A Quantitative Model of Corporate Risk Compensation

Robert L. Shuler, Jr.

*Johnson Space Center, NASA, Houston, USA*

Email: robert.l.shuler@nasa.gov        Alt: Robert@InertiaFirst.com

Phone: 281-413-7713 (cell)

Fax: 281-483-3419

Address: 2101 NASA Parkway, mail code EV5, Houston, TX 77058

Mr. Shuler works at NASA’s Johnson Space Center where he has developed both technology and processes for reliable operations, fault tolerance and certification of critical systems in space environments. He holds 5 patents and has authored numerous papers in the areas of radiation tolerance, automated coding, fault-tolerant real-time systems, and quantum inertia and gravity. He has managed a large systems integration and test facility. Mr. Shuler has received numerous awards including the NASA Exceptional Achievement Medal, and the Director’s Innovation Award. Current interests include the sociology and economics of reliable systems and the equity premium.

July 2013
A Quantitative Model of Corporate Risk Compensation

While risk compensation is well known, there are few quantitative models other than risk homeostasis, and virtually no models incorporate the effect of innovation on failure rates. A quantitative micro-economic model is developed in which corporate actors are assumed to be maximizing profit, or pressured by competition from those that do. By various assumptions, government and end user actors can be included. The model provides insight, sometimes unexpected, into what conditions cause changes in failure rates, higher or lower, and also into why paradigms such as risk compensation may dominate at certain times and not at others. The model also provides additional options for risk management for government entities that are barred from using insurance and futures markets.

Keywords: risk compensation; risk homeostasis; unintended consequences; risk analysis; failure rate; product safety; defect ratio; failures in time; innovation

Introduction

Regimes of unintended consequences are well known. These arise from various causes and interactions. For this investigation a focus on economic causes is adopted, together with attention to a failure rate of some system or product in operational use. The failures may or may not entail a safety hazard, but the case of a safety hazard is of particular interest.

There are four categories or phases of human investigation into uncertainty and risk. *Risk analysis* is based on a statistical and engineering hypothesis and is approximately 5000 years old, that we know of, brought about by the necessity of estimating how many years supply of grain should be stored as a hedge against drought.

*Risk Management* is based on a management hypothesis, i.e. a call to more complex action that just drought hedging, and was pioneered by de Meer, Pascal, Fermat, Bernoulli, de Moivre and Bayes from the 17th century. Its tools include insurance, futures and derivatives, for example, the pre-sale of farm crops. There have been many
important modern additions, particularly that of Markowitz [1952] regarding the optimal selection of portfolios. In general the concept of portfolio diversification is similar to redundancy. Both can be tools of risk management. Diversification of suppliers was often used in the early days of high risk aircraft and spacecraft development. It has since fallen out of favor with public funders, but is being used today for the NASA Commercial Crew and Cargo program where some private funds are available. The tools of insurance and futures are also not generally available to publically funded activities in the U.S.

*Risk Compensation* is based on an economic hypothesis. Peltzman [1975] put forward an argument that users of products or systems (such as automobile safety devices) may engage in “risk compensation,” maximizing some other utility when risk decreases, so that overall risk does not diminish from the use of safety devices as much as expected, if at all. The result of this is that, for example, the reduction in automobile fatalities from wearing seat belts might be only a fraction of what engineering tests show that it should be.

Wilde [1982] argues for a stronger theory of *Risk Homeostasis* in which compensation is more of psychological than economic origin, and an exact quota of risk is maintained in the individual by a sort of risk thermostat.

The literature abounds with studies that both support and refute each of the latter two theories. For a good summary see Hedlund [2000]. 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. Researchers consider factors such as whether the measures require user action (seat belts) or not (air bags), whether they provide some feel of increased safety or performance (anti-lock brakes), or whether the user may be possibly unaware of the presence of safety measures (side impact resistant reinforcements).
Stetzer and Hofmann [1996] 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. The method of arriving at that decision will be treated separately. It may be deliberate in consideration of economic or moral factors, or it may be evolutionary in that entities which make the most market-effective decisions come to control more resources naturally. Viscusi [2000] has pointed out that consciously making product risk decisions at a corporate level may be detrimental in and of itself, since jurors award punitive damages in injury cases perversely in proportion to the amount of analysis and value of life used in corporate analysis. Nevertheless, general reliability analyses are bound to be made, and corporate culture and policy will result in de facto decisions.

