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Dr. Curtis Travis
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Dear Dr. Travis:

PROPOSED PUBLICATION IN RISK ANALYSIS JOURNAL

Submitted herewith for proposed publication in the Risk Analysis Journal is a paper entitled, "The Societal Impact Value of Risk."

In support of the validity of the insights and conclusions in the paper, I am also enclosing a "Note to Editor" which outlines some "reality tests." This material could be polished up and cleared for publication as an appendix to the paper, if you think desirable.

I will be pleased to respond to comments and suggestions which your reviewers may have.

Thank you for your attention.

Sincerely,

D. E. Simpson
Nuclear Consulting

Attachment

The Societal Impact Value of Risk

D. E. Simpson

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THE SOCIETAL IMPACT VALUE OF RISK

D. E. SIMPSON [1]

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ABSTRACT

A key ill-defined issue in the management and regulation of potentially hazardous conditions is that of the value to be associated with a reduction (or existence) of human health risks, such as radiation exposure or hazardous substance ingestion. Empirical observations of societal behavior patterns lead to a relationship for the quantitative value of societal risk impact which is consistent with general societal risk acceptance, is not inconsistent with "de facto" risk regulation, and is suitable and appropriate as a specification or guide for risk management and risk regulation.

This societal risk impact expression is:

$$\text{Impact (\$/year)} = (8\text{X}10^7)\ NR_i^{4/3}$$

where

R_i = individual annual mortality risk

N = number of persons in the population sharing the risk and benefits

The change in Impact which can be derived from a regulation or risk management activity is the value of annual benefit which society would expect to forego (or annual equivalent cost to incur) in consideration of the activity.

1. The Management and Regulation of Risk

Management and regulation of societal risks require that judgments be made on the value of actions to reduce or avoid specific risks. Such value judgments are necessarily a societal function; there are no scientific principles which can define a "right" answer.

Two key issues contribute to controversy and confusion in the management and regulation of risks:

A. What is the economic worth of a given level of individual risk? (What is the value of a statistical life?)

B. What rewards or benefits does society expect in acceptance of societal risks?

Stephen Breyer, Associate Justice of the U.S. Supreme Court, has recently published a book(2) which describes the confusion and inconsistency of current U.S. risk regulation. The title implies the problem. Breyer further quotes Milton: "Chaos umpire sits, and by decision more embroils the fray by which he reigns."

A vast literature exists exploring the subjects of risk analysis, risk management, and regulations. No answers to the questions on value of risks have been developed which have received broad use and acceptance. Nevertheless, it appears that society does exhibit a degree of consistency in risk assessment which can be defined and used for reasonable and rational decision-making.

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(2) Breyer, Stephen; Breaking the Vicious Circle - Toward Effective Risk Regulation; Harvard University Press, Cambridge, MA. 1993.

The empirical assessment of societal risk value can be considered in four parts:

- Benefits associated with common risks
- "Risk aversion"
- Value of individual risk
- Accommodation of uncertainty

2. Assessment of Risk Value

2.1 Benefits Associated With Common Risks

Consider the sum total of the risks of living in the U.S.; the "gross national risk." All the aspects of life present risks of damages, injury, illness, and premature death which are accepted as essentially unavoidable. The associated benefit can be quantified in dollars as the gross national product; in the U.S. today this amounts to some six trillion dollars. The consequences of the risks include the factors noted above: damages, injuries, illnesses, and premature deaths. The premature death rate is a reasonable index of risk, understanding that the other costs to society also occur in rough proportion.

In the U.S., today's life expectancy is about 75 years. The population is approaching 300 million. A nominal death rate is $\approx 3 \times 10^6$ fatalities/year.(3) Estimating the "premature" death rate at 20% of the total, the benefits/risk ratio for the U.S. "gross national risk" is about

$$\frac{6 \times 10^{12}\ \text{\$/year}}{6 \times 10^{5}\ \text{premature fatalities/year}} = \text{\$10 million per premature fatality.}$$

---

(3) The current death rate is lower; the implied steady state rate is higher. This nominal value is suitable for illustration.

