

USING SIMULATION WITH A LOGIT CHOICE MODEL TO ASSESS THE COMMERCIAL FEASIBILITY OF AN ADVANCED ENVIRONMENTAL TECHNOLOGY

Paul J. Kauffmann

Engineering Management
Old Dominion University
Norfolk, Virginia 23529-0248, U.S.A.

ABSTRACT

A critical issue in advanced technology product development is assessing economic feasibility based on the potential for commercial success. This is particularly difficult for an environmental product that has intangible benefits such as reduced air emissions. Corporate confidentiality compounds this problem since many of the target customers of the new product do not allow product developers to access important process, cost, and environmental operating information.

This paper describes the application of simulation to enhance the power of a choice model to evaluate the feasibility of an advanced environmental technology for the metal casting industry. Using simulated industry data that describes the critical operating and environmental characteristics of lead technology adapters, a binary logit choice model estimates the probability of commercial success for the new technology. This methodology has application to the general problem of assessing the intangible benefits of advanced technology and contributes to the literature describing the interdisciplinary use of simulation to enhance decision science modeling.

1 INTRODUCTION

Recent environmental legislation has produced a negative financial impact on the domestic cast metal industry. The American Foundrymen's Society (1995) estimates that the current annual cost of these regulations is \$1.25 billion and will grow to nearly \$2 billion by the end of the century. McKinley and Jefcoat (1994) estimate the impact of environmental compliance is now at 3% to 4% of sales and by the end of the century will grow to 6%. This paper presents a portion of a study that examined this regulatory impact issue and involved a broad cross section of the cast metal industry including environmental regulators and suppliers.

Air emissions that result from the decomposition of organic, sand binders during the metal - casting process are a particular environmental concern. "End of pipe" solutions, such as fume scrubbers and incinerators, are the only option currently available to reduce these emissions. This approach increases operating costs and adds to the financial problems of the industry. An advanced, low emission binder system is a possible alternative that may eliminate or reduce the source of the problem. However, the last widely adopted "break through" binder technology is over fifteen years old and recently introduced products have had limited industry acceptance (Ashland, 1993). From this history, it is unclear whether an advanced sand binder system with reduced emission characteristics is a commercially feasible product and a possible solution to the air emission issues of the cast metals industry.

Discussion with binder manufacturers indicates that an advanced binder should target the needs of a small group of leading firms that set the pace in adopting new technologies. The high production iron and steel foundries are the technology leaders and innovators for the cast metal industry and will have a critical influence on the success of a new binder system. The literature of technology diffusion and adoption supports this view and identifies the importance of pace setting adopters that exert significant influence on subsequent adopters and their decision processes (Lilien et al. 1992). In particular, Keeney and Lilien (1987) indicate that high technology products must meet with success with a small number of high volume buying firms. The sales demographics of the industry are consistent with this perspective since 20-30% of the customer base accounts for 70% of the sales for most binder products.

This paper demonstrates an interdisciplinary application of discrete event simulation to environmental product development. In the context of evaluating advanced binder concepts, a binary logit choice model is developed to identify the combinations of emission reduction and cost impact that achieve a high probability

of selection by the market leaders. Use of the model as a product development tool is demonstrated with simulated industry process and emission data. The results provide guidance for identifying environmental products with the highest potential for commercial success.

2 CHOICE MODEL

The selection between an advanced binder system with reduced air emissions or a fume incinerator can be described as a choice between simultaneously available alternatives based on a tradeoff evaluation of attributes. Lilien et al. (1992), Gensch et al. (1990), and Gensch (1987) identify the logit choice model as the most frequently used algorithm for a simultaneous, compensatory (tradeoff) based evaluation. Lilien et al. (1992) and Louviere and Woodworth (1983) indicate that the logit model is particularly useful for new product evaluations.

