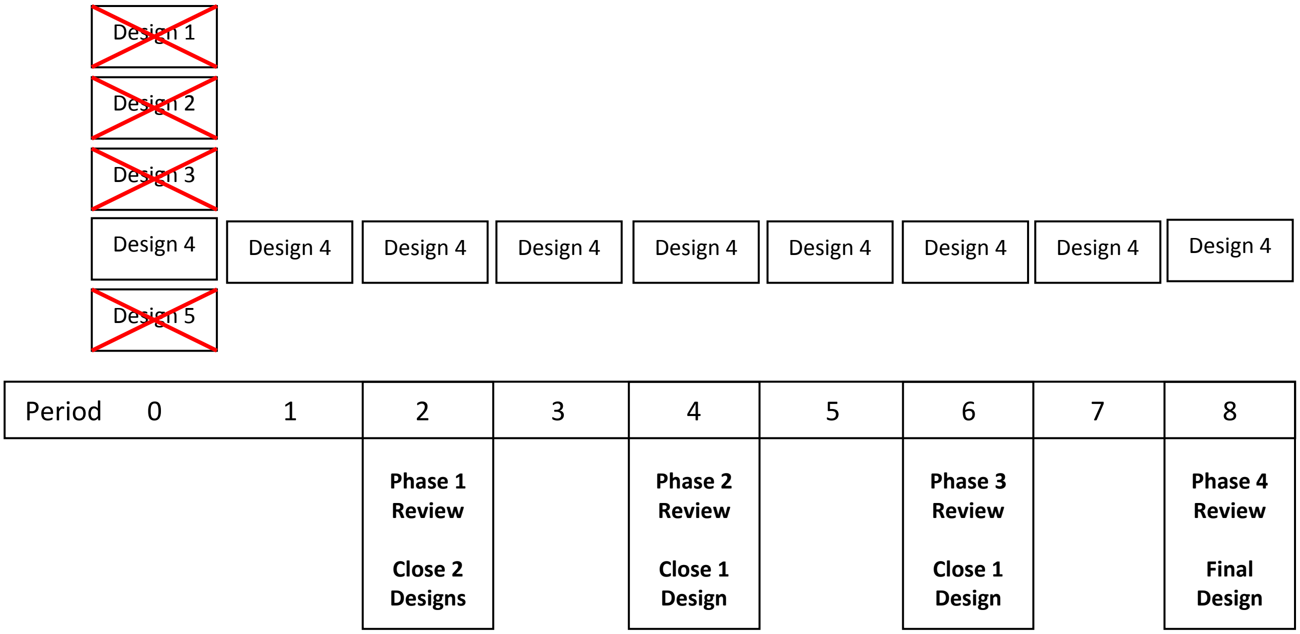

Figure 4: Deterministic (point-based) design decision process as modeled for simulation, example with data from Table 1.

During each subsequent phase made up of two periods, research, analysis, testing and prototyping occur, resulting in a more accurate forecast of the actual performance level of the particular design (meaning the performance level will change through each period, as shown below in Table 1). At the end of the design phases the final performance level is reached.

Table 1: Model data for deterministic design case shown above in Figure 4.

Period	0	1	2	3	4	5	6	7	8
Design 1 performance level	73.9	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 2 performance level	82.8	87.3	71.0	85.8	75.9	80.5	76.1	78.6	78.4
Design 3 performance level	72.8	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 4 performance level	86.9	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 5 performance level	76.1	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Required performance level	80	77.9	82.2	81.0	81.8	80.4	77.9	77.9	77.9

4.2 Flexible Design

In the flexible case, similar to set-based design, five designs are initially considered. None are eliminated during Phase 0. During each subsequent phase made up of two periods, research, analysis, testing and prototyping occur, resulting in a more accurate forecast of the actual performance level for each design.

In the flexible case, the design process has close decision rules at each end of phase, as shown with an example case below(data in Table 2, and graphic representation inFigure 5).

Table 2: Model data for flexible design case shown below in Figure 5.

