Putting a value on human life

Philip Thomas
Professor of Risk Management
Safety Systems Research Centre
South West Nuclear Hub
philip.thomas@bristol.ac.uk
http://www.jvalue.co.uk/
https://www.sciencedirect.com/journal/process-safety-and-environmental-protection/vol/112/part/PA

Averting human harm; cost-benefit analysis

- We all want to reduce harm to the nation's citizens.
- But we also know that our resources are limited and we cannot spend our all on improving safety.
- So we **have to find a balance** between what we want to spend on a health and safety measure and the reduction in harm that it brings about.
- We are therefore faced with the awkward question of **how to put a value on human life**.

Fundamental question:

What benefit is conferred when a safety measure or health care intervention a "saves" a person's life?

Answer:

The benefit is the **restoration of that person's life to come**.

This is the basis of the **J-value** method, J for Judgement.

- **Problem**: we cannot predict how long anyone is going to live.
- **BUT** actuarial tables give us the **expected life to come** for a person of a **given age** and a **given gender**.
- So we can value **life expectancy** – the average life to come for someone of a given age and gender.

Historic Interim Life Tables, United Kingdom

Period expectation of life
Based on data for the years 2005-2007

Age	Males				
x	m_x	q_x	l_x	d_x	e_x
0	0.005504	0.005489	100000.0	548.9	77.16
1	0.000402	0.000402	99451.1	40.0	76.59
2	0.000259	0.000259	99411.1	25.7	75.62
3	0.000180	0.000180	99385.4	17.9	74.64
4	0.000131	0.000131	99367.5	13.0	73.65
5	0.000120	0.000120	99354.5	11.9	72.66
6	0.000121	0.000121	99342.6	12.1	71.67
7	0.000093	0.000093	99330.5	9.3	70.68
8	0.000115	0.000115	99321.2	11.4	69.69
9	0.000118	0.000118	99309.8	11.7	68.69
10	0.000104	0.000104	99298.1	10.3	67.70
11	0.000135	0.000135	99287.8	13.4	66.71
12	0.000143	0.000143	99274.4	14.2	65.72
13	0.000179	0.000179	99260.2	17.8	64.73
14	0.000196	0.000196	99242.4	19.5	63.74
15	0.000254	0.000254	99222.9	25.2	62.75

Life expectancy: some figures

- **81** is the life expectancy **at birth** in the UK.
- **42** years is the population-average life expectancy in the UK.
- **3¼** years is how much life a person living in Harrow, North London **loses** by moving to Manchester.
- **4½** months is how much life a Londoner **loses** as a result of air pollution.

J-value: an objective method for valuing human life

- The **satisfaction** or **utility** that the average person gets from his disposable income over the rest of his life depends on
  - the person's **income, *G***, and
  - the person's **length of life, *X***.
- Spending more on safety will **extend lifetime**, but **decrease the amount to be spent** on other utility-bringing activities and there needs to be a **balance**.

- The maximum sensible safety spend will occur when the **gain in overall satisfaction from living longer** is exactly balanced by the **decrease in enjoyment from having less disposable income**.

- The **J-value** is the ratio: **actual safety expenditure** divided by the maximum sensible **safety spend** occurring at the **balance point**.

- The J-value is based on the **Life Quality Index**.

Derivation of the Life Quality Index - 1

An individual's quality of life, Q_1, may be modelled as a function of **income**, G, and **expected free time** from now on, F, in a general way **analogous to the dimensional analysis of pumps**:

$$Q_1 = \alpha_1 G^{\beta} F^{\gamma}$$

where α_1, β and γ are constants to be determined.

Derivation of the Life Quality Index - 2

$Q_1 = \alpha_1 G^{\beta} F^{\gamma}$

is, in fact, a standard **Cobb - Douglas utility function**, which can be developed into the **Life Quality Index**:

$$Q = G^{1-\varepsilon} X$$

Here

X is life expectancy (from now on) and

ε is **risk - aversion**.

Population averages are used for X and ε.

G is taken to be the GDP per head for ethical reasons: **the next day of life** is valued **the same for every person in the nation**.

The meaning of the Life Quality Index

The term

$$G^{1-\varepsilon}$$

is a standard economic expression for the utility of income the average person will receive each year.

Thus the **Life Quality Index** emerges as the **total satisfaction** the average individual can expect to experience over the rest of his/her life:

$$Q = G^{1-\varepsilon} X$$

Maximising total satisfaction for the rest of one's life is a reasonable description of the aim each one of us has in life, and **maximising utility** is one of the **fundamental tenets** of economics.