The binary form of the logit choice model (Amemiya, 1981) fits the context of assessing economic feasibility based on the probability of purchase or failure to purchase. It assumes that the decision-maker selects one of two alternatives based on the utility or value of the purchased alternative exceeding that of the non purchased alternative. If value is expressed in monetary terms based on the NPV of the two alternatives, NPVb (binder) and NPVe (equipment), the binary logit model may be written as:

$$P(\text{new binder purchase}) = \frac{\exp(NPVb)}{\exp(NPVb) + \exp(NPVe)} \quad (1)$$

Concepts of industrial buying and prospect theory suggest additional development of the binary logit model for advanced technology applications. Qualls and Puto (1989) and Puto (1987) suggest that high-risk industrial purchasing decisions are made in a manner consistent with decision framing and prospect theory. The decision-maker frames alternatives in relation to a low risk reference that serves as the zero point for comparison of the outcomes. The alternatives (prospects) are then evaluated in terms of the gains or losses related to this reference. For a metal casting decision maker faced with the necessity of reducing emissions, the known choice is control equipment since the performance and costs of this option are known and measurable. In this context, control equipment is identified as the reference point and assigned a value of zero (i.e. NPVe = 0). This allows expression of the probability of new binder purchase in Equation (1) in terms of the perceived value of the binder alternative alone.

$$P(\text{new binder purchase}) = \frac{\exp(NPVb)}{1 + \exp(NPVb)} \quad (2)$$

Since the monetary value of a reduced emission binder is a function of both manufacturing performance and air emissions impact:

$$\text{(Monetary value of new binder)} = f(\Delta \text{ manufacturing}) + f(\Delta \text{ emissions}) \quad (3)$$

Or in net present value terms,

$$NPV_{\text{new binder}} = NPV_{\text{manufacturing}} + NPV_{\text{emission reduction}} \quad (4)$$

Specific values for Equation (4) can be developed. Product developers have access to cost models that can evaluate the manufacturing impact of advanced binder concepts. For example, Smart Economics® is the cost model of Ashland Chemical and is used as a tool for customers to evaluate the costs of current binder alternatives. On the other hand, the NPV of emission reduction must be evaluated indirectly in terms of the costs that would be incurred by the currently available approach to reduce emissions.

A recent industry survey identified fume incinerators as the emission control technology most appropriate for cast metal applications (Kauffmann, 1997). Environmental engineers and regulators utilize the Office of Air Quality Planning Standards (OAQPS) Control Cost Manual (EPA, 1991) to estimate the operating costs of incinerators. Figure 1 uses the OAQPS cost model to define the value of emission reduction in terms of the avoidance of incinerator operating costs.

The values in Figure 1 can be used in Equation (4) and (2) to develop estimates of decision - maker choice based on the emission reduction and cost impact of a new product concept. Figure 2 shows the estimates developed from Equation (2) for the probability of selection of an advanced binder based on a range of combinations of emission reduction and annual operating cost.

3 SIMULATION OF INDUSTRY DEMOGRAPHICS

The choice model has the potential to direct product development activities and identify product concepts with a high probability of selection. This step requires description of the target market in terms of process and emission characteristics that are compatible with Equation (2). Since sand and metal are the primary process materials for an iron foundry, one of these should serve as a basis to develop information for the choice model.