Period	0	1	2	3	4	5	6	7	8
Design 1 performance level	85.5	79.0	82.1	93.7	89.2	86.5	85.5	CLOSE	CLOSE
Design 2 performance level	77.3	95.6	93.0	90.9	90.9	CLOSE	CLOSE	CLOSE	CLOSE
Design 3 performance level	76.8	68.3	53.0	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 4 performance level	70.5	93.7	74.0	69.2	68.7	75.2	77.3	72.3	72.7
Design 5 performance level	85.3	85.0	95.4	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Required performance level	80	82.1	78.6	81.5	77.7	80.1	79.7	79.7	79.7

At each decision point, the performance level of all the open designs are compared to the current customer requirement, and the design which is farthest from the customer requirement is closed. In this model, at the end of the first phase (second period), two designs are closed. Next one design is closed at the end of the second phase, and finally one more design is closed at the end of the third phase, leaving the final design to be refined during Phase 4.

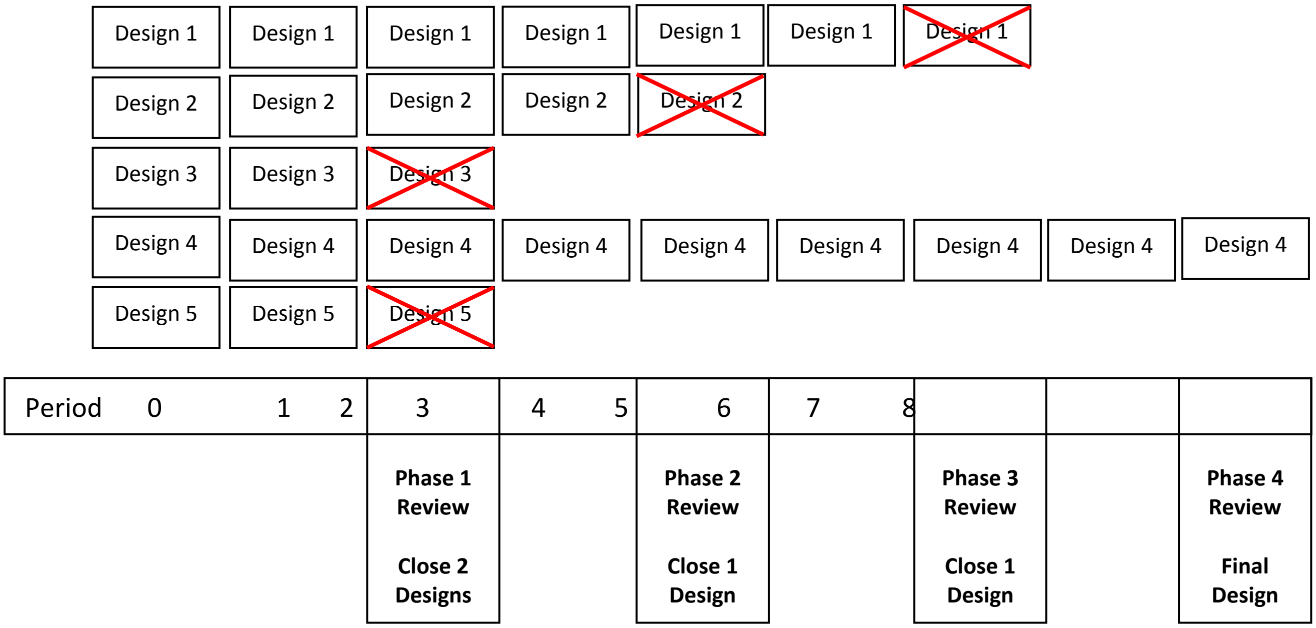

Figure 5: Flexible (set-based) design decision process as modeled for simulation, example with data from Table 2.

5.0 SYSTEM DESIGN MODEL

The model assumes that the project time line will be strictly adhered to. Therefore in the typical time-cost-quality trade-off, this model assumesfixed time and cost for each unique decision rule, with qualitybeing the output goal.

