INCIDENCE AND LIKELIHOOD RISK AND SAFETY INDICES

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ABSTRACT

Logarithmic risk and safety *incidence* indices for application in the risk assessment for a *large* population that is subjected to some forms of common hazards such as disease or natural disasters, are introduced.

For a *limited* size population, more appropriate *likelihood* indices are derived for the comparison of hazardous activities that are peculiar to a small population that is engaged in a hazardous or other societal activity. The approach possesses a large domain of applicability. It matches intuition and provides a measurement of the levels of safety or risk on a logarithmic scale. Every unit increase in the incidence Safety Index corresponds to a Risk decrease by a factor of 10. The risk and safety indices sum up to a value of 10. Their values are defined over the interval [0, 10].

As illustrations, the methodology is applied to the analysis of the hazardous activities in a large population, the Beaufort wind scale as relevant in the monitoring and control of wind turbines, and to the unemployment situation from the local, regional and national perspectives. Useful insights for the allocation of resources, remedial actions, monitoring, and control strategies can be deduced from the proposed indices than from just the row data.

1. INTRODUCTION

Logarithmic risk and safety *incidence* indices for application in the risk assessment for a *large* population that is subjected to some forms of common hazards such as disease or natural disasters, are introduced. More appropriate for a *limited* size population, *likelihood* indices are derived for the comparison of hazardous activities that are peculiar to a small population that is engaged in a hazardous or other societal activity.

Initially suggested by Lewis [1], the concept is developed in detail, and applied to specific situations that show its usefulness in risk assessment and resource allocation [2].

The logarithm to a base 10 of a number x is the power to which 10 must be raised to equal the number under consideration.

For instance if we consider the number x:

$$x = 10^n,$$

its logarithm to the base 10 of x is:

$$\begin{aligned}\log_{10} x &= \log_{10} 10^n \\ &= n \log_{10} 10 \\ &= n.1 \\ &= n\end{aligned}$$

where:

$$\log_{10} 10^1 = 1$$
$$\log_{10} 1 = \log_{10} 10^0 = 0$$

Example 1

$$\log_{10} 100 = \log 10^2 = 2$$
$$\log_{10} 10{,}000 = \log_{10} 10^4 = 4$$

For numbers in between the powers of 10, the base 10 logarithm lies between the two nearest powers of 10.

Example 2

$$\log_{10} 100 = 2$$
$$\log_{10} 500 = 2.699$$
$$\log_{10} 1{,}000 = 3$$

2. INCIDENCE SAFETY INDEX

Consider a certain societal activity or exposure to natural or man-made hazards resulting in a number of deaths d in a given time period such a year.

For a total population of t persons, the per capita death frequency f is:

$$f_{incidence} = \frac{d}{t} \left[\frac{deaths}{person.year} \right] \quad (1)$$

A logarithmic Safety Index, SI, can be defined as the logarithm to the base 10 of 1/f, or the negative logarithm to the base 10 of f as:

$$\begin{aligned} SI_{incidence} &= \log_{10} \frac{t}{d} = -\log_{10} \frac{d}{t} \\ &= \log_{10} \frac{1}{f} = -\log_{10} f, \forall f \neq 0 \end{aligned} \quad (2)$$

The less risky the activity or exposure; the higher the value of the Safety Index SI. On the other hand, the more risky the activity or exposure, the lower the value of SI.

3. INCIDENCE RISK INDEX

A Risk Index RI can also be defined as:

$$\begin{aligned} RI_{incidence} &= 10 - SI_{incidence} \\ &= 10 - \log_{10} \frac{1}{f} = 10 + \log_{10} f, \forall f \neq 0 \end{aligned} \quad (3)$$

This bears resemblance to the Richter earthquake magnitude scale, where the larger the magnitude of the detected seismic signal; the larger is the expected damage from the earthquake.

A value of 10 on this scale corresponds to a Safety Index of zero, or assured death. A low Risk Index corresponds to a high Safety Index, and vice versa.

4. COMPARISON OF RISK AND SAFETY INDICES

The data in Table 1 show the number of deaths in a year period for several activities and their associated per capita death frequency and Risk and Safety Indices. It conveys the insight of where societal resources should be allocated; which, unfortunately, is not always the norm. In that regards, uninformed political perceptions based on preconceived biases seem to predominate.

Every unit increase in the incidence Safety Index corresponds to a Risk decrease by a factor of 10.

5. DISTINCTION BETWEEN LIKELIHOOD AND INCIDENCE RISK AND SAFETY INDICES

The incidence safety and risk indices are indications of *incidence*, but not of *likelihood*. They are useful for the assessment and comparison of common activities and exposures to hazards such as illnesses, and in general activities and procedures applied to a large population.

It should be noted that in statistics, there is a distinction between "probability" which allows the prediction of unknown outcomes based on known parameters, and "likelihood" which allows us the estimation of unknown parameters based on known outcomes.

Some hazardous activities, such as Bungee cord jumping or sky diving, are usually practiced by a small population. Accordingly, the likelihood of the activity can be more appropriately expressed by a modified index considering only the population t' that is at risk.