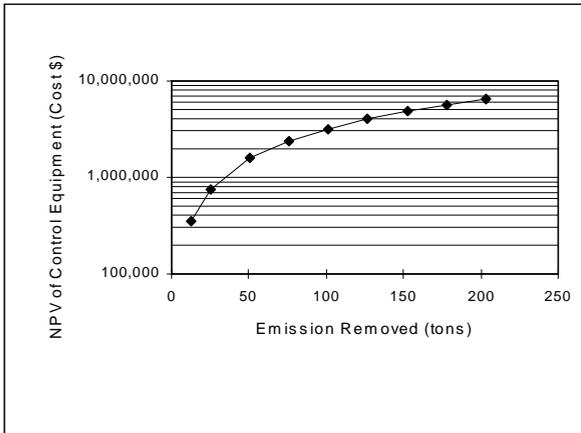


Figure 1: Monetary Value of Emission Reduction in Terms of Incineration Costs

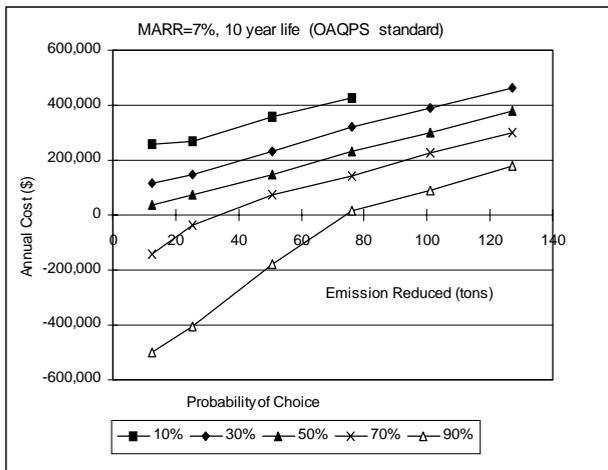


Figure 2: Probability of Selection of Reduced Emission Binder

To estimate process based air emissions, recent research indicates that rates based on tons of sand used in mold and core making are accurate predictors of volatile organic compound (VOC) emissions in metal pouring and cooling (Kauffmann, 1997). Sand throughput is also a useful index for evaluating the manufacturing cost impact of a new binder, since the binder material is mixed with sand in fixed proportions to form the molds and cores required by various part shapes. Characterizing the market leaders based on sand throughput supports modeling both emission and costs for a new binder product concept.

Unfortunately the leading foundries do not divulge detailed process or environmental data. Due to competitive and regulatory implications, this information is often considered confidential. This section demonstrates the use of discrete event simulation to develop the industry information necessary to evaluate a

hypothetical reduced emission binder using the choice model. Based on empirically derived distributions for the tons of iron processed and the associated sand to metal ratio of the products produced, simulation develops the distribution of annual sand usage. This process information can then be used with the emission rate and cost impact projections for the new product to predict the probability of commercial success. The simulation uses the following hypothetical new product scenario:

- A binder developer has identified a new concept that reduces VOC emissions. Laboratory tests indicate a reduction equivalent to 0.065 lbs. of VOCs per ton of foundry sand processed.
- A proprietary cost model (e.g. Smart Economics®) has evaluated the manufacturing cost performance of the new binder and determined the increase over current systems is \$0.10 per ton of sand.

The product developer wonders if this product has potential for market success.

3.1 Distribution Development

The choice model may provide insight to answer this question, but industry demographics are needed to support this analysis. The knowledge of field service engineers and sales representatives can be used to fill this gap and develop the distribution information for simulation modeling.

3.1.1 Tons of Iron Processed per Year

Using the expert opinion of this group, the distribution of the random variable representing the tons of iron processed per year by the industry leaders was identified as right skewed. Based on estimates for the low, high and mode (most likely) values of 50,000, 250,000, and 100,000 tons of iron per year a beta distribution with shape parameters (1.25, 3.75) was selected to represent this random variable. The appendix contains a summary of the method employed to identify these distribution values and additional references on this topic.

3.1.2 Sand to Metal Ratio

The sand to metal ratio expresses the weight of the sand in a casting compared to the weight of the metal. The amount of iron processed annually can be converted to annual sand usage by identifying the distribution of the average sand to metal ratio for the target foundries. The field engineers estimated that the target market sand to metal ratio was normally distributed with a mean of 5.5 and a standard deviation of 0.75. The method employed to develop this result is detailed in the appendix.

3.2 Simulation Target and Results

To evaluate commercial feasibility, binder researchers are primarily interested in achieving levels of cost impact and emission reduction that influence a high proportion of the target market. The simulation focused on identification of a probability of product selection that represented 70% of the target market.

Sample sets of random observations from the beta and the normal distributions (described above) were generated and multiplied to develop a distribution for the annual tons of sand processed annually by the target market.

$$\left[\begin{matrix} \text{(Beta)} \\ \text{Annual tons} \\ \text{of iron} \end{matrix} \right] \left[\begin{matrix} \text{(Normal)} \\ \text{Sand} \\ \text{to metal ratio} \end{matrix} \right] = \left[\begin{matrix} \text{Annual tons} \\ \text{of sand} \end{matrix} \right] \quad (5)$$

The developed sand distribution can be used with sand based emission rates and the proprietary cost models to evaluate the emission reduction and operating cost impact of a new product. Figure 3 and 4 demonstrate histograms characterizing one iteration of 250 random observations and using the cost and emission impact data for the hypothetical binder.

