The calculation of accident risks in fitness for work assessments: diseases that can cause sudden incapacity

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Risk equations have been developed to assist in determining fitness for work of people with diseases that may cause rapid loss of control. The four equations calculate the frequency of fatal injury to the person with the disease, the frequency of fatal injury to colleagues in the workplace, and the cost of fatal injury and property damage to the employer. It is suggested that the additional risk of fatal injury to the person with the disease should not exceed the fatal injury rate in high-risk industries such as forestry, fishing and mining. It is also suggested that the additional risk of fatal injury to each colleague should be no more than one-tenth of the fatal injury rate due to motor vehicle accidents in the community. Two hypothetical case examples are given, demonstrating the use of the equations. The equations highlight the need to examine the risks associated with individuals, their specific jobs and their workplaces. They also highlight significant uncertainties in the determination of fitness, which perhaps have been underestimated in the past. Wherever possible, redundant defences should be utilized to prevent accidents in the event of sudden incapacity.

Key words: Accident prevention; diabetes; discrimination; duty of care; epilepsy; fitness for work; ischaemic heart disease; risk assessment.

Received 9 October 2000; revised 12 February 2001; accepted 1 March 2001

Introduction

The determination of fitness for work of a person who has a disease that may cause rapid loss of control, such as epilepsy, diabetes mellitus or ischaemic heart disease, is fraught with difficulty for several reasons. First is the paucity of epidemiological studies on the subject. Many studies have examined motor vehicle accidents [1–14], while very few have examined industrial accidents [15,16]. Limitations have included small size, selection bias and non-differentiation of high-risk subgroups. These problems are very difficult to overcome. Secondly, there is wide variation in the frequency with which loss of control occurs in individuals with the same disease. Thirdly, the hours of work during which individuals are in direct control of a process vary greatly. Fourthly, the likelihood that loss of control will result in damage to property or injury to people also varies greatly.

The last two points are specific to each job and workplace. To satisfy duty of care requirements without discriminating against people, it is therefore important to undertake a case-specific assessment of risk. In order to do this, knowledge of the relevant medical history, the proposed job and the work location is required.

To help make decisions on fitness for work in these difficult situations, the author has developed equations for the calculation of risks attributable to loss of control. Comparison of the calculated risks with risks that are accepted by society helps decide whether they are acceptable or not. This is a form of risk evaluation [17].

Methods

Equations were developed to estimate the frequency of fatal injury to the person with the disease, the frequency
of fatal injury to colleagues in the workplace, and the cost of fatal injury and property damage to the employer.

Boolean algebra was used, as it is in fault tree analysis [17]. By way of example, imagine a situation where an event ‘A’ depends on event ‘B’ occurring AND event ‘C’ occurring. The probability of event A occurring is equal to the probability of event B occurring multiplied by the probability of event C occurring. Now imagine a situation in which either event B OR event C will cause event A. The probability of event A occurring is now equal to the probability of event B occurring plus the probability of event C occurring.

Four equations were derived. They calculate: (i) the estimated frequency of a fatal injury to the person with the disease—termed the frequency of fatal personal injury: \( F_{\text{FPI}} \) (year\(^{-1}\)); (ii) the estimated frequency of a fatal injury to each colleague at risk—termed the frequency of fatal colleague injury: \( F_{\text{FCI}} \) (year\(^{-1}\)); (iii) the estimated cost of damage to property: \( C_{\text{PD}} \) (£/year); and (iv) the estimated cost of fatal injuries: \( C_{\text{FI}} \) (£/year).

\[
F_{\text{FPI}} = F_{\text{LOC}} \cdot P_{\text{O}} \cdot P_{\text{FPI}}
\]

(1)

where \( F_{\text{LOC}} \) is the frequency of loss of control (year\(^{-1}\)), \( P_{\text{O}} \) is the probability that the person is operating the process at the time of losing control and \( P_{\text{FPI}} \) is the probability that the loss of control results in fatal injury to the person operating the process.

\[
F_{\text{FCI}} = \frac{F_{\text{LOC}} \cdot P_{\text{O}} \cdot P_{\text{FCI}} \cdot N_{\text{FT}}}{N_{\text{R}}}
\]

