WHY IS ROAD SAFETY BETTER UNDER DRIVING IMPAIRMENT DUE TO BOTH MARIJUANA AND ALCOHOL THAN EACH SEPARATELY? DATA ANALYTICS ANSWERS

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Abstract: Thought of encountering fatal road accidents due to *impaired driver(s)* scars public, regulating agencies, and mothers against drunk driving (MADD). For details, refer http://www.alcoholfacts.org/CrashCourseOnMADD.html . Motivated by the facts (see in Table 1) that the average number of fatal accidents caused by drivers impaired due to *alcohol alone* is worse than by drivers impaired due to *marijuana alone*. Surprisingly, a non-triviality appears. Why is it that the road safety is better when the drivers are impaired by both alcohol and marijuana? With an appropriate probability model for the incidences of fatal accidents, this article examines and explains the statistical reasons. This probability model is named *confounded Poisson distribution (CPD).* Statistical properties of CPD are identified and applied to analyze and demystify the uncertainty patterns using the fatal accidents that occurred in USA during 2013-2015 among the drivers in the age brackets 18 through 75+ years.

Key words: Confounded Poisson distribution, fatal accidents, conscious self-control, road safety, *psychologic cautionary alertness.*

1. Motivation:

Fourth major cause of deaths in USA is fatal traffic accidents (http://www.cdc.gov/nchs/fastats). Mainly its root-cause *driving impairment*. Road safety is a top priority not only to the *National Safety Board*, Federal and State agencies but also to the mothers against drunk driving. Blood alcohol concentration (BAC) is a serious cause of impairment. The BAC is identified by breath test, oral fluid test, or blood test. After a lapse of a few hours, the BAC perhaps diminishes and the driver might recover driving skill.

Another cause of impaired driving is use of marijuana (https://www.drugabuse.gov). Legal or illegal use of marijuana is increasing. Marijuana is also known in its botanical name cannabis and it is used to cure mental and physical defects. Short term effects are memory loss, impaired motor skills, and feelings of paranoia. Long term effects are addiction and behavioral problems (Ashton, 2001).

Since 1996, sixteen states and the District of Columbia in the USA have decriminalized the use marijuana for medical reason (Li et al, 2011). Marijuana alleviates cancer, HIV/AIDS, multiple sclerosis, Alzheimer's disease, post-traumatic stress disorder, epilepsy, Crohn's disease, and glaucoma. Cannabis is an effective alternative to narcotic painkillers. It is not clear how long marijuana might keep the driving impairment, because its chemical remains are detectable in body fluids for weeks after intoxication (Li et al., 2011, Hartman and Huestis, 2013).

The marijuana users are seen to frequently combine it with alcohol. There is a controversial opinion that road safety is lesser when marijuana is combined with alcohol in comparison with either marijuana or alcohol separately. The effect of marijuana does not dissipate away but rather stays on longer within the body's organs (https://www.drugabuse.gov/research-reports). Consequently, the marijuana effect could worsen the impairment when the driver is drunk with a significant BAC. Could the data on fatal traffic accidents during 2013-2015 in USA confirm it? It is rejected in this article with a probability model, which is named *confounded Poisson distribution (CPD)* here and its statistical properties.

2. Data clues and literature review about driving impairment:

First, let us look at the incidences of fatal accidents among drivers age brackets: 18-24, 25-39, 40-59, 60-74, and 75+ years in USA during 2013-2015 in Table 1 for data clues. The incidences increase until the age increases to 59 years and then decline with an overall average of 1,322. Interestingly, the average number of fatal accidents are 208, 89.5, and 44.6 respectively with the driving impairment cause alcohol alone, marijuana alone, and both alcohol & marijuana. Marijuana alone is lesser damaging compared to alcohol alone. However, contrary to any intuitive common sense, a simultaneous consumption of alcohol and marijuana damages in least the road safety. How do we explain this apparent non-triviality by a statistical methodology is the aim of this article? In other words, do drivers who consume marijuana simply exercise an extra *psychologic cautionary alertness* when compared to just alcoholic drivers? If so, how do we capture it and explain in holistic sense?