Our society seems to accept a premature fatality, plus proportional costs of damages, injuries, and illnesses as a consequence of generating the benefits of $10 million dollars of GNP and the associated standard of living.

2.2 Risk Aversion

Many observers have noted that society seems less accepting of risks with high consequences and low probability, than equal risks of lower consequences and higher probability. This has been termed "risk aversion," although it may be rather an aversion to more severe risk consequences.

The concept of "risk aversion" is a philosophically reasonable protective mechanism. The aversion to large consequences ensures that society assigns relatively higher impact value to risks which pose greater threat to the society.

Introducing the term, Impact, risk aversion implies that the societal Impact of a risk increases more than proportionally to increasing consequences of the risk.

Observations and supporting data published decades ago by C. Starr(4) indicated that:

- individuals voluntarily accept risks in proportion to the cube of the perceived personal benefit or value of an activity,
- society as a whole accepts risks which result in consequences roughly proportional to the cube root of the societal benefit.

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(4) Starr, Chauncey, "Benefit-Cost Studies in Sociotechnical Systems." Perspectives on Benefit-Risk Decision Making. The National Academy of Engineering. Washington, DC. 1972.)

These observations can be used to develop a risk impact relationship of the form:

$$I_R = A \times NR_i^{4/3}$$

where

I_R = societal risk impact (\$/yr.)
N = number of people who share in the risk and benefit
R_i = individual annual mortality risk
A = constant of proportionality

Since the actual societal consequence of the activity is NR_i, this relationship shows impact generally increasing more rapidly than consequences, as risk increases. (The development of this relationship is described in Appendix A.)

Let us define the Impact of the "gross national risk" to be equal to the gross national product, in order to quantify the constant, A.

$$I\ (GNP) = 6x10^{12}\ \$/yr.$$

$$= (A)(3x10^8)(2x10^{-3})^{4/3}$$

$$A = \frac{6x10^{12}}{7.5x10^4} = 8x10^7$$

It appears (from Starr's observations) that there is a pattern of consistency in public decision making regarding acceptability of risks. This pattern is reasonably represented by characterization of a risk "Impact" which is described by:

$$I_R = (8x10^7)NR_i^{4/3}$$

This relationship incorporates the concept of risk (consequence) aversion explicitly, through the incorporation of risk to a power greater than unity. There are other, more subjective, factors influencing risk acceptability which can affect the societal risk acceptance in specific instances. These factors are averaged out in this quantification.

2.3 Value of Individual Risk

Implicit in the above risk impact relationship is a statistical mortality value function which varies with the level of individual risk. Dividing the risk impact by the risk (NR_i) defines the statistical mortality value, V_M.

$$V_M = \frac{(8x10^7)\ NR_i^{4/3}}{NR_i} = 8x10^7\ (R_i)^{1/3}$$

The statistical mortality value is a reasonable representation of the economic cost (or benefit foregone) which society would expect to allocate to save one statistical life (and proportional injury, illness, and damage). This relationship is shown graphically in Figure 1.

This value was deduced (above) to be about ten million dollars for the sum total of accepted/acceptable risks ($R_i = 2x10^{-3}$). This corresponds to $20,000 per person per year for the population.

For the lower risk associated with motor vehicle usage ($R_i = 2x10^{-4}$), the indicated statistical mortality value is about five million dollars ($1000 per person per year).(5)(6)

(5) This implies that the U.S population would be willing to pay a tax of about $10, per capita, per year, to reduce the motor vehicle consequences by 500 deaths per year (one percent). Reference (6) reported a "willingness-to-pay" study indicating a mean value of $385 for a 20% motor vehicle fatality reduction for one year (approximately $4/percent).

(6) Risk Analysis, Volume 12, No. 4, pages 495-503 (1992).

The Environmental Protection Agency considers acceptable risk for regulatory purposes to be in the range of 10^{-6} to 10^{-4} lifetime excess cancer incidence risk.(7) A lifetime risk of 10^{-4} corresponds to an annual risk of about 10^{-6}. This is roughly the risk of death by natural catastrophe. At this risk level, the indicated statistical mortality value is about one million dollars; this is only $1 per person per year for the population at risk.