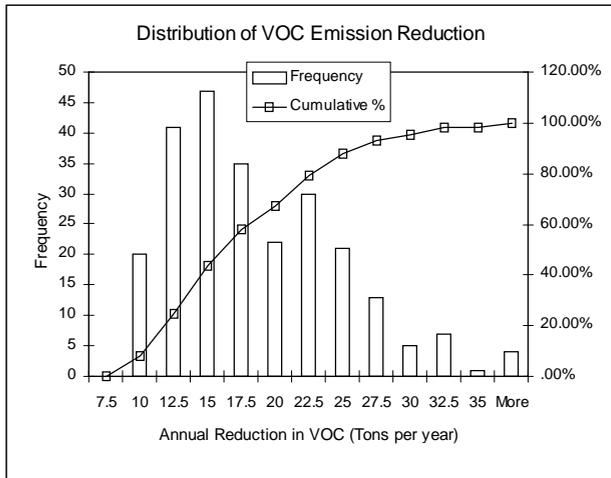


Figure 3: Simulated Distribution of Emission Reduction

To develop an estimate of the 70th percentile of emission reduction and cost impact for the new product, thirty sets of 250 observations were developed. The 70th percentiles of emission reduction and cost impact were averaged for these iterations as an estimate of the 70th percentile of emission reduction and cost impact for the target market. Based on these results, the proposed new

product reduces VOC emissions by 21 tons per year or less and increases cost by \$65,000 per year or less for 70% of the target market.

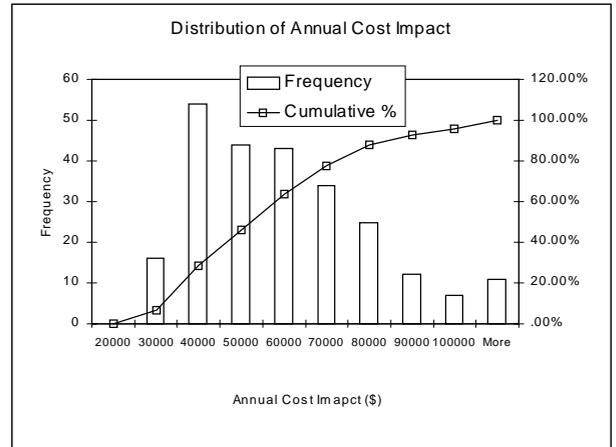


Figure 4: Annual Cost Impact of New Environmental Product

4 PRODUCT DEVELOPMENT IMPLICATIONS

The simulated 70th percentile points can be mapped into the product space (described in Figure 2) to evaluate the probability of success for the new binder under evaluation. Figure 5 describes this mapping and identifies the area that encloses 70% of the target market for the new binder. The probability of new product choice for 70% of the target market ranges between 40% and 55%

As product development progresses and more precise estimates of choice are required, this simulation method may be used to define an expected value of choice for a new product. Using more detailed market data and methods similar to this example, a joint probability distribution, $f(x, y)$, can be developed for the random variables annual emission reduction (x) and annual cost impact (y). The probability of choice as defined by equation (2) is a function of these two random variables, $g(x, y)$. The expectation of a function of random variables is defined as:

$$E[g(x, y)] = \iint g(x, y)f(x, y)dx dy \quad (6)$$

Equation (6) may be solved using graphical or numerical techniques to define an expected value for the probability of choice of a given binder concept.