Project performance levels were modeled as random walks. Each design's starting performance level was a random deviation from the initial customer requirement, thus modeled to represent a selection of ideas which span the design space. The performance level at each subsequent phase is a random deviation from the previous phase, as shown below in Figure 6 for the set-based design decision. The "volatility" for each phase is a model variable. In this case, it varied for each phase, but grew smaller as time went on.

The customer requirement level was also modeled as a random walk variable. The customer requirement was modeled with less volatility than the design performance levels, and started at a fixed level. For Phase 4 of design (the last two periods of test and refinement) the customer requirement is "locked" and does not change.

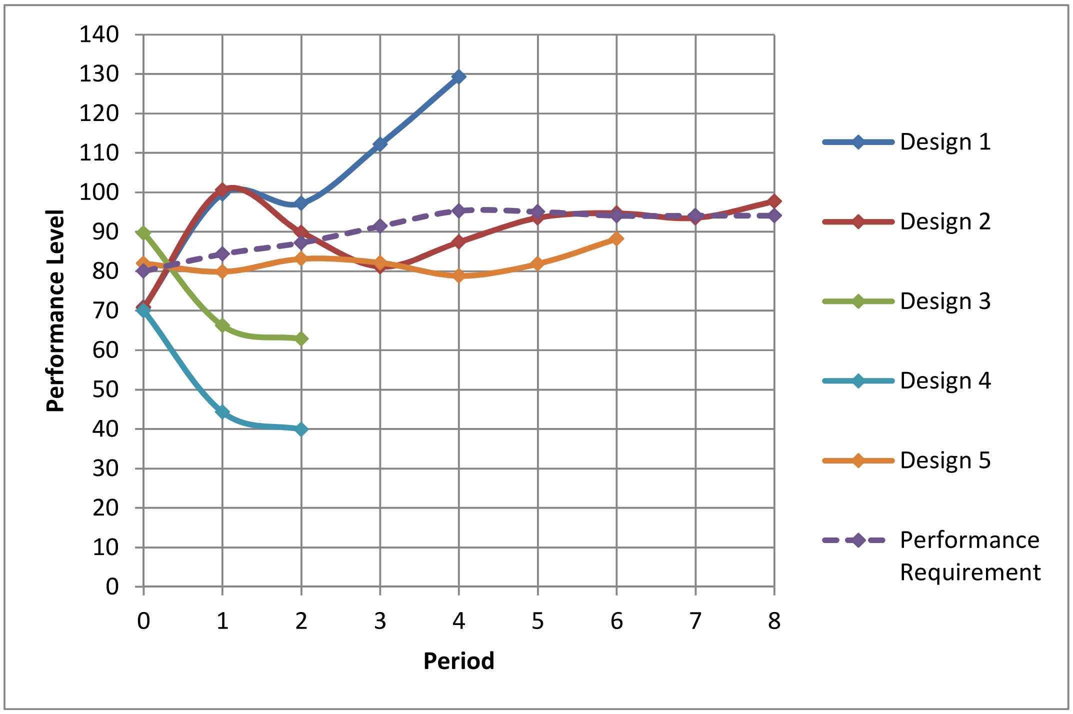

Figure 6: One example of set-based design decisions and design performance level dynamics.

For the above case, Design 2was selected in the set-based design process. Corresponding decisions for the set-based method for this case are shown below in Table 3. Design 5 would have been selected forthe point-based design processbased on estimates from Period 0.

Table 3: Set-based design decisions for case shown in Figure 6 above.

Period	0	1	2	3	4	5	6	7	8
Design 1 decisions	OPEN	OPEN	OPEN	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 2 decisions	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
Design 3 decisions	OPEN	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 4 decisions	OPEN	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 5 decisions	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSE	CLOSE	CLOSE

The model was initially set-up with costs, sales, and timeline data based on a case study of a pocket calculator developed at Hewlett-Packard [4] in order to realistically represent a product design and development process. These values were adjusted until model behavior matched expectation.

