Challenging the inevitability of suicide: the effect of gun regulation on overall suicide rates and portfolio of preventative measures

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Abstract:

Firearms suicides were responsible for 23,854 fatalities in the United States in 2017, more than all other suicide methods combined. After unintentional injury, suicides are the 2nd leading cause of death for adults aged 25-34, young adults aged 15-24, and children aged 10-14. In this work, we challenge the notion that suicide is inevitable. We argue that regulatory measures to reduce firearm suicides are not only effective, but they do not exacerbate suicides by other means, thus reducing overall suicide rates. We examine the number of firearm regulations across the United States and analyze their association with suicides by firearm, non-firearm methods, and the overall suicide rate. These regulatory measures, and more broadly process-centric measures, are but one method of modifying the risk of suicide. Using a system engineering perspective, we identify many levers that contribute towards firearm suicide prevention. We introduce the safety principle of defense-in-depth, along with its companion observability-in-depth, and examine their relevance and applicability to the burden of firearm suicides. The lines of defense or safety barriers can be implemented in a variety of ways; for example, some are technical in nature, while others are regulatory and/or organizational. Broadly speaking, these safety barriers adopt three roles: preventing the suicide from occurring (e.g., secure firearm storage), blocking further escalation of the suicide sequence (e.g., suicide prevention lifelines), and mitigating the consequences (e.g., reducing the lethality of the method). We synthesize past, present, and innovative lines of defense into a *portfolio of preventative measures*, in the hope that it may contribute one small step towards suicide prevention.

Keywords: firearm, suicide, prevention

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1. Introduction

The burden of suicide has afflicted families and communities for centuries, and there is a proliferation of sobering statistics that we could cite to motivate this paper. For example, in 2017, more than 47,000 Americans took their lives—that is roughly 129 suicides per day or one suicide every 11 minutes. The vast majority of suicide attempts are committed using non-firearm methods (e.g., suffocation, poisoning, cutting, etc.); **only about 10% of attempters use a gun**. However, firearm-suicides account for over half of all suicide fatalities—nearly 24,000 in 2017. Suicide afflicts people of all ages. After unintentional injury, suicides are the 2nd leading cause of death in the United States for adults aged 25-34, young adults aged 15-24, and children aged 10-14 [1]. As tragic as these statistics are, we believe they seldom get the attention they deserve.

High-visibility firearm-related incidents, such as public mass shootings, are stark reminders of the fragility of life and the lethality of firearms. Unfortunately, firearm suicides are the true silent-but-deadly killers of our friends and family, despite what may be conveyed by the media. For example, in 2017, the Federal Bureau of Investigation reported 30 "active shooter incidents[1]" that resulted in the death of 138 individuals [2]. In contrast, that same year, 23,854 Americans shot and killed themselves with a gun [1]. These statistics reflect the overwhelming burden of firearms on our communities, and while we recognize both the complexity of this issue and the political sensitivity that is intrinsic to firearm conversations in this country, we cannot ignore these tragedies.

Some people say that suicide is inevitable. They argue that measures to reduce one method of suicide, if effective, will only exacerbate suicides by other means—that those committed to killing themselves will find a way to do so. In this work, we challenge this notion by highlighting the effectiveness of one such measure—firearm regulations—to reduce firearm suicides and show that they do not exacerbate suicides by other means, thus reducing overall suicide rates. We recognize, however, that this regulatory lever is but one method of modifying the risk of suicide (and an obstinate one at that), and we argue that there is a proliferation of content- and engineering-centric solutions, beyond purely legislative measures, that can contribute to firearm suicide prevention.

In this work, we also introduce a new set of perspectives to the community of researchers and professionals pursuing suicide prevention. These perspectives originate from the domain of system safety, and they generally apply to a class of adverse events known as *system accidents*. We argue that suicides, and more specifically, firearm suicides, share a phenomenological sameness with system accidents and that the tools of system safety can be used to prevent and block the suicide sequence (the concatenation of events leading up to the act of suicide) and to mitigate its consequences. We hope that this new perspective will foster creativity and innovation in the design phase of firearms, and to further this objective, we review and catalog past, present, and future preventative measures against firearm suicides.

The objectives of this work are thus three-fold: (1) to illustrate the effectiveness of the regulatory lever in modifying the risk of firearm suicide without exacerbating suicides by other means; (2) to introduce the suicide prevention community of researchers to the system safety principle of defense-in-depth and to examine its relevance and applicability to the burden of firearm suicides; (3) to synthesize past, present, and innovative lines of defense into a *portfolio of preventative measures*, in the hope that it may contribute one small step towards suicide prevention.

The remainder of this paper is organized as follows. In Section 2, we analyze the associations between state firearm regulation and suicide rates. In Section 3, we introduce the safety principles of defense-in-depth

[1] Defined as one or more individuals actively engaged in killing or attempting to kill people in a populated area.

and observability-in depth and examine their applicability to the burden of suicide, following which we provide our *portfolio of preventative measures* against firearm suicides. We conclude this work in Section 4.

2. Statistical analysis of suicide rates and gun laws across the U.S.

In this section, we provide a statistical analysis of suicide rates by method—namely firearm, non-firearm, and all methods, and investigate their association with the number of gun laws across the United States.

2.1. Data and methods

We obtained statewide age-adjusted (2000 U.S. Standard Population) suicide rates (per 100,000 people) from the Centers for Disease Control and Prevention (CDC), Multiple Cause of Death, 1999-2017 Database. We used the International Classification of Disease Tenth Revision (ICD-10) codes to parse the suicide rates by method (see step 6 of [4]). Table I shows our classifications of ICD-10 codes for all suicides, suicides by firearm, and those by non-firearm methods.

Table I. ICD-10 codes for suicide rates by the method used.

Method	**ICD-10 Codes**
All suicides	*U03, X60-84, Y87.0
Suicides by Firearm	X72-74
Suicides by Non-Firearm	*U03, X60-71, X75-84, Y87.0