Maintaining life quality

Life quality is maintained when

$$\frac{\delta Q}{Q} = \frac{\delta X}{X} + (1-\varepsilon)\frac{\delta G}{G} = 0 \quad \Rightarrow \quad \delta G = \frac{G}{1-\varepsilon}\frac{\delta X}{X}$$

This calls for a **balance** between **extra life expectancy**, δX, per person brought by the safety measure and its **cost**, which appears as a loss of disposable income per person, $-\delta G$.

The maximum spend per person, δG, gives a simple but **realistic** representation of desirable safety expenditure.

The change in life expectancy, δX, that a safety measure will bring about can be found from the change in the hazard rate using **actuarial methods**.
GDP per head, G, may be estimated from **national statistics**, while risk-aversion ε has been estimated from **pan-national statistics**.

The J-value

The J-value can then be found as

$$J = \frac{\delta \hat{G}}{\delta G}$$

where $\delta \hat{G}$ is the amount being considered for spending on the safety system per person protected.

You are spending too much if J is bigger than 1.0

Validation of the J-value

- There are clear arguments in favour of the J-value:
  - it is based on established economic principles
  - it uses objective parameters.
- And, uniquely, the J-value has now been **validated against empirical data**.

The proof of the pudding is in the eating: **testing the J-value method against empirical data**.

- Hypothesis: The J-value gives an accurate representation of the way that **people all over the world** generally decide **how much they will spend on life extending measures.**
- The **J-value model** for safety spending predicts that people in richer countries will **live for longer** and that population-average life expectancy will follow the **J-value line** on the **Bristol curve** as GDP per head increases.

- The **Bristol curve** plots **population-average life expectancy** against **GDP per head** on logarithmic axes.
- The J-value model predicts a defined **straight line** on the Bristol curve.
- The slope of the line will depend on the complement of **risk-aversion**, *ε*, which, from previous measurements and estimates **should lie between roughly 0.8 and 1.0.**

Assumptions of the J-value model

- **Risk-aversion** stays **constant** as wealth and life expectancy increase in tandem and is thus the same for all nations in the world
- On average, the peoples in all nations will spend the **same fraction of their income** on life extending measures, at a J-value of unity: J = 1, implying good value for money.
- The **net discount rate** (social discount rate *minus* national growth rate) is **constant**.

Predicting the "Bristol curve" of log population-average life expectancy vs. log GDP per head data for 180 out of 193 nations in the UN

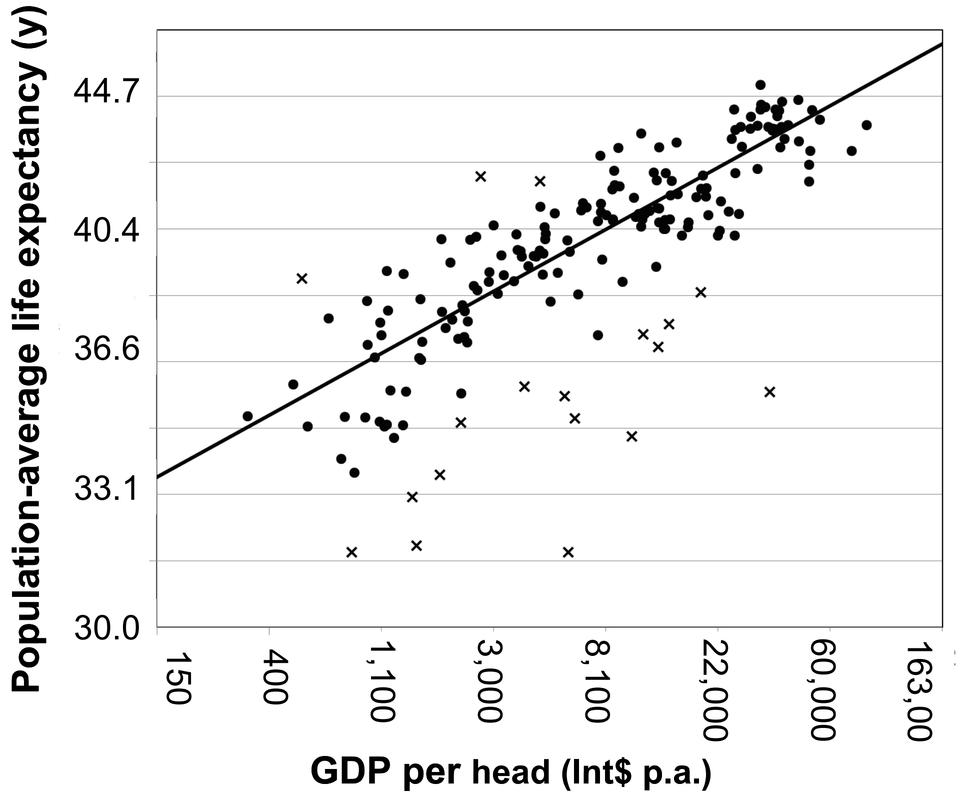
The J-value model predicts a straight line

R^2 = 0.6 for 180 nations

18 outliers (marked with crosses) were excluded from the final fit.