(2)

where \( F_{\text{LOC}} \) is the frequency of loss of control (year\(^{-1}\)), \( P_{\text{O}} \) is the probability that the person is operating the process at the time of losing control, \( P_{\text{FCI}} \) is the probability that the loss of control results in fatal injury to a colleague, \( N_{\text{FT}} \) is the number of colleagues in the fatal trajectory and \( N_{\text{R}} \) is the total number of colleagues at risk—those who could have been in the fatal trajectory.

\[
C_{\text{PD}} = F_{\text{LOC}} \cdot P_{\text{O}} \cdot P_{\text{MLD}} \cdot C_{\text{MLD}}
\]

(3)

where \( F_{\text{LOC}} \) is the frequency of loss of control (year\(^{-1}\)), \( P_{\text{O}} \) is the probability that the person is operating the process at the time of losing control, \( P_{\text{MLD}} \) is the probability that the loss of control results in maximum likely damage and \( C_{\text{MLD}} \) is the cost of maximum likely damage (£).

\[
C_{\text{FI}} = 10^6 \cdot [F_{\text{FPI}} + (F_{\text{LOC}} \cdot P_{\text{O}} \cdot P_{\text{FCI}} \cdot N_{\text{FT}})]
\]

(4)

where \( F_{\text{LOC}} \) is the frequency of loss of control (year\(^{-1}\)), \( P_{\text{O}} \) is the probability that the person is operating the process at the time of losing control, \( P_{\text{FCI}} \) is the probability that the loss of control results in fatal injury to a colleague and \( N_{\text{FT}} \) is the number of colleagues in the fatal trajectory. A value of £1 000 000 is assigned to each life lost.

\( F_{\text{LOC}} \) can be estimated from the medical history. For example, a person with epilepsy may have a history of seizures approximately every 3 months or may have not had a seizure for 5 years. The \( F_{\text{LOC}} \) of these histories is 4 year\(^{-1}\) and 0.2 year\(^{-1}\), respectively. Alternatively, an estimate may be made using clinical judgement.

\( P_{\text{O}} \) can be estimated from the number of hours per week spent operating the process and the number of weeks worked per year:

\[
P_{\text{O}} = \frac{\text{hours operating per week} \times 168 \text{ h per week}}{\text{weeks worked per year} \times 52 \text{ weeks per year}}
\]

(5)

\( P_{\text{FPI}} \) and \( P_{\text{FCI}} \) are scenario specific. However, in most scenarios, the probability of the following factors will apply and should be multiplied to calculate an estimate of \( P_{\text{FPI}} \) or \( P_{\text{FCI}} \):

\( P_{\text{FPI}} \):

- The probability that a colleague takes no corrective action (\( P_{\text{NCA}} \)); for example, fails to push an emergency stop button on a piece of machinery.
- The probability that the process continues to operate after loss of control with sufficient energy to cause fatal injury to the operator (\( P_{\text{PFPI}} \)); for example, that the accelerator of a truck is still depressed.
- The probability that the process has a trajectory that will cause fatal personal contact (\( P_{\text{PFPT}} \)); for example, a truck heading towards a reinforced concrete pillar.

\( P_{\text{FCI}} \):

- The probability that a colleague takes no corrective action (\( P_{\text{NCA}} \)).
- The probability that a colleague takes no evasive action (\( P_{\text{NEA}} \)); for example, fails to jump out of the way of an oncoming forklift.
- The probability that the process continues to operate after loss of control with sufficient energy to cause fatal injury to a colleague (\( P_{\text{PFCT}} \)).
- The probability that the process has a trajectory that will cause fatal contact with a colleague (\( P_{\text{FCIT}} \)).
- The probability that the process has a trajectory that will cause fatal contact with a colleague (\( P_{\text{FCIT}} \)); for example, a forklift heading towards a colleague. In this example, the probability depends on the number of people working in the area and how confined the area is. In a closed system, however, such as a falling mine cage (lift), where the winder driver has lost control, the probability is not dependent on either of these factors. Provided there is at least one person in the cage, the probability of a fatal trajectory is 1.00. A similar scenario is a falling passenger aircraft, where the sole pilot has lost control.

