TITLE:
A System Dynamics model of Australian suicidal behaviour and suicide prevention strategies

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Abstract:

Suicide remains one of the leading causes of death in young people and contributes significant social, economic and health system costs to Australia. The rate of suicide has remained constant in the Australian population despite substantial government and private investment, significant community and political momentum, and efforts to improve coordination and alignment of programs and services. Dynamic simulation modelling is increasingly being recognised as a valuable decision support tool to help guide investments and actions to address complex public health problems such as suicide. In particular, system dynamics (SD) modelling provides a useful tool for asking high level 'what if' questions; testing at an aggregate level the likely impacts of different combinations of policies and interventions before they are implemented in the real world. This paper reports the development of an SD model of suicide prevention in Australia and its findings. Additionally, the paper highlights the value of dynamic modelling methods for managing complexity and uncertainty and demonstrates its potential utility as a decision support tool for policy makers and program planners for suicide prevention.

INTRODUCTION

Suicide remains one of the leading causes of death in young people and contributes significant social, economic and health system costs to Australia. (KPMG Health Economics, 2013; Australian Bureau of Statistics, 2012; Page et al., 2013; Milner et al., 2013a). The rate of suicide has remained constant in the Australian population (although a slight increase has been noted in the most recently recorded period) (Milner and Page, 2016), whereas deaths attributable to motor vehicle accidents have been falling in absolute numbers despite a rising population over the period from 2000.

The extent to which specific suicide prevention policies and programs over the last two decades have had an impact on population-level suicide rates in Australia is unclear (Page et al., 2011). This is despite substantial national and state government investment, resources contributed by business, community and philanthropic sources, senate committee inquiries, implementation frameworks, and efforts to improve coordination and alignment of programs and services. (National Mental Health Commission, 2014; Australian Institute of Family Studies, 1999; Department of Health and Ageing, 2008; Community Affairs References Committee, 2010)

The ability to design effective policy for suicide prevention in the population is challenged by: (1) the complex aetiology of suicide, (2) limited generalisable evidence for interventions that prevent suicide in populations, and (3) the quality and timeliness of surveillance data on suicidal behaviour (and other intermediate indicators) to measure impact of suicide prevention initiatives.

There are also often incongruous priorities between suicide researchers, policy makers and health service providers. The time, scope and rigour required for conducting research to implement and evaluate combined multi-level approaches to suicide prevention using traditional epidemiological approaches are often incongruous with the priorities and timelines

of health service providers and policy makers who usually require local or context specific information (Atkinson et al., 2015a; Atkinson et al., 2015b). Priorities for policy makers include determining how best to allocate available resources and investments in suicide prevention, by drawing on evidence to establish specific risk and protective factors for a given local area or service setting, identify where best in the lifecourse to intervene, and to select interventions believed likely to produce significant impacts.

While there is some evidence for effective prevention strategies in particular contexts (Mann et al., 2005), it is unlikely that a single intervention will have population-level impacts on suicide given the complex interplay of aetiological factors associated with suicidal behaviour within a complex health and social services system. Additionally, interventions that may have promising effects on preventing suicide (Knox et al., 2010) in one context may not be generalisable to other contexts, and their likely effects over time and in combination is unknown. Acknowledgement of this complexity and the application of complex systems tools and approaches to support decision making offer significant promise in guiding prevention initiatives that can address these issues (Atkinson et al., 2015a).

The current paper addresses some of these challenges by combining objective data on suicidal behaviour, with the recent reviews of evidence of suicide prevention strategies, to develop a system dynamics (SD) model as a potential tool for policy makers to provide timely and population-specific information on levels of suicidal behaviour. The SD model in this paper demonstrates the potential for these models to provide a platform for integrating diverse evidence sources into an analytic tool that can allow policy makers to explore in a robust, risk free and low cost way the likely impacts of different policy and intervention scenarios over the short and longer term, and can be used to conduct virtual experimentation where real-world studies are not feasible. In the words of Barry Richmond, the model uses a "Shared Operational Language" which helps policy makers, those with lived experience of suicidal behaviour, researchers, and modellers explore and address suicidal behaviour and prevention strategies from their different perspectives.