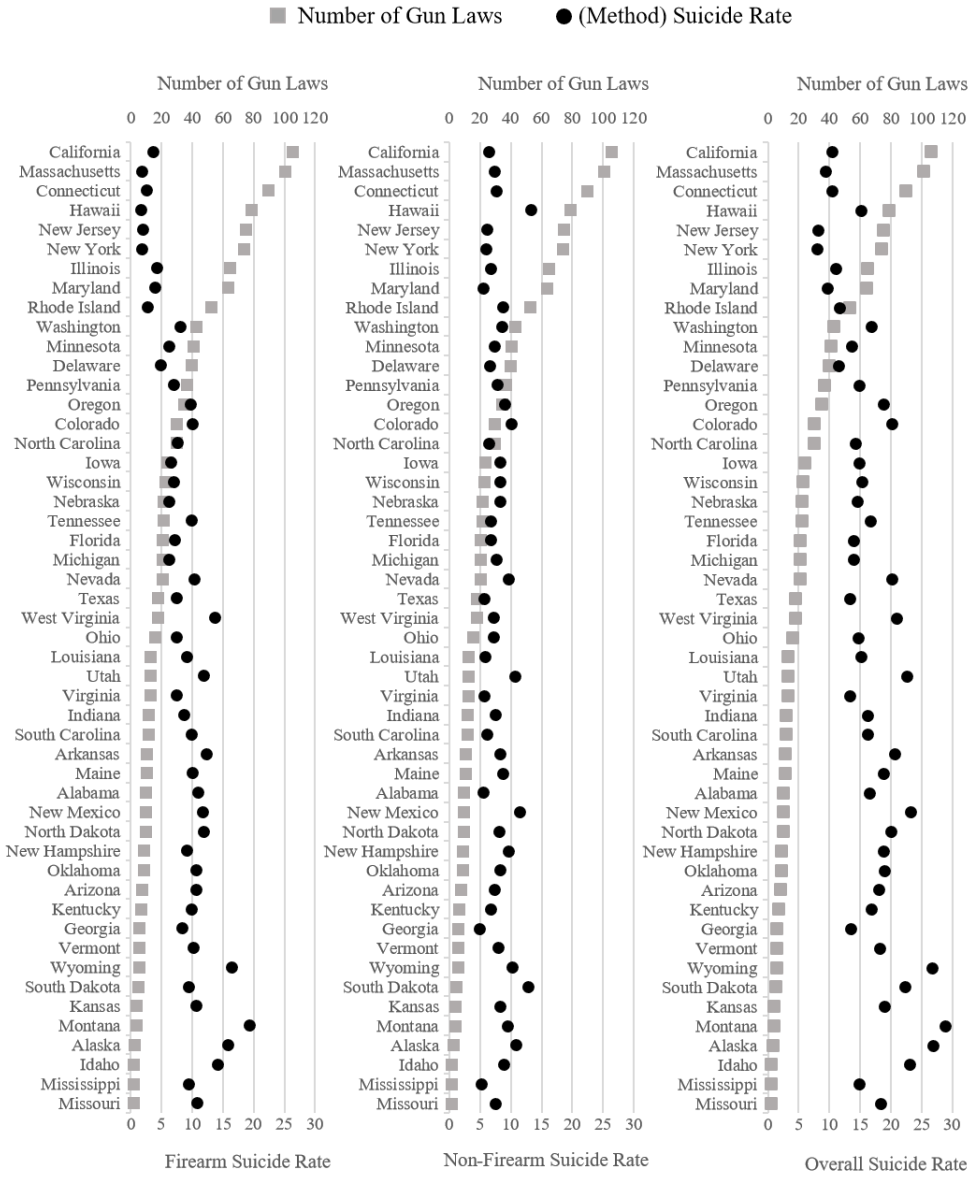
The State Firearm Law Database provided us with a library of firearm-related laws in each state for the years 1991 to 2016 [6]. In this preliminary study, we only consider the number of firearm provisions as our predictor variable. Henceforth we will use 'firearm provision' and 'gun law' interchangeably. We chose to limit our regression models in this way to highlight the effectiveness (to be demonstrated) of the regulatory lever in mitigating the risk of suicide. Considering various subcategories of firearm laws and their association with suicide rates serves as a fruitful venue for future work.

To quantify the associations (or lack thereof) between our predictor and the response, we conducted a thorough regression analysis of the suicide rates (by method) on the number of gun laws across all states. In this work, we provide the model, the regression coefficients, the correlation coefficient, and both F and partial-F test results for each suicide method. We also include the Analysis of Variance (ANOVA) tables, as well as the confidence intervals for our estimated coefficients.

2.2. Results and discussion

Recall that this paper hypothesizes that methods to reduce suicides by one method (firearms) do not exacerbate suicides by other means. In other words, we are challenging the notion that suicide is inevitable. The results of our statistical analysis directed towards this hypothesis are described in the sub-sections that follow.

The unaltered datasets of the number of gun laws and suicide rates by firearm, non-firearm, and all methods are shown in Figure 1 for the 50 United States. We separate them into panels (a), (b), and (c), respectively, to avoid excessive clutter.



(a) (b) (c)

Figure 1. The number of gun laws and suicide rates by (a) firearm, (b) non-firearm, and (c) all methods for the 50 United States.

Some key descriptive statistics are also provided below in Table II, and box-plots are shown in Figure 2.

Table II. Descriptive statistics of the variables involved in our regression analysis.

Variable	**Abbr.**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Q1**	**Q2**	**Q3**
Number of Gun Laws	(NGL)	27.14	27.4055	2	106	9	17	37
Firearm Suicide Rates	(FSR)	8.680	3.87124	1.8	19.4	6.4	9.2	10.7
Non-Firearm Suicide Rates	(NFSR)	8.022	1.85410	5.1	13.4	6.7	7.8	8.9
Overall Suicide Rates	(OSR)	16.702	4.75143	8.1	28.9	13.8	16.3	19.1

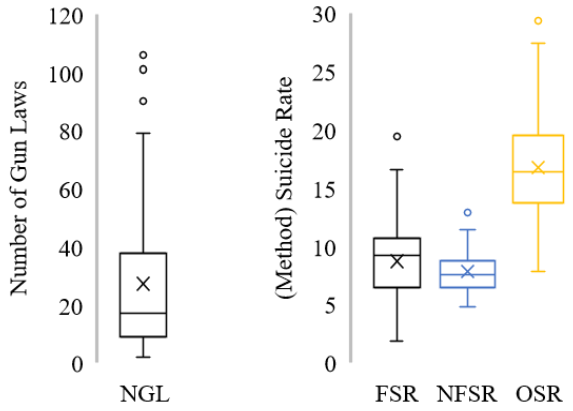


Figure 2. Box-and-whisker plots for the variables in our regression analysis.

Figure 1 provides our first indication that there is an association between the number of gun laws and suicide rates. For example, consider panel (a). It shows that, generally speaking, as the number of gun laws increase, the firearm suicide rates decrease. This trend appears to be absent in panel (b) but reappears in panel (c). We can statistically assess these (apparent) associations via regression analysis, discussed in the following subsections.

2.2.1.Firearm suicide rates and number of gun laws

Shown in Figure 3 are firearm suicide rates and number of gun laws.