To get further insight and confirmation of this non-triviality, let us examine whether it repeats if we make group categories in terms of seniors (that is, age is above 60 years) versus non-seniors (that is, age in years fall in 18-59) as done in Table 2. Again, contrary to an intuitive common sense, a simultaneous consumption of alcohol and marijuana is least damaging the road safety. How do we explain this apparent non-triviality by a statistical methodology is the aim of this article?

Table 1. Number of fatal accidents caused by impaired driving during 2013-15 in USA (Source: Arnold, L. S. and Teft, B. C., May 16, 2016, from http://AAA.foundation.org)

Driver's age in years	**Total fatal accidents**	**Due to alcohol alone**	**Due to marijuana alone**	**Due to both alcohol & marijuana**
18-24	861	165	129.15	75
25-39	1,459	322	159.031	88
40-59	2,340	351	117	42
60-74	1,574	165	40.924	17
75+	378	37	1.512	1
Mean	1322.4	208	**89.5234**	44.6
Variance	555563.3	16596	**4316.111411**	1369.3

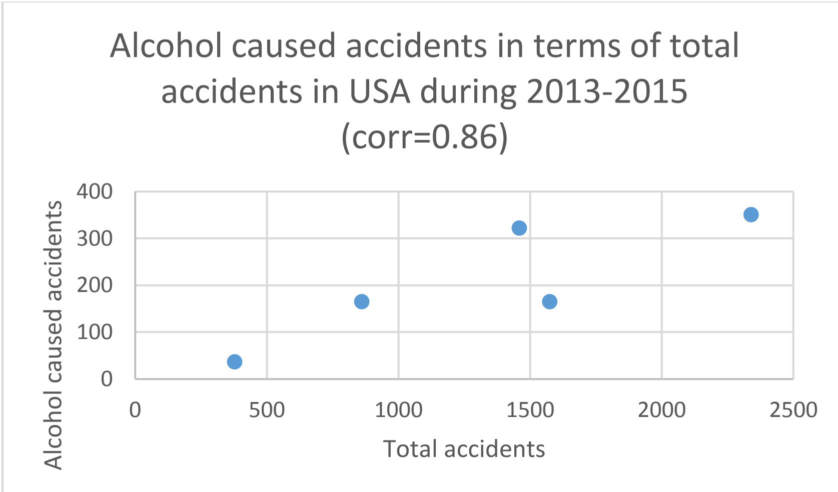

Figure 1 Alcohol caused accidents versus total accidents

Table 2. Comparison of driving impairment between adults (18-59) and Seniors (>60)

category	#fatal accidents	Due to alcohol **alone**	Due to marijuana **alone**	Due to both alcohol & marijuana
Adult (18-59)	4,660	838	405	205
Seniors (>60)	1,952	202	42	18
mean	1160	243.5	144.09	81.5
variance	178802	12324.5	446.43	84.5

Now, let us probe the relations among just alcohol, just marijuana, and alcohol-marijuana combinations caused patterns (with their correlation coefficients) fatal accidents in terms of total number of fatal accidents. Such relations are exhibited in Figures 1 through 3. Drinking alcohol alone (at a correlation level, 0.86) is most highly connected and the next is using marijuana alone (at a correlation level, 0.46) with the total number of fatal accidents. The least connected (at a correlation, 0.21) is the combination of alcohol and marijuana with the total number of fatal accidents. These data clues suggest that the impaired driver's *psychologic cautionary alertness* is too important to be missed in the scientific enquiry of driving impairment and hence, a new probability model for the data is sought and obtained in the next section.

3. ***Confounded Poisson distribution*** with its statistical properties and methodology:

There is a need to capture the confounded influence of marijuana and alcohol on the driving impairment. It has been investigated to some extent (not probabilistically) by Ramaekers et al. (2000), Sivakumar and Krishnaraj (2012), It is common to apply probability ideas to demystify the pattern of fatal accidents due to alcohol and/or marijuana (Davis, 2003 and Fuchs et al., 2012).

Let $Y = y$ be a random *number of fatal accidents* incurred by a driver who might be operating under driving impairment due to alcohol and/or marijuana usage. Suppose that the parameters $\theta > 0$ portrays the *marginal influence level* of either alcohol or marijuana as just only one of them but not both are used by the impaired driver. Then, the probability pattern of fatal accidents is explainable using the usual Poisson distribution, $p(y|\theta) = \theta^y / y! e^\theta ; y = 0,1,2,....., \infty ; 0 < \theta < \infty$

with mean, $\mu_y = E(y|\theta) = \theta$ and variance, $\sigma_y^2 = \mu_y$.