Consequently, it is more appropriate to consider the likelihood Safety and Risk Indices as:

$$\begin{aligned} SI_{likelihood} &= \log_{10} \frac{t'}{d} = -\log_{10} \frac{d}{t'} \\ &= \log_{10} \frac{1}{f_{likelihood}} = -\log_{10} f_{likelihood} \end{aligned} \quad (4)$$

$$\begin{aligned} RI_{likelihood} &= 10 - SI_{likelihood} \\ &= 10 - \log_{10} \frac{1}{f_{likelihood}} = 10 + \log_{10} f_{likelihood} \end{aligned} \quad (5)$$

where:

$$f_{likelihood} = \frac{d}{t'} \left[\frac{deaths}{person.year} \right], \forall f_{likelihood} \neq 0 \quad (6)$$

Example 3

If 10,000 people practice sky-diving and 20 persons among them die per year, then:

$$\begin{aligned} SI_{likelihood} &= -\log_{10} \frac{d}{t'} \\ &= -\log_{10} \frac{20}{10,000} \\ &= -\log_{10} \frac{1}{500} \\ &= \log_{10} 500 \\ &= 2.7 \end{aligned}$$

$$\begin{aligned} RI_{likelihood} &= 10 - SI_{likelihood} \\ &= 10 - 2.7 \\ &= 6.3 \end{aligned}$$

Example 4

Playing Russian Roulette by a single individual with a revolver with a six shots magazine should result in:

Table 1: Incidence Risk and Safety Indices values for hazardous activities in a large population. USA population considered as $t = 300 \times 10^6$ persons.

Activity	**Number of deaths per year d**	**Per capita death frequency [deaths/(person.year)] f = d/t**	**Incidence Safety Index SI**	**Incidence Risk Index RI**
Heart and circulatory disease	624,000	2.08×10^{-3}	2.68	7.32
Cancer deaths	500,000	1.67×10^{-3}	2.78	7.22
Premature death from smoking by heart, lung disease	300,000	1.00×10^{-3}	3.00	7.00
Motor vehicle accidents	55,791	1.86×10^{-4}	3.73	6.27
Vietnam War	43,000	1.43×10^{-4}	3.84	6.16
Accidental falls	17,827	5.94×10^{-5}	4.23	5.77
Fires and hot substances	7,451	2.48×10^{-5}	4.61	5.39
Drowning	6,181	2.06×10^{-5}	4.69	5.31
Poisons	4,516	1.51×10^{-5}	4.82	5.18
Bicycle riding	2,900	9.67×10^{-6}	5.01	4.99
Firearms	2,309	7.70×10^{-6}	5.11	4.89
Machinery, 1968	2,054	6.85×10^{-6}	5.16	4.84
Air Travel	1.778	5.93×10^{-6}	5.22	4.78
Water Transport	1,743	5.81×10^{-6}	5.24	4.76
Falling objects	1,271	4.24×10^{-6}	5.37	4.63
Electrocution	1,148	3.83×10^{-6}	5.41	4.59
Railways	884	2.95×10^{-6}	5.53	4.47
Lightning	160	5.33×10^{-7}	6.27	3.37
Hurricanes	93[†]	3.10×10^{-7}	6.51	3.49
Tornadoes	91[††]	3.03×10^{-7}	6.52	3.48
Kidnappings	50	1.67×10^{-7}	6.78	3.22
Bee stings	47	1.57×10^{-7}	6.80	3.20

† 1901-1972 average

†† 1953-1971 average

$$
\begin{aligned}
SI_{likelihood} &= -\log_{10} \frac{d}{t'} \\
&= -\log_{10} \frac{1}{6} \\
&= \log_{10} 6 \\
&= 0.78
\end{aligned}
$$

$$
\begin{aligned}
RI_{likelihood} &= 10 - SI_{likelihood} \\
&= 10 - 0.78 \\
&= 9.22
\end{aligned}
$$

This is a high risk, and unwise, activity indeed; with a likelihood risk index of 9.22, close to its maximum attainable value of 10.

6. BEAUFORT WIND SCALE INCIDENCE AND RISK AND SAFETY INDICES

The Beaufort Wind Scale is a historical wind speed classification developed for use by sailors and mariners. It was originally based on the sea states, and then extended to the land effects of the wind. The derived incidence safety and risk indices are shown in Table 2, and can be used for monitoring and for the implementation of control strategies of wind turbines.

It can be noticed that as the wind speed increases, the Safety Index SI decreases from 2.0 to zero, at the same time that the Risk Index RI increases from 8 to 10.

Table 2: Beaufort Wind scale Incidence and Safety Indices as applied to wind turbines monitoring and control. t = 34 m/s.