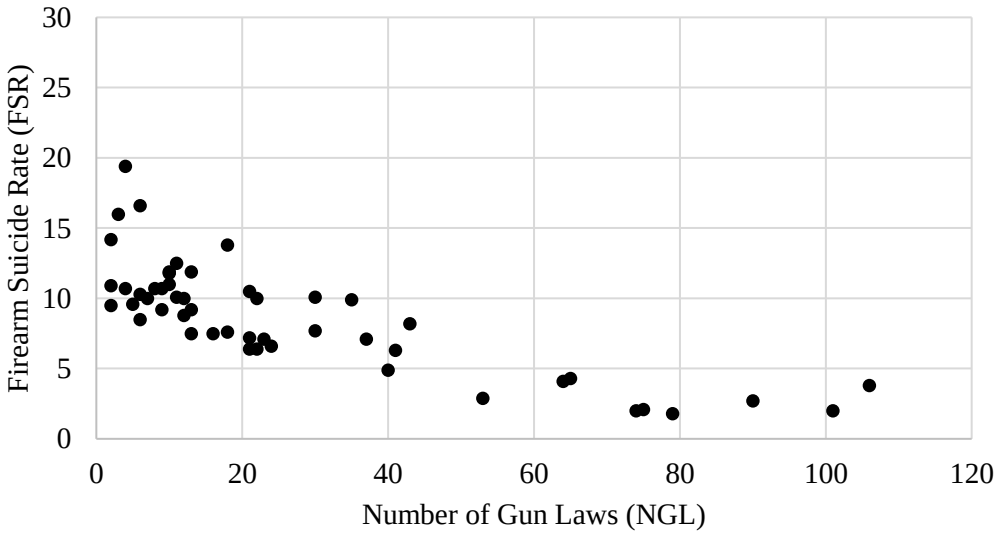


Figure 3. Firearm suicide rates and number of gun laws across the 50 United States.

It is important to note that linear regression is not restricted to linear models. For example, the best-fit model to this dataset was found to be an exponentially decaying model, taking the form as shown in Eq. (1a). We can transform this into a linear model by taking the natural logarithm of Eq. (1a), as shown in Eq. (1b).

$$\widehat{FSR} = \hat{a} \cdot e^{\hat{b} \cdot NGL} \qquad (1a)$$

$$\ln\left(\widehat{FSR}\right) = \ln(\hat{a}) + \hat{b} \cdot NGL \qquad (1b)$$

The transformed data set is shown in Figure 4, along with the linear regression model.

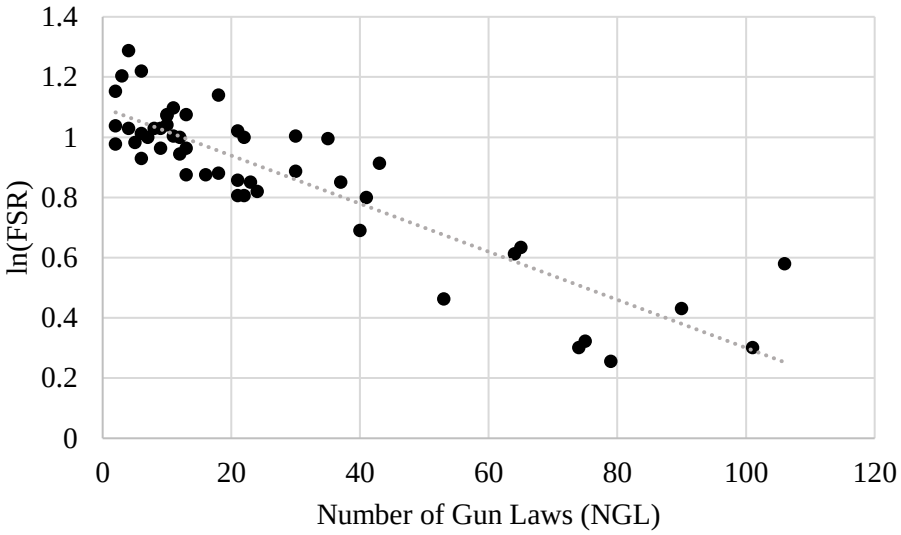


Figure 4. Transformed dataset of firearm suicide rates and number of gun laws.

We thus conduct the regression analysis of the logarithm of the firearm suicide rates *on* the number of gun laws. The key statistical results and their interpretations are shown in Table III.

Table III. Results of the regression analysis of firearm suicide rates on number of gun laws across the United States.

Source	SS	dof	MS
Model	**12.434**	**1**	**12.434**
Residual	**3.4860**	**48**	**0.0726**
Total	**15.920**	**49**	**0.3249**

No. of Obs.	= **50**
F(1,48)	= **171.20**
Prob > F	= **0.0000**
R-squared	= **0.7810**
Root MSE	= **0.26949**

$\ln\left(\widehat{FSR}\right)$	Coef.	Std. Err.	t	P > |t|	[95% Conf.	Interval]
$\hat{b}$	**-0.0184**	**0.0014**	**-13.08**	**0.000**	**-0.0212**	**-0.0156**
$\ln(\hat{a})$	**2.5299**	**0.0539**	**46.93**	**0.000**	**0.0291**	**2.6382**

Consider for example the F-statistic, shown in Table III as $F(1,48) = 171.20$. This number represents the ratio of the mean model sum of squares to the mean residual sum of squares, shown in Table III as Model MS and Residual MS, respectively. It is a measure of how much variability the model managed to explain as compared to how much variability remains unexplained. If this value is unitary, it means that the model only explained as much as was left unexplained. For our model, the F-statistic is 171.20. We can test for the statistical significance of this value using the F-test. Here we posit the *null hypothesis* that there is no association between the all predictors and the outcome, i.e., $\ln(a) = b = 0$; the *alternative hypothesis* is that there is. The corresponding p-value for the F-test is given in Table III as $Prob > F$. This is the conditional probability that, given that the *null hypothesis* is true, we observe an F-statistic as extreme or more as the one we observed (171.20). The p-value associated with this F-test is less than 0.0000 for our

model, far exceeded the common threshold of 0.05. Thus, **we *soundly* reject the null hypothesis that there is no statistically meaningful association between the number of gun laws and firearm suicide rates in favor of the alternative: that there is**. In other words, we have shown that the number of gun laws is a statistically meaningful predictor of firearm suicide rates. In fact, considering the correlation coefficient (given as "R-squared" in Table III), we see that **the number of gun laws alone explains over 78% of the variability in firearm suicides rates across America.**

These results are confirmed by the t-tests at the bottom of Table III, their corresponding p-values, and their 95% confidence intervals. Consider, for example, the estimated coefficient $\hat{b}$. Shown first is the estimated value of the coefficient, here -0.0184, following which we have the (estimated) standard error of the coefficient, here 0.0014. For the t-test, the *null hypothesis* is that the true coefficient we are estimating is zero—that is, $b = 0$—of course, the *alternative hypothesis* is that it is non-zero. The t-statistic is how far the estimated coefficient is from the null hypothesis in units of standard errors. If this value is close to zero, it means that the null hypothesis coefficient and the estimated coefficient are not much different. For the estimated coefficient $\hat{b}$, its corresponding t-statistic is -13.08, which means that the estimated value of $\hat{b} = -0.0184$ is roughly 13 standard deviations negative of the null hypothesis, $b = 0$. The corresponding p-value is the conditional probability that, given the null hypothesis is true, we obtain a t-statistic as extreme or more as the one we observed, (-13.08). The corresponding p-value for the t-test is given in Table III as $P > |t|$. The p-value associated with this t-test is less than 0.000 for the coefficient $\hat{b}$, again, far exceeding the common threshold of 0.05. Thus, we reject the null hypothesis that the coefficient on the number of gun laws is zero, and we confirm that the number of gun laws is a statistically meaningful predictor of firearm suicide rates across America. This statement is supported by the fact that the 95% confidence interval does not contain 0.