The design process consists of four four-month phases, with design reviews and decisions at the end of each phase. The cost of development through each of these phases was calculated as a variable cost - a product of the number of designs carried through each period. As is a common observation of the product design process, the development costs grow through the later phases of designs.

At the end of the design phase, the product can be sold. The utility curve for the design performance level was chosen to be parabolic, such that the loss in revenue is a function of the square of the difference between actual and required performance, as shown below in Figure 7. This means that ending with a performance level higher than the final requirement is no better than ending below the requirement.

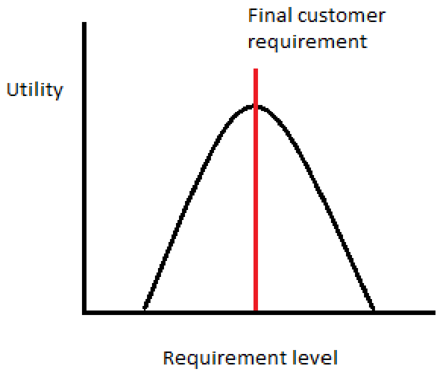

Figure 7: Parabolic utility curve for product design model.

An annual discount rate of 10% was used in analysis, adjusted to an effective discount rate of 1.6% for each two month period. Due to lack of precedence of discount rates in product design analysis, this discount rate was chosen as it is a typical value in capital-intensive, long-term projects.

6.0 SIMULATION RESULTS

A Monte Carlo simulation with 5000 runs was performed with @RISK. The results show that neither design was stochastically dominant. See the cumulative distribution functions (Figure 8) below.

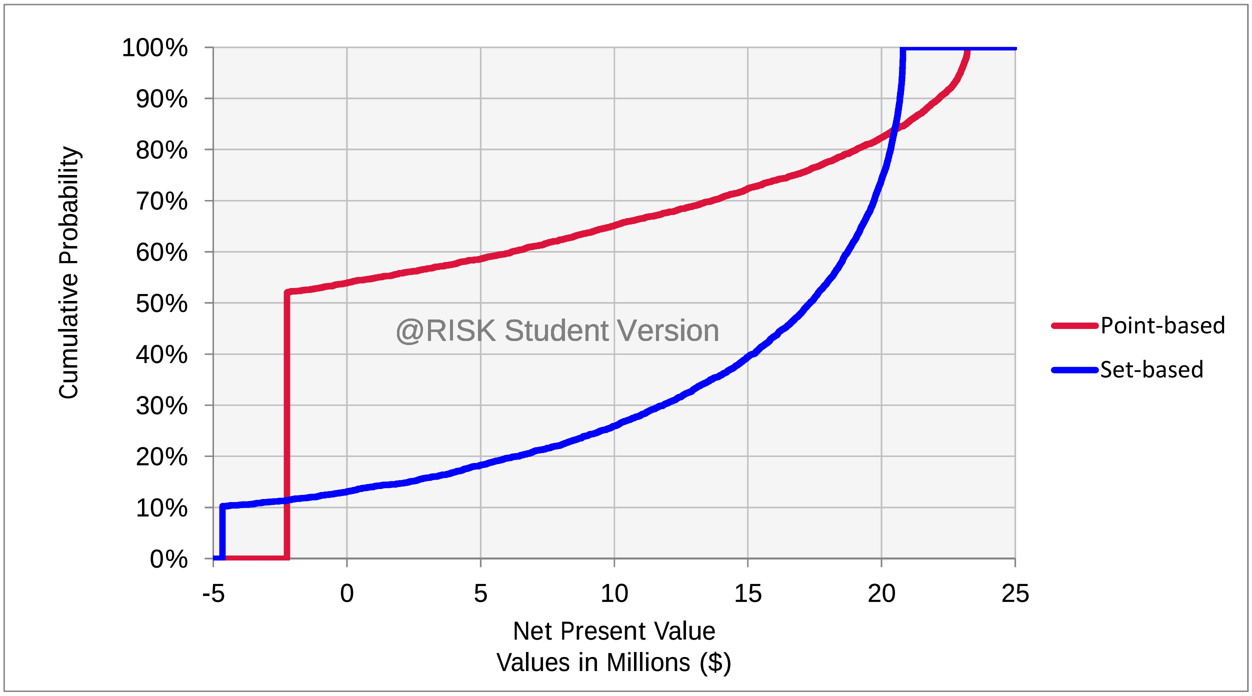

Figure 8: Cumulative distribution function for the two design processes.

