International Journal of Engineering Innovation & Research
Volume 4, Issue 1, ISSN: 2277 – 5668

# Optimizing Innovation and Calamity

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***Abstract:*** **The aim of this paper is to develop a model to quantify both economic and technical processes (e.g. engineering and policy formation), in regards to safety (or crash rate) and features (innovation). Empirically a relationship may be construed from findings of risk compensation or even risk homeostasis, but these are psychological factors and applicable to individuals, not corporations. Our method is to rigorously derive a microeconomic model showing that risk changes can be explained by utility optimizing providers (businesses, governments, engineers) and consumers (users, citizens). The model terms are development, manufacturing & testing costs, utility to consumers (innovation), crash rate and defect ratio. Results show some unexpected results that may guide corporate or government planning.**

***Keywords*****: Risk Compensation, Risk Homeostasis, Unintended Consequences, Risk Analysis, Failure Rate, Product Safety, Defect Ratio, Failures in Time, Innovation, Productivity**

## I. Introduction

Some relationships between product design and manufacturing costs, product features, profitability, and eventual product reliability and crash rates are known, but many are not. Many such relationships are unexpected, and most are only empirically known. In some industries it is a great advantage to be able to ascertain ahead of time what type of failure rate will occur, as even one or a few failures may ruin the reputation of a company. For this empirical studies which have been unable to ascertain in which cases different findings apply are not useful. A more general analytical model is needed. We will review historical types of risk analysis to illustrate this.

Traditional studies of optimizing usually optimize only one parameter, or have a fixed utility weighting between the parameters. We will use an economic weighting. The term "optimization" herein means finding the equilibrium condition predicted by the model without unnecessary and company-threatening trial and error. However, different companies may wish to optimize the parameters differently, and our model does not exclude deliberate deviations, but does warn of inevitable costs.

We also draw a conclusion about the most economically cost effective way of optimizing failure rate and compare it to more heuristic methods already in use. In that way we provide further justification for these heuristic methods, which can often be neglected in favor of a mad rush to reduce time to market. Being able to quantify the impact of certain actions enables management to "optimize" in the qualitative sense their product's position in the market.

In this paper we develop a microeconomic relationship between resources spent on innovation, testing, the cost impact of failures (dysphemistically called "crashes" as in plane crash or computer crash), and the utility of the product or service to consumers. An estimation of risk or crash rate will be a principle product of this model.

We will assume that utility maximizing entities (profit in the case of companies) will innovate and produce new features and performance until the cost of innovation rises to the incremental utility from the new features or performance. Here after consider "features" to also encompass performance.

Simple examples would be the range, speed, passenger capacity and automatic operation of aircraft, or the ability to process merchant transactions easily through the internet. Supersonic passenger planes have gone out of service because the incremental cost did not cover operation nor did it cover future development. But conventional aircraft range, capacity and automation have been greatly expanded. Range can lead to more and longer flights out of radar coverage over open ocean or hostile territory. Automation can lead to pilot lack of proficiency and inability to take over in an emergency, or even to correct simple landing misalignment. Greater passenger capacity increases the loss of life in event of a crash. Lower costs lead to greater utilization and even to utilization in more marginal conditions.

Let us briefly review current methods of analyzing risks like these. There are economic, engineering, and psychological models.

*Risk analysis* uses a statistical and engineering hypothesis. It is thought to have first been used 5000 years ago to estimate the number of years supply of grain, or how large a cistern of water, needed to be stored as a hedge against drought. Civilizations stood or failed on such decisions. The cliff dwellers of the southwest U.S. and the jungle dwellers of Central America are thought to have abandoned their cities when cistern systems proved inadequate.

*Risk Management* is a more complex strategy developed by de Meer, Pascal, Fermat, Bernoulli, de Moivre and Bayes from the 17$^{th}$ century, including insurance, futures and derivatives, for example. Modern additions include that of Markowitz [1] regarding optimal portfolios.

*Risk Compensation* is generally viewed as economic in nature. Peltzman [2] argued that users of automobile safety devices may engage in "risk compensation," maximizing some other utility when risk decreases.

Wilde [3] proposed a psychological theory of *Risk Homeostasis,* a sort of risk thermostat maintained by the individual.

For a summary of data supporting or refuting these last two theories see Hedlund [4]. The general consensus is that they explain at least some of the data, but it is unclear ahead of time when such effects are going to be important. Stetzer and Hofmann [5] point out that while these two theories posit the behavior of individuals, almost all studies measure aggregate behavior, which they argue can be troublesome to compare. The plan of this paper is to posit an aggregate (usually corporate) point of decision.