The general plan of the work will be to develop a microeconomic relationship between development, test and operational phases; discuss how market, economic and societal decisions interact with the model; and examine how the model might explain well known organizational behavior.

The details of risk analysis during the *development* phase often fall to *engineering* groups, particularly system engineering, or if it is primarily a software project then software engineering. The author searched and could not find journal articles in the field of system engineering which mention either risk compensation or risk homeostasis. Most of the theoretical work on risk compensation is published in various economics and safety journals, and risk homeostasis was introduced in risk and psychology journals. Each discipline has its own practitioners and preferred viewpoints and approaches.
It is not clear, for example, that system engineers are likely to encounter papers in economics journals, however related to system engineering they may be, nor that they would be impressed by the arguments used, such as the psychology of risk homeostasis. Economists, on the other hand, find such arguments not even particularly novel, since one of the central tenets of economics – modern portfolio theory – takes as its goal that investors wish to maximize return at a given fixed level of risk. That sounds a lot like what is taken as a postulate to be tested in risk homeostasis theory. And to an engineer it may sound like a superstition to be refuted. In engineering there is a psychological motivation to believe that the tools of engineering work, i.e. that improving the reliability or operability of a system has real benefit and is not optimized away on a whim. Thus the domain of the engineer is reliability theory, which examines the failures due to the physical characteristics of a system, its environment, and usage.

The data papers examining these theories frequently appear in safety journals. This data is rarely able to distinguish why an effect occurred, but most results confirm some degree of risk compensation, for some reason. And some of the data is surprising and striking and counter-intuitive. An engineer at the author’s institution was involved in a project to improve fire safety blankets in 2002, and when asked about possible risk compensation effects he reacted with understandable disbelief. But the very next year Schindler [2003] reported that effective fire safety blankets, largely used only in the U.S., induce risk taking and a higher firefighter death rate. It is common for engineers, and even some economists to calculate costs and benefits of safety measures as if usage and human behavior were an unalterable constant, for example Katarelos [2008] develops a $\Delta$cost/$\Delta$risk model for shipping and also applies it to air transportation. There is no $\Delta$behavior in his model. But in general data suggests that usage patterns change when risk changes.
The temptation for an engineer to try and develop a quantitative model of such consistent and sometimes dramatic effects is strong. At least some of the data suggests a relation to economic cost models. Parry [2004] holds that tax costs can reduce traffic accidents. Cummins [1999] and Cohen [2003] report that no fault insurance and mandatory insurance induce unsafe driving. The data are not uniform, and a model might provide advance insight into which types of safety or reliability improvements are more effective when deployed. For example, Carlsson [2004] asks if safety is more valuable in the air, since we seem to pay more for it there. Levitt [2001] reports that when sample selection is accounted for, the cost per life saved for air bags is 60 times greater than for seat belts.

While much of the data and theory focuses on the behavior of individual users or groups of individuals, corporations determine much of the risk landscape from which users choose. Corporate behavior, closely coupled to profits and losses, may be more amenable to an economic model than user behavior. The approach we will take is to form an economic model for both corporate and user behavior based on competition, and to analyze how user behavior might deviate when users are not working or competing.

The relation between innovation and operational failure rate has been little studied. Searches for papers relating to innovation and risk reveal much focus on managing the development risk of innovation, but not the operational risk. Searches relating to innovation and safety turn up many studies of innovation for the sake of safety, or innovative safety measures, like for example the fire safety blankets discussed above, but no study of how innovation generally affects safety or failure rates. Yet that there is such a relationship is well known anecdotally. For example, many computer users habitually avoid “release 1.0” of anything, assuming the bugs have not been
worked out. However, in the longer term it is generally assumed that once mature, innovative technologies will provide more reliable operational service. Few would disagree that transportation and communication, for example, are more reliable than 100 or 1000 years ago.