6.1 Interpretation of the Cumulative Distribution Function

Note from the cumulative distribution functions (CDFs) that neither distribution has a down-side or up-side tail. The point-based distribution has a minimum of -$2,243,407 and the set-based -$4,657,918 (a difference of $2,414,511). These minimums are the discounted development costs. The probability of this low value occurring is 52.0% for the point-based design and 10.2% for the set-based design.In both cases, this minimum is a result of the final design performance level being so far from the final distribution that the product will not sell. A tail is not created because it is not possible to lose money beyond development costs from a poor design. A terrible design and a poor design will both result in zero sales, and thus “bin” at the bottom of the distribution, resulting in the vertical lines at the down-side of the distribution.

This difference in development costs is also exactly observed at the upside of the distributions. The difference between the maximum value of the point-based design ($23.2million) and the maximum of the set-based design ($20.8 million) is again $2,414,511, the difference in development costs. This amounts to a 17.8% larger maximum for the point-based design process. This shows that, as one would expect, the development costs are small compared to the upside for a successful product.

The symmetry of development costs as the difference between the methods at both tails is an effect of the assumption that the best possible design resulting from the point-based method is the same of that for the set-based method (exactly equal to the customer requirement). The parabolic utility curve results in an optimal solution, and thus there is no upside-tail.

The discounted development cost for the set-based design process ($4,657,917) is equal to slightly more than twice as much as the point-based process ($2,243,407), as is expected from carrying the extra designs through the future stages.

The parabolic nature of the two CDFs is an effect of the parabolic utility curve used to model sales.

6.2 Performance Metrics

Presented in Table 4is a comparison of a number of performance metrics for the two design methods.

Table 4: Comparison of results for both design methods, with the better result highlighted in gray.

Metric	Point-based	Set-based	% Difference
ENPV	$6,023,742	$13,500,280	124%
P_5	-$2,243,407	-$4,657,918	108%
P_{95}	$22,948,920	$20,775,600	9%
Std Dev	$10,040,560	$8,410,015	16%
Development Cost	$2,243,407	$4,657,917	126%
ENPV/Development Cost	4.03	4.00	1%

Development cost is a sum of discounted costs during the design phase.

The comparison table shows that there would be reasons to choose either design method. If the decision maker was risk-neutral, they would likely chose the set-based method since the expected net present value is higher; in fact, it is more thantwice as large as the ENPV for the point-based case.

If the decision maker was risk-averse, it is possible they would choose the point-based method since the loss at P_5 is smaller. However, it is also possible that they would take into account that, as stated above, there is a 52.0% chance that the ENPV will be the minimum in the point-based method, versus only 10.2% for the set-based method. This statistic could very well play a role in their risk-averse decision making.

The P_{95} results only differ by 9%. If the decision maker was risk-seeking and interested in "milking" value regardless of small differences relative to change in risk, they might choose the point-based method for the higher upside value.

The standard deviation is smaller with the set-based design method than the point-based; if robustness was very important for the decision maker, this could be an important metric in their choice of method.

6.3 Break-Even NPV Probability

In addition to the metrics above, the zero $ NPV probability for the point-based design is 53.9%, meaning that half of the time, the project is expected to have a negative NPV. On the other hand, the zero NPV probability for the set-based design is 13.1%, four times smaller than that of the point-based.

It is not surprising that there are significant sections of the CDF curves under the $0 NPV level. The factors that lead to a successful new product are still somewhat of a mystery to designers, and there are many failed products developed for every successful one.

6.4 Stability of Results

The Monte Carlo simulation was performed again with 10000 runs to check the stability of results. As shown in Table 5, there was no significant change in results (percentage difference was less than 5% in all cases), indicating that 5000 runs is enough to achieve stable results over the uncertainties in the model.