Using the estimated coefficients, we revert our linear model to the exponentially decaying model, as shown in Eq. (2) along with our best-fit curve superimposed on the dataset in Figure 5.

$$\widehat{FSR} = 12.552 \cdot e^{-0.0184 \cdot NGL} \tag{2}$$

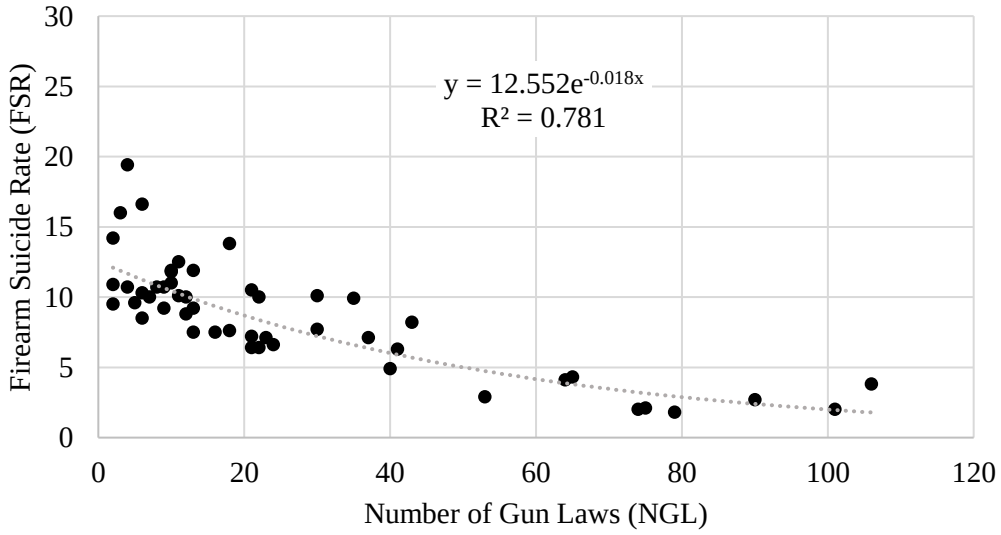


Figure 5. Best-fit model to firearm suicide rates as a function of the number of gun laws.

These results presented in this subsection are bittersweet. On the one hand, these results are stark reminders of the lethality of firearm suicides. We remind that the reader that firearm suicides account for more than half of all suicides in the U.S. (in 2017, there were 47,173 suicides, 23,854 of which were committed with

a firearm). But on the other hand, these results show that merely the number of firearm provisions, not even filtering for provisions that might contribute towards suicide prevention, is a dominant predictor of firearm suicide rates across America. This is an indication that we are not powerless against firearm suicides, that we have means of modifying the risk of suicide by firearm at least. But reducing firearm suicides alone may not be sufficient.

Recall that the motive of this paper is to challenge the notion that suicide is inevitable: that measures that reduce suicides by one method will only exacerbate suicides by other means. In this subsection, we have shown that firearm regulations, by their mere existence, are associated with reduced firearm suicide rates. In the next section, we examine suicides by other means and their association (if any) with the number of gun laws.

2.2.2.Non-firearm suicide rates and number of gun laws

Shown in Figure 6 are non-firearm suicide rates and number of gun laws.

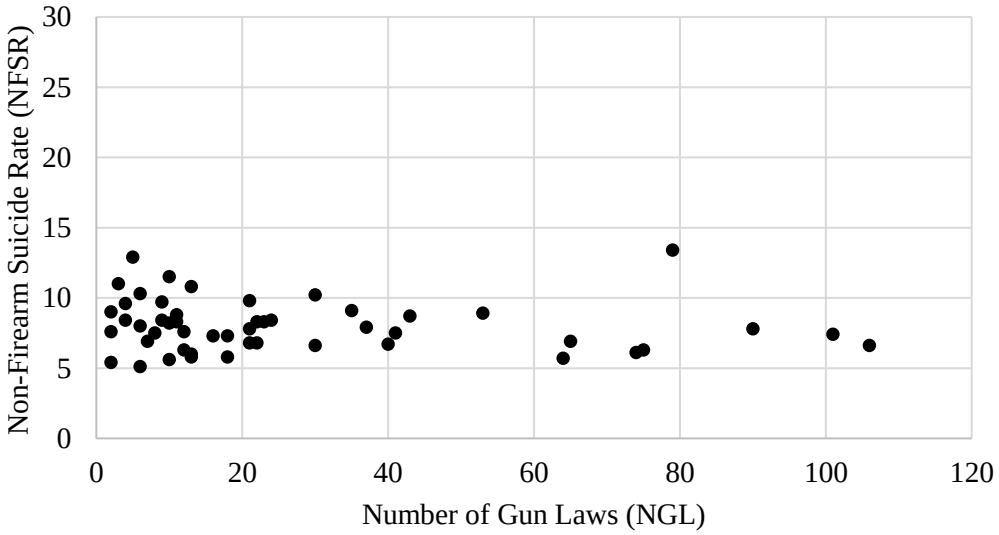


Figure 6. Non-firearm suicide rates and number of gun laws across the 50 United States.

At first glance, there is no clear association between non-firearm suicide rates and the number of gun laws. Nevertheless, we assume a linear model, taking the form as shown in Eq. (3), and we conduct a regression analysis of non-firearm suicide rates *on* the number of gun laws.

$$NFSR = \hat{a} + \hat{b} \cdot NGL \tag{3}$$

The key statistical results and their interpretations are shown in Table IV.

Table IV. Results of the regression analysis of non-firearm suicide rates on number of gun laws across the United States.