Both engineers and economists tend to make assumptions that parameters outside of their usual models are "constant." For example, engineers might assume that driving style does not change in response to airbags or seatbelts. Economists have sometimes assumed employment and wages are constant when considering the impact of innovation or productivity, for example Okishio [6] writing on "Technical change and the rate of profit."

A striking example of miscalculation is given by Schindler [7] writing in 2003 on the effectiveness of fire safety blankets, largely used only in the U.S., concluding that they induce risk taking and a higher firefighter death rate. Apparently the cost and benefit of this device was estimated as if human behavior were an unalterable constant. The author's present model was developed one year earlier than Schindler's analysis and was disclosed to an engineer involved in a fire safety blanket redesign who disregarded it. Perhaps the lesson of this mistake will persuade readers to take heed.

Do corporate or government risk tendencies differ from the results garnered for individuals? CEOs have been found to tolerant more risk than the general population (Graham [8]). Nguyen [9] and Sorah [10] tie risk behavior to ultimate corporate profitability, with only Nguyen offering that the link is a rational one. It will be our supposition that companies will experience market pressure to adapt toward optimal behavior, and we presume they will change accordingly, or be reorganized by market forces.

We further suppose that governments respond to economic forces, eventually, regardless of their type. A reader of an early draft asked if citizens really act sufficiently on objections to taxes (the costs they are paying for the service-product of government). King John was forced to agree to the Magna Charta by 25 barons who felt greatly over taxed. The Arab Spring was started because a street vendor in Tunisia was unable to make ends meet, as he had been hassled by the police to pay too many fees and fines. He said "I just want to work" and set himself on fire. Numerous governments, many that had nearly totalitarian, were changed.

## II. Approach

The approach will be to develop an economic model for corporate and user behavior based on competition, and a microeconomic relationship between innovation and operational failure rate. That relationship has been little studied. However, if users respond to an increase in the safety or reliability of a product or service by adjusting their usage such that the aggregate safety changes, then would we not suppose that they might respond to some other feature in a similar way? In an economic model, where all features and also reliability are modeled in economic terms, then once given an economic weight, we would suppose a similar response from users. In this way, innovation becomes related to aggregate failure rates.

Aggregate failure rates are directly related to aggregate corporate or social costs, and independent of whether failures are per mile, per hour, per transaction, etc. A general model is developed, independent of a particular technology or application.

This is not an empirical study. The author would certainly like to see an empirical study done, but it is likely to be expensive and difficult.

Finally, the results will be only statistically valid. The personalities of managers and developers and customers may dominate particular cases. Over time economic forces should move results in the direction the model indicates.

## III. Model

At each operating point, for small changes in product features, production process, and usage, it should be valid to approximate the relationships as incrementally linear. Most data-oriented studies suppose only one such relationship, and attempt to discover if it is true. Our methodology will allow a more complex relationship to be developed, which has greater possible explanatory power, but which is perhaps more difficult to verify with data.

### *A. Cost of change axiom*

We assume that corporations will add features or make other changes or introduce product lines, which we will call "features," until there is no *incremental* profit from doing so. For a governmental model, we can assume that nations add regulations, stimuli and incentives intended to promote economic activity until various measures of economic activity decline instead of rise, such as total output, rate of growth of output, total employment, or even average wages. This assumption recognizes that governmental policy is not immune to the same sort of economic forces that drive corporations. In fact a government's ability to take any effective action, including waging war, is dependent on its economic prowess, or upon having allies with economic prowess, so if the boundary is drawn large enough to encompass resource suppliers, the entity behaves economically.

We assume that if consumers are willing to pay more than the cost of design, test, production, marketing and distribution, the products (features) will be produced. Similarly citizens must be willing to pay taxes associated with regulations or incentives, and will sustain the positive or negative economic impacts. It is of no concern to the model whether this happens quickly via the shrewd choices of managers, market analysts and politicians, or slowly via random experimentation with products and policies. The eventual equilibrium is assumed. This is an equilibrium model. All factors of consumer utility (what consumers or citizens are willing to pay), and all direct costs are subsumed in the term $P_f$ which is profit from the features. $P_f$ provides the incremental incentive to add features or otherwise make changes that benefit the corporation or nation. We do not dwell on how "profit" might be defined for nations in this paper but leave that to other investigators. Suffice it to give simple examples, such as the increased economic activity due to policy or regulation or incentive minus the costs of implementing those policies. One might even take aggregate corporate profit in the national markets, or more fairly profit plus wages to include benefits to all citizens. So we may speak of "national profit" in this way.