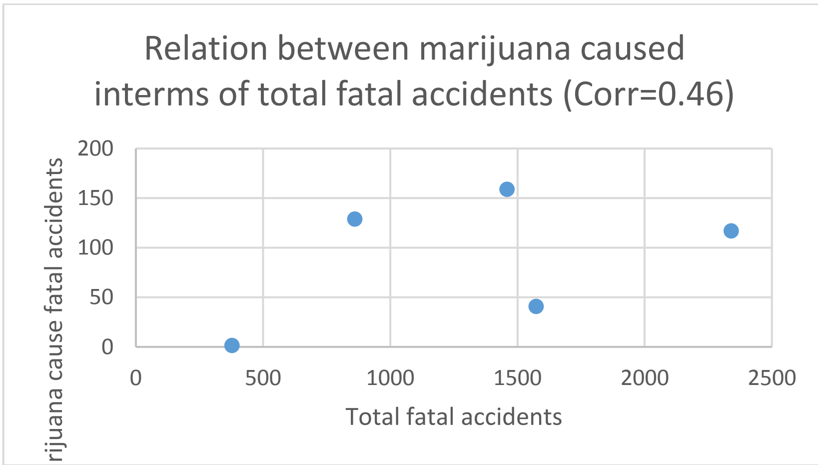

Figure 2. Marijuana caused accidents versus total accidents

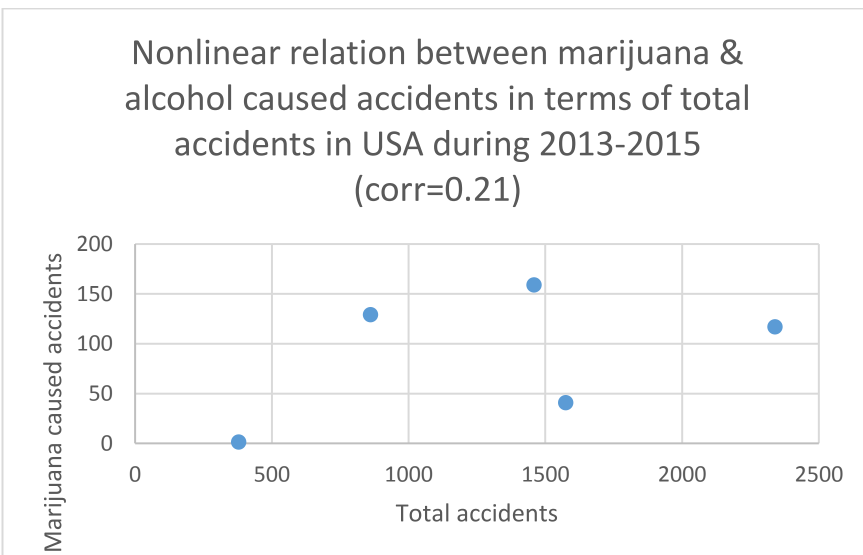

Figure 3. Marijuana caused accidents in terms of alcohol caused accidents

A challenge is in developing an appropriate distribution to model the uncertain pattern of fatal accidents caused by driving impairment under the influence of both alcohol and marijuana. In accordance with data based clues in the earlier section, driving impaired drivers must have been exercising a level of *psychologic cautionary alertness*. Because it is not measured in the data, it ought to be a parameter, $\delta \geq 0$ in our discussions. Furthermore, only when the driving impaired drivers have repeatedly incurred two or more accidents, such a *psychologic cautionary alertness* could be traced and it is the basis to infuse it as a weight factor, $w(y, \delta) = \delta y[y-1]$ in the probability modeling. Such modeling is recognized as *size biased sampling* in statistics literature (see Patil and Rao, 1978 for details). Hence, we suggest to use

$$p(y|\theta,\delta) = (1+\delta y[y-1])(\theta e^{-\delta\theta})^{y} / y!(e^{\theta e^{-\delta\theta}})(1+\delta[\theta e^{e^{-\delta\theta}}]^{2});$$
$$y = 0,1,2,.....,\infty; 0 < \theta < \infty; 0 \le \delta \le \theta^{-1} \qquad (1)$$

to capture and explain the level of *psychologic cautionary alertness,* $\delta \ge 0$ due to combined use of marijuana and alcohol, in addition to the marginal influence of alcohol on causing fatal accidents by the impaired drivers. We name the probability distribution in (1) a *confounded Poisson distribution (CPD)* in (1).