R^2 = 0.8 for 162 nations:

The model explains 80% of the variation in ln(X) in terms of changes in ln(G)



Conclusion from the validation exercise

- **All the world's nations** act as if they want to maximise their life quality index, $G^{1-\varepsilon}X$.
- To do so, they will trade off **income** against **life extending measures**.
  - Those measures will include **health care** but also good **sanitation**, safe **transport systems** and better and safer **industry** and **infrastructure**.
- The value of **risk-aversion** for all the nations in the world is found to be 0.95, which is close to other estimates: 0.82, 0.83, 0.85 and 1.0.
- The net discount rate is found to 0.0, so life expectancy should not be discounted.

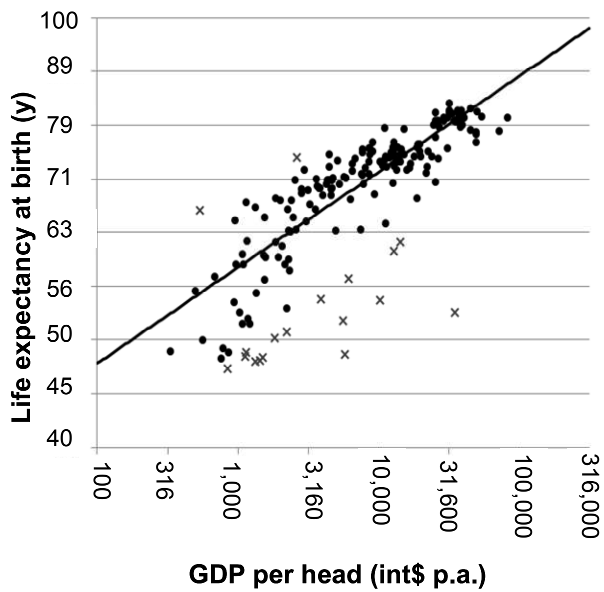
University of BRISTOL

The J-value gives the first explanation of the Preston curve

The J-value model predicts the shape of the (Samuel) **Preston curve**, which plots life expectancy *at birth* against GDP per head. The J-value model predicts the risk-aversion to be $\varepsilon_P = \varepsilon - 0.04 = 0.91$. This is confirmed by the data.

J-value theory suggests that for rich countries, $\varepsilon = \varepsilon_P = 0.91$.

$\varepsilon = 0.91$ may also be derived from UK data on the average lifetime work fraction under the assumption that the employee enjoys his working time only half as much as his free time – a 50-50 deal with his employer.



Pure time discount rate and global warming

- The **Stern Review** of the Economics of Climate Change, was carried out for the UK Government in 2006.
- Lord Stern assumed a long-run growth, g, of per capita output of 1.3% per year and, **more controversially**, a pure time discount rate, λ, of **0.1%** p.a.
- The argument for the value of λ was described by Yale economist, William Nordhaus, as "**actually neither necessary nor sufficient**".
- The recommendation for "**sharp and immediate reductions in greenhouse gas emissions**" depended critically and "**decisively on the assumption of a near-zero time discount rate [λ]**" (Nordhaus).
- The J-value validation exercise shows, however, that $\lambda = g(1-\varepsilon)$.
- Allowing for long-term development, $\varepsilon = 0.91$, so, using $g = 1.3\%$ per year, the equation yields **λ = 0.12% p.a., confirming Stern's hypothesis**.
- See also Stern, N., 2015, *Why are we waiting,* MIT Press, Cambridge, USA.

Summary

- The Preston curve of life expectancy at birth against GDP per head has been explained for the first time.
- Frank Ramsey's and Lord Stern's hypotheses of a very low pure time discount rate have been corroborated.
- **The J-value method for assessing how much should be spent on safety measures has been validated against empirical data.**

As low as reasonably practicable (ALARP)

- The adverb, "reasonably", brings in considerations of time, trouble and hence cost.
- The J-value gives a quantification of ALARP:
  - health and safety spending at J = 1 is shown by the data to comply with what people all over the world regard as reasonable to spend on life-extending measures.

Gross disproportion

- If desired, gross disproportion can be incorporated very easily into the J-value method:
  - instead of setting the boundary for overspending at **J > 1**, set it at, for example, **J > 3**, if a factor of **3** is decided as an the appropriate level of disproportion expected; or any other number > 1.

So what about the UK's "value of a prevented fatality" or VPF?

- It needs to be realised at the outset that the idea of a VPF, with its single value for people of all ages, suffers some logical drawbacks.