METHODS

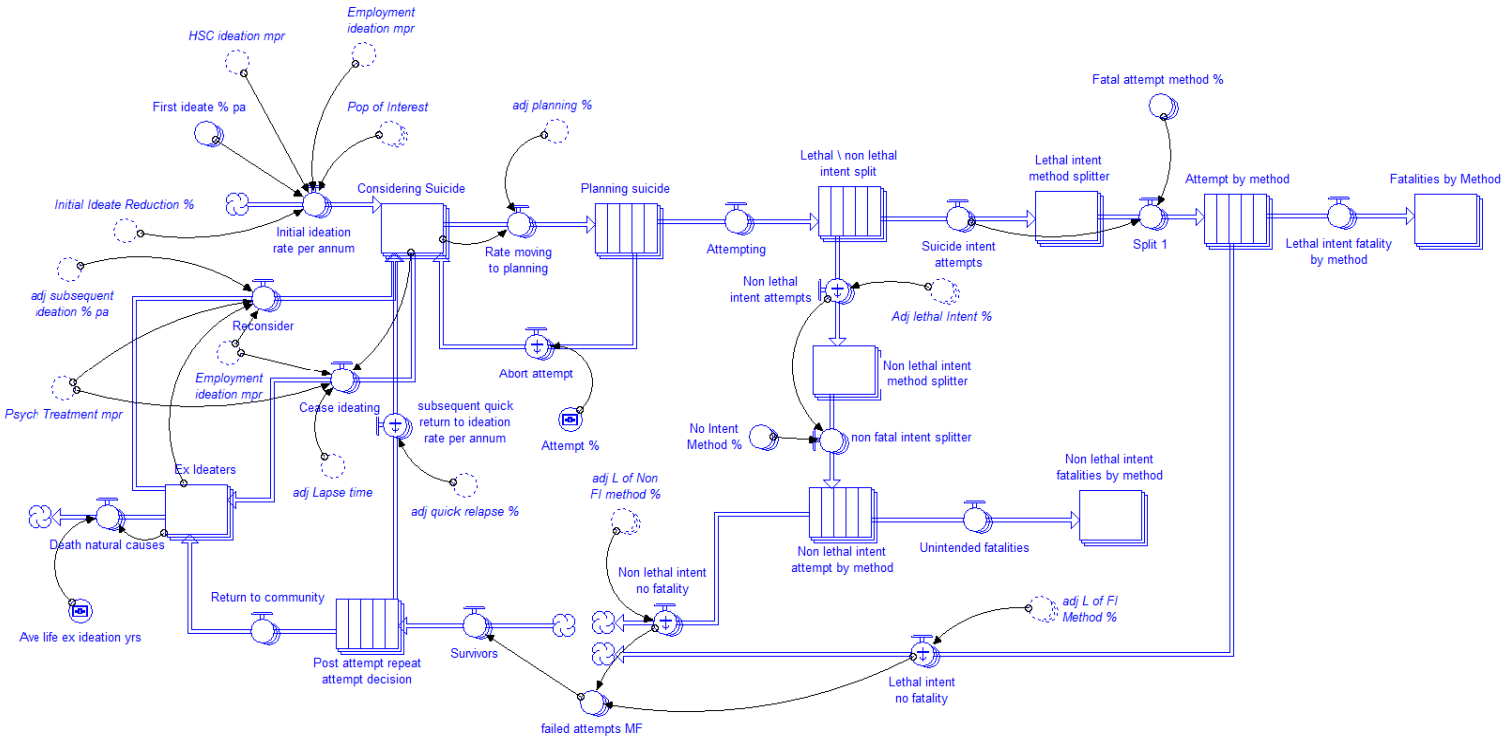
System Dynamics Model

The model structure was developed in collaboration between system scientists and content experts, and reflects a series of states in the Australian population moving from no suicidal thoughts or behaviours, to suicidal ideation, to the planning of suicidal acts, to attempted suicide and completed suicide. This progression from ideation to behaviour, modified by level of intent and lethality of method, is broadly consistent with current conceptualisations of suicidal behaviour (Silverman et al., 2007). However, it is important to note that there remains debate regarding the nomenclature of the range of suicidal behaviour that occurs in populations (Silverman et al., 2007). Conceptualising the causal pathway in this manner also enabled representative data sources to be used to validate the model on the two key outcomes of interest (i) cases of hospital treated attempted suicide, and (ii) cases of suicide.

It is important to note that suicide is a complex human behaviour and the culmination of the interaction of a range of socio-economic, cultural, familial and interpersonal, and psychological risk factors over the life-course (Maris, 2002). Considering suicide as a process is an over-simplification of this complex behaviour, and the SD model presented in the current paper does not incorporate many feedbacks or the complex individual mechanisms

and trajectories that are likely to be present at the individual-level. However, the application of system dynamics applies a level of mathematical rigour that ensures consistency with observed data inputs at the aggregate, population-level and provides decision support capability that accounts for behavioural and population dynamics.

Figure 1: Structure of the model of Australian suicidal behaviour



Data inputs