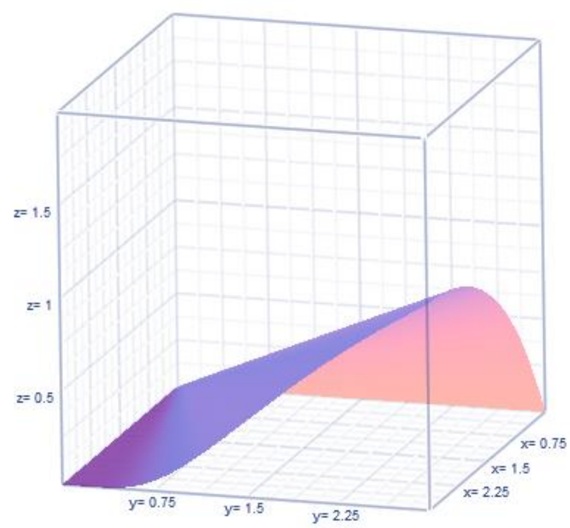

Figure 4. Risk inflation level, $\theta e^{-\delta\theta}$ for a fatal accident

The CPD was introduced by Shanmugam (2011) in another context to generalize the modified power series distribution (MPSD). When only alcohol or marijuana but not both is the cause of driving impairment, the *psychologic cautionary alertness* parameter is non-existent by default (that is, $\delta = 0$). Consequently, the *DPD* (1) reduces to the usual *Poisson distribution (PD)* which portrays the pattern of traffic accidents due to alcohol or marijuana, where the parameter θ portrays the *marginal driving impairment*.
Interestingly, when the number of accidents are already at a specified number, y , for an additional one more accident to happen, the probability is dynamically changing by an amount

$$p(y+1|\theta,\delta) = [\frac{\theta e^{-\delta\theta}\{1+\delta y(y+1)\}}{(y+1)\{1+\delta y(y-1)\}}]p(y|\theta,\delta)$$

in the *amplifier*, $[\frac{\theta e^{-\delta\theta}\{1+\delta y(y+1)\}}{(y+1)\{1+\delta y(y-1)\}}]$ varies not only due to the effects alcohol and/or marijuana but also in the neighborhood of the number, y of accidents. Realize that $p(y=0|\theta,\delta)$ portrays the probability of road safety. The *jump-start probability* from the road safety to a non-safety is then portrayed by the probability inflator, $\theta e^{-\delta\theta}$ in Figure 4. Realize that under this concept, the probability of making a fatal accident jumps to $p(y=1|\theta,\delta)=\theta e^{-\delta\theta}p(y=0|\theta,\delta)$, where $p(y=0|\theta,\delta)$ denotes the probability of making no fatal accident and the *risk inflation level* is $\theta e^{-\delta\theta}$ which is controlled by the marginal impairment influence of alcohol, $\theta>0$ and *psychologic cautionary alertness,* $\delta\geq 0$. The Figure 4 depicts their nonlinear behavior.

The mean of the *CPD* (1) is

$$\mu_y = E(y|\theta,\delta)=\theta e^{-\delta\theta}(1+\frac{2\delta\theta e^{-\delta\theta}}{1+\delta[\theta e^{-\delta\theta}]^2}) \tag{2}$$

after algebraic simplifications. Without the influence of marijuana (that is, $\delta=0$), the mean (2) reduces to $E(y|\theta,\delta=0)=\theta$. A graph (see Figure 5) illustrates confounding influences of marijuana and alcohol on driving impairment. Without marijuana influence (that is, $\delta=0$), the expected number $z=E(y|\theta,\delta=0)=\theta$ of fatal accidents with a driving impairment due to alcohol alone is simply an Euclidean plate (that is, z = θ). Otherwise (that is with the influence of marijuana), the expected number of fatal accidents with driving impairment due to alcohol's effect is twisted nonlinearly as in Figure 5.