One term is taken separately, which is the aggregate cost of the operational crash rate of the product, $C_R$. This is the revenue lost due to a specific crash rate. In the case of national markets, it is the economic loss by some measure (wages or GNP for example, or even corporate profits). It may be lost due to customers choosing other products, getting bogged down and not being able to buy more product, or imposed costs such as fines, penalties and lawsuit losses. It includes only the costs that the corporation or nation eventually bears in some form, not costs that society bears (in the case of corporations) or that other nations bear (for example certain costs of war, trade or global environment destruction). As to what specifically constitutes a "crash," this is the analyst's choice. Whatever risk the analyst wishes to evaluate is designated as a "crash" and its costs are subsumed in $C_R$.

Profit and crash rate cost are treated as aggregates over any convenient time interval, such as a product life cycle, or annually. The cost of change axiom in these terms is stated as

$$P_f - C_R = 0 \quad (1)$$

The cost of change axiom is inspired by, but not necessarily identical to, the concept of a balance between marginal utility and marginal cost, which is well known in the literature going back to Adam Smith or beyond, and usually stated from the consumer point of view. This axiom does not care what the features are or what consumer preferences are. It does not assume whether the features are safety related or not. Nor does it assume any relation between the features and increased or decreased profits. Those assumptions will come in later axioms.

Safety itself can of course be considered a feature which consumers may be willing to pay for. There is something similar to our axiom in the narrow context of safety in the literature. The marginal utility of safety was noted by Spence [11] (via Savage [12]). Consumer willingness to pay for a marginal increase in safety is equal to the marginal cost of supplying that safety (safety may be thought of as the inverse of the crash rate). The cost of change axiom posits this from the point of view of costs to the producer of the safety (costs being the negative of utility), and isolates that cost from all the other costs to the producer. But it is really a consequence of the principle of marginal utility, and is adopted as axiomatic. Our axiom applies to all features, not just safety features.

### *B. Development Crash Rate Approximation*

For our purposes, a crash is some kind of *failure* or calamity of interest, and crash rate may be taken to be equivalent to the usual metric of *failures in time (FIT)* used in reliability theory. Failures in time can be taken reciprocally as *mean time between failure (MTBF)*, useful when estimating the number of hours that equipment can be reliably counted upon to operate. For cost and impact purposes, the FIT concept, which we call crash rate, is convenient.

It is traditional (and often required by regulation, not to mention sound engineering practice) to collect information during the development process to estimate operational failure rates. Products, systems or equipment are evaluated during the design phase by analysis. Problems are found and corrected. In a federal system, often laws on automobile safety, retirement and health insurance and the like are first implemented in a few states, which may be taken as the national counterpart of the product development cycle.

Some types of products, such as software, involve failures almost entirely of the design flaw type, but are so complex that not all design flaws can be found and removed from finished products. Laws or regulations are essentially "software" and share this characteristic. In either the case of latent design flaws, or materials reliability, the development, testing and certification processes provide indications of the eventual product reliability. For this reason, we wish to have an explicit term for development failures (development crashes) in our model. This term will consider the cost of the development crash rate, i.e. the cost of finding and fixing failures during development, testing and certification, or partial or trial roll-outs of policy or law.

Much effort in all technology fields goes into tools, processes and procedures designed to make things easier to design, which usually makes it easier to find and fix design flaws. The fields of system engineering and project management make a specialty of identifying problems early to reduce the cost of finding and fixing problems. Likewise reliability engineering attempts to reduce such costs during development, and prevent problems from occurring in the first place. It is a fair statement, then, that most techniques which reduce the cost of developing features also aim to improve the development process and will reduce the development crash rate.

