A framework for implementing a modular open source health economic model (MOSHEM) in youth mental health that is accountable, reusable and updatable

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Abstract

Summary: Health economists make limited use of the modular and open source approaches to model building that other disciplines use to make modelling projects more transparent, efficient and sustainable. We propose a framework for a modular open source health economic model (MOSHEM) in youth mental health. The framework includes of set of 20 standards for implementing a MOSHEM that is accountable (seven standards), reusable (nine standards) and updatable (four standards). We provide a rationale for each standard. The framework also includes software toolkit of six R packages for authoring MOSHEM modules (data structures and algorithms), supplying those modules with data and using the modules to implement reproducible modelling analyses. We describe an early application of the framework to developing utility mapping models that currently meet 18 framework standards. We discuss the potential benefits and challenges of extending this initial work to develop a more extensive MOSHEM for undertaking a range of economic analyses in youth mental health.

Code: Visit https://www.ready4-dev.com for more information about how to find, install and apply the framework and model.

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1 Introduction

Computational models, particularly those addressing economic topics, have become essential tools for health policy development [1,2]. Although influential and widely used, health economic models typically have a number of limitations that at best restrict their usefulness and which in some cases may facilitate harmful misuse.

There is a strong case for making health economists more accountable for the appropriate use and social acceptability of their models. Users of models should be able to assess their adequacy for a particular purpose [3]. This goal is difficult to achieve in the current context of the poor reproducibility [4–6] and frequently insufficient validation [7] of health economic models. Many health economic models are released with undeclared errors [8]. The value judgments that strongly shape health economic analyses are rarely made explicit, omissions that may lead to socially unacceptable policy recommendations [9]. A modelling team's value judgments about what questions to address, the most important features of a system to represent and the weighting of different types of evidence may be poorly aligned with those of the people impacted by decisions informed by model analyses [10]. As health economic models adopt more sophisticated techniques, the need for accountability grows. More complex models may be more prone to propagation errors [11] and models designed to address multiple questions should be expected to meet more onerous verification and validation obligations [12,13]. The nature and extent of individual model authorship contributions may be less clear in models implemented over longer time-frames with a large and changing group of collaborators [10].

The resource and skills intensive undertaking of modelling could be made more tractable if it was easier for health economists to re-use each other's models [14]. However, as many health economic models are owned by pharmaceutical companies and consultancies, commercial considerations can limit the reuse of models and their constituent code and data [13]. Legal and ethical issues such as privacy and confidentiality requirements further limit public release of some model artefacts [15]. Transferring a health economic model developed for one jurisdiction for application in another typically involves retaining some features and updating others [16]. However, models do not always make implementation choices (for example, use of concepts with standardised meanings across jurisdictions, supplying context specific data as replaceable data-packs and distributing source code under licenses that allow derivative works) that facilitate model transferability.

Health economic models should be updated and refined as new evidence emerges and decision contexts change [17], but this occurs infrequently [18]. Funding for health economic modelling projects rarely extend to provision of medium term support for model updates and improvements. The career trajectories of health economists can also mitigate against adequate maintenance of a model, it being relatively common for model authors to have moved on from the team that owns the model and / or from working on the health condition for which the model was developed.

A potential strategy for improving model accountability, reusability and updatability is to make models both modular and open-source.

A modular model is constructed from multiple reusable and replaceable sub-models (modules) [19]. Modules can share inputs and outputs with other modules or can be run as independent models [20]. Advantages of modular models include feasibility (large projects are broken into smaller tasks, with each component independently developed and tested) and flexibility (making it easier to selectively replace or update specific parts of a model and to scale up or down the level of granularity) [19]. Modular approaches are currently being used to facilitate the development of complex computational models in disciplines such as biology [19], neuroscience [21] and ecology [20]. In health economics the related and enabling concept of reference models has been recommended [22], but peer reviewed studies describing modular health economic models remain relatively rare, though examples exist in infectious disease [23] and cardiology [24].

Modular models provide an opportunity for multiple modelling teams to contribute to, test and reuse models. To enhance this capacity, modular models may be implemented as open source projects that give others liberal permissions to access and use model source code and data [19–21]. Although there appears to be in principle support from many health economists for greater use of open source health economic models (OSHEMs) [15], actual implementations are rare [13,25,26]. Barriers to adoption of OSHEMs include concerns about intellectual property, confidentiality, model misuse and the resources required to support open source implementations [15,27]. Adherence to good practice guidance is an essential requirement for healthcare modelling [2], but guidelines for implementing OSHEMs remain scarce, piecemeal and need improving [28].