Source	SS	dof	MS
Model	**2.2609**	**1**	**2.2609**
Residual	**166.18**	**48**	**3.4622**
Total	**168.45**	**49**	**3.4377**

No. of Obs.	= **50**
F(1,48)	= **0.65**
Prob > F	= **0.4230**
R-squared	= **0.0134**
Root MSE	= **1.8607**

$\widehat{NFSR}$	Coef.	Std. Err.	t	P > |t|	[95% Conf.	Interval]
$\hat{b}$	**-0.0078**	**0.0097**	**-0.081**	**0.423**	**-0.0273**	**0.0117**
$\hat{a}$	**8.2347**	**0.3722**	**22.12**	**0.000**	**7.4864**	**8.9830**

Consider, for example, the F-statistic, shown in Table IV as $F(1,48) = 0.65$. Recall that this ratio of how much the model has explained *to* how much was left unexplained. A value of 0.65 means that more variability remains unexplained than the model managed to explain. The hypothesis test for the F-statistic returns a p-value of 0.4320. Recall that this is the conditional probability that, given the null hypothesis is true (that there is no association between the predictors and outcome), we observe an F-statistic as extreme or more than the one we observed (0.65). A p-value of 0.432 is far short of the common threshold of 0.05; therefore, **we *cannot* reject the null hypothesis that there is no association between the predictors and response variable, and we say that the number of gun laws is *not* a statistically meaningful predictor of non-firearm suicide rates.** Since we only have a single predictor, the t-test yields an identical p-value of 0.423, which is supported by the fact that 0 exists within the 95% confidence interval.

The implications of these results cannot be overstated. In the previous subsection, we showed that increasing the number of gun laws is strongly associated with reduced firearm suicide rates. The notion of the inevitability of suicide implies that where there are reduced firearm suicides, there will be an increase in suicides by other means. The results presented in this subsection directly contradict this notion. Here we see that measures that reduce suicides by firearms do not exacerbate suicide by other means. Put another way, it is not that people who live in states with fewer gun laws are more suicidal, it is that these people have access to much more lethal means.

2.2.3. Overall suicide rates and number of gun laws

Thus far, we have shown the strong association between firearm suicides and the number of gun laws, as well as the lack of any statistically meaningful association between non-firearm suicides and the number of gun laws. Since these two types of suicides are mutually exhaustive of the set of all suicides, one can predict that there will be a statistically meaningful association between overall suicide rates and the number of gun laws as well.

Shown in Figure 7 are the overall suicide rates and number of gun laws.

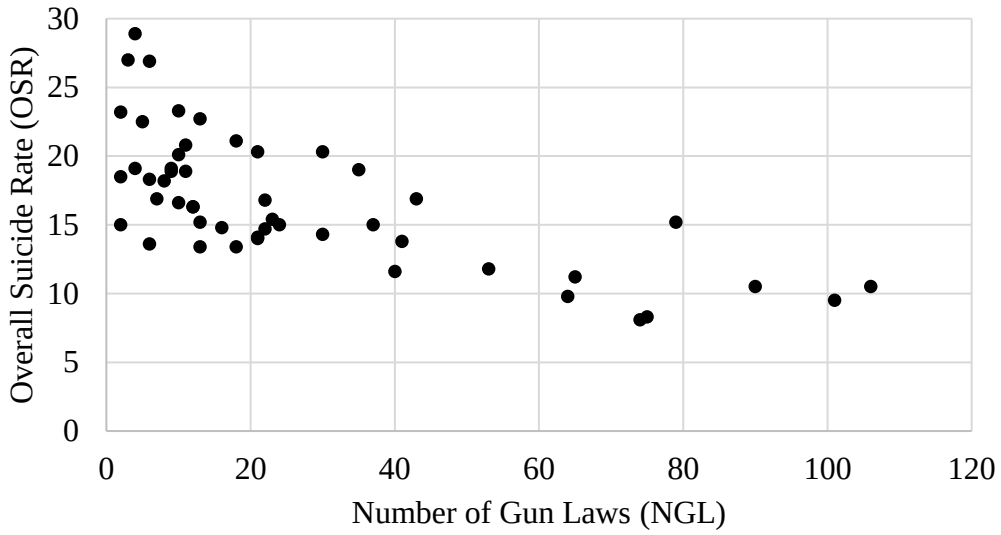


Figure 7. Overall suicide rates and number of gun laws across the United States.

The best-fit model to the overall suicide dataset was found to be an inverse model, taking the form as shown in Eq. (4a), which is easily linearized by taking the reciprocal as in Eq. (4b).

$$\widehat{OSR} = \frac{1}{\hat{a} + \hat{b} \cdot NGL} \tag{4a}$$

$$\frac{1}{\widehat{OSR}} = \hat{a} + \hat{b} \cdot NGL \tag{4b}$$

The transformed dataset is shown in Figure 8, along with the linear regression model.

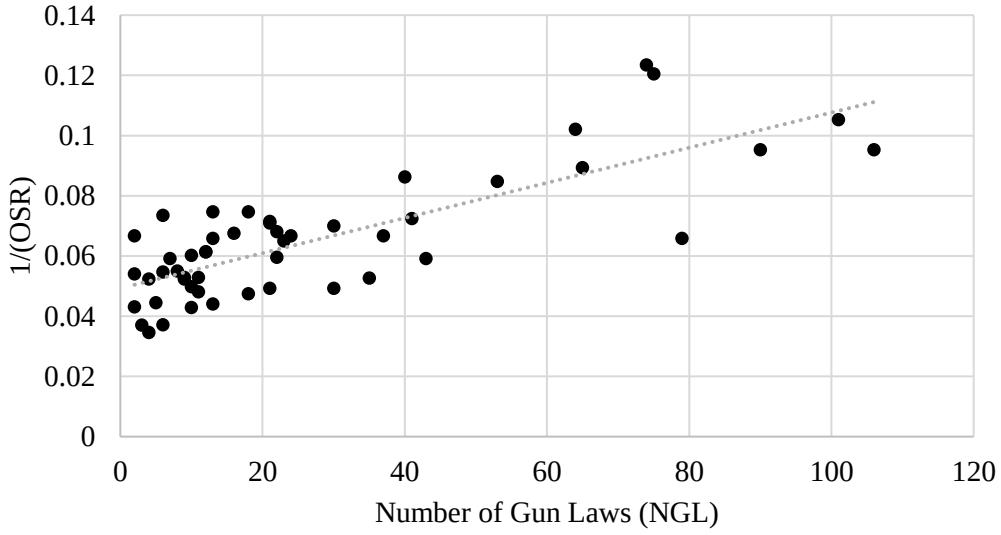


Figure 8. Transformed dataset of overall suicide rates and number of gun laws.

We thus conduct regression analysis of (the inverse of) overall suicide rates *on* the number of gun laws; the results are presented in Table V.

Table V. Results of the regression analysis of overall suicide rates on the number of gun laws across the United States.