In order to determine maximum acceptable risk levels, it is useful to examine risks that have already been accepted by society. The population of Australia in 1998 was
The number of deaths caused by motor vehicle accidents in the same year was 1731. The average risk was therefore $9.23 \times 10^{-5}$ year$^{-1}$. It seems reasonable to expect that the additional risk of fatal injury to a colleague imposed by employment of an applicant should be significantly less than this. I suggest a maximum acceptable risk of $10^{-5}$ year$^{-1}$ for $F_{FCI}$, approximately an order of magnitude lower. This equates to a 0.045% chance of fatal injury during a 45 year career for each colleague at risk.

The highest work-related fatal injury rates in Australia between 1989 and 1992 occurred in the following industries: construction, agriculture, transport and storage, mining, fishing and forestry. The rates ranged from $1.0 \times 10^{-4}$ to $9.3 \times 10^{-4}$ year$^{-1}$. Although an applicant may be willing to accept a higher personal risk of fatal injury than his colleagues would, it seems unreasonable to allow the additional risk to significantly exceed that which is found in these high-risk industries. I suggest a maximum acceptable risk of $10^{-3}$ year$^{-1}$ for $F_{FPI}$. This equates to a 4.5% chance of fatal injury in a 45 year career.

Case examples

Two hypothetical case examples are given to demonstrate use of the equations.

Case example 1

A person with epilepsy applies for a job as a storeman at a smelter. The job requires that he drive a forklift for a total of 4 h per week in an area $15 \times 15$ m. There are 4 weeks of annual leave per year. There are 10 storemen, any three of whom are likely to be in the forklift area at any one time. The applicant has a history of two grand mal seizures per year for the last 2 years. His general practitioner attributes his seizures to episodes of poor medication compliance. Therapeutic levels have been obtained on the current regimen, which has remained unchanged for 2 years. No significant side-effects have been reported.

The risk calculations are as follows:

**Equation 1:**

$F_{FPI} = F_{LOC} P_O P_{FPI}$

$F_{LOC} = 2$ year$^{-1}$

$P_O = (4/168) (48/52) = 0.022$

$P_{FPI} = P_{NCA} P_{FPHE} P_{FPIT} = 0.9 \times 0.05 \times 0.2 = 0.009$

$F_{FPI} = 4.0 \times 10^{-4}$ year$^{-1}$

**Estimate rationale:**

$P_{NCA} = 0.9$. I estimate that the chance of a colleague being able to jump on board the runaway forklift and control it is ~10%. In other words, the chance of no effective corrective action is 90% or 0.9.

$P_{FPHE} = 0.05$. I estimate that the chance that the accelerator remains depressed and that sufficient space exists for acceleration to reach a lethal speed for the driver is ~5% or 0.05.

$P_{FPIT} = 0.2$. I estimate that the chance of the forklift trajectory coinciding with a very solid object, or an object causing fatal entanglement, is ~20% or 0.2.

**Equation 2:**

$F_{FCI} = (F_{LOC} P_O P_{FCI} N_{FT})/N_R$

$F_{LOC} = 2$ year$^{-1}$

$P_O = (4/168) (48/52) = 0.022$

$P_{FCI} = P_{NCA} P_{NEA} P_{FCIE} P_{FCIT} = 0.9 \times 0.1 \times 0.2 \times 0.05 = 0.0009$

$N_{FT} = 1$

$N_R = 10$

$F_{FCI} = 4.0 \times 10^{-6}$ year$^{-1}$

**Estimate rationale:**

$P_{NCA} = 0.9$. As outlined for equation (1).

$P_{NEA} = 0.1$. I estimate that the chance of a colleague being able to jump out of the way of a runaway forklift is ~90%. In other words, the chance of no evasive action is 10% or 0.1.

$P_{FCIE} = 0.2$. I estimate that the chance that the accelerator remains depressed and that sufficient space exists for acceleration to reach a lethal speed when striking a colleague is ~20% or 0.2.

$P_{FCIT} = 0.05$. I estimate that the chance of the forklift trajectory coinciding with one of three people in an area $15 \times 15$ m is ~5% or 0.05.