2.4 Allowance for Uncertainty

Unfortunately, one can never calculate risks, or Impact, with certainty. Judgments must be made to decide how much allowance should be made to cover uncertainty. Excessive allowance means resources expended without corresponding benefits. Inadequate allowance means occasional occurrence of unexpected consequences.

For a log normal variable the average value exceeds the median value by a factor, the <u>exponent</u> of which varies as the <u>square</u> of the log standard deviation. This illustrates the potentially large uncertainty allowances which may be appropriate. Other uncertainty distributions call for other uncertainty factors.

Note that the uncertainty factor is <u>not a conservatism</u>. If the uncertainty represents real variability in conditions or circumstances, then the uncertainty factor accounts for infrequent but inevitable accumulations of adverse factors, and it is necessary to account for the variability in allocating resources for risk reduction. If the uncertainty represents lack of precise knowledge, the above relationship highlights the potential value of obtaining better data.

(7) [40CFR196 (staff working draft). Environmental Protection Agency Radiation Clean-up Regulation. May 11, 1994, page 68 (citation: 56CFR33058). Also cited is a conclusion that 10^{-4} is the "de facto level of acceptable risk in a statistically significant number of federal regulatory decisions." (citation: Travis, et al., 1987)].

In summary:

- Acceptable risk impact must be demonstrated by the probability-weighted average, or effective, risk; not simply by the best estimate.

- Large uncertainties in risk impact, and corresponding justified risk-abatement costs, can result from relatively small uncertainties in physical, biological, and sociological data.

3.0 Conclusion

A reasonable, rational, and consistent value of risk can be determined that is empirically consistent with actual wide-spread societal actions. This defines a risk Impact which is