Source	SS	dof	MS
Model	**0.0125**	**1**	**0.0125**
Residual	**0.0075**	**48**	**0.0002**
Total	**0.0201**	**49**	**0.0004**

No. of Obs.	= **50**
F(1,48)	= **79.99**
Prob > F	= **0.0000**
R-squared	= **0.6250**
Root MSE	= **0.01252**

$1/\widehat{OSR}$	Coef.	Std. Err.	t	P > |t|	[95% Conf.	Interval]
$\hat{b}$	**0.0006**	**0.0001**	**8.94**	**0.000**	**0.0005**	**0.0007**
$\hat{a}$	**0.0493**	**0.0025**	**19.68**	**0.000**	**0.0443**	**0.0543**

The F-test on this model returns a p-value of less than 0.0000. Thus, we soundly reject the null hypothesis that there is no association between our predictor and the response, and we say that the number of gun laws is indeed a statistically meaningful predictor of overall suicide rates. Considering the correlation coefficient, we can see that the number of gun laws alone explains nearly 63% of the variability in suicides by all methods across the U.S. These results are confirmed by the t-test and the associated p-value for the estimated coefficient $\hat{b}$, as well as its corresponding 95% confidence interval. The p-value for the t-test on $\hat{b}$ is less than 0.000, which means that we soundly reject the null hypothesis that this coefficient is zero—a conclusion confirmed by the absence of zero in the 95% confidence interval.

Using the estimated coefficients, we revert our linear model to the inverse model, as shown in Eq. (5) along with our best-fit curve superimposed on the dataset in Figure 9.

$$\widehat{OSR} = \frac{1}{0.0493 + 0.0006 \cdot NGL} \tag{5}$$

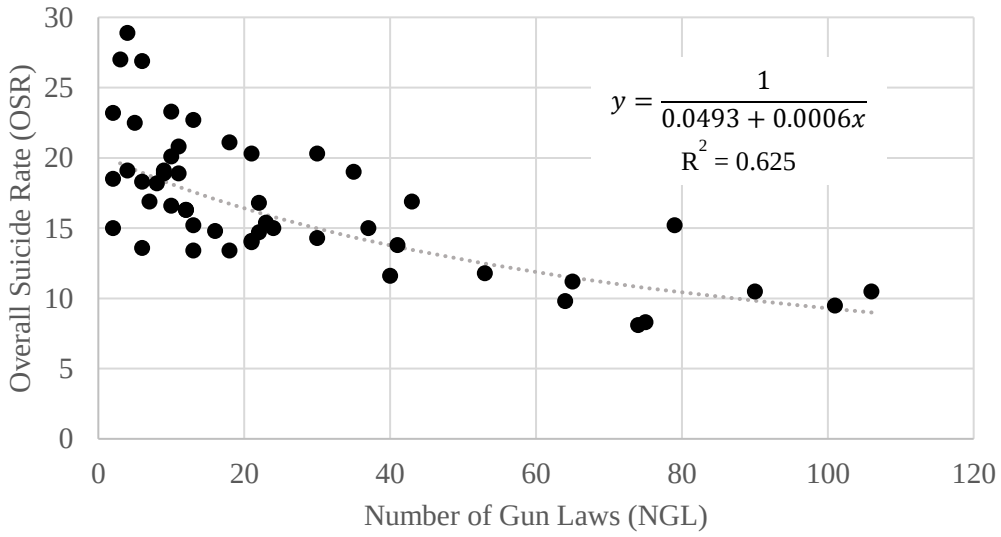


Figure 9. Best-fit model to overall suicide rates as a function of number of gun laws.

2.3. Implications and Limitations

It is important to see beyond these statistics and reflect on both their implications and limitations.

We have shown that firearm legislation is strongly associated with reduced firearm suicide rates, yet unassociated with non-firearm methods, and thus strongly associated with overall suicide rates as well. The implication of our finding is that we are not powerless against the burden of suicide and that there is a way to modify the risk of overall suicide rates by targeting firearm suicides. We acknowledge that this legislative "lever" is broad in scope and difficult to modify, and we understand that discussions revolving around guns in America are highly polarized. Nevertheless, we emphasize that just because a topic is controversial does not mean that we should avoid it, especially when human lives are at stake. Unfortunately, suicide in America is a silent killer, slowly taking the lives of our friends and family, while remaining off the media radar threshold and thus absent in the majority of political discussions. We hope that this work sparks both interest in the problem of suicide and inspiration among decision-/policy-makers, as (and we repeat for emphasis) we are not powerless against the burden of suicide.

There are a few limitations to this work that should be discussed. First, as mentioned in sub-section 2.1, we only considered the number of gun laws per state as the single predictor variable in our regression analysis. We chose to do this because the objective of this paper was not to create a model that "explains" the entire problem of suicides in America, but rather, to highlight the modifiable risk factor that is the absence of state firearm legislation. More developed models that build off those presented in this work are encouraged and left as a fruitful venue for future work. Second, and related to the first limitation, we did not filter the gun laws that may or may not be more relevant to the problem of suicide. In other words, the manifestation of these laws are not all created equal, and we suspect that some laws will be more strongly associated with suicides than others (e.g., child access prevention laws and prohibitions for high-risk gun possession). The effectiveness of specific state firearm legislation will be explored in a follow-up work. Finally, we must acknowledge that statistically meaningful associations do not imply causal relationships. We cannot say, for example, that more gun laws *cause* lower suicide rates but only that they are *strongly associated* with lower suicide rates. This nevertheless opens the door to the possibility of preventative measures, beyond the purely legislative, that target firearm suicides.

3. Defense-in-depth tailored to firearm suicides and portfolio of preventative measures

In this section, we introduce the system safety principle of defense-in-depth to suicide prevention community of researchers and professionals, and we examine its applicability to the burden of suicide.

3.1. Suicides and system safety

Broadly speaking, system safety is concerned with the prevention of an adverse class of events called *system accidents*. These accidents are characterized by both temporal depth and diversity of agency. Conventionally, system safety and its principles apply to the realm of engineering systems, but they need not be restricted to this domain. Saleh et. al., have developed a set of domain-independent and technologically-agnostic system safety principles—one of which is the principle of defense-in-depth—which we adopt in this work and tailor to the burden of suicide. By relating system accidents to suicides, we emphasize that we are not suggesting that suicides are accidents but only that they share a phenomenological sameness, as we will discuss in the following sub-sections. We note that in this context, a system is analogous to an individual.