**Equation 3:**

$C_{PD} = F_{LOC} P_O P_{MLD} C_{MLD}$

$F_{LOC} = 2$ year$^{-1}$

$P_O = (4/168) (48/52) = 0.022$

$P_{MLD} = 0.1$

$C_{MLD} = £20\,000$

$C_{PD} = £88$ year$^{-1}$

**Estimate rationale:**

$P_{MLD} = 0.1$. The maximum likely property damage due to the runaway forklift is damage to stores, shelving and the forklift itself. I estimate that the probability of doing £20\,000 damage is ~10% or 0.1. This obviously depends on the value of the listed items.
Equation 1: \[ F_{FP} = F_{LOC} P_O P_{FCI} P_{FP} \]

Not relevant—there is no significant risk of the winder driver being killed by loss of control of the winder.

Case example 2

A person with type 1 diabetes mellitus applies for a job as a winder driver in an underground mine. The job requires that he operate the winder for a total of 40 h per week. There are 4 weeks of annual leave per year. The mineshaft cage carries a maximum of 70 workers at a time. The time-weighted average number of workers in the cage is 10. There are 400 underground workers employed at the mine. The applicant has had type 1 diabetes for 5 years, understands the management of his condition, and can demonstrate good control by means of a blood glucose diary and glycosylated haemoglobin levels. He can describe the symptoms of impending hypoglycaemia and carries sweets to correct this if necessary. He has, however, had two episodes of hypoglycaemia causing irrational behaviour and incapacity.

The risk calculations are as follows:

Equation 2: \[ F_{FCI} = (F_{LOC} P_O P_{FCI} N_{FT})/N_R \]

Estimate rationale:

\( P_{NCA} = 1.0 \). The winder driver works alone so there is no possibility of corrective action being taken by a colleague.

\( P_{NEA} = 1.0 \). The mine workers are enclosed within the moving cage and have no means of evasive action.

\( P_{FCIE} = 0.5 \). I estimate that the chance that the winder continues to run at speed is 50% or 0.5. This is because the winder is stationary or decelerating for much of a shift.

\( P_{FCIT} = 1.0 \). All the mine workers in the cage are in the trajectory.

Equation 3: \[ C_{PD} = F_{LOC} P_O P_{MLD} C_{MLD} \]

Estimate rationale:

\( P_{MLD} = 0.5 \). The maximum likely property damage due to a falling cage is destruction of the cage itself, damage to the mineshaft and lost production. I estimate that the probability of doing £5 000 000 damage is ~50% or 0.5. This obviously depends heavily on the value of lost production and therefore on the speed of repairs.

Equation 4: \[ C_{FI} = 10^6 [F_{FP} + (F_{LOC} P_O P_{FCI} N_{FT})] \]

Not relevant—there is no significant risk of the winder driver being killed by loss of control of the winder.
(FPI) is not relevant in this case. The estimated frequency of fatal injury for each of the applicant’s colleagues (FPCI) is $1.1 \times 10^{-3}$ year$^{-1}$, which is significantly higher than the suggested limit of $10^{-3}$ year$^{-1}$. The cost of property damage and fatal injuries based on the estimated values and frequencies of occurrence is £660 000 year$^{-1}$. It seems that the risk of fatal injury is unacceptable in this case and that the costs are high. It would seem reasonable to certify the applicant as unfit for this particular job.

Discussion

Brown and Shorvon, in the epilepsy chapter of *Fitness for Work* [21], highlight the need for individual risk assessment when considering job applicants with epilepsy: ‘In the case of epilepsy, the decision must be based on risk assessment and medical evidence and never on prejudice or assumption’; and ‘Every case will need to be assessed on its merits by a suitably qualified team after examination of the medical and occupational evidence’.

Waclawski and Gill, in the diabetes mellitus chapter of *Fitness for Work* [22], note that there is a trend towards individual risk assessment in those who develop insulin-dependent diabetes mellitus while employed in occupations potentially exposed to hazardous situations, such as firefighting.

It is difficult, however, to strike the right balance between duty of care and anti-discrimination when making fitness for work decisions about applicants at risk of infrequent but rapid and substantial loss of control. I think an important step towards determining the balance is establishing the limits of acceptable risk. I have suggested using the risk of fatal injury in the highest risk occupations as a limit for the applicant’s risk. This is clearly a level of risk that most people choose not to accept, but which society deems acceptable for people who are willing to take the risk. The level of risk that an applicant imposes on other workers must be considerably lower. I have suggested as a limit one-tenth of the average risk of death in a motor vehicle accident.