Logical problems with the single-valued VPF - 1

- The alternative to regarding the restoration of life to come as the benefit of the safety measure is to choose to consider that each living person possesses a "**vital spark**" or something similar that is **not related to the duration of future life**.
- Making this "vital spark" the sole item of value will then yield a **single-valued VPF**.
- But now we have **moved away from science** into the realm of metaphysics, **removing the possibility** of **scientific discussion** or **rational challenge**.

Logical problems with the single-valued VPF - 2

- If the true benefit is the restoration of life to come, then a **single-valued VPF implies** that the average value of **a future day for an old person** will be **much more valuable** that the average value of a future day **for a young person**.
- For a very old person, the **value per unit time** of the last few minutes will tend towards a Dirac delta function – an **infinite spike**.
- Neither of these consequences corresponds with what a reasonable person might think.

University of BRISTOL

SAFETY SYSTEMS RESEARCH CENTRE

The message from Professor John Broome

"If you expose somebody to risk by driving down a street and, as a matter of bad luck, you kill her, then what you have done is to deprive her of the rest of her life.

"That may be a big deprivation or it may be a comparatively small deprivation.

"If she is young, with a full life ahead of her, it is a very big harm that you have imposed on her.

"On the other hand, if she was not very far from death in any case, then it is a much smaller harm that you have imposed on her.

"The value of life is a quantitative matter. Some people suggest that life has an infinite value but it does not: it has a finite value and it is a matter of quantity."

– **John Broome, White's Professor of Moral Philosophy, Oxford University**, RAEng Seminar on *The Economics and Morality of Safety*, 16 February 2006

Hierarchy for measuring the value of a good

1. the market value if a **free market** in the good exists – ideal way
2. the value deduced from **revealed preferences** – "I have always thought the actions of men the best interpreters of their thoughts" – John Locke
3. the value deduced from **stated preferences**, typically from opinion surveys – **Problem**: "respondents in stated preference surveys may have an incentive to **deliberately misrepresent** their true preferences in order to achieve a more desirable outcome for themselves ... individuals may overstate their valuations of the good if they believe their responses influence its provision and are unrelated to the price they will be charged for it" Fujiwara and Campbell - Greenbook valuation techniques 2011.

The UK VPF is based on the 3rd – and least reliable – option

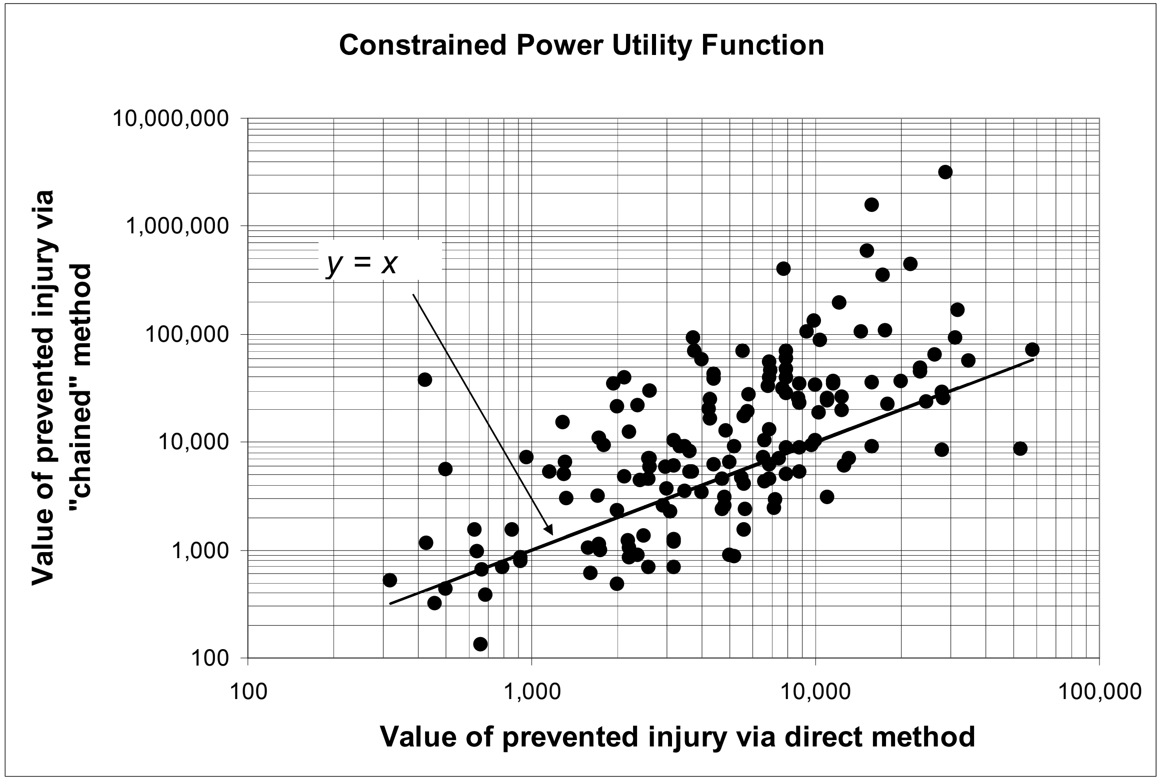
- But there are **further issues** with the UK VPF.
- Because the opinion surveyors rejected the results of their first two surveys to find the VPF as unreliable.
- Hence the UK VPF is based on a survey of 167 people conducted 20 years ago, with the results interpreted using a method of the surveyors' own devising: the **2-injury chained method**.