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 the narrow theory of risk homeostasis, where risk is supposed to be the controlling parameter, maybe they would not. But 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 in the broad sense becomes entangled with aggregate failure rates.

Why do we specify aggregate failure rates? We do so because this is directly related to aggregate corporate or social costs. Such a model is independent of whether failures are per mile, per hour, per transaction, etc. A general model can be developed, independent of the unique characteristics of a particular technology or application.

The Theory

Use of linear approximations

The relations we seek are likely to be non-linear and perhaps highly complex. However, 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. This is true provided the relationships do not have extreme sensitivities to small changes, i.e. discontinuities. This will generally involve assuming an incrementally linear relationship, supposing a constant of proportionality, and giving that constant a
descriptive name. However, when the operating point changes significantly, the “constants” are no longer constant. 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.

**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. 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. It is of no concern whether this happens quickly via the shrewd choices of managers and market analysts, or slowly via random experimentation with products. The eventual equilibrium is assumed. All factors of consumer utility (what consumers 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.

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. 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 eventually bears in some form, not costs that society bears.

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
\[ P_f - C_r = 0 \]  

(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. The marginal utility of safety was noted by Spence [1975, via Savage 1999]. 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.

**Development Crash Rate Approximation**

We have not yet defined crash rate, specifically “crash.” Any consistent definition can be used, as long as it is not so qualitative that it cannot be measured. For example, a computer crash is easy to define. The computer stops working and has to be re-booted. The same definition can be applied to a specific software program. Or one can set a threshold of interest. For automobiles, a dollar value of damage can be set as a threshold, or loss of life, etc. For aircraft, unplanned or uncontrolled contact with the ground will usually suffice, literally a “crash.” So for our purposes, a crash is some kind of failure 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 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. Prototypes are built and tested, and fixes are developed for unacceptable failures, whether design flaws or issues of reliability and fatigue. 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. 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. Since we have an economic model, to predict crash rates, this term will need to consider the cost of the development crash rate, i.e. the cost of finding and fixing failures during development, testing and certification. These are significant costs. For example, the costs of certifying automobiles for the U.S. market keep some overseas manufacturers from selling cars in the U.S. The cost of certifying airplanes is also very high. For products which are software, or firmware, which account for a large share of all technology products, it can be argued that initial design is very easy and most of the costs are for debugging. Certainly testing is a large fraction of the cost of spaceflight equipment and vehicles. It can cost hundreds of thousands of dollars, for example, to certify an inexpensive battery for use in space.

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.

The actual relationship between the development cost of features, and the development crash rate, may be complex and non-linear. But given an operating point, a certain level of features and tools, and assuming the relationship is approximately continuous, we can linearize the relationship as discussed earlier. For this purpose we invent an arbitrary constant of proportionality, $K_f$, which relates the incremental cost of the features to the development crash rate:

$$\Delta \cos t(features) = K_f \times \text{crashrate}(development)$$

$$\iff K_f = \Delta \cos t(features) / \text{crashrate}(development)$$

It is apparent that $K_f$ 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:

$$C_f \approx C_d R_d + M$$

It will be useful to rewrite this relation as the development crash rate approximation giving:

$$R_d \approx (C_f - M) / C_d$$  \hspace{1cm} (2)$$

**Operational crash rate approximation**

The post-deployment failure rate is often found to be related to the 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. Because of complexity and the randomness of use, these show up over time as the product encounters ever varied conditions of use and/or the environment and technology around it changes. 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:

$$R_o \approx DR_d$$

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

$$R_o \approx (C_f - M)D / C_d$$

$$\iff C_f \approx R_o \frac{C_d}{D} + M$$

(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.