$$I_R = (8\times10^7) \times NR_i^{4/3} \times UF$$

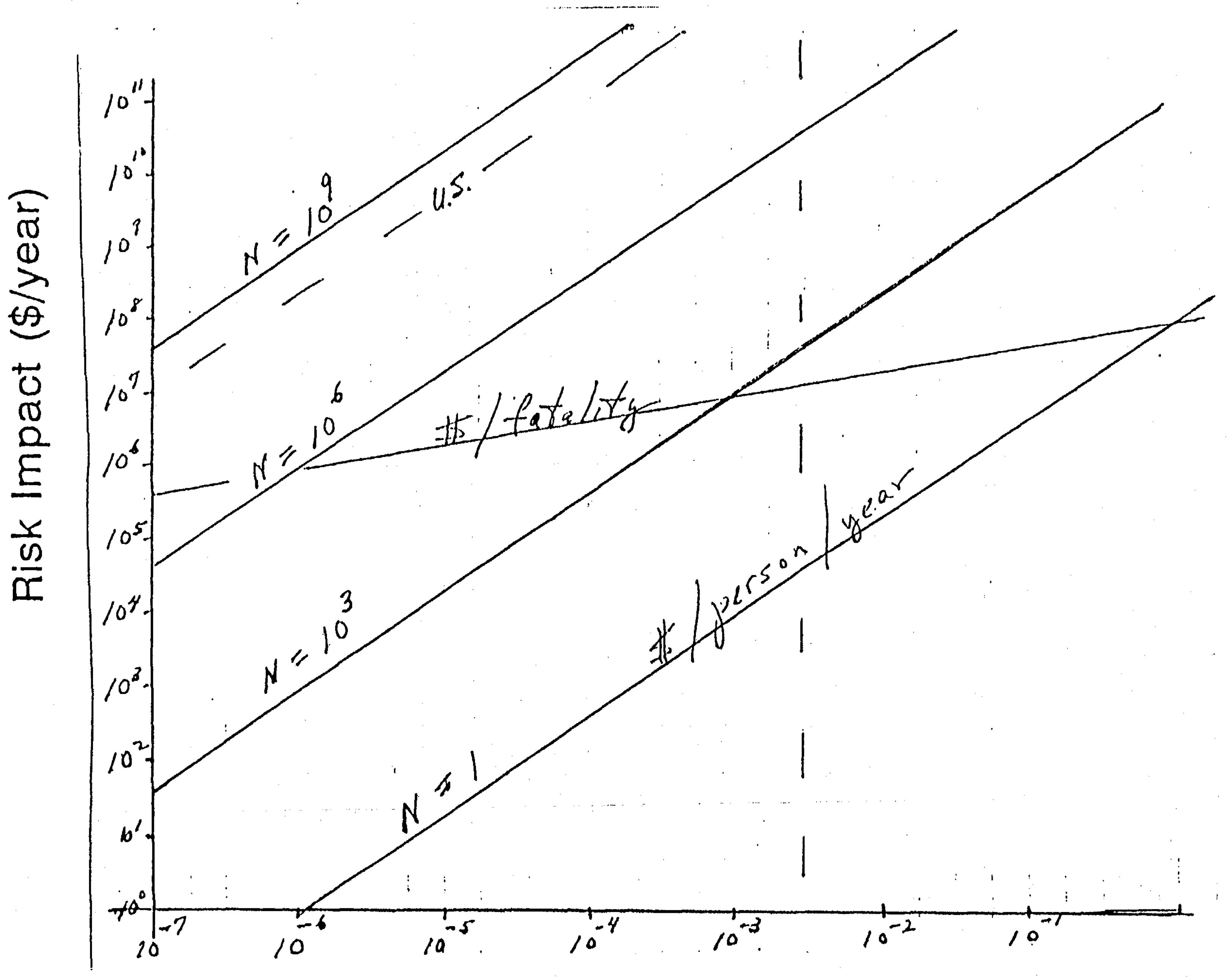
where

I_R = societal risk impact ($/year)
N = population at risk, and sharing in benefits
R_i = individual annual premature mortality risk
UF = uncertainty factor

The change in the Impact due to a risk reduction activity defines the dollar value of that activity in terms of annual benefits which should be forgone (or annual equivalent costs incurred) to achieve the risk reduction.

FIGURE 1

Societal Risk Impact



APPENDIX A

SOCIETAL RISK IMPACT - ANALYSIS OF AN EMPIRICAL PATTERN OF RISK ACCEPTANCE

Seminal observations on societal acceptance of risk in consideration of benefits were published in the 1960's and 1970's by C. Starr. (Reference: Benefit Cost Studies in Sociotechnical Systems. Chauncey Starr, Perspectives on Benefit-Risk Decision Making. The National Academy of Engineering, Washington DC, 1972). Starr found a major difference between the magnitude of risk accepted voluntarily and that accepted involuntarily. In both cases he observed that the acceptable individual risk varied in proportion to the cube of the individual perceived benefit. He also reported data, notably for the historical risk and utilization of motor vehicles, indicating that the participation in a potentially beneficial activity increases with diminishing individual risk, roughly in inverse proportion to the 4/3 power of the risk; this implies a societal consequence increasing as the cube root of the societal benefits.

Mathematically, the observations from Starr's work are: *

$$R_i = k_i B_i^3$$
$$N = k_2 R_i^{-4/3}$$

where

R_i = individual annual mortality risk
N = number of persons sharing risk and benefits
B_i = individual perceived benefit

From this, it is apparent that the societal benefit increases in inverse proportion to the individual risk

$$B_s = NB_i = k_2 k_1^{-1/3} R_i^{-1}$$

and the acceptable risk consequences (P_s) increase roughly as the cube root of the societal benefit:

$$P_s = NR_i = k_2 R_i^{-1/3} = k_2^{2/3} k_i^{1/9} B_s^{1/3}$$

In terms of societal benefit of an activity, Starr's observations define an acceptable individual risk and number of participants:

$$R_i = C_1 B_s^{-1} \qquad C_1 = k_2^{-1} k_1^{1/3}$$
$$N = C_2 B_s^{4/3} \qquad C_2 = k_2 C_1^{-4/3}$$

---

* The data on participation can be interpreted to indicate an inverse proportionality to a power of risk which might be represented by 4/3, 3/2, 5/3 or perhaps more or less. Selection of the 4/3 value gives the most simple result, because it eliminates a power other than unity for the population number parameter, N, in expressions for societal risk impact and statistical mortality value.