We plan to develop a modular OSHEM (MOSHEM) of youth mental health that is accountable, reusable and updatable. Open source approaches have been recommended to help develop the mental health modelling field [29] but only one mental health related model (in Alcohol Use Disorder [30]) is currently indexed [RECHECK] in the Open Source Models Clearinghouse [25,31]. We are aware of just one other open source mental health model - a reference model in Major Depressive Disorder - that is currently in development [32].

In this paper, we introduce a framework for developing a modular youth mental health MOSHEM. Specifically we:

(i) describe a framework that is comprised of:

- a set of standards for implementing a MOSHEM; and
- a modelling toolkit (repositories and software) to author MOSHEM modules, supply them with data and undertake reproducible analyses consistent with those standards.

(ii) provide a worked example of how we used the framework to develop and apply MOSHEM modules for utility mapping.

2 Framework

To help us implement a MOSHEM in youth mental health, we have developed a framework that:

- specifies a set of standards for MOSHEM development and use; and
- provides a modelling toolkit (repositories and software) for authoring model modules, managing data and implementing reproducible analyses consistent with those standards.

2.1 Standards

Based on published guidance on computational modelling in health economics and other disciplines and our own experience, we have identified 20 standards that we believe are important for implementing a MOSHEM that is accountable (seven standards), reusable (nine standards) and updatable (four standards). The standards are specified in Table 1 and are discussed below.

2.1.1 Standards for an accountable MOSHEM

Guidance on transparency in health economic modelling published over ten years ago [12] made recommendations on documenting models but notably did not include recommendations on sharing model code and data. However, more recent and multidisciplinary healthcare modelling guidance [2] recommends using existing digital repository services to these types of digital model artefacts. Some types of repository such as GitHub [33] provide tools for disseminating work in progress code and providing highly transparent records of the complete development history and individual authorship contributions of a software project, while others such as Zenodo [34] and Dataverse [35] provide persistent storage solutions that generate a Digital Object Identifier (DOI) for each code and data collection.

Model code and data should be clearly documented, potentially with different versions for technical and non-technical users [12]. Consistent use of meaningful naming conventions when authoring code is recommended [36,37]. Code can be made easier to follow by using the practices of abstraction [38], where only simple, high level commands are routinely exposed to reviewers, and polymorphism [39], where the same command (e.g. "simulate") can be reused to implement different algorithms of the same type. Programs to implement model analyses can be made comprehensible to even non-technical users through the use of literate programming techniques that integrate computer code with plain English descriptions.

An essential component of quality assuring health economic models is verification - ensuring that calculations are correct and consistent with model specifications [40]. One useful concept for informing model users about the extensiveness of verification checks is code coverage [41] - the proportion of model code that has been explicitly tested. Transcription errors - mistakes introduced when transferring data between sources, models and reports - are very common in health economic models [8]. The risk of these errors might be lower if there was full transparency across all steps in a study workflow. Scientific computing tools now make it relatively straightforward to author programs that reproducibly execute all steps in data ingest, processing and reporting [36].

Code and data should be distributed with tools that make it easy for potential users to appropriately cite each model artefact.

Table 1: Framework standards

Characteristic	Standard	Meaning
Accountable - it is easy to see who developed, tested and applied a model and how they did it.		
	A1	Open online repositories are used to permanently archive, uniquely identify and transparently record development history and authorship of model code and data.
	A2	Model code and data are documented.
	A3	Model code uses a simple and consistent syntax.
	A4	Model analyses and reporting are implemented using literate programming.
	A5	Code coverage is reported.
	A6	All parts of a study analysis and reporting workflow can be reproduced and/or replicated.
	A7	Model code and data are distributed with tools to support appropriate citation.
Reusable - a model and its components can be used in other models and by other modellers.		
	R1	Model code is made available for re-use under copyleft or permissive licenses.
	R2	Non-confidential model data is licensed for liberal re-use (subject to additional terms for de-identified human data).
	R3	Model code and data are stored and managed separately.
	R4	Module data structures are encapsulating and inheriting.
	R5	Module algorithms are implemented as functions and linked to module data-structures as methods.
	R6	Model module data-structures and algorithms are distributed as code libraries
	R7	Test data is available to demonstrate generalised applications of model code.
	R8	Models are distributed with validated tools to support their safe and appropriate re-use.
	R9	Simple user-interfaces allow non-technical users to configure and run models.
Updatable - a model and its components are maintained and continuously improved.		
	U1	Model code and data are version controlled.
	U2	Model code and data use semantic versioning.
	U3	Continuous integration is used to verify model code updates.
	U4	Deprecation conventions are used to retire model code and data.