Table 5: Statistics for simulation with 5000 and 10000 runs.

Metric	5000	10000	% Difference	5000	10000	% Difference
	Point-based	Point-based		Set-based	Set-based	
ENPV	$6,023,742	$6,059,114	0.59%	$13,500,280	$13,486,150	0.10%
P_5	-$2,243,407	-$2,243,407	0.00%	-$4,657,918	-$4,657,918	0.00%
P_{95}	$22,948,920	$22,964,260	0.07%	$20,775,600	$20,775,020	0.00%
Std Dev	$10,040,560	$10,128,610	0.88%	$8,410,015	$8,386,354	0.28%
Development Cost	$2,243,407	$2,243,407	0.00%	$4,657,917	$4,657,917	0.00%
ENPV/Development Cost	2.69	2.70	0.59%	2.90	2.90	0.10%

6.5 Effect of Risk

The simulation was re-run with less volatility in the customer requirement and design performance levels, to represent a lower risk project. As can be seen below in Table 6, the value of flexibility is significantly less.

Table 6: Comparison of results for two design methods comparing risky and less risky projects.

Metric	Low Risk			High Risk		
	Point-based	Set-based	Difference (S-P)	Point-based	Set-based	Difference (S-P)
ENPV	$20,792,930	$20,421,900	-$371,030	$6,023,742	$13,500,280	$7,476,538
P_5	$14,094,430	$19,264,210	$5,169,780	-$2,243,407	-$4,657,918	-$2,414,511
P_{95}	$23,205,740	$20,799,860	-$2,405,880	$22,948,920	$20,775,600	-$2,173,320
Development Cost	$2,243,407	$4,657,917	$2,414,511	$2,243,407	$4,657,917	$2,414,511
ENPV/Development Cost	9.3	4.4	-4.9	2.7	2.9	0.2

Examining ENPV above, it can be seen that the value of the flexibility is much higher in the high risk project than in the low risk. In the low risk project, the point-based ENPV is even higher than the set-based process ENPV; the cost of the flexibility is not worth the increase in performance level resulting from the flexibility.

It should be noted that in the model, only the performance level, and not the development cost, is a function of the level of risk. Further work would explore the relationship between riskiness and development cost per product to gain a better understanding of the cost-performance trade-off.

The flexible approach to design is especially useful for high risk situations. High risk in product design is often a result of evolutionary, novel designs with high uncertainty in performance.

7.0 CONCLUSION

Much has been learned from the modeling and simulation presented above. First of all, it was eye-opening to view set-based design through the lens of flexible systems developed in class; principles such as the value of information, the inaccuracy of our ability to forecast, and delaying of decisions are important in both. It was valuable to reinforce the intuitive beliefs about set-based design with actual simulation results, and to reason about the assumptions on which the model depends. Further, the author had no previous experience with Monte Carlo simulation and found it a powerful means of analyzing model outcomes. The value of flexibility, particularly in high-uncertainty projects, was further reinforced through investigation of the simulation model.

Future work would include the addition of rework in the design model. It would be valuable to use actual detailed project data from a company so that accurate breakdowns of costs and actual estimates of engineering technical values over a project's life could be inputted in the model. Finally, it would be of interest to explore a larger space of design decisions for the current model – the number of designs initially considered, the timing of the close decisions, and the nature of convergence to the final design.