Furthermore, to visualize the scenarios of with and without marijuana caused impairment when the driver is already intoxicated by alcohol, why not reparametrize the mean (2) and express as

$$\sigma_y^2=\mu_y+\mu_y{}^2\delta\{\frac{4+\theta e^{-\delta\theta}(\theta e^{-\delta\theta}-2)}{1+\theta e^{-\delta\theta}(\theta e^{-\delta\theta}+2)}\} \tag{3}$$

where $\sigma_y^2=\text{var}(y|\theta,\delta)$ is the variance.

In the regular Poisson chance mechanism, the variance, σ_y^2 is identical to the mean μ_y and hence, their relationship is an Euclidean plate (see in Figure 5). However, in the case of *confounded Poisson distribution (CPD)* in (1), the variance, σ_y^2 is bent quadratically (see the *bent Poisson plate* in Figure 5) by a nonlinear force $\mu_y{}^2\delta\{\frac{4+\theta e^{-\delta\theta}(\theta e^{-\delta\theta}-2)}{1+\theta e^{-\delta\theta}(\theta e^{-\delta\theta}+2)}\}$ involving the mean μ_y. When the *confounding parameter,* δ is absent (that is, $\delta=0$), the nonlinear force is nullified and consequently, no bending of Poisson plate occurs. Its implication is then that there is more *volatility* in the relationship between the variance and the mean in the case of *confounded Poisson distribution (CPD)* in (1). Otherwise, there is a *constant Poisson volatility*. In other words, the *confounding parameter,* δ quantifies the force causing to drift from the constant Poisson volatility.

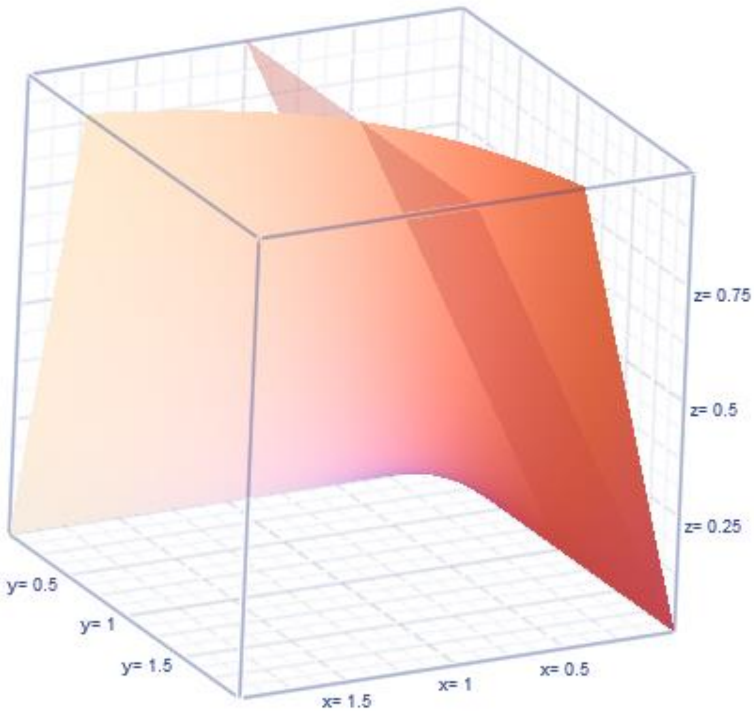

Figure 5. Normed confounding space of $z = \delta\theta$ (in a unit scale for z)

Next, let us examine the *road safety level* with *zero tolerance* (that is, no fatal accident due to any cause) *of driving impairment* is most desired by the public and traffic regulating agencies. There have been movements by the mothers against drunk driving in USA and elsewhere in other nations. To configure the chance for such zero tolerance of impairment in scenarios in which drivers could be impaired due to alcohol or marijuana influence confounded with alcoholism, we need to obtain the *survival function (SF)* of the *confounded Poisson distribution (CPD)* in (1). After algebraic simplifications (see Shanmugam, 2011 for details), the SF is obtained and it is

$$SF(m|\theta,\delta) = \sum_{y=m}^{\infty} p(y|\theta,\delta)$$
$$= [\chi^2_{2\theta e^{-\delta\theta},2mdf} + \delta(\theta e^{-\delta\theta})^2 \chi^2_{2\theta e^{-\delta\theta},2(m-2)df}] / [1+\delta(\theta e^{-\delta\theta})^2] \quad (4)$$