The risk calculations I have outlined are an attempt to determine whether individual applicants represent acceptable or unacceptable risks to themselves, their prospective colleagues and their prospective employer. This approach has the advantage that it takes into consideration not only the frequency of loss of control, but also the relevant probabilities of that loss of control causing fatal injury or damage to property at work.

A limitation of the calculations is that they are designed to assess the risks in terms of fatal injury and do not consider the risks of non-fatal injury. The calculations required to do this would be impractically complex given the range of possible injuries to be considered. Another limitation is the omission from the equations of various costs that may result from an accident, such as compensation, litigation, damage to business reputation and lost time due to psychological trauma in witness employees. Although somewhat crude, estimates of these costs could be incorporated into the term $C_{MLD}$ when calculating property damage.

Another consideration is where more than one employee has an increased risk of loss of control. If the risks are imposed on the same group of colleagues, then the risks of fatal colleague injury are additive. This may have the effect of limiting the number of people at increased risk who are employed in the same area.

The major areas of uncertainty in the fatal injury calculations are as follows:

- The predicted frequency of loss of control. There will be significant uncertainty in this estimate irrespective of whether the historic frequency or clinical judgement is used. I expect that an error of up to one order of magnitude is likely in most cases.
- The estimated probabilities of fatal energy and fatal trajectory occurrence. Careful consideration of the scenario will reduce the uncertainty. However, I expect that an error of up to one order of magnitude is likely in most cases for each probability. For some scenarios, the probabilities of fatal energy and fatal trajectory are more certain. An example is a passenger aircraft where the sole pilot has lost control. The probabilities of the aircraft crashing into something, and at speed, are almost certain.
- The estimated probabilities of no corrective action and no evasive action. I expect an error of up to one order of magnitude in most cases for each of these probabilities.

The combined uncertainty of the fatal injury calculations is, therefore, likely to be between one and five orders of magnitude. This very significant degree of uncertainty highlights the difficulty in determining fitness for work in these cases. If a cautious approach were to be taken using upper estimates of frequencies and probabilities, then few cases would be certified fit and discrimination would be likely to be alleged. If a liberal approach were taken, using lower estimates of frequencies and probabilities, then few cases would be certified unfit and duty of care would suffer. I think the best approach is probably to use estimates of frequencies and probabilities that represent the middle road between these two extremes and state the degree of uncertainty inherent in the assessments. For some scenarios, the uncertainty will be great. For others, such as the aircraft or mine cage, the uncertainty will be much less.

Although further epidemiological studies of the risk of work accidents attributable to various medical conditions would be of value, certain barriers are likely to be encountered. These include:
• The need for very large studies to collect sufficient accident data on the small proportion of the workforce who have the relevant conditions. This also limits the determination of risk by exposure classifications such as industry, occupation or task.
• The existing fitness for work assessments cause a selection bias. Workers employed in safety-critical jobs have already been selected because they do not have a medical condition that may increase the risk of loss of control.
• Employers may be reluctant to engage in this sort of research for fear of discovering elevated risks attributable to existing staff and the associated legal consequences.

In discussing loss of operator control, it is also very important to emphasize the need for redundancy of defences in systems. Wherever possible, operations should not depend solely on the control of an operator to prevent an accident. This is especially so where the consequences could be fatal or catastrophic. For both case examples, it would be possible to design devices that cause operation to cease upon loss of control by the operator. Corporations should encourage equipment manufacturers to build redundant defences such as these into their products. A caveat on the use of redundant defences is that deficiencies in any one of the defences should not be allowed to persist [23]. Otherwise, failure of another defence may ‘unexpectedly’ give rise to an accident.

In summary, my intention has been to develop accident risk equations that assist in fitness for work decisions. They highlight the need to examine the risks associated with individuals, their specific jobs and their workplaces. They also highlight significant uncertainties in the determination of fitness, which perhaps have been underestimated in the past. Wherever possible, redundant defences should be utilized to prevent accidents in the event of sudden incapacity. Professional judgement, of course, remains essential to fitness for work assessments.

References