2.1.2 Standards for a reusable MOSHEM

To make model code and data widely re-usable by others, it is important to provide users with appropriate and explicit permissions. In the context of open source models, there are two broad categories of licensing options. Some guidance strongly recommends the use of permissive licensing [36] that provides users with great flexibility as to the purposes (including commercial) for which the content could be re-used. An alternative approach is to use copyleft licenses [42] that can require content users to distribute any derivative works they create under similar open source arrangements. For code, it may be appropriate to adopt the prevailing open source licensing practice within the programming language being used. For data, it may not be sufficient to simply choose between a permissive license like the Public Domain Dedication (CC0) [43] or a copyleft option such as the Attribution-Share Alike (CC-BY-SA) [44]. In addition to ensuring that data is ethically appropriate for disseminate in open access repositories, responsible custodianship of some de-identified or aggregated data may involve using or adapting template terms of use [45] which have a number of ethical clauses (for example, prohibiting efforts to re-identify research participants).

Storing and managing model code and data separately, can make it easier to apply models to different decision contexts and, when necessary, to selectively restrict access to data that are confidential, while disseminating all other model artefacts. Clear distinctions should be made between model modules (code that defines abstract data structures and the algorithms that can be applied to data described by these structures), model datasets (digital information such as parameter values, unit records, etc) and model analyses (code that specifies the data to be supplied to modules and selects which module algorithms to apply to that data).

The coding practice of encapsulation [38] can be used to help ensure that model modules can be safely combined [46]. In some cases, combining modules may mean new versions of modules have to be created that account for their effects on each other. The coding concept of inheritance [38] can be used to efficiently achieve this objective as well as to facilitate selective editing of modules when transferring models to different decision contexts [46]. Writing algorithms as collections of functions (short, self-contained and reusable software routines that each perform a discrete task) is recommended as good practice for scientific computing [36]. Functions to implement model algorithms can be associated with module data structures (also known as a class) via a special type of function called a method. Model modules of a similar type or purpose can be efficiently distributed and documented by bundling them as code libraries. It is good practice to make available test or toy data to demonstrate the use of model algorithms [36].

Statistical models are a common output of health economic evaluations, but they are often not reported in a format that enables others to confidently and reliably re-use them [47]. Open source approaches can help address this by disseminating code artefacts that enable easy and appropriate use of a statistical model to make predictions with new data. However, great care must be exercised when doing so if models are derived from data on human subjects as some software artefacts by default contain a copy of the source dataset. Such dataset copies must therefore be replaced (for example, with synthetic data) and the amended artefact's predictive performance then retested before any public release. Another way to make MOSHEMs easier to use is to develop simple user-interfaces for non-technical users. In the open source R language, such user-interfaces are typically developed with the Shiny package, for which a tutorial aimed at health economists is available [48].

2.1.3 Standards for an updatable MOSHEM

To avoid MOSHEMs going stale - losing validity and usefulness with time - they should be routinely updated. Each update of code and data should be uniquely identifiable and retrievable, a goal that can be facilitated by use of version control tools [2]. Labeling each change using semantic versioning [49] conventions can signal the potential importance of an update to users of model code and data. Continuous integration [50] tools can help verify that each code update passes multiple quality tests. Finally, using deprecation conventions that take an informative and staged approach to retiring old code and data reduces the risk that model revisions have unintended consequences on third party users.

2.2 Modelling toolkit

We have developed a toolkit to help streamline the process of developing and using MOSHEMs that meet the standards listed in Table 1. The toolkit is comprised of online repositories and software.

2.3 Repositories

We created a GitHub organisation where all framework software source code is stored, documented, version controlled and continuously integrated [51]. That was linked to an account we set up at code codecov [52] for tracking our unit tests and the Zenodo community [53] we created to store citable archived copies of release copies of our software. Finally, to manage datasets for use in models developed with the framework, we created a dedicated collection within the Harvard Dataverse [54].

2.4 Software

As a foundation for implementing our framework, we authored a development version R package that defines a template class for model module data structures [55] and a novel syntax for implementing the algorithms that will be attached to model modules. To enable the syntax and module template be applied to modelling projects, we then created five additional development version R packages that provide tools for authoring:

- documented model module data-structures [56];
- documented functions (including methods), written in a consistent house style [57];
- citable, quality assured module libraries [58];
- model datasets [59];
- model analyses and reports [60].