where $\chi^2_{2\theta e^{-\delta\theta},2mdf}$ is the tail area of chi-squared distribution with $2m$ degrees of freedom (df) and up to the percentile $2\theta e^{-\delta\theta}$. The cumulative chi-squared distribution is easily accessible in textbooks and software. The *road safety level* with *zero tolerance* as discussed above is then configured as

$$\Pr(Y=0|\theta,\delta) = 1 - SF(m=1|\theta,\delta) = [\chi^2_{2\theta e^{-\delta\theta},2df}]/[1+\delta(\theta e^{-\delta\theta})^2] \quad (5.1)$$

which is under the joint influence of marijuana and alcohol. In the presence of driving impairment due to alcohol only (that is, $\delta = 0$), the *road safety level* with *zero tolerance* is

$$\Pr(Y = 0 | \theta, \delta = 0) = 1 - SF(m = 1 | \theta, \delta = 0) = [\chi^2_{2\theta, 2df}]. \quad (5.2)$$

Clearly, the *road safety level* $\chi^2_{2\theta,2df}$ in (5.2) with driving impairment due to alcohol alone is higher than the *road safety level* $[\chi^2_{2\theta e^{-\delta\theta},2df}]/[1+\delta(\theta e^{-\delta\theta})^2]$ in (5.1) with driving impairment due to both marijuana and alcohol. Hence, the *confounded Poisson distribution (CPD)* in (1) helps to establish that the road safety level worsens when already impaired drivers due to alcohol consume marijuana also. We proved above that the volatility is also increasing along with mean number of accidents with marijuana and alcohol causing impaired drivers.

Next, let us examine the odds ratio, $\Re(\theta,\delta)$ of road safety under the driving impairment due to both marijuana and alcohol versus due to alcohol alone. First, note that the odds of road safety is $Odds_{marijuana\&alcohol} = \frac{\chi^2_{2\theta e^{-\delta\theta},2df}}{\delta(\theta e^{-\delta\theta})^2 + 1 - \chi^2_{2\theta e^{-\delta\theta},2df}}$ under the driving impairment due to both marijuana and alcohol. Secondly, the odds of road safety is $Odds_{alcohol} = \frac{\chi^2_{2\theta,2df}}{1-\chi^2_{2\theta,2df}}$ under the driving impairment due to alcohol alone. Hence, the odds ratio is

$$\Re(\theta,\delta) = \frac{Odds_{marijuana\&alcohol}}{Odds_{alcohol}} = \{\frac{\chi^2_{2\theta e^{-\delta\theta},2df}}{\chi^2_{2\theta,2df}}\}\{\frac{1-\chi^2_{2\theta,2df}}{\delta(\theta e^{-\delta\theta})^2 + 1 - \chi^2_{2\theta e^{-\delta\theta},2df}}\} \quad (6)$$

which tends to one when the *psychologic cautionary alertness* level becomes negligible (that is, $\delta \to 0$). Otherwise (that is, $\delta \to \infty$), the odds ratio shrinks.

Finally, the asymptotic maximum likelihood estimators of the parameters in *confounded Poisson distribution (CPD)* in (1) (see Shanmugam, 2011 for details) are

$$\hat{\delta} \approx \left| \frac{s_y^2 - \bar{y}}{\bar{y}^2(2\bar{y} - s_y^2)} \right|, if\, 2\bar{y} \neq s_y^2 \quad (7)$$

and

$$\hat{\theta} \approx \left| \frac{\bar{y}}{(1-\hat{\delta}\bar{y})} \right|, if\, 1 \neq \hat{\delta}\bar{y}\,. \quad (8)$$