The societal risk consequence (or cost) is simply

$$NR_i = C_1 C_2 B_s^{1/3}$$

But the "IMPACT" of the risk requires another consideration; the value of the individual risk. By extension of the observation that acceptable individual risk varies as the cube of the perceived individual benefit, the value of risk may reasonably be taken to be proportional to individual risk to the 1/3 power. That is:

$$V_R = AR_i^{1/3}$$

Now, IMPACT is defined as:

$$\begin{aligned} I_R &= V_R \times NR_i \\ &= A \times NR^{4/3} \end{aligned}$$

Note that

$$N \cdot R^{4/3} = (C_2 B_s^{4/3})(C_1^{4/3} B_s^{-4/3}) = C_2 C_1^{4/3}.$$

Thus the defined impact is independent of B_s, and dependent only on N and R_i.

The constant, A, was evaluated in the text on the basis of the U.S. gross national product and the gross risk of premature death.

A reasonable expression for the societal impact of risk associated with actual or projected conditions, or changes, (without allowance for uncertainty) is:

$$I_R \quad = \quad (8\text{x}10^7)\ NR_i^{4/3}\ (\$/\text{year})$$

This expression is consistent with empirically observed societal risk acceptance, including "risk-aversion."

NOTE: This relationship does not address the issue of the special societal perceived impact of catastrophes. An extension of the logic leads to the special case that:

$$I_{CAT} = I_R \times (M_{CAT})^{1/3}$$

where I_{CAT} = societal impact of the risk of a catastrophic event

M_{CAT} = number of fatalities which would occur in the projected catastrophe

I_R = societal risk impact based on the individual annual mortality risk associated with the projected catastrophe, and the number of people exposed to the risk.

NOTE TO EDITOR

REALITY TESTS OF SOCIETAL RISK IMPACT RELATIONSHIP

The validity of the societal risk impact relationship, and the value of the constant, is not necessarily self-evident.

Some explorations have been undertaken to assess whether the relationship is consistent with actual societal value and perceptions, as they can be demonstrated or as they have been evaluated in other research.

These explorations all support the practical validity of the derived expression.

I. COMPARISON WITH DIRECT ECONOMIC COST OF PREMATURE FATALITY

A. The direct economic societal cost of a premature fatality may reasonably be taken as the loss of average per capita GNP contribution for the years of life lost. The individual subsistence cost for the years lost, and the increased health care cost of injuries and illness are in opposing direction and can reasonably be neglected.

B. The average years of life lost due to premature fatality may be approximated as 15 years. Data reported by Landon, and data compiled by Corello, Sandman and Slovic show that heart disease and cancer fatalities cause an average loss of life of about 15 years; accidents cause a loss of 20-30 years.

C. Using values of GNP = 6×10^{12} \$/year, and U.S. population = 3×10^{8} persons, the annual per capita GNP contribution is \$20,000. The 15-year contribution is \$300,000.

D. The societal risk impact relationship $I = (8\times10^{7})NR^{4/3}$ is consistent with a statistical mortality value, V_m, of

$$V_m = (8\times10^{7})R^{1/3}$$

If $V_m = 3\times10^{5}$

then $R^{1/3} = \dfrac{3\times10^{5}}{8\times10^{7}} = .375\times10^{-2} = 3.75\times10^{-3}$

and $R = 5\times10^{-8}$

The lifetime mortality risk, using a 50-year lifetime exposure value, is $(50)(5\text{x}10^{-8}) = 2.5\text{x}10^{-6}$. This lies within the range of "acceptable risks" [10^{-4} to 10^{-6}] defined by EPA for CERCLA purposes.