The effect of a person's wealth

- The 2-injury chained method uses a complex framework for interpreting the survey results based on the utility of a person's **wealth**.
- The final step in the process is to take the **average of all the individual VPFs**.
- For this to have a chance of working, the **167** people in the sample would need to **represent the UK wealth distribution**.
- The average wealth per UK adult in 1997 was **£78,300**.
- The average wealth from the VPF study can be back-calculated via one of the surveyors' utility functions as either **£1,730** or **£5,252** – far too low.
- (One wealth being 3 times the other is another problem).

Same measurement, different answers

- The 2-injury chained method used two different ways to measure the same quantity – the value of prevented injury for the same injury, the first direct and the second "chained".
- Common sense suggests that two measurements of the same quantity, the "value of a prevented injury" *for the same injury* should be the same.
- The measurements **need to be the same** for the **VPF to be valid**
- Using the 2-injury chained method, they turn out to be **very different** and **barely correlated**.



Log scale for each axis. Note the **very high degree of scatter** on each axis. VPI (£$_{1997}$):

£300 - £60,000 (x-axis)

£100 - £3M (y-axis)

Best fit: ***y* = 8.24*x***

R^2 = 0.07

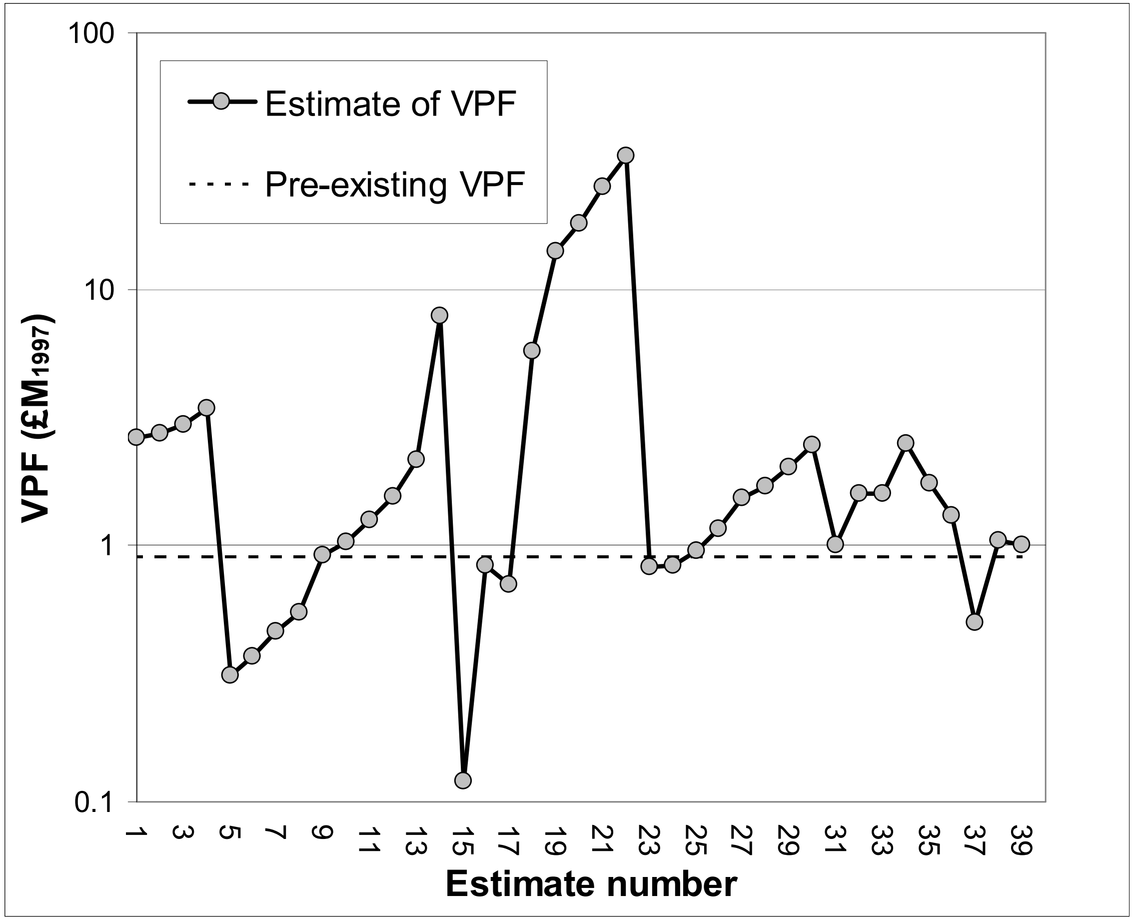
VPI (£$_{1997}$) for same injury **(utility function giving highest correlation)**