We can approximately linearize the relationship between the development cost of features and the development crash rate as discussed earlier, and for this purpose we invent an arbitrary constant of proportionality, $K_1$, which relates the incremental cost of the features to the development crash rate:

$$D\,cost(features) = K_1 * crashrate(development)$$
$$\hat{U}\ K_1 = D\,cost(features) / crashrate(development)$$

It is apparent that $K_1$ is the "cost of development crashes," for which we will adopt the symbol $C_d$. To arrive at the total cost of the features, we must add manufacturing, marketing, distribution and other costs which we will designate as $M$, and we assume they accrue over the product life cycle. Using $C_f$ as the marginal cost of the features, and $R_d$ as the marginal development crash rate, we can state:

$$C_f \approx C_d R_d + M$$

For national entities $M$ will be the ongoing cost of a bureaucracy, and $C_d$ the cost of investigative boards and enforcement. It will be useful to rewrite this relation as the *development crash rate approximation* giving:

$$R_d \approx (C_f - M) / C_d \qquad (2)$$

### C. Operational crash rate approximation

The post-deployment failure rate is often found to be related to developmental failure rate by what is called the defect ratio. In the case of conventional reliability measures, this can be the ratio of defects in the field to defects in a pre-deployment screening process. In the case of complex technology or software products, an analogous quantity is sometimes called defect leakage, i.e. the ratio of defects which "leak" through the testing and certification process. We adopt $R_o$ as the operational crash rate, and use $D$ for the defect (or defect leakage) ratio, and assume that a marginal (incremental) relation between development and operational crash rate can be approximated as follows:

$$R_o \approx DR_d \qquad (3)$$

Substituting the development crash rate approximation (2) into the operational crash rate approximation (3) we have:

$$R_o \approx (C_f - M) D / C_d$$
$$\Leftrightarrow C_f \approx R_o \frac{C_d}{D} + M \qquad (4)$$

With (4) we now have elucidated an indirect relation between the cost of the features, and the eventual operational crash rate. This relation is enforced by our assumption of eventual equilibrium, and of course will not hold in the transient case as companies make unprofitable "mistakes" in product development, but eventually it will hold, either because corporate managers and engineers are smart enough or lucky enough to find it, or because their competition finds it and supersedes them.

### D. Profit axiom

We now introduce the economic utility to customers or citizens of the product or policy with the specified added or improved features as a fundamental measure which we equate to what they will pay, and therefore to the revenue the producer realizes. We can measure this revenue, denoted $V_f$, per life cycle, per annum, or in whatever way is convenient, as long as it is consistent with the other terms in our model. Using our model of costs (4) we can express the profit derived from this revenue stream as:

$$P_f = V_f - C_f \approx V_f - R_o \frac{C_d}{D} - M \qquad (5)$$

We do *NOT* assume of course that nations maximize profit of an individual corporation. This may cause some confusion. Corporations maximize their own profit. And nations optimize the collective profit of the nation, as previously discussed.

The revenue on a national scale would be something like gross receipts, or total value of economic activity, again a matter for analysts to choose. The model is general. While it is desirable to know the value of all components of the model, it is not even necessary. We might not know defect ratio, for example. Then we could not make quantitative predictions about how additional testing would affect the results, only qualitative. But we could still draw conclusions about how innovation was affecting risks.

### E. The crash rate model

Using (1) to substitute the equilibrium incremental crash rate costs for profits in(5), and solving for crash rate, we have:

$$C_R \approx V_f - R_o \frac{C_d}{D} - M$$
$$\Leftrightarrow R_o \approx (V_f - M - C_R) \frac{D}{C_d} \qquad (6)$$

We can further express crash rate costs in terms of crash rate by defining a new term, average cost per crash $C_c$, such that $C_R = C_c R_o$. Using this in (6) and again solving for crash rate we have:

$$R_o \approx (V_f - M - C_c R_o) \frac{D}{C_d}$$
$$\Leftrightarrow R_o (1 + \frac{C_c D}{C_d}) \approx (V_f - M) \frac{D}{C_d} \qquad (7)$$
$$\Leftrightarrow R_o \approx \frac{V_f - M}{C_c + C_d / D}$$

The equation (7) is the essence of the model and we call it the crash rate equation. A consolidated reminder of term definitions is provided in Table 1. The remainder of this paper will analyze the characteristics and implications of the crash rate equation, discuss whether it seems to fit known examples from industry experience, and compare to paradigms such as Six Sigma.

Table 1: Terms used in the crash rate model

| | |
|---|---|
| $R_o$ | operational crash rate |
| $V_f$ | value of the features (or function) per unit |
| $M$ | cost of manufacturing, marketing, distribution |
| $C_d$ | (engineering) costs per development problem |
| $D$ | defect ratio |
| $C_c$ | cost per crash |

## IV. Interpretation

Figure 1 shows equation (7) annotated to reflect the effects of the various parameters. On the left is the operational crash rate. Neglecting manufacturing, development and test costs we see that the operational crash rate would be a simple ratio of the value of the product (or features) to the average cost of crashes or calamities. This subset of the equation could be applied to either corporations-governments or customers-citizens.