8.0 REFERENCES

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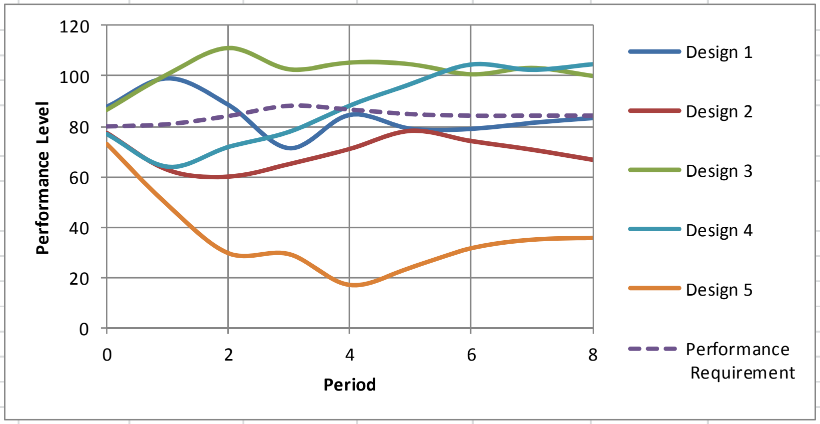
9.0 APPENDICES

9.1 One run of the point-based simulation

NPV Model - Point-based Design

Each period is 2 months		
Sales revenue for performance level = requirement per year	$80,000,000	
Constant used in penalty calculation for performance level missing custmer requirement	$35,000	
Time horizon	20	periods
Discount rate	2%	
Number of initial design alternatives	5	



Period	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Design 1 performance level	87.8	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 2 performance level	77.4	62.8	60.1	65.1	71.1	78.2	74.2	70.8	66.8
Design 3 performance level	86.6	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 4 performance level	77.0	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 5 performance level	73.0	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Required performance level	80	80.9	84.1	88.2	86.7	84.9	84.3	84.3	84.3
Close option timing	TRUE								
Number of alternatives to close	4								
Design 1 Difference between required and estimate	7.8								
Design 2 Difference between required and estimate	2.6	18.1	24.0	23.1	15.6	6.6	10.1	13.5	17.5
Design 3 Difference between required and estimate	6.6								
Design 4 Difference between required and estimate	3.0								
Design 5 Difference between required and estimate	7.0								
Design 1 decisions	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 2 decisions	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
Design 3 decisions	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 4 decisions	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 5 decisions	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Cost for one product through this phase		$100,000	$100,000	$250,000	$250,000	$375,000	$375,000	$500,000	$500,000

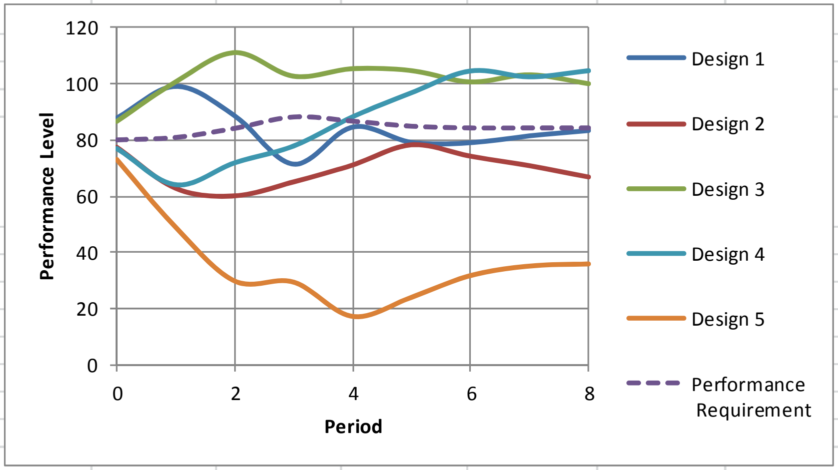
Period	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Revenue for design										$2,664,058	$2,664,058	$2,664,058	$2,664,058	$2,664,058	$2,664,058	$2,664,058	$2,664,058	$2,664,058	$2,664,058	$2,664,058	$2,664,058
Development costs/production costs		$100,000	$100,000	$250,000	$250,000	$375,000	$375,000	$500,000	$500,000												
Other costs										$2,131,247	$2,131,247	$2,131,247	$2,131,247	$2,131,247	$2,131,247	$2,131,247	$2,131,247	$2,131,247	$2,131,247	$2,131,247	$2,131,247
Discounted development costs		$98,425	$96,875	$238,374	$234,620	$346,388	$340,933	$447,419	$440,373												
Cashflow	$0	-$100,000	-$100,000	-$250,000	-$250,000	-$375,000	-$375,000	-$500,000	-$500,000	$532,812	$532,812	$532,812	$532,812	$532,812	$532,812	$532,812	$532,812	$532,812	$532,812	$532,812	$532,812
DCF	$0	-$98,425	-$96,875	-$238,374	-$234,620	-$346,388	-$340,933	-$447,419	-$440,373	$461,881	$454,608	$447,448	$440,402	$433,466	$426,640	$419,922	$413,309	$406,800	$400,393	$394,088	$387,882
Present value of cashflow	$2,843,433																				
Discounted development cost	$2,243,407																				
Net present value	$2,843,433																				