3.2. Defense-in-depth

This sub-section is adapted from [7]. The safety principle of defense-in-depth is founded on the notion of an *accident sequence*. The accident sequence (for our purposes, henceforth referred to as suicide sequence) is defined as the concatenation of events from the initiating event to the "accident," in this case: suicide. The initiating event is the event that drives the system outside of "nominal" conditions. We acknowledge that the pathology of the "initiating event," in the context of suicide, is highly complex, and we dare not conflate the many contributing factors that drive suicidal behavior to a single event, but we will continue to refer to the "initiating event" as the aggregation of life events, environment, mental health, etc., that contribute to making a person suicidal. This idea of a suicide sequence necessitates the definition of a "system state." A useful representation of the system state in the context of suicides is through a hazard level or the proximity of an individual to committing suicide. It is important to note that while no two suicides are the same, they share a phenomenological sameness, in that the suicide sequence can be broadly categorized into three phases: initiation, escalation, and finally suicide. It is within these phases that we integrate defense-in-depth, as we will see shortly.

Defense-in-depth is constituted by several pillars, among which are as follows:

i) Multiple safety barriers placed along potential accident sequences;
ii) Safety not relying on a single defensive element (hence the "depth" qualifier);
iii) Safety barriers which are diverse in nature and include technical, operational, organizational, and regulatory measures.

In this context, the various safety barriers have different objectives and perform different functions—namely (i) preventing the suicide sequence from initiating, (ii) blocking further escalation of suicide sequence, and (iii) mitigating the consequences. It is these three "lines of defense" that constitute defense-in-depth and its three functions.

A hypothetical individual's suicide sequence with the application of defense-in-depth is visualized in Figure 10, where the hazard level is portrayed as a physical dimension. Notice, however, the accident sequence need not be a concatenation of discrete events, but rather it can be a continuous compounding of several factors. Included in Figure 10 are a few examples of safety barriers categorized into their respective functions within the hypothetical suicide sequence.

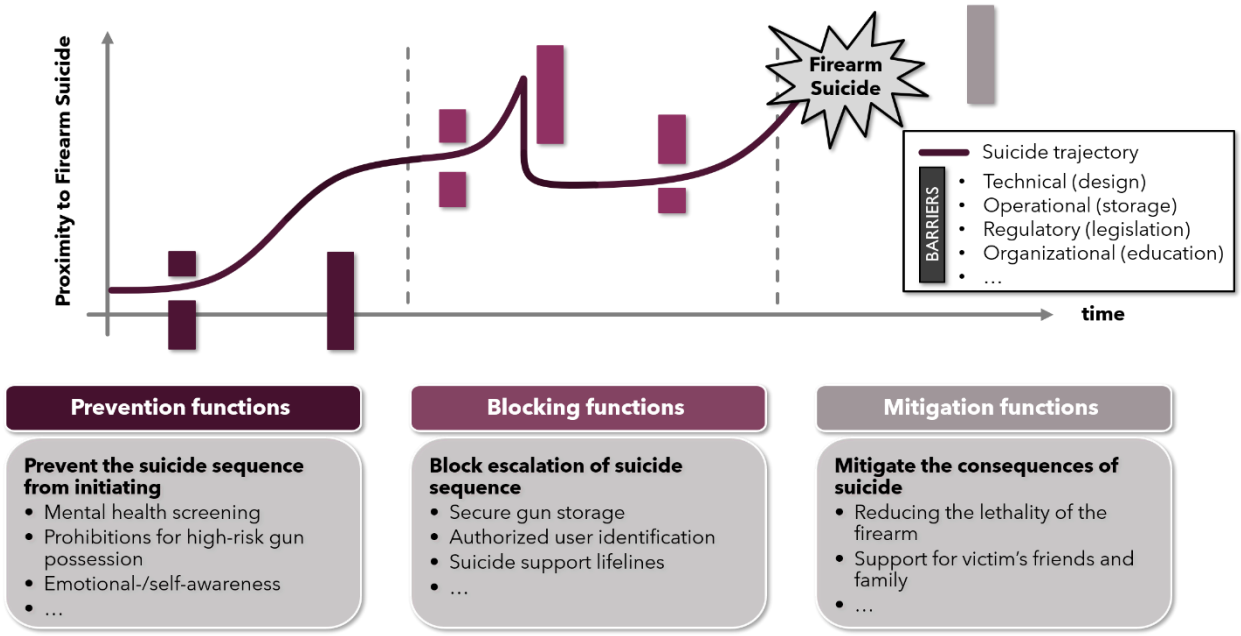


Figure 10. A hypothetical suicide sequence with the safety principle of defense-in-depth applied. Also shown are examples of safety barriers grouped by their respective functions.

As shown in Figure 10, safety barriers can manifest in a variety of different ways. Consistent with defense-in-depth, the barriers can be categorized into technical measures (e.g. design choices), operational (e.g. firearm storage), regulatory (e.g. legislation), organizational (e.g. education), among others. However, most of these measures ultimately boil down to policies that should be consistent among the responsible entities, such as gun manufacturers, gun owners, and firearm dealers. This need for consistent policies and operating procedures inherently makes the broadest category of safety barriers regulatory in nature. Nevertheless, these regulations can be distinguished with more granularity and assessed according to their effectiveness (as will be done in a follow-up work). For example, gun storage regulations are legislative but are operational in nature. Furthermore, regulatory safety barriers are but a subset of all safety barriers, which implies that there are barriers beyond legislative, e.g., design-centric barriers, such as childproof gun safes, etc., that can exist outside of legislation.

With this framework for categorizing and designing safety barriers for firearm suicide prevention, it is possible to compile a portfolio of preventative measures that address the accident prevention functions described earlier. Furthermore, by creating a common language for assessing the merits of safety barriers, such as regulation, the conversation around gun laws targeting firearm suicide may be de-politicized to an extent, allowing more effective discourse surrounding firearm suicide prevention—eventually enhancing the inverse relationship between gun regulation and suicide rates.

3.3. Portfolio of preventative measures

We conducted a brief literature review of various preventative measures against firearm suicide. We provide a selection of such measures here—organized by their function in the context of defense-in-depth (preventing, blocking, and mitigating). This list is by no means exhaustive. In fact, we imagine this portfolio to be an open document, one that grows and is improved with time. We hope that this portfolio will foster creativity among policy-makers, weapon designers, and their operators, in developing new solutions and safety barriers against the burden of suicide.

3.4. Prevention safety barriers

As discussed previously, there are countless contributing factors that drive a person to become suicidal. For example, Socio-Ecological Model (SEM) is used by the CDC, among other entities, to prevent violence—including self-violence—from occurring [8]. The model considers the complex interplay between individual, relationship, community, and societal factors, and it allows one to understand the diversity of factors that put people at risk for suicide. In a similar spirit to defense-in-depth, this model suggests that in order to prevent suicide, it is necessary to act across multiple levels simultaneously.