Data courtesy of **Prof. M. Jones-Lee**, as used in **Carthy, T, Chilton, S., Covey, J., Hopkins, L., Jones-Lee, M., Loomes, G., Pidgeon, N. and Spencer, A., 1999, "On the contingent valuation of safety and the safety of contingent valuation: Part 2 – the CV/SG chained approach",** *Journal of Risk and Uncertainty*, Vol. 17, 187 – 213.

University of BRISTOL

- The **2-injury chained method** has **failed a fundamental test** of its validity: **it must be regarded as invalid**.
- The opinion surveyors were apparently aware of the problem and its scale ("**we were fully aware of, and open about this discrepancy**"*), but decided to carry on anyway.
- They have said that their first useful contribution was the provision of "**evidence which, when blended with judgement, helped consolidate the VPF**"*.
- But the range over which they gave themselves freedom to exercise their judgement was enormous.

* Chilton, S., Covey, J., Jones-Lee, M., Loomes, G., Pidgeon, N., Spencer, A., 2015, "Response to Thomas and Vaughan", *Process Safety and Environmental Protection*, Vol. 93, pp. 293 – 298



The finally recommended VPF is conceded by the authors to be a "judgement call" – the judgement of the surveyors, not the surveyed.

The 39 steps to the UK's official VPF (£1997)

- It would be surprising if a figure derived from the invalid 2-injury chained method were to be correct.
- And indeed it is **incorrect**.
- The new information from the validation of the J-value against pan-national data allows the monetary value of the population-average life expectancy for the UK in 2015 to be calculated objectively. It is between 4 and 5 times higher.

University of BRISTOL

SAFETY SYSTEMS RESEARCH CENTRE

Comparison of valuations of life

Population-average expected life, UK, based on J-value (2015, £M)	US Department for Transportation VSL (2015, £M) (Revealed preference)			UK VPF: 1995/6 rejected surveys (full analysis*) (2016, £M)		UK VPF: 1997 survey of 167 people. 2-injury chained method (2016, £M)
	Lower	Middle	Upper	Lower	Upper	
8.6	**3.94**	**7.01**	**9.78**	**16.0**	**22.0**	**1.83**

* Thomas, P. and Vaughan, G., 2014, "Explaining Perceived Inconsistencies in “Stated Preference” Valuations of Human Life", *American Journal of Industrial and Business Management*, Vol. 4, No. 9, 442-473.

Summary on the UK VPF

- The UK VPF was derived 20 years ago using an **invalid** method.
- The value produced by this invalid method produces is **wrong**.
- The UK VPF values life in the UK between 4 and 5 times **too low**.

University of BRISTOL

The problems with stated preference methods

- Even the UK VPF opinion surveyors saw their 2nd useful purpose as:
  - **"demonstrating the need and potential for further work to improve the methodology of stated preference elicitation in respects where limitations undoubtedly exist."**
- By contrast the **US Department of Transportation** has decided to **move up the measurement hierarchy** from stated preferences to **revealed preferences**.
- This puts the US DoT assessment method in the same class as the J-value.
- The J-value has the **further, unique benefit** that it has been **validated against empirical data**.

Inaccuracy of the VPF approach. Example: the mismatch from applying a VPF to a radiation risk

- Nuclear risks require a consideration of what is actually at stake, which is the **potential loss of some life expectancy**.
- For radiation cancer victims, those who **actually die of a radiation induced cancer**, the average loss of life expectancy will be between **9 and 22 years**.
- The average loss of life expectancy in an **immediately fatal accident** (explosion, car crash, rail crash) is **42 years**.
- This very large difference means that the VPF is **unsuitable for use** in assessing a nuclear safety system to prevent a **big nuclear accident**, for example.

- The **J-value** has been used in the NREFS project to shed light on the authorities' responses after Chernobyl and Fukushima.