**Profit axiom**

We now introduce the economic utility to customers of the product 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 from the sale of the product. 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:

$$P_f = V_f - C_f \approx V_f - R_o \frac{C_d}{D} - M$$

(5)

**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:

$$C_R \approx V_f - R_o \frac{C_d}{D} - M$$

$$\iff R_o \approx (V_f - M - C_R) \frac{D}{C_d}$$

(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:

$$R_o \approx (V_f - M - C_c R_o) \frac{D}{C_d}$$

$$\iff R_o \approx (1 + \frac{C_c D}{C_d}) \approx (V_f - M) \frac{D}{C_d}$$

$$\iff R_o \approx \frac{V_f - M}{C_c + C_d / D}$$

(7)

A consolidated reminder of the definitions of terms is provided in Table 1.
\[ R_o \] operational crash rate

\[ V_f \] value of the features (or function) per unit time

\[ M \] cost of manufacturing, marketing, distribution per unit time

\[ C_d \] (engineering) costs per development problem

\[ D \] defect ratio

\[ C_c \] cost per crash

Table 1: Terms used in the crash rate model

**Analysis**

While keeping in mind that equation (7) is an incremental relation between marginal costs and rates, not absolute costs and rates, we can nonetheless draw many interesting conclusions. This is especially true for cases where one term or another clearly dominates. We will now look at several categories of products to see if experiences are consistent with the model.

**Commodities**

For commodities, with certain exceptions, production and marketing costs \( M \) approach the market value \( V_f \). This is the essence of a commodity. It is both universally needed, and able to be produced, without esoteric technology or risks. Reports of people dying from consumption of bad rice or wheat are extremely rare. Sugar and salt have health effects when consumed in excess, but producers are not held liable so those costs do not enter the crash rate model. Asbestos ceased to be a commodity after producers were held liable. In general, the small numerator implied by \( M \rightarrow V_f \) implies a low crash rate.

The cost per crash \( C_c \) for a commodity is often enormous. This also keeps crash rate low, since the term occurs in the denominator. A good example is the energy
industry. Energy (e.g. oil) can produce massively damaging spills and violent community-impacting explosions. We do not yet know if the world will succumb to global warming, but even if it does the crash rate will be extremely low, i.e. $R_o \approx 1/\text{ever}$ crash in all of history. Such a low rate of course violates the statistical equilibrium of our derivation.

**Technology and software**

At the current time, 100,000 transistors cost about as much to make as a single grain of rice. 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. Who has not dealt with dropped calls and a computer that has to be constantly re-booted?

For software that must handle financial or life critical functions, costs are enormously greater. Software productivity for manned spacecraft control can be as low as one source line of code (SLOC) per day, fully verified. Productivity can be hundreds of times higher for non-critical applications. So the crash rate model is quite consistent with our general shared social experience with technology.

However, in the denominator is one surprise, the ratio $C_d/D$. The surprise is not in the ratio itself, but in our use of it. If the cost per defect during development $C_d$ increases, the denominator increases and operational crash rate decreases. In other words, testing expenditures can decrease crash rate. 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.

However, according to the model, 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 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.

For example, many people wonder how a large and very capable software company can produce version after version of its flagship product, claiming each time it has fixed stability problems. And yet users find stability problems remain and in some cases increase. Software development has a long history of improvement in the process of creating and debugging software. Hand coding gave way to assemblers, then compilers, on-line editing and debugging, structured programming, object oriented programming (OOP), application programming interfaces (APIs), and so forth. Each advance in software or hardware led to an array of new features which increased usage of software systems to the point where now most people have several computers, and use their phone as a computer. What used to require a command line interface with a precise protocol is now done by vague flicks of the finger or thumb across a touch screen. The software must handle and interpret input from any screen object at any time, not just the next valid command. Even pocket devices are expected to do many things at once, some of which involve real time processing demands, vast storage requirements, and interaction with many other computer and network systems developed at different times by different vendors using ever changing interface standards. It’s not surprising in that context that more testing is required.

**Extension to public sector**

Our analysis has been microeconomic based on a profit relation. However, we have avoided specifying how the decision is made. It could be made by market forces, with more profitable organizations gradually gaining market share and capitalization share in
a manner similar to Lo’s [2013] adaptive market hypothesis. Or it could be the result of savvy or lucky decision making.

The results can be extended to non-profit and governmental organizations in several ways.

First, there are explicit pressures to allocate funds efficiently between governmental and private organizations. These decisions may not always be rational. They are essentially political. But at least there is consideration and debate of whether funds are best expended through the public or private sector. This puts pressure on public sector managers to reach an efficiency level comparable to the private sector. They may not perfectly arrive there, but there is pressure.