The model was developed using available historical time series of hospital treated attempted suicide (Pointer, 2013) and cases of suicide from 1999 to 2014 (obtained from the Australian Bureau of Statistics), separately for males and females. Stratified models by sex were developed to reflect the 3 to 4 fold difference in the incidence of suicide between males and females (Page et al., 2013). Nationally representative estimates of suicidal ideation and suicide planning, for males and females, were obtained from the most recent National Survey of Mental Health and Wellbeing (Johnston et al., 2009), and the level of suicidal intent for suicide attempts was obtained from the Australian National Survey of Self Injury (Martin et al., 2010). The most common methods of suicidal behaviour for suicide attempts and suicides were also incorporated, as a reflection of the differing methods used by males and females, and also the differing levels of suicidal intent and lethality. These methods included 'self-poisoning' (ICD-10 Codes X60- X69), 'gases and vapours' (including carbon monoxide and motor vehicle exhaust gas) (X67), 'hanging' (X70), 'drowning' (X71), 'firearms' (X72-X74), 'cutting' (X78) 'jumping from a high place': (X79), and 'other' (X75, X76, X77, X80, X81, X82, X83, X84).

Table 1: Self-reported suicidal ideation, planning, attempts and suicidal intent in Australia (2007) (Johnston et al., 2009; Martin et al., 2010)

	Total	Males	Females
	% (95% CI)	% (95% CI)	% (95% CI)
Life-time suicide ideation	13.3 (12.2-14.1)	11.5 (10.0-13.0)	15.0 (13.7-16.3)
Life-time planning	4.0 (3.4-4.5)	2.9 (2.2-3.7)	4.9 (4.1-5.8)
Life-time suicide attempt	3.2 (2.8-3.7)	2.1 (1.5-2.7)	4.4 (3.7-5.1)
Suicide ideation (previous 12 months)	2.3 (1.9-2.7)	1.8 (1.3-2.4)	2.7 (2.2-3.3)
Suicide planning (previous 12 months)	0.6 (0.4-0.7)	0.4 (0.3-0.6)	0.7 (0.4-1.0)
Suicide attempt (previous 12 months)	0.4 (0.3-0.6)	0.3 (0.1-0.5)	0.5 (0.3-0.8)
Suicidal intent in those those reporting non-fatal suicide attempt	70.6 (66.8-74.2)	66.5 (59.0-73.4)	73.1 (68.5-77.3)