E. The societal risk impact statistical mortality values at the bounds of the EPA lifetime risk range of 10^{-4} to 10^{-6} are:

At $R_1 = 1/50\ (10^{-4}) = 2\text{x}10^{-6}$

$R_1^{1/3} = (2^{1/3})(10^{-2}) = 1.25\text{x}10^{-2}$

$V_m = (8\text{x}10^7)R^{1/3} = 1.0 \text{ x } 10^6\ \$$

At $R_2 = \frac{10^{-6}}{50} = 2\text{x}10^{-8}$

$R_2^{1/3} = (20^{1/3})(10^{-3}) = 2.8 \text{ x } 10^{-3}$

$V_m = 2.2 \text{ x } 10^5\ \$$

F. This assessment shows that the societal impact relationship

$$I = (8\text{x}10^7)NR^{4/3}$$

is "risk averse" (i.e., the "impact" exceeds the average direct economic cost) for individual risk values above $2.5 \text{ x } 10^{-6}$ lifetime excess mortality risk (or $5 \text{ x } 10^{-8}$ annual mortality risk); this individual risk value is low in the range of EPA "acceptable risk," below which EPA regulation does not call for any effort or cost to be expended for risk reduction.

G. Conclusion

The societal risk impact relationship is quantitatively consistent with public values, as indicated by law and regulatory practice.

II. COMPARISON WITH SOCIETAL BENEFIT VALUE OF MOTOR VEHICLES

A. U.S. motor vehicle accidents cause roughly 50,000 annual fatalities in a population of $2.5\text{x}10^8$ persons; the average annual mortality risk is $2\text{x}10^{-4}$.

B. The calculated societal impact,

$$I = (8\text{x}10^7)\ NR^{4/3}$$

is

$$\begin{aligned} I &= (8\text{x}10^7)(2.5\text{x}10^8)(2\text{x}10^{-4})^{4/3} \\ &= (8\text{x}10^7)(2.5\text{x}10^8)(1\text{x}10^{-5}) \\ &= 2\text{x}10^{11}\ \$/\text{year} \end{aligned}$$

C. The societal value of motor vehicle usage is equal to the cost expended. Estimate:

10^8 motor vehicles
10^4 miles/vehicle/year
0.5 \$/vehicle/mile
$(0.5)(10^8)(10^4) = 5\text{x}10^{11}$ \$/year

D. The societal risk impact relationship is consistent with the value of the societal benefits for motor vehicle usage.

III. COMPARISON WITH RESEARCH STUDIES

Many authors have analyzed the "value of a life" from various perspectives.

Mauskopf (a), et al., found a value of $5M to be a good baseline value based on a "careful study" by Moore and Viscusi(b). This was also a central value of assessments reported by Fisher, et al.(c); the range of these assessments was from 1.6 to 8.5 million dollars.

Keeney(d) looked at the other side of the coin: how much can diversion of resources into risk abatement induce mortality risk? Illustrative examples of the analysis method implied that diversion of some 3 to 7 million dollars could induce one fatality, due to unavailability of the resources for support of standards of living. The impact of such an effect falls on the poorer members of the society.

Lind, et al.(e) published a comprehensive analysis of risk management. Among other things they concluded that the cost per life saved for a safety program should exceed 4.2 to 5.2 million dollars (based on a "human development index," HDI, or a "life product indicator," LPI). They also indicated an alternate value of about two million dollars, based on share of the gross national product, GNP.

An evaluation in the United Kingdom also led the UK's National Radiation Protection Board to conclude a "central value" for a statistical life to be some 3 to 4.5 million dollars(f).

The consistency among these assessments is much more remarkable than the spread. All of the values noted above fall within the range of 1 to 10 million dollars.

The statistical mortality value corresponding to the societal risk impact relationship, $V = (8x10^7)R^{1/3}$, is consistent with the above assessments, for individual annual mortality risks (Ri) in the range of common public experience. See tabulation below.

R_i	$R_i^{1/3}$	V_R	$\frac{I_R}{N}$ ($/year)
10^{-3}	10^{-1}	$8x10^6$	8000
10^{-4}	$4.5x10^{-2}$	$3.7x10^6$	370
10^{-5}	$2.2x10^{-2}$	$1.7x10^6$	17
10^{-6}	10^{-2}	$8x10^5$	0.8

Also tabulated above is the per capita risk impact, $\underline{I/N}$ which is a measure of the "worth" ($/year) to each individual to sustain the given level of risk.