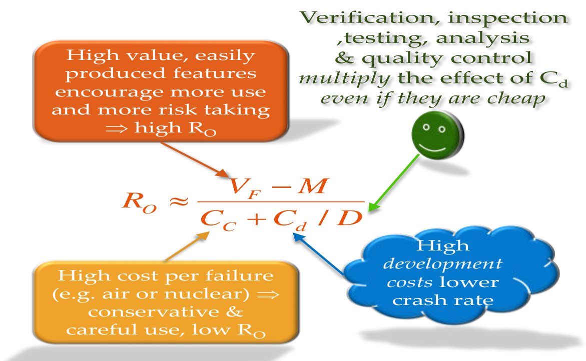


Fig. 1: Interpretation of crash rate model

The remaining three parameters apply only to provider entities, corporations or governments. First we see that manufacturing (or monitoring-enforcement) costs are in the numerator and are negative. The numerator is the incremental profit to the entity after design (or policy formulation) and development (implementation) costs are recouped. We do not expressly address marketing, but it could be lumped with manufacturing for this purpose. What we see from the numerator is simply that if manufacturing costs are high, the entity cannot afford to bear a high crash rate liability.

In the denominator we see that development costs add to crash costs. This also tends to lower crash rate, but like manufacturing, it lowers profits (utility) at the same time.

Finally we see that the defect ratio is in the denominator of a denominator term. Defect ratio effectively leverages the development costs in terms of reducing overall crash rate. A very low defect ratio is highly desirable. On the other hand, achieving a low defect ratio is only additive, either to development or manufacturing costs depending on the type of product (or policy) and the steps taken to achieve the low ratio. This suggests defect ratio is a promising lever to influence overall crash rate without sacrificing utility (profitability or benefits).

Notice that a high defect ratio (undesirable) is comparable to a high rate of "policy mistakes" as nations evolve their policies. Thrashing around in the policy area prevents the use of the best tool (low defect ratio) for improving stability and reliability without compromising benefits. For example, consider the stability of markets generally. Our analysis suggests that we might ensure market stability by having a lot of oversight (M) and a correspondingly low economic growth rate (which we presume is fueled by profit). But more beneficially we might have minimal oversight and high economic growth with the crash rate moderated by a very low defect ratio – which essentially means getting policy right the first time. Few nations do.

## V. Categories and Examples

In the following we examine two types of industries to see if the crash rate model corresponds to experience.

For *commodities*, with certain exceptions, production and marketing costs $M$ approach the market value $V_f$. A commodity is usually producible without esoteric technology or risks. Rarely do we hear of people dying from bad rice, wheat or coffee.

In general for commodities the small numerator implied by $M \rightarrow V_f$ implies a low crash rate. The cost per crash $C_c$ for a commodity, if there is one, is often enormous, and this term occurs in the denominator. Consider what would happen if people were dying from bad rice. The effects of holding Asbestos producers liable may be viewed as an extremely large crash that effectively removed asbestos as a commodity or a viable product of any sort. Crashes of the magnitude of the BP Gulf spill or earthquakes from fracking will act as a definite risk deterrent. Imagine if producers were held responsible for climate change!

*Software* which is widely distributed on the internet and developed by open source organizations is essentially free. So both $M$ and $C_c$ are reduced. This suggests the crash rate for software and technology will be enormous, and it is. For software that must handle financial or life critical functions, costs are enormously greater and the crash rate lower.

Software has provided a crucible of evolution from which the experience of many projects teaches lessons that would take eons to learn in other fields. If the cost per defect during development $C_d$ increases, the denominator increases and operational crash rate decreases. If the testing process is very thorough, resulting in a low defect rate $D$, the term $C_d/D$ increases and again crash rate is lowered. In other words, testing expenses have a highly leveraged effect in reducing crash rate.

However if a company engages in "process improvement" and invests in new development technology that reduces the cost $C_d$ of finding and fixing bugs during development, and other factors are constant, then operational crash rate could actually increase. To remedy this problem, the company would have to test to a lower defect ratio than previously, thus doing more testing, which still might cost less. But to lower engineering costs and test only to the same level as before should lead to a higher crash rate.