Table 2: Repetition of suicidal behaviour in those with a previous suicide attempt (Carroll et al., 2014)

	Total	Males	Females
	% (95% CI)	% (95% CI)	% (95% CI)
Non-fatal repetition			
Within 1 year	16.3 (15.1-17.7)	16.9 (13.6-20.8)	16.4 (13.1-20.4)
Within 2 year	16.8 (14.7-19.2)	-	-
Within 5 years	22.4 (17.0-28.9)	-	-
Fatal repetition			
Within 1 year	1.6 (1.2-2.1)	2.7 (1.8-4.0)	1.2 (0.7-1.9)
Within 2 year	2.1 (1.6-2.8)	-	-
Within 5 years	3.9 (3.2-4.8)	-	-

Table 3: Proportion of suicide and attempted suicide by method

	Suicide			Attempted suicide		
	Males	Females	Total	Males	Females	Total
Self-poisoning	9.8	29.0	14.5	73.1	85.2	80.6
Gases	9.1	6.0	8.4	2.4	0.5	1.2
Hanging	58.3	46.1	55.4	4.1	1.1	2.2
Drowning	1.6	2.6	1.8	0.1	0.1	0.1
Firearms	8.1	1.6	6.6	0.2	0.0	0.1
Cutting	3.0	2.3	2.8	16.2	11.1	13.0
Jumping	4.3	6.0	4.7	0.8	0.5	0.6
Other	5.7	6.4	5.8	3.1	1.5	2.1

Attempted suicide data from (Pointer, 2013). Suicide data for comparable period (2012-2014) from Australian Bureau of Statistics mortality data. ICD-10 Codes: Self-poisoning (X60- X69); Gases (X67); Hanging (X70); Drowning (X71); Firearms (X72-X74); Cutting (X78); Jumping (X79); Other (X75, X76, X77, X80, X81, X82, X83, X84)

Table 4: Proportion of non-fatal suicidal behaviour with suicidal intent by method, and case-fatality ratio (2012-2014) by method.

	(A) Non-fatal suicide with intent			(B) Case fatality ratio					
				Without suicidal intent			With suicidal intent		
	Males	Females	Total	Males	Females	Total	Males	Females	Total
Self-poisoning	65.8	71.9	70.4	2.4	1.2	1.6	3.6	1.6	2.3
Gases	86.0	89.0	87.2	41.6	29.5	38.8	45.3	31.9	42.2
Hanging	57.7	88.7	68.8	72.2	59.9	69.3	81.8	62.8	77.1
Drowning	57.4	100.0	68.2	70.2	49.4	61.4	80.4	49.4	66.3
Firearms	51.4	100.0	52.8	86.9	65.1	85.2	92.8	65.1	90.5
Cutting	72.9	77.1	75.3	3.3	0.7	1.9	4.5	0.9	2.6
Jumping	92.9	0.0	68.6	49.6	29.5	40.9	51.4	100.0	60.5
Other	73.7	75.9	74.8	25.4	12.9	20.2	31.6	16.3	25.3

Suicidal intent obtained from the Australian National Epidemiological Study of Self-Injury (ANESSI) (Martin et al., 2010) in response to the question: *"When you attempted suicide, did you actually want to die?"*
Case fatality ratio: number of suicides / (number of suicides + number of suicide attempts)

A recent systematic review of peer-reviewed intervention studies to identify the 'best' strategies for reducing suicide in Australia was used to extract population preventive fractions for different health service related suicide prevention initiatives (Krysinska et al., 2015) (Table 5). The population preventive fraction refers to the proportion of cases of suicide that would be prevented in the population if the given intervention was implemented. The strategies described in this review were selected as they are currently the subject of a large-scale community-trial (the 'LifeSpan model') being led by the Black Dog Institute (Sydney, Australia) (Tye et al., 2015), and have been the recent focus of debate among population health researchers (Hegerl and Kohls, 2016; Pirkis, 2016) and of government funding strategies.