Second, the public and private sector draw from the same pool of employees, vendors, and management consultants. They tend to do things in ways more similar than critics of either sector realize, even if there is no particular reason to be similar. So the crash rate model can be extended to the public sector by cultural similarity of the pieces.

Third, the public and private sector draw on the same technological pool for methods and processes of doing things. They use the same kinds of computers and software, vehicles, and so forth. So parts of their development and testing methodology and costs are very similar.

And finally, even government agencies may in the long run have to absorb costs of their mistakes. In the 1980s after the Space Shuttle Challenger exploded following launch, funds were appropriated for a replacement orbiter. But the NASA budget was not fully increased by that amount. The development of a space station and other programs were delayed. Following a second catastrophe in the 2000s, the loss of the Columbia, the flight rate was reduced, limited to safe haven destinations (mostly the
International Space Station), and by the end of the decade the program had been canceled, at least in part because of safety concerns. The function of supplies and crew transportation to the space station is to be provided by the private sector. Both safety and costs are components of this discussion, which indicate the factors represented in the crash rate model are certainly influencing this large government program.

Relation to risk compensation

The crash rate model differs from risk compensation in several important ways. We already discussed that the crash rate model is corporate, and risk compensation is primarily a theory of individual action. They can both yield an unexpected rise in incidents (crashes, failures or accidents), but for different reasons which we will compare.

In the crash rate model, crash rate can unexpectedly rise when development processes improve, and the cost of finding and fixing problems decreases. To put this more strongly: when the cost of adding new features decreases, corporations will chase larger profits by adding more new features. This will cease when the impact of operational failures offset the value of the new features. The decreasing of required effort for some activity (new development) leads to more of that activity. The increased activity (functionality, features, number of customers, and usage by customers) leads to the increased crash rate.

In risk compensation, the decrease in risk (rather than cost) leads to similar increases in activity, which leads to an increased crash rate. The increase may take the form of, for example, driving more miles, in which case the crash rate per mile might not increase but the total crashes would increase. Or it may take the form of faster activity, faster driving, and more efficient use of time, which can lead to crash rate increases by all measures.
So the crash rate model is driven by cost, and risk compensation is driven by risk. The crash rate model is corporate and risk compensation is personal. But Corporations are composed of people. And risk can be related to costs using the expected value principle. Once the risk/cost equivalence is made, from there the models operate in a similar way to produce the unexpected results.

It is possible to go even further in comparing the crash rate model to risk compensation, by noting similar roles for technology. Not always, but often, safety improvements are the result of technology. Certainly air bags are technology. Fire safety blankets are through time improving with technology. Global Positioning System navigation devices and cellular phones are dramatic technology devices that can be used to improve safety. Do people take more risks because of these devices? That is the premise of risk compensation. Do corporations make more of these devices because people will buy them? That is the premise of capitalism and profit seeking. Do corporations use these same devices and technologies to improve their operation and develop even more features and devices at lower cost? Yes they do.

Risk homeostasis is a much stronger assertion, and does not appear to be directly comparable to a microeconomic model. However, that does not mean crash rate is all economics and no psychology. We have discussed how, indeed, it can be applied to the public sector largely on psychological grounds. Perception of improvement, by process engineers or by consumers buying products, and even perception of acceptable failure, all have psychological factors.

**Air travel safety**

As noted by Carlsson et. al. [2004], we are willing to pay more for safety in the air, or put in terms of our model, the crash rate for air travel is lower than expected. There could of course be psychological reasons for this. People may fear the lack of control
over even mundane failures, and may choose instead to drive their own vehicles. In the survey conducted by Carlsson, this is what travelers said. However, the survey also indicated that people are willing to pay more for a given safety improvement (from 1.0 in a million to 0.5 in a million chances of serious mishap) when the cost of the trip was higher. The comparison was between air and ground taxi, not a private vehicle, in which travelers might be willing to invest more. And as with any survey, there is no guarantee people will over time behave as they claim.

We do know that air travel is very safe compared to automobile travel. Let us explore avenues for that within the context of our model, starting with a look at the assumptions.