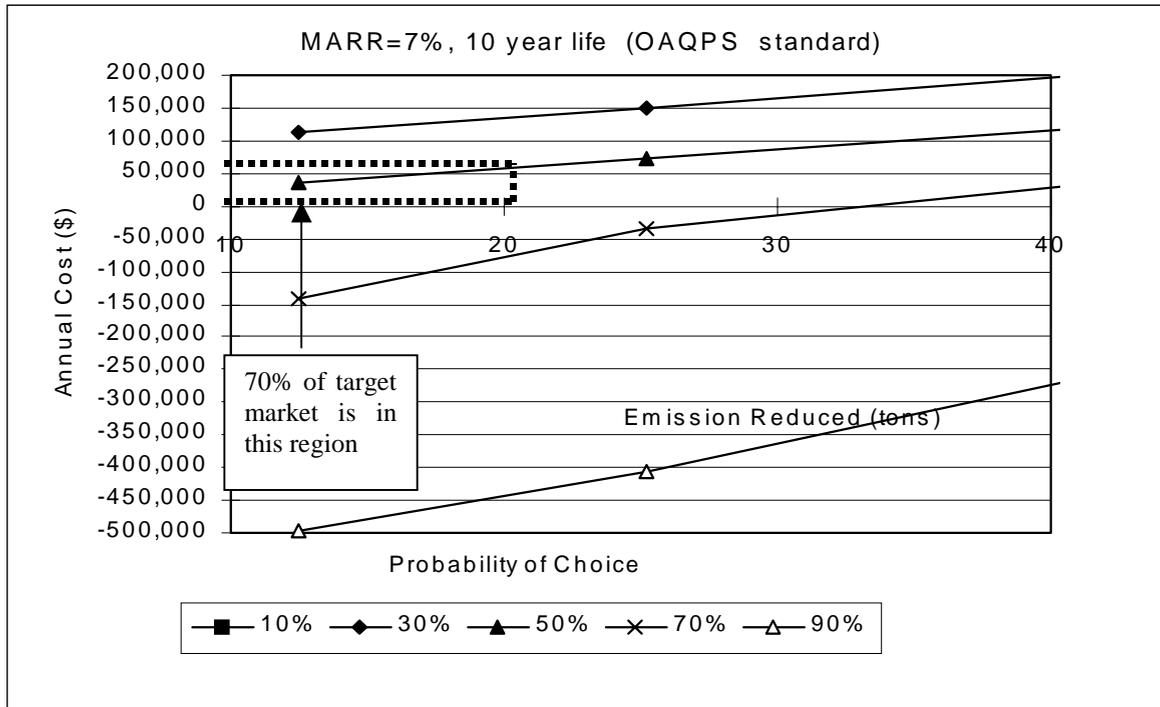


Figure 5: Product Feasibility Analysis by Choice Model and Simulated Market Characteristic

5 CONCLUSIONS

This paper has demonstrated the use of discrete event simulation to support the product development of advanced environmental technology. The approach produced results that were accepted as credible by product developers at a leading binder manufacturer. Future steps will test the model on previously unsuccessful products to refine the predictive capability.

As product life cycles diminish and research expenditures are more closely evaluated, improved analytical tools must be developed to promote effective product development decisions. Simulation is an important component in this effort.

ACKNOWLEDGEMENTS

Thanks are due to the binder manufacturer who supported this research by providing information, insight, and expert information.

APPENDIX

This appendix provides additional detail and references for the methods employed to estimate the parameters for the beta and normal distributions used to develop the simulated process information.

A.1 Beta Distribution

A common approach to determine a distribution in the absence of data is to assume a beta distribution. Based on selection of shape parameters (a, b), the beta can describe a wide range of left and right skewed conditions. This distribution also provides a model fitting method based on expert estimates of the lowest (L), highest (H), and most likely value (Mo) of the random variable (Law and Kelton, 1991). This approach begins with the expression of the mode (M) of the standardized beta (low = 0, high = 1) in terms of both the estimates and the shape parameters:

$$M = \frac{Mo - L}{H - L} = \frac{a}{a + b} \quad (A-1)$$

For the standardized beta, the expected value and variance in terms of the shape parameters are:

$$E(X) = \frac{a + 1}{a + b + 2} \quad (A-2)$$

$$Var(X) = \frac{(a + 1)(b + 1)}{(a + b + 3)(a + b + 2)^2} \quad (A-3)$$

Assuming that the standard deviation of the standardized beta is one sixth of the standardized range (high - low = 1)

and rewriting equation (A-1) as $b = (a / M) - a$, we can substitute these results into (A-3) to obtain

$$a^3 + (7M - 36M^2 + 36M^3)a^2 - 20M^2a - 24M^3 = 0 \quad (\text{A-4})$$

Using (A-1) and the estimated values (L, H, Mo) to determine M, (A-4) can be solved for distribution parameter (a). In turn (a) can be used with (A-1) to solve for the distribution parameter (b).