Table 5: Estimated population preventable fraction for each of the proposed suicide prevention strategies included in the SD model (modified from (Krysinska et al., 2015)).

	Suicide attempts			Suicide		
	RR	% Exposure	PPF%	RR	% Exposed	PPF%
Reducing access to suicide means	0.50	0.5	0.50	0.72	11.0	4.1
School-based programmes	0.55	3.7	2.9	-	-	-
Gatekeeper training	-	-	-	0.67	10.5	4.9
GP training	-	-	-	0.92	76.9	6.3
Psychosocial treatment	0.68	18.4	8.0	0.75	18.5	5.8
Coordinated/assertive aftercare	0.40	16.3	19.8	-	-	-
Brief contact interventions	-	-	-	0.58	1.6	1.1

RR - Relative Risk
PPF - Population preventable fraction

Impacts of intervention scenarios.

Three approaches were considered to assess the hypothesised impact of the interventions described above over the forecast period of 2015-2025. First, each of the health service interventions outlined in Table 5 were considered separately to forecast the impact on attempted suicide and suicide. Secondly, all of the health service interventions were

considered in combination. Thirdly, hypothetical changes in the lethality of each of the selected methods of suicidal behaviour were considered. These model runs assumed a 20% absolute reduction in lethality for each of the methods described above (self-poisoning', 'gases and vapours', 'hanging', 'drowning', 'firearms', 'cutting', and 'jumping from a high place'). That is, to assess the hypothesised impact on subsequent suicide if the lethality of, for example, hanging, could be reduced by 20%. Finally, the combined effects of the health service interventions, plus the combined effects of reductions in lethality of method were considered.

An interactive model can be examined online at:
http://saxinstitute.scem.uws.edu.au/netsims/suicide-1/suicide_v403/index.html

RESULTS

The model estimated an historical time series (2000-2014) for males (Figure 2A) and females (Figure 3A) that was within 5% of the observed suicide data for an equivalent period. The model forecasts an increase in suicide frequency from 2014 to 2025 from 2,154 to 2,879 for males and 689 to 942 for females.

Comparative runs of the model investigating the impact of health service interventions individually suggest that General Practitioner training in the identification and management of patients presenting with risk factors for suicide (such as mental illness) or suicidal ideation, and coordinated assertive aftercare for those who present to hospital services following a suicide attempt, result in the largest declines in suicide over the forecast period. For GP training there was a 12% estimated decline in males (Figure 2B; Table 6) and females (Figure 3B; Table 6). The other health service interventions had negligible impacts on suicide trends when simulated individually. In combination, the estimated decline for all health service interventions was 27% for males (Figure 2B; Table 6) and 28% in females (Figure 3B; Table 6).

Simulated reductions in lethality of method also resulted in declines in suicide over the forecast period (2014-2025). For both males and females the largest decline in suicide for reductions in lethality of method was for hanging (7% in males; 6% in females) (Figure 2C; Figure 3C; Table 6). In combination, the reduction of lethality of method by 20% for all of the selected methods was 17% for males (Figure 2C; Table 6) and 16% for females (Figure 3C; Table 6).

In models combining the effects of all health service interventions, plus reductions in lethality of method, the estimated decline in suicide was 39% for both males (from 2,879 to 1,744) and females (from 942 to 571) (Figure 2D; Figure 3D; Table 6).

Figure 2: Model outputs for male suicide (2000-2014) and comparative model runs for the forecast period 2015-2025.