It is possible that the use of air travel violates the assumption of competitive economic pressure on the user (traveler). Slightly more than 50% of all air travel was for pleasure or leisure in 2001, according to the U.S. Department of Transportation [2008]. This kind of recreational travel is different than, for example, racing or paragliding. It is not the travel itself that is recreational. The travel is only a means to an end. Possibly the economic utility of recreational travel is not as great as business travel, and users will avoid trips which appear to be dangerous. Even in regard to business travel, the age of internet has made competing options such as video conferencing very cheap and easily available and generally accepted by business partners. So before applying the crash rate model, one needs to determine the validity of the assumptions, and the true field of competition.

Strictly within our model, we see that the cost of testing airplanes is very high. And the cost of crashes, and even relatively minor (non-fatal) incidents if they occur in multiples, can be extraordinary. For example, at this writing the fleet of Boeing 787’s has recently been grounded for an extended period because of failure of a lithium ion
battery module to contain failures. Deliveries of 787’s were on hold while Boeing expended additional funds for testing. Meanwhile customer airlines could generate no revenue from those aircraft.

The cost of multiple crashes is likewise high. After 4 crashes, the de Haviland Comet 1, first commercial passenger jet, was taken out of service from 1954 until 1958, when the third revision (Comet 4) was introduced. 1959 was the last year a new jet product was introduced with the brand DH, though the company was acquired by Hawker Siddeley and developed a successful business jet, which was sold again and is now manufactured in the United States. Many of today’s air travelers, however, will still remember and have a negative association to the airline brand ValuJet, which began in 1993 by buying many older aircraft, and after many safety incidents and harsh criticism from the FAA had a notorious fatal crash (Flight 592). The airline then had serious financial problems, and merged with the smaller AirTran, taking the name of the smaller carrier. So the cost of a crash can in some cases go far beyond the equipment lost and the compensation to injured or deceased customers.

It is interesting to note in this context that if ticket costs are taken to be representative of $V_f$, low ticket costs would tend to push crash rate down. The world’s largest low cost airline, Southwest Airlines, ranks 21 out of 60 on the JADEC [2012] safety rankings. But to the extent low cost carriers hold down recurring costs $M$ then this effect is reduced as value to the company of each flight remains high. The real leverage is in the defect ratio, and whether an airline performs inspection and maintenance is critical. Note that Southwest recently acquired AirTran. Safety ranking information for AirTran was not readily available at this writing. 5 of the 7 largest low cost airlines rank in the top half of the JADEC rankings, ranging from 14 to 23. One airline GOL spoils the overall ranking of the group. Nevertheless, the data are
sufficient to conclude that low cost does not have to mean unreliable, and we at least keep open that $V_f$ may indeed play the role we suggest.

**Options for influencing crash rate**

The crash rate model suggests that companies competing with each other in a market, using similar technology, must converge on similar crash rates. It is possible a company can make a marketing issue out of the reliability of its products, and this has been done for automobiles, phones, computers, and many other devices. In that case $V_f$ increases if $R_o$ decreases, which requires some intervention against the natural action of the model.

However, if an executive at the top seeks to influence a large organization to have a specific $R_o$, how can it be done? The crash rate model suggests improving development processes runs some risk of backfiring, if middle managers use the advantage to seize market opportunities, and add too many features. However, spending money on testing, that is, on making a very low defect ratio $D$, seems to be an unmitigated benefit. It inflates the $C_d/D$ term, increasing the denominator and reducing the crash rate.

Indeed, testing and quality control in general work. For several decades, this seemed to be the strategy of the entire nation of Japan. It also was a premise of the early space program. However, in the last two decades of globalization, all costs have been under attack, and costs ranging from testing to research have been deemed ancillary and have been cut. The result is reductions of $M$ and $C_d$ which, according to our model, will increase crash rate.

**Conclusion**

A model has been developed that relates development process parameters to
operationally deployed crash rate. This model operates at a corporate level, and provides insight into what kinds of changes might affect product reliability and safety. There is a rough analogy to risk compensation, though in detail the models address different regimes. Process improvement and feature development are often culprits in unexpected outcome. Testing adds to costs, but has a predictable positive outcome.

References