Greer (1970) provides a graphical approach to solve (A-4) in terms of M alone. Additional details may be found in Hillier (1971).

A.2 Normal Distribution

The distribution of the average sand to metal ratio was estimated to be distributed normally. The service engineers were asked to identify the sand to metal ratio values that defined the middle 50% of the distribution (between the lower quartile and upper quartile). This range represents 1.35 standard deviations ($2 * 0.675$ Z score). These results were used to define the mean and standard deviation of the average sand to metal ratio for the target foundries. Additional details on this approach and comments on accuracy can be found in Canada et al. (1996).

REFERENCES

- Amemiya, Takeshi. "Qualitative Response Models: A Survey." *Journal of Econometric Literature*, Vol. 19, December 1981, pp. 1483-1583.
- American Foundrymen's Society. *Foundry Industry Research Plan - 1995*, Des Plaines, IL: American Foundrymen's Society, 1995.
- Ashland Chemical. "Air Quality Concerns," Technical Bulletin, Columbus, OH: Ashland Chemical, Inc., 1993.
- Canada, John. R. William G. Sullivan, and John A. White. *Capital Investment Analysis for Engineering and Management*. Upper Saddle River, NJ: Prentice Hall, 1996.
- EPA. "Office of Air Quality Planning and Standards (OAQPS) Control Cost Manual, Fourth Edition," Report No. EPA/450/3-90/006, Research Triangle Park, NC: OAQPS - Environmental Protection Agency, Jan. 1990.
- Gensch, Dennis H. "Empirical Evidence Supporting the Use of Multiple Choice Models in Analyzing Populations," *Journal of Marketing Research*, Vol. 26, May 1987, pp. 197-207.
- Gensch, Dennis H., Nicola Arersa, and Steven P. Moore. "A Choice Modeling Market Information System That Enabled ABB to Expand Its Market Share," *Interfaces*, Vol. 20, No. 1, February 1990, pp. 6-25.
- Greer, W. R. "Capital Budgeting Analysis with the Timing of Uncertain Events." *The Accounting Review*, Vol. 45, No. 1, January 1970, pp. 103-114
- Hillier, F. S. *The Evaluation of Risky Interrelated Investments*, Amsterdam: North-Holland, 1971.
- Kauffmann, Paul J. "Economic Feasibility Model for a Reduced Emission Binder System for the Cast Metal Industry." Unpublished doctoral thesis, Industrial Engineering Department, Pennsylvania State University, 1997.
- Keeney, Ralph L., and Gary L. Lilien. "New Industrial Product Design and Evaluation Using Multiattribute Value Analysis," *Journal of Product Innovation Management*, Vol. 4, 1987, pp. 185-198.
- Law, Averill M. and W. David Kelton. *Simulation Modeling and Analysis*, New York: McGraw Hill, 1991.
- Lilien, Gary L., Philip Kotler, and K. Sridhar Moorthy. *Marketing Models*, Englewood Cliffs, NJ: Prentice Hall, 1992.
- Louviere, Jordan J. and George Woodworth. "Design and Analysis of Simulated Consumer Choice on Allocated Experiments: An Approach Based on Aggregate Data," *Journal of Marketing Research*, Vol. 20, Nov. 1983, pp. 350-367.
- McKinley, M. and A. Jefcoat. "Emission Characterization and Treatment Technologies," Des Plaines, IL: American Foundrymen's Society, 1994.
- Puto, Christopher P. "The Framing of Buying Decisions," *Journal of Consumer Research*, Vol. 14, December 1987, pp. 301-315.
- Qualls, William J. and Christopher P. Puto. "Organizational Climate and Decision Framing: An Integrated Approach to Analyzing Industrial Buying Decisions," *Journal of Marketing Research*, Vol. 26, May 1989, pp. 179-192.

AUTHOR BIOGRAPHY

PAUL KAUFFMANN is an assistant professor in the Engineering Management Department at Old Dominion University. Previously he was a plant manager and engineering director with Philip Morris, USA. He received a BSEE and MENG in mechanical engineering from Virginia Tech and Ph.D. in industrial engineering from Penn State. His research interests include operations and technology decision analysis.