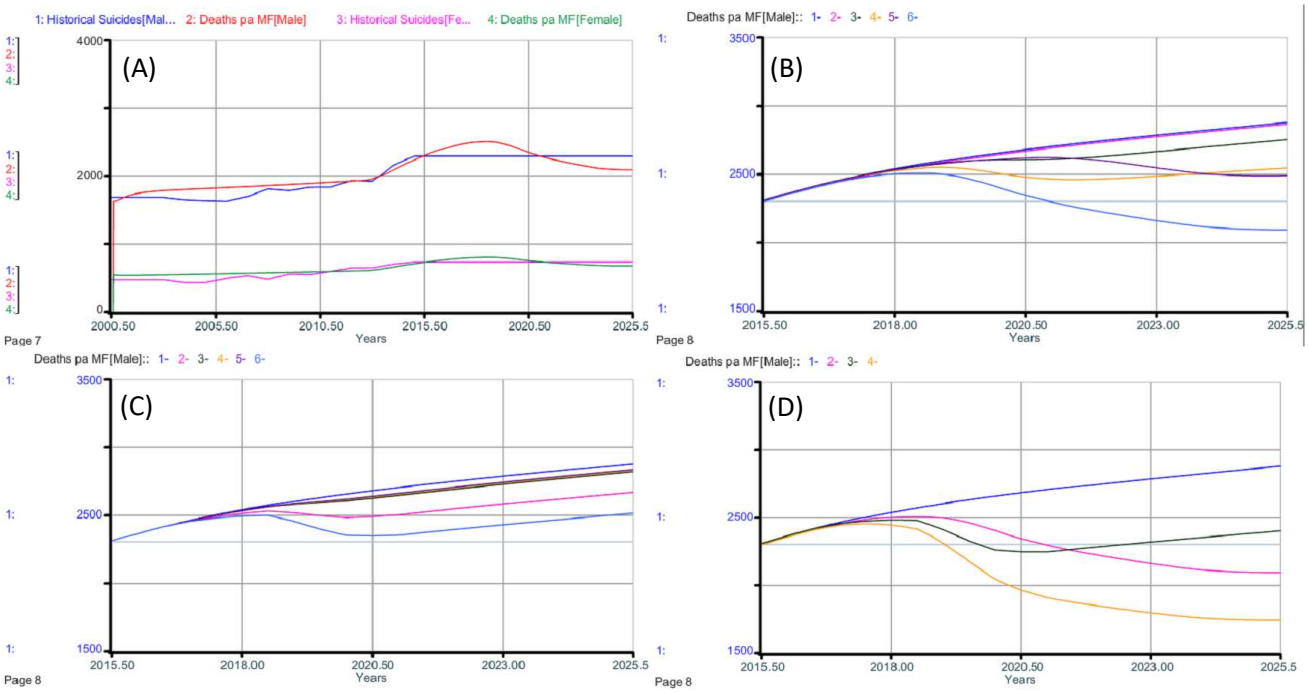


Fig. (B) Impacts of health service intervention: 1- No intervention; 2- Brief contact interventions; 3 - Psychosocial treatment; 4- GP training; 5 - Coordinated after care; 6 - All health service interventions combined.
Fig. (C) Impacts of 20% reduction in lethality: 1- No intervention; 2 - Hanging; 3- Self-poisoning; 4 - Gases and vapours; 5 - Firearms; 6 - All methods combined
Fig. (D) Combined effects of health service interventions and method lethality reduction: 1- No intervention; 2 - All health service interventions; 3 - All methods combined; 4 - Both health service interventions and methods combined.

Figure 3: Model outputs for female suicide (2000-2014) and comparative model runs for the forecast period 2015-2025.