The NREFS Project: Management of Nuclear Risk Issues: Environmental, Financial and Safety

- Sponsored by the Engineering and Physical Science Research Council as a contribution to the UK-India Civil Nuclear Power Collaboration.
- 4 UK universities, led by Philip Thomas as Principal Investigator. The work was completed during his time at the University of Bristol (2015 onwards):

CITY UNIVERSITY LONDON

MANCHESTER 1824 The University of Manchester

The Open University

THE UNIVERSITY OF WARWICK

University of BRISTOL

The closing papers of the NREFS study were published as a Special Issue, Vol. 112A, of *Process Safety and Environmental Protection*, 20 Nov 2017

Loss of life expectancy after the Chernobyl reactor accident of 1986

- The average person living **in the UK** lost: **2 h 40 min**.
- The **116,000** people relocated in 1986: **9.3 days**.
- But what if the "Chernobyl 116,000" had **not** been relocated?
  - **85,000** would have lost, on average, **3 months** life expectancy
  - **31,000** would have lost more than **9 months** and needed to be relocated according to the **J-value**.
  - Under the 95th percentile heuristic (ICRP Representative Person), where whole settlements would be relocated if **5%** would lose 9 months' life or more, raises the figure to **72,000**.

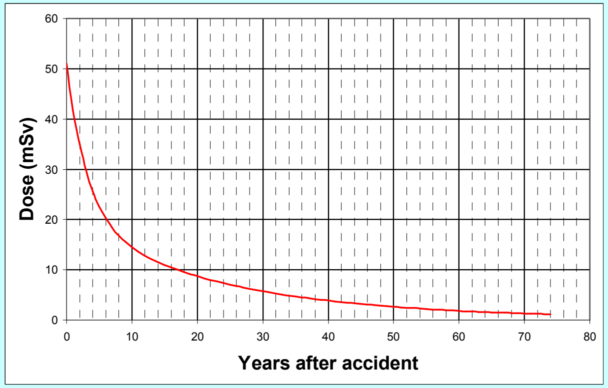
Life expectancy saved by the second mass relocation after Chernobyl in 1990

- **220,000** people were relocated after 1990.
- The most highly exposed **1,000** of these would have lost **3 months** life expectancy if they had not been moved away, **two thirds** of what the average Londoner loses to air pollution at the current time.
- The J-value recommends that **none of these 220,000** people should have been asked to move out.
- The J-value recommends that at least **80%** of the people moved after Chernobyl **should not have abandoned** their homes.

Increase in life expectancy from moving away from Fukushima Daiichi

- The **16,000** inhabitants of Tomioka Town faced the highest radiation dose, **51 mSv** in year 1.
- This will have fallen to the Japanese Government's safe-return annual dose of **20 mSv** in about 6 years – we should be past that point now.
- Some villages, such as Naraha Town (original pop. **7,700**), 1st year dose **7 mSv**, have been declared "open" since 2015. Only **1500** had returned to Naraha by April 2017.

Falling dose rates with time



- People in Tomioka would have gained just under **3 months** life expectancy by relocating for 6 years.
- The residual dose, starting at 20 mSv and decaying over 70 years will cost them a further **2 – 3 months**

The J-value recommendation on relocation after Fukushima

- Relocate **none** of the **160,000** people who moved away after the Fukushima Daiichi accident, **not even those living in Tomioka Town**.
- The loss of life expectancy is only about **2/3** of the loss of life Londoners can expect to lose as a result of air pollution.
- *Note: this result was achieved using the J-value, which we have seen values people's lives **more than 4 times higher** than the **UK VPF**, so it is not a "soft" approach by existing UK standards.*

Conclusions from the NREFS analysis

- The big lesson is **how small** the radiation damage has been to the members of the public from even the **biggest** nuclear reactor accidents.
- Most of the harm has come from what can now be seen to be **unjustified fear and worry** and from the **social disruption and dislocation** caused by relocation of hundreds of thousands of people.
- In the past, the so-called **solution has become the problem**.
- Remediation should be the watchword for any future big nuclear accidents **not** relocation.
- These conclusions are borne out by the 3 methods used in NREFS:

1. **J-value** (J for Judgement) assessment applied to the **Chernobyl and Fukushima Daiichi** accidents (*led by City, University of London then Bristol University*)
2. **Optimal economic control** (including health effects) applied to **hundreds** of conceivable big nuclear accidents worldwide (*led by Manchester University*)
3. **Public Health England's nuclear accident consequence codes, PACE-COCO2**, applied to a big accident at a **fictional nuclear reactor** located between Southampton and London (*led by the Open University*).

Dealing with big nuclear accidents in the future

- We ought to be able cope with big nuclear accidents in the future **more sensibly and effectively** than we have in the past.
- Doing so will
  - **protect the people better** and
  - **save the nation hundreds of billions of pounds** in the process.