## VI. Comparison to "Six Sigma"

The origin and nature of the term "six sigma" is almost lost, along with the memory of the dramatic effect it had on the transfer of manufacturing from American to Japanese companies, and the global transfer of wealth to Japan. Popular Six Sigma associations and websites (Six Sigma Online [13], iSix Sigma [14], Process Quality Associates [15]) give histories that begin with Motorola in the late 1980s. This was actually *after* a dramatic transfer of industrial might to Japan, especially in the auto industry, that prompted President Regan to forcefully negotiate a revaluation of currency exchange rates with Japan, and his anti-regulation administration passed sufficient tariffs to force most Japanese auto manufacturers to open plants in the United States. While this was going on, American auto manufactures were still engaged in "planned obsolescence."

Only in one of the three histories above do we learn from a brief anecdote about Japan that in 1970 they acquired a Motorola television factory and decreased the defect rate to 5% of the previous value. And Motorola brags about taking 17 years to learn from this? The author owned 3 Motorola RAZR phones in a 14 month period, all of which broke, not counting one which was delivered broken. The lesson forgotten, Motorola Mobility was sold to Google and then to the Chinese company Lenovo. No one could fix the culture of features over quality, and in retrospect the matchup with feature-innovator Google was doomed from the start on this account. Google's Android phones were not considered as feature rich as iPhones, but were produced by quality-focused Asian companies HTC and Samsung. The author has owned a steel-cased HTC phone for more than 3 years, dropped it several times and even left it in his pocket to be laundered in the wash, and it still works fine.

The Japanese were heavily influenced following WWII by the American engineer Deming, who did not take the dry statistical approach that is attributed to Six Sigma in the post-1987 American academic and industrial literature. He didn't even use the term six sigma. He emphasized philosophical viewpoints represented by highly abstract equations (Akpose [16]) not unlike those of our model, such as:

*Quality = (Results of work efforts) / (Total costs)*

When people focus on quality, Deming said, quality tends to increase and costs fall over time. When people focus on costs, costs increase and quality declines over time. The author has witnessed 40 years of the steady creep of "full cost accounting" in both government and industry over his career, with exactly the results that Deming predicted [the author's qualitative impression].

It is counter-intuitive that costs should fall when one focuses on quality. Surely there are some limits to such a notion? While this is well outside our current scope, if we compare Deming's assertion to the prediction of our model that spending money to test to a lower defect rate (higher quality) highly leverages the funds expended and lowers failure or "crash" costs, the prediction does not seem so farfetched.

## VII. Application to Markets and Nations

Making national government or economic processes more efficient, without requiring better policy or superior reliability at the same time, could according to our model lead to market or political instability and calamity. This is unexpected.

National items which might be compared to innovation or efficiency include productivity, rates of economic growth, and the equity premium [17]. Productivity has been increasing steadily for over a century, at least in western nations. The difference between interest rates and business returns (the equity premium, approximately) might be considered as the "efficiency" of finance. Either of these could have unexpected consequences on stability. Low interest rates clearly contributed to a housing bubble in 2006-9. Monetary policy has struggled since ancient times with the problem that success leads often to bubbles and failure. Might we be overlooking suitable analogies of "test and verification" in the political and economic arena that could bring down our policy defect ratio (including lending policies of banks, and other business policies, not just government policy) without restraining us to perpetually low economic growth?

An interesting explanation of the equity premium has appeared [18] in which, among other factors, perpetually low interest rates must be artificially enforced by monetary agents to avoid productivity-induced deflation. If such is true, the policy of applying perpetually low rates and avoiding bubbles would have to be practically perfect, with a very low defect ratio.

## VIII. Conclusion

A model has been developed that relates development process parameters to operationally deployed crash rate. This model operates at a corporate or national level, and provides insight into what kinds of changes might affect product or policy reliability, safety and effectiveness. Efficiency improvements and feature development are often culprits in unexpected outcome. Testing adds to costs, but has a predictable positive and even leveraged outcome. When governments or economies become more efficient, they must also be held to a higher standard in order to avoid increasing prospects for instability.

In future work, the author will analyze a hypothetical case study showing how to recover from missed test objectives and deliver on original program goals. Purely financial analysis of late phase project difficulties will often produce cuts to operational usage rates, costs and testing resulting in higher profit margins on a scaled back operation, but higher crash rates. A crash rate analysis may instead suggest increased testing, and changes (e.g. lower profit margins) to increase usage, recouping the costs over greater volume with a lower crash rate.

## Acknowledgements

This work was supported by the NASA Johnson Space Center.

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