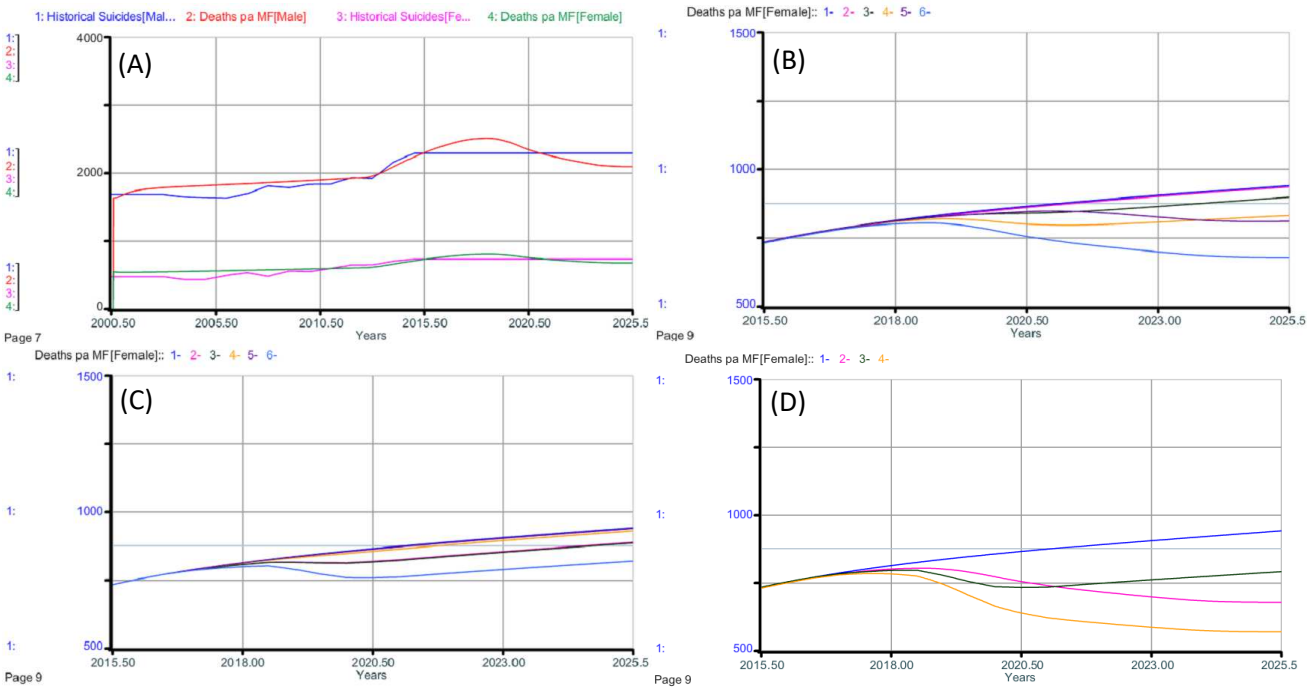


Fig. (B) Impacts of health service intervention: 1- No intervention; 2- Brief contact interventions; 3 - Psychosocial treatment; 4- GP training; 5 - Coordinated after care; 6 - All health service interventions combined.
Fig. (C) Impacts of 20% reduction in lethality: 1- No intervention; 2 - Hanging; 3- Self-poisoning; 4 - Gases and vapours; 5 - Firearms; 6 - All methods combined
Fig. (D) Combined effects of health service interventions and method lethality reduction: 1- No intervention; 2 - All health service interventions; 3 - All methods combined; 4 - Both health service interventions and methods combined.

Table 6: Summary of estimated reductions in suicide in 2025, following combinations of selected interventions and reductions in lethality of method

	Males		Females	
	No. of suicides	% reduction	No. of suicides	% reduction
Estimated total suicides in 2025 (no intervention)	2,879		942	
Health service interventions:				
Brief contact interventions	2,868	0.4	937	0.5
Psychosocial treatment	2,754	4.3	899	4.6
General Practitioner training	2,546	11.6	832	11.7
Coordinated after care	2,490	13.5	811	13.9
All health service interventions	2,093	27.3	679	27.9
20% reduction in method lethality in :				
Hanging	2,670	7.3	889	5.6
Self-poisoning	2,820	2.0	939	0.3
Gases	2,830	1.7	931	1.2
Firearms	2,835	1.5	887	5.8
Combined methods above	2,401	16.6	792	15.9
Combined service interventions and reduction in lethality	1,744	39.4	571	39.4