9.2 One run of the set-based simulation

NPV Model - Set-based Design

Each period is 2 months

Revenue for performance level = requirement for first year	$80,000,000	
Constant used in penalty calculation	$35,000	
Time horizon	20	periods
Discount rate	2%	
Number of initial design alternatives	5	



Period	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Design 1 performance level	87.8	99.1	88.6	71.4	84.6	79.1	79.0	81.4	83.3
Design 2 performance level	77.4	62.8	60.1	65.1	71.1	CLOSE	CLOSE	CLOSE	CLOSE
Design 3 performance level	86.6	100.7	111.1	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 4 performance level	77.0	64.0	71.9	77.8	88.2	96.8	104.5	CLOSE	CLOSE
Design 5 performance level	73.0	48.9	29.8	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Required performance level	80	80.9	84.1	88.2	86.7	84.9	84.3	84.3	84.3
Close option timing			TRUE		TRUE		TRUE		
Number of alternatives to close			2		1		1		
Design 1 Difference between required and estimate	7.8	18.2	4.4	16.8	2.1	5.8	5.3	2.8	0.9
Design 2 Difference between required and estimate	2.6	18.1	24.0	23.1	15.6				
Design 3 Difference between required and estimate	6.6	19.8	26.9						
Design 4 Difference between required and estimate	3.0	16.8	12.3	10.3	1.6	11.9	20.3		
Design 5 Difference between required and estimate	7.0	32.0	54.3						
Period	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Design 1 decisions	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
Design 2 decisions	OPEN	OPEN	OPEN	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 3 decisions	OPEN	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Design 4 decisions	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSE	CLOSE	CLOSE
Design 5 decisions	OPEN	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Cost for one product through this phase		$100,000	$100,000	$250,000	$250,000	$375,000	$375,000	$500,000	$500,000

Period	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Revenue for design										$13,302,963	$13,302,963	$13,302,963	$13,302,963	$13,302,963	$13,302,963	$13,302,963	$13,302,963	$13,302,963	$13,302,963	$13,302,963	$13,302,963
Development cost		$500,000	$500,000	$750,000	$750,000	$750,000	$750,000	$500,000	$500,000												
Other costs										$10,642,370	$10,642,370	$10,642,370	$10,642,370	$10,642,370	$10,642,370	$10,642,370	$10,642,370	$10,642,370	$10,642,370	$10,642,370	$10,642,370
Discounted development cost		$492,126	$484,376	$715,122	$703,860	$692,776	$681,866	$447,419	$440,373												
Cashflow	$0	-$500,000	-$500,000	-$750,000	-$750,000	-$750,000	-$750,000	-$500,000	-$500,000	$2,660,593	$2,660,593	$2,660,593	$2,660,593	$2,660,593	$2,660,593	$2,660,593	$2,660,593	$2,660,593	$2,660,593	$2,660,593	$2,660,593
DCF	$0	-$492,126	-$484,376	-$715,122	-$703,860	-$692,776	-$681,866	-$447,419	-$440,373	$2,306,402	$2,270,081	$2,234,331	$2,199,145	$2,164,513	$2,130,426	$2,096,876	$2,063,854	$2,031,353	$1,999,363	$1,967,877	$1,936,887
Present value of cashflow	$20,743,191																				
Discounted development cost	$4,657,917																				
Net present value	$20,743,191																				