Beaufort Number	Wind Speed 10 meters height [m/s] d	Description	Wind Turbine Effects	Land Effects	Fraction of maximum f = d/t	Incidence Safety Index SI	Incidence Risk Index RI
0	0.0 -0.4	Calm	-	Smoke rises vertically	0.01	2.00	8.00
1	0.4 -1.8	Light	-	Smoke drifts, vanes unaffected	0.01-0.05	2.00-1.30	8.00-8.70
2	1.8 -3.6	Light	-	Tree leaves move slightly	0.05-0.11	1.30-0.96	8.70-9.04
3	3.6 -5.8	Light	Small size turbines start	Tree leaves in motion, Flags extend	0.11-0.17	0.96-0.77	9.04-9.23
4	5.8 -8.5	Moderate	Start up of electrical generation	Small branches move	0.17-0.25	0.77-0.60	9.23-9.40
5	8.5 -11.0	Fresh	Useful power generation at 1/3 of capacity	Small trees sway	0.25-0.32	0.60-0.49	9.40-9.59
6	11.0 -14.0	Strong	Rated power range	Large branches move	0.32-0.41	0.49-0.39	9.59-9.61
7	14.0 -17.0	Strong	Full capacity	Trees in motion	0.41-0.50	0.39-0.30	9.61-9.70
8	17.0 -21.0	Gale	Shut down initiated	Walking difficult	0.50-0.62	0.30-0.21	9.70-9.79
9	21.0 -25.0	Gale	All wind machines shut down	Slight structural damage	0.62-0.74	0.21-0.13	9.79-9.87
10	25.0 -29.0	Strong gale	Design criterion against damage	Trees uprooted; much structural damage	0.74-0.85	0.13-0.07	9.87-9.92
11	29.0 -34.0	Strong gale	-	Widespread damage	0.85-1.0	0.07-0.00	9.92-10.00
12	>34.0	Hurricane	Serious damage	Disaster conditions	>1.0	0.00	10.00

7. EXTENSION TO OTHER RISK ACTIVITIES

Application of the concepts of incidence and likelihood risk and safety indices can be extended to other societal activities where the damage is not just deaths, but could be injuries, economic loss, or environmental degradation. Other units for the risk estimates can be used such as probabilities.

As an example, the regional likelihood of unemployment in central Illinois is shown in Table 3. Insight can be gained from the SI and RI values regarding the allocation of job and economical development resources to different locations.

It can, for instance be inferred from the Risk Index RI values that Macon County in the Central Illinois Region; with the largest RI value of 9.09 compared with the regional value of 8.97, the state value of 9.0, and the national value of 8.98, is deserving of special attention for programs aimed at job creation.

On the other hand, McLean County with the minimum value of 8.87 appears prosperous from the job perspective. This matches the realities on the ground; because of the existence of a regional airport, car assembly plant and several university campuses.

Table 3: Regional Likelihood Risk and Safety Indices values for unemployment in Central Illinois counties. Data: Illinois Department of Employment Security, USA Department of Labor. Data not seasonally adjusted, August 2009.

County	Labor Force size t'	Jobless number d	Unemployment ratio f = d/t'	Likelihood Safety Index SI	Likelihood Risk Index RI
Champaign	102,834	8,733	8.49×10^{-2}	1.07	8.93
Coles	26,708	2,545	9.53×10^{-2}	1.02	8.98
Douglas	9,968	899	9.02×10^{-2}	1.04	8.96
Edgar	10,099	1,034	1.02×10^{-1}	0.99	9.01
Ford	7,300	772	1.06×10^{-1}	0.97	9.03
Iroquois	16,034	1,561	9.74×10^{-2}	1.01	8.99
Macon	54,723	6,794	1.24×10^{-1}	0.91	9.09
McLean	89,533	6,659	7.44×10^{-2}	1.13	8.87
Moultrie	8,033	782	9.73×10^{-2}	1.01	8.99
Piatt	8,938	772	8.64×10^{-2}	1.06	8.94
Vermillion	37,539	4,534	1.21×10^{-1}	0.92	9.08
Region	371,709	35,085	9.44×10^{-2}	1.03	8.97
State	6,630,889	656,043	9.89×10^{-2}	1.00	9.00
USA	154,897,000	14,823,000	9.57×10^{-2}	1.02	8.98

8. DISCUSSION

Application of the concepts of incidence and likelihood risk and safety indices can be extended where the damage is not just deaths, but could be unemployment, injuries, economic loss, or environmental degradation. Other units for the risk estimates can be used such as just probabilities. A different range for estimation such as the interval [0, 100] can be used for larger ranges of variation.

More specific risk could also be addressed such as radiological risks where other risk units prevail such as the risk from the exposure to different effective doses of radiation [3]. For instance, the slope of the death from cancers risk versus the radiation effective dose or dose equivalent is given as 7.9×10^{-4} [cancer deaths / (person.rem)].

The approach has a large domain of applicability compared with the more restrictive specialized indices such as the Richter scale used in the measurement of earthquakes magnitudes. It matches intuition and provides a measurement of the levels of safety or risk in different situations. The methodology is applied to the analysis of the hazardous activities in a large population, the Beaufort wind scale as applies to the monitoring and control of wind turbines, and to the unemployment situation from the local, regional and national perspectives. Useful insights for the allocation of resources, remedial actions, monitoring, and control strategies can be deduced from the proposed indices than from just the row data.

9. REFERENCES

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