DISCUSSION

This paper describes the application of a system dynamics model of suicide and attempted suicide in Australian males and females, which also incorporates current 'best-evidence' relating to strategies for prevention (Krysinska et al., 2015). The model replicated historical time series of suicide for both males and females over the period 2000-2014. In comparisons of the simulated effects of health service interventions, the largest estimated impact on declines in suicide were for GP training (Isaac et al., 2009) and coordinated assertive aftercare (Hvid et al., 2011). Simulated reductions in lethality of method by 20% for selected methods of suicidal behaviour (that is, assuming that interventions were available to reduce lethality of method), also suggested that the largest declines would be achieved with reductions in the lethality of hanging.

The National Mental Health Commission (National Mental Health Commission, 2014) has called for a 50% reduction in suicide over the next decade. Based on the health service interventions being considered as the best approaches to prevent suicide, findings from the model presented in this paper suggest that this 50% reduction will not be achieved and that additional strategies need to be considered. Additionally, those methods that are most amenable to intervention, such as self-poisoning (Amos et al., 2001; Oliver and Hetzel, 1972; Spittal et al., 2012), jumping (Pirkis et al., 2013), and firearms (Miller et al., 2002), appear to have the smallest impact on suicide declines. Whereas, hypothesised changes to lethality of hanging - a method not amenable to intervention - had the largest estimated impact on suicide declines over the forecast period.

There are a number of methodological considerations in interpreting the findings in this paper. As noted above, while the SD model presented is able to account for behavioural and population dynamics that impact population level changes over time in intentional self-harm, aggregate models such as these are an over-simplification that do not consider the complex individual mechanisms and trajectories associated with suicidal behaviour. Agent based models may be more appropriate in capturing these mechanisms. However, the application of system dynamics applies a level of mathematical rigour that has not previously been applied to secular trends in suicide, and is also consistent with observed data inputs at the aggregate, population-level.

The routinely collected mortality and hospital admissions data used to calibrate the model are high quality data sources. There is some under-enumeration of suicide cases due to the misclassification of suicides to ICD codes relating to unintentional injury and events of 'undetermined intent', however this does not preclude the use of these data particularly in studies of time-series analyses. Additionally, hospital admissions data are likely to under-estimate the total population-level of attempted suicide, in that hospital suicide attempts captures only those cases serious enough to warrant medical intervention.

The health service interventions incorporated into the model represent a limited set of potentially important interventions. As noted above, these interventions were selected as they are currently the subject of a large-scale community-trial (the 'LifeSpan model') being led by the Black Dog Institute (Sydney, Australia) (Tye et al., 2015), and have been the recent focus of debate among population health researchers (Hegerl and Kohls, 2016; Pirkis, 2016) and priority areas in government funding strategies. The extent to which the underlying relative risk estimates are applicable to the Australian context warrants consideration, as does the representativeness and precision of the the prevalence estimates used in the calculation of the

population preventive fractions. However, in the context of using SD models to inform the prioritisation of evidence-based interventions, they provide hypothesised effects that can subsequently assessed using empirical data. Other evidence on potentially effective interventions from observational studies, for example relating to educational achievement (Gunnell et al., 2011), unemployment (Milner et al., 2013a; Milner et al., 2013b) or early intervention for mental illness (Rickwood et al., 2014), may be additional areas for consideration in subsequent dynamic models of suicidal behaviour.

The current paper demonstrates the utility of using a system dynamics (SD) model as a potential tool for policy makers to ask 'what if' questions and test the potential impact of intervention and policy scenarios over time before implementing solutions in the real world. Recent advances in modelling software and transparent participatory approaches are enabling suicide prevention researchers, policy makers, practitioners, consumer representatives and modellers to collaboratively develop such models drawing on diverse evidence sources. This offers promise in providing tools that are better aligned to the decision support needs of policy makers and able to facilitate consensus building for action.

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