The trend of the per capita risk impact is consistent with societal values reflected in risk regulations; that is, regulations generally imply that risk, at some low level, becomes negligible.

IV. ALTERNATE VALUATION OF IMPACT CONSTANT

Lind, et al.(e) (Table C-21) present data correlating changes of GDP (gross domestic product) with changes in average life expectancy. For the U.S., the ratio of % ΔGDP to %ΔLE is reported as 10. Other technologically advanced nations generally tend to show a ratio of 10 to 20, more or less.

This would imply that an investment of 10% of GNP would be justified to extend the life expectancy by 1%. This could be done by reducing the premature mortality rate by 5% (assuming each premature mortality reduces the individual life span by 20% [15 years]).

The calculated impact of premature mortality at a risk (R_1) of 2×10^{-3} is

$$I_1 = A\,N\,(2\times10^{-3})^{4/3}$$

If $$R_2 = 1.5\times10^{-3}$$

$$I_2 = A\,N\,(1.5\times10^{-3})^{4/3}$$

Then $$I_2 - I_1 = A\,N\left[(1.5\times10^{-3})^{4/3} - (2\times10^{-3})^{4/3}\right]$$

$$= -\,A\,N\,(2.52 - 1.72)\times10^{-4}$$

$$= -\,A\,N\,(0.8\times10^{-4})$$

$$\Delta I = 6\times10^{11}\ \$/\text{year}\ [10\%\ \text{of GNP}]$$

$$= (3\times10^{8})(0.8\times10^{-4})$$

$$A = \frac{6\times10^{11}}{2.4\times10^{4}} = 2.5\times10^{7}$$

A reasonable argument can be made, objectively, that the value of 8×10^{7} for the impact constant is an over-valuation by about a factor of three. On the other hand, the general agreement of the larger value with the body of research on societal value of life is a reasonable argument, sociologically, to retain the larger value.

V. SOCIETAL SURVIVAL STRATEGY

It is reasonable to expect that sociological/psychological risk aversion would have the effect of valuing a statistical life at never less than its economic societal contribution, no matter how small the risk; <u>and</u> of valuing a life at a prohibitive level if faced with near-certain death.

This "strategy" ensures that societal attention is focused where the key threats are:

- where the mortality rates are highest, if individual risks are low;
- where the individual risk is high, if mortality rates are low.

A typical representation of this approach could be, for example:

$$V_m = a + b\ R^{1/n} + cR$$

A set of values consistent with societal observations is:

$$V_m = 3\ [10^5 + 10^7\ R^{1/3} + 10^9\ R]$$

For the "gross national risk" of 2×10^{-3}, for example, V_m (GNR) = 10^7, which agrees with the previous empirical value. See Figure.

In the range of R from 10^{-3} to 10^{-6}, mortality values calculated by this expression closely parallel

$$V_m = (8 \times 10^7) R^{1/3}$$

For general risk management purposes; that is, for individual annual mortality risk below about 10^{-3}; the societal value of a statistical mortality V_m, can be taken as