4. **Illustration with fatal accidents data in USA during 2013-2015:**

In this section, we demonstrate the application of the results of Section 2 using the fatal accidents that occurred in USA during the years 2013-2015 as displayed in Table 1 (Source: Arnold, L. S. and Teft, B. C., May 16, 2016, from http://AAA.foundation.org). There were 6,612 fatal accidents inflicted by drivers in the age brackets: 18-24, 25-39, 40-59, 60-74, and 75+ years under driving impairment in the period. Among those fatal accidents, 223 were due to the consumption of both marijuana and alcohol with a variance of $s^2 = 1,369.3$, while 1,040 were due to the consumption of only alcohol with a variance of $s^2 = 16,596$ and 448 were due to the consumption of only marijuana with a variance of $s^2 = 4,316$. Clearly, alcohol is a more volatile and serious cause of driving impairment. The consumption of both is lesser volatile and lesser serious hazard to road safety than either alcohol or marijuana separately. This is counter-intuitional. What does the impaired drivers do for such a counter-intuitive operation of motor vehicle? We think that they must be exercising conscious based *psychologic cautionary alertness.* Because *psychologic cautionary alertness* is not measured in the data collection, it ought to be a parameter, $\delta \geq 0$ in data analysis. Hence, the *confounded Poisson distribution (CPD)* in (1) is appropriate to analyze and interpret the data evidences.

By default, note that the parameter, δ must be zero for the data in Table 1 on fatal accidents caused by those under driving impairment due to alcohol or marijuana but not both. Using the maximum likelihood estimator (8), the data based estimate of the incidence parameter is $\hat{\theta} \approx 208$ and $\hat{\theta} \approx 89.52$ respectively in the case of driving impairment due to alcohol or marijuana alone. Using the maximum likelihood estimator (7), the data based estimate of the *psychologic cautionary alertness* parameter and the incidence parameter are $\hat{\delta} \approx 0.00052024$ and $\hat{\theta} \approx 45.65$ in the case of driving impairment due to both alcohol and marijuana. Clearly, there is a finite non-zero but mild level of *psychologic cautionary alertness*. Even with a mild level of *psychologic cautionary alertness,* the incidence parameter of fatal accidents under driving impairment due to alcohol decreases from 208 to 45.65.

Using the estimates of the parameters, we note that, for road safety, the $Odds_{marijuana\&alcohol}$ under the driving impairment due to both marijuana and alcohol is 2.12538E-20, while the $Odds_{alcohol}$ under the driving impairment due to alcohol alone is 1.48035E-20. Hence, their odds ratio is $\Re(\theta, \delta) = 1.435$, suggesting that the road safety is 1.435 times better under the driving impairment due to both marijuana and alcohol than under the driving impairment due to alcohol alone.

Now, let us examine whether the theme repeats when the data in Table 2 are looked upon in terms of seniors (age is 60 years or above) versus non-seniors (below 60 years of age). By default, note that the parameter, δ must be zero for the data on fatal accidents caused by those under driving impairment due to alcohol or marijuana but not both. Using the maximum likelihood estimator (8), the data based estimate of the incidence parameter is $\hat{\theta} \approx 243.5$ and $\hat{\theta} \approx 144.09$ respectively in the case of driving impairment due to alcohol or marijuana alone. Using the maximum likelihood estimator (7), the data based estimate of the *psychologic cautionary alertness* parameter and the incidence parameter are $\hat{\delta} \approx 0.0000057$ and $\hat{\theta} \approx 81.5$ in the case of driving impairment due to both alcohol and marijuana. Clearly, there is a finite non-zero but mild level of *psychologic cautionary alertness.* Even with a mild level of *psychologic cautionary alertness,* the incidence parameter of fatal accidents under driving impairment due to alcohol decreases from 243.5 to 81.5. Using the estimates of the parameters based on categorizing data in terms of seniors versus non-seniors, we again note that, for road safety, the $Odds_{marijuana\&alcohol}$ under the driving impairment due to both marijuana and alcohol is 3.87896E-36, while the

$Odds_{alcohol}$ under the driving impairment due to alcohol alone is 3.8761E-36. Hence, their odds ratio is $\Re(\theta, \delta) = 1.00$, suggesting that the road safety is quite balanced between the cases of under the driving impairment due to both marijuana and alcohol and the case of under the driving impairment due to alcohol alone.

5. Conclusions:

Contrary to a deductive logic, we learned surprisingly, from the data analytics, that the road safety is better under the driving impairment due to marijuana and alcohol than the road safety under the driving impairment due to alcohol alone. These non-intuitive insights might not have been realized without the involvement of *confounded Poisson distribution (CPD)* in (1). There may be much more still undiscovered mysterious findings with respect to the phenomenon called driving impairment which is a great concern to the public in general and mothers against drunk driving in particular.

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