There are preventative measures that can be erected at the individual level by considering biological and personal history factors that increase the likelihood of committing suicide. Some of these factors include age, education, income, substance use, or history of abuse. Preventative measures at this level promote attitudes, beliefs, and behaviors that prevent violence (again, including self-violence) and might include education and life skills training.

There are also preventative measures at the relationship-level that consider relationships that might increase the risk of suicide. The people close to the (potential) victim of suicide, including their peers, partners, and family members, all influence their behavior and contribute to their life experiences. Preventative measures at this level might include parenting or family-focused prevention programs, as well as mentoring and peer programs designed to reduce depression and promote both physically and psychologically healthy relationships.

The community-level explores the settings of the potential victim, such as schools, workplaces, neighborhoods, etc., in which social relationships occur and seeks to identify the characteristics of these settings that are associated with becoming a victim of suicide. Preventative measures at this level impact the social and physical environment and might include reducing social isolation, improving economic and housing opportunities in neighborhoods, as well as the climate, processes, and policies within school and workspace settings.

Finally, the societal level looks and the broad social factors that create a climate in which self-violence is encouraged (or not). Some of these factors include social and cultural norms, while others include large societal factors such as health, economic, educational, and social policies that contribute to putting people at risk for suicide.

The socio-ecological model is undoubtedly useful in understanding the complex factors that put people at risk of suicide, and we note the applicability of the tools from Machine Learning to this prevention phase [9], but the preventative measures that stem from SEM are primarily focused on preventing the suicide sequence from initiating—they have little to say when a suicide sequence has already begun.

3.5. Blocking safety barriers

In the event that a suicide sequence has begun, there are still relevant and applicable safety barriers that can be erected to block the suicide sequence from escalating. Some of these safety barriers are technological and operational in nature, and this serves as a prime location for weapon designers and dealers to intercede [10].

One technological safety barrier against firearm suicide can be broadly labeled as “smart guns.” These are firearms that are personalized in such a way that unauthorized users of the gun cannot fire it. This would target the victims of firearm suicides that are not the owners of the gun, e.g., children, spouses, and other members of the household. Specific manifestations of smart guns are, for example, a firearm with a radio-frequency identification (RFID) chip located in the gun which is only operable when in the vicinity of the activation object located with the authorized user. Another example would be biometric readers that confirm the authorized user before unlocking the safety switch. Weapons can also be fitted with facial/voice recognition devices, childproof safety switches, etc. There are also technologies in which the firearm is

paired with the user's cell phone or smartwatch, and again, only operable within the vicinity of the authorized user.

These technological preventative measures deserve more attention than they receive, as they have largely been unadopted in America. Nevertheless, we implore weapon designers and dealers to think deeply about ways to remove the threat of injury to oneself and others *by design* without compromising the value of the weapon in terms of its sport or protection.

Within the operational domain, there are a host of preventative measures that the owners of firearms can take to block the suicide sequence from escalating. The simplest measure might be to simply keep the gun in safe. Several states actually require that firearms (if in a household) be kept in a safe [11]. In combination with the smart-gun, and safe would serve as a secondary, or even tertiary, line of defense against firearm suicide among non-owners of the firearms. We acknowledge that this particular preventative measure has the drawback of reduced accessibility to the firearm, which would be problematic in an emergency. We note however, that the smart technology that is available to the gun is also available to the gun safe, including RFID and other quick access biometric authorization techniques (fingerprints, voice recognition, etc.).

Thus far it would seem that blocking safety barriers can only be erected to obstruct unauthorized users of the gun from committing suicide, but there are a few barriers that may be put in place to protect against the victim killing themselves with their own gun. A traditional example would be suicide prevention lifelines, in which the objective is to use a human connection to de-escalate suicidal behavior.

We note again that proper implementation of defense-in-depth is one that uses multiple diverse safety barriers to prevent suicide from occurring. But even after this tragedy, there are a set of safety barriers that can be put in place to mitigate the potential consequences.

3.6. Mitigation safety barriers

Suicides can be a tremendous emotional burden to the friends, family, and peers of the victim, and there is a host of *postvention* techniques that are used to (i) facilitate the healing of the individual from the grief and distress of suicide loss, (ii) mitigate other negative effects of exposure to suicide, and (iii) to prevent suicide among people who are at high risk after exposure to suicide [12]. Preventative measures here are usually at the organizational level. For example, the Suicide Prevention Resource Center encourages that all settings such as schools, workplaces, towns, health care providers, etc., be prepared to respond to a suicide death. Specific measures in this context include working with news media to encourage safe reporting, working with those affected to aid mourning in ways that avoid increasing the risk of contagion, and building capacity for ongoing support and treatment of those affected.

We remind the reader that the proper implementation of defense-in-depth is one that uses a set of multiple and diverse safety barriers to prevent the suicide sequence from initiating, to block its escalation, and to mitigate the potential consequences.

4. Conclusion

In this work, we first connected firearms and suicide in the U.S. While most conversations about gun control in this country are initiated after high-visibility mass shootings, the true, silent killer of our friends and family is suicide. We noted that while the vast majority (over 90%) of attempters use non-firearm methods, over half of all suicide fatalities are committed with a gun. Unfortunately, firearm regulation is primarily responsive to mass shootings; however, and we say this with a heavy heart, not that many people die from mass shootings. In 2017, 185 people were shot and killed in mass shootings, whereas 23,854 people shot and killed themselves with a gun.

These sobering statistics motivated our research into the relationship between the number of firearm regulations in this country and suicide rates. More specifically, we wanted to challenge the notion suicide is inevitable: that measures that reduce suicides by one method (firearms) do not exacerbate suicides by other means. We conducted a regression analysis on the number of guns laws and suicides by (i) firearms, (ii) non-firearm methods, and (iii) all methods; and we found the following results:

- The number of gun laws is strongly associated with firearm suicide rates: over 74% of the variability in firearm-suicide rates across the United States is explained by the number of gun laws alone.
- There is no statistically meaningful association between the number of gun laws and suicides by non-firearms.
- The number of gun laws is strongly associated with overall suicide rates: over 62% of the variability in suicide rates by any method across this US is explained by the number of gun laws alone.

These findings directly contradict the inevitability of suicide; they imply that we are not powerless against the burden of suicide, and we can reduce overall suicide rates by targeting firearm suicides.

We then introduced the system safety principle of defense-in-depth and examined it applicability to the burden of firearm suicide. We recognized that the regulatory lever is but one method to modify the risk of suicide, and there are a host of other safety barriers that can erected to fulfill the three functions of defense-in-depth: (i) to prevent the suicide sequence from initiating, (ii) to block its escalation, and (iii) to mitigate the potential consequences. We aggregated past, present, and future safety barriers into a *portfolio of preventative measures* to spur both the imagination of failure and creativity of solutions among all members of the safety value chain in the hope that it might one day contribute one small step towards suicide prevention.

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