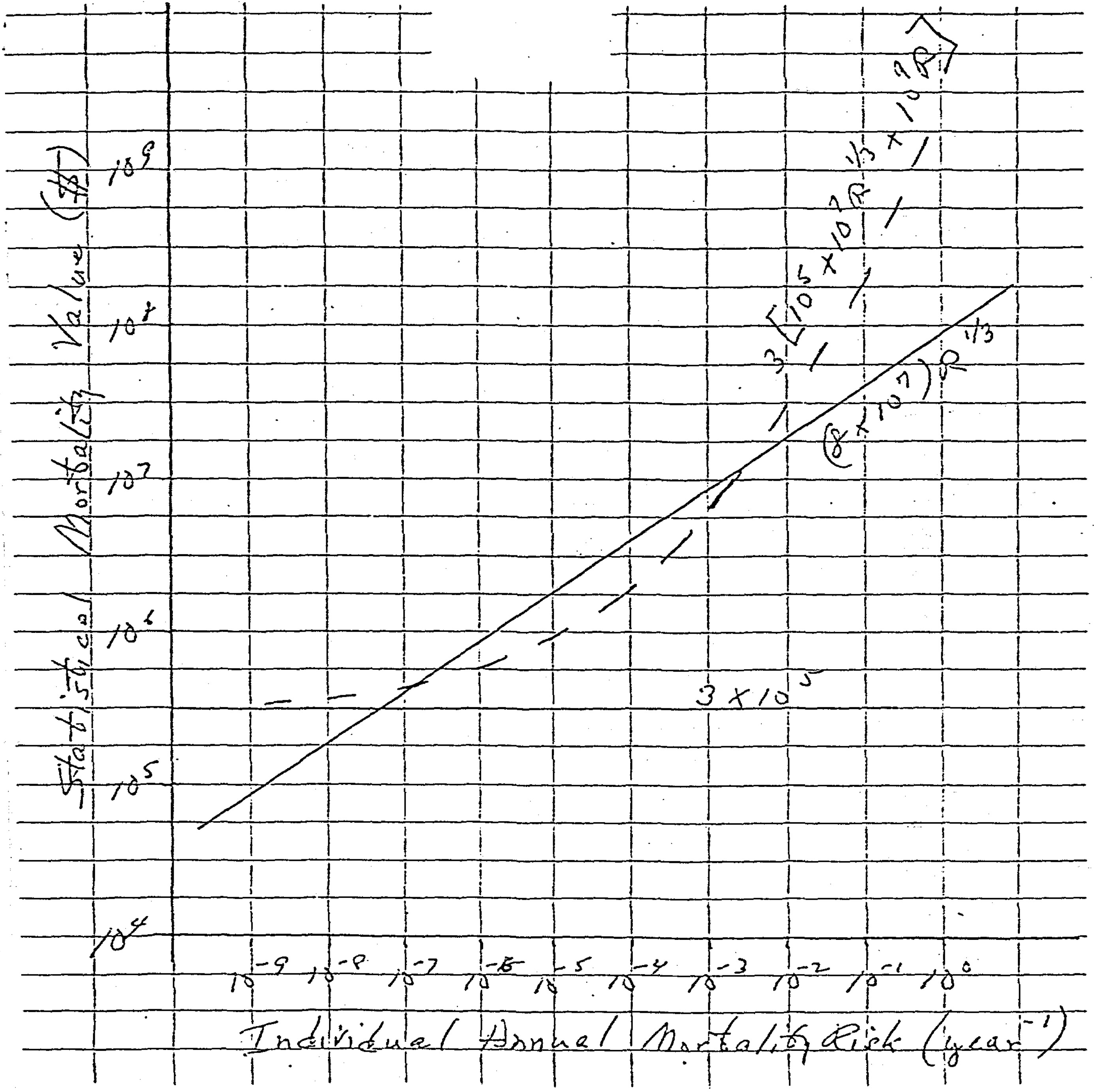
$$V_m = aR^{1/3} \quad \text{, when } V_m > V_m \text{ (minimum)}$$
$$V_m \text{ (minimum)} = V_{econ}$$

The constant, "a", seems to be about 8×10^7 (maybe a factor of 3 less). The economic value of a statistical life (V_{econ}) is about 15 years of per capita GNP, which is about \$$3 \times 10^5$.

The upper end of the conceptual mortality value range may or may not exist in actual societal practice. It would come into play in situations involving very high risks (and correspondingly few participants). It seems likely that society would support the implication that no economic benefit could be so large as to justify exposing people to certain death. On the other hand, the implication that a virtually unbounded investment is justified to save a life is at least open to question.

This area of philosophical inquiry is declared beyond the scope of this study!

FIGURE


Statistical Mortality Value ($)
10^9
10^8
10^7
10^6
10^5
10^4
$3[10^5 \times 10^7 R^{1/3} \times 10^9 R]$
$(8 \times 10^7) R^{1/3}$
3×10^5
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
Individual Annual Mortality Risk ($year^{-1}$)

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