The VPF

- Even an accurately derived VPF gives **at best** an approximate valuation of human life.
- Its single-valued nature means that it cannot discriminate
  - between different types of risks
  - between risks to populations with different age structures
- The figure for the UK VPF is too flawed to be fit for purpose and should not be used any more.

Applying the J-value to improve health and safety

The J-value is ideally suited because

- it is entirely objective
- it deals with what is actually at stake: life expectancy
- it has been validated against empirical data
- it is easy to understand for public, media, and politicians
- it creates a level playing field across all industries
- it can assess all safety systems from initial design to upgrades
- the J-value framework has been extended to allow for harm to the environment as well as humans.

Decision makers, politicians and public can be confident that they are getting **correct recommendations** from a cost-benefit analysis because they will be using **a validated** method that can **therefore be trusted.**

Selected bibliography

J-value and J-value validation

1. Thomas, P. and Waddington, I., 2017,"Validating the J-value safety assessment tool against pan-national data", *Process Safety and Environmental Protection*, Vol. 112A, 179 – 197, November. Available at: https://ac.els-cdn.com/S0957582017302896/1-s2.0-S0957582017302896-main.pdf?_tid=e4b52f78-d2c5-11e7-b19e-00000aacb360&acdnat=1511713484_c1408cbb7d734eb48189c8bec89fcd68
2. Thomas, P., 2017, "Corroboration of the J-value model for life-expectancy growth in industrialised countries", Volume 13, *Nanotechnology Perceptions,* pp. 31 – 44. Available at: http://www.jvalue.co.uk/papers/2017-CorroborationOfJvalue.pdf

Problems with the UK VPF

1. Thomas, P. and Vaughan, G., 2014, "Explaining Perceived Inconsistencies in "Stated Preference" Valuations of Human Life", *American Journal of Industrial and Business Management*, Vol. 4, No. 9, 442-473. http://www.scirp.org/journal/PaperInformation.aspx?paperID=49597&#abstract
2. Thomas, P.J. and Vaughan, G. J., 2015, "Testing the validity of the "value of a prevented fatality" (VPF) used to assess UK safety measures", *Process Safety and Environmental Protection*, Vol. 94, pp. 239 – 261. http://www.sciencedirect.com/science/article/pii/S0957582014000962
3. Chilton, S., Covey, J., Jones-Lee, M., Loomes, G., Pidgeon, N., Spencer, A., 2015, "Response to Thomas and Vaughan", *Process Safety and Environmental Protection*, Vol. 93, pp. 293 – 298.
4. Thomas, P.J. and Vaughan, G. J., 2015, " 'Testing the validity of the "value of a prevented fatality" (VPF) used to assess UK safety measures': Reply to the comments of Chilton, Covey, Jones-Lee, Loomes, Pidgeon and Spencer", *Process Safety and Environmental Protection*, Vol. 93, pp. 299 – 306. http://www.sciencedirect.com/science/article/pii/S0957582014001797

University of BRISTOL

5. Jones-Lee, M., Loomes, G., 2015, "Final response to Thomas and Vaughan", *Process Safety and Environmental Protection*, Vol. 94, pp. 542 – 544
6. Thomas, P. J. and Vaughan, G. J., 2015, "Pitfalls in the application of utility functions to the valuation of human life", *Process Safety and Environmental Protection*, Volume 98, Pages 148–169. http://www.sciencedirect.com/science/article/pii/S095758201500124X
7. Thomas, P. and Waddington, I., 2017, "What is the value of life? A review of the value of a prevented fatality used by regulators and others in the UK", *Nuclear Future*, Volume 13, Issue 1, pages 32 – 39. Available at: http://www.bristol.ac.uk/cabot/news/2017/research-review-safety.html and http://www.wcsim.co.uk/files/8314/8767/9271/What_is_the_Value_of_Life_-_Published_pdf.pdf

Reponding to a big nuclear accident

1. Waddington, I., Thomas, P. J., Taylor, R. H. and Vaughan, G. J., 2017, "J-value assessment of relocation measures following the nuclear power plant accidents at Chernobyl and Fukushima Daiichi", *Process Safety and Environmental Protection*, Vol. 112A, 16 – 49, November. Available at: https://www.sciencedirect.com/science/article/pii/S0957582017300782
2. Thomas, P. J., 2017, "Age at death from a radiation-induced cancer based on the Marshall model for mortality period", *Process Safety and Environmental Protection*, Vol. 112A, 140 – 178, November. Available at: https://ac.els-cdn.com/S0957582017302677/1-s2.0-S0957582017302677-main.pdf?_tid=cb233492-d2c5-11e7-a70a-00000aab0f26&acdnat=1511713441_53af629d444baea86eb13aee2155d4d9