The six R packages, their primary focus, the framework standards they support and the third-party packages they depend on are summarised in Table 2. When used in conjunction with framework repositories, the six packages extend existing R packages provide strong support for implementing 17 of the framework standards. However, the software only weakly supports implementing the standards relating to disseminating statistical models (Y1) and user-interface development (Y2) and does not yet provide any workflow tools to help implement the standard for deprecation conventions (I4). Standards not supported or weakly supported by our software can be met with existing developer tools in R and we plan to progressively integrate these third-party tools with our own in future releases of our software. Another future priority is to submit production versions of each R package for review by and archiving on the Comprehensive R Archive Network (CRAN) [61].

Table 2: Framework software to enable the readyforwhatsnext model to meet TIMELY guidelines

Package	Focus	Guideline	Depends on these R packages
ready4	Syntax	T3 M3	assertthat bib2df dataverse dplyr fs Hmisc kableExtra knitr lifecycle magrittr methods natmanager piggyback purrr readr readxl rlang rmarkdown rvest stats stringi stringr testit testthat tibble tidyRSS tools utils zen4R
ready4fun	Functions	T2-3 E1	desc devtools dplyr generics gert Hmisc knitr lifecycle lubridate magrittr methods piggyback pkgdown purrr readxl ready4 ready4show ready4use rlang sinew stats stringi stringr testit testthat tibble tidyr tools usethis utils xfun
ready4class	Modules	T2-3 M2 E1-2	devtools dplyr fs gtools Hmisc knitr lifecycle magrittr methods purrr ready4 ready4fun ready4show rlang stats stringi stringr testit testthat tibble tidyr usethis utils
ready4pack	Libraries	T1 I1-3 M1-2 E1 L1,3	dataverse dplyr knitr lifecycle magrittr methods purrr ready4 ready4class ready4fun rlang stringr testthat tibble tidyr utils
ready4use	Data	T1-2 M1 E3 L2-3	data.table dataverse dplyr fs Hmisc knitr lifecycle magrittr methods piggyback purrr readxl ready4 ready4show rlang stats stringi stringr testit testthat tibble tidyr utils
ready4show	Reporting	T2,4,6 Y1-2	dataverse DescTools dplyr flextable grDevices here Hmisc kableExtra knitr knitrBootstrap lifecycle magrittr methods officer purrr ready4 rlang rmarkdown stringi stringr testthat tibble tidyr utils xtable

Table 3: Framework checklist applied to utility mapping study

	Standard	Met?	Description
A1	Public	Yes	Development and archived code for 5 libraries (youthvars, scorz, specific, TTU and youthu) [62–66], 3 programs [67–69], 2 sub-routines [70,71] and 2 datasets [72,73] are available. See https://www.ready4-dev.com/docs/getting-started/software/libraries/types/module/ (for libraries), https://www.ready4-dev.com/docs/getting-started/software/executables/programs/ (for programs) and https://www.ready4-dev.com/docs/getting-started/software/executables/subroutines/
A2	Documentation	Yes	All code libraries have documenting websites with URLs that concatenate 'https://ready4-dev.github.io/' and the package name (e.g. https://ready4-dev.github.io/youthvars). All three Markdown programs are self-documenting, with one [67] including additional instructions in a README file. Only one sub-routine [71] is documented with a meaningful README file. All datasets have meaningful metadata descriptors.
A3	Syntax	Yes	All libraries, programs and sub-routines use the same house style, which allows most library documentation to be written by algorithms from the ready4fun package [57]. All libraries except [66] use framework syntax, as does one program [67].
A4	Literate programming	Yes	All programs use literate programming.
A5	Code coverage	No	No current reporting of code coverage.
A6	Reproducibility	Yes	All parts of the study workflow from raw data ingest through to data processing, analysis, reporting and dissemination of study outputs can be reproduced (if granted access to source data) or replicated (using supplied synthetic data) with one program [67].
A7	Citation tools	Yes	All libraries have a CITATION file in the inst directory. All code repositories have a CITATION.cff file. All datasets have citation generating metadata.
R1	Code licenses	Yes	All code libraries, programs and sub-routines use GPL-3 licenses.
R2	Data terms	Yes	Datasets use amended version of template provided by Harvard Dataverse [45].
R3	Separation	Yes	All development code is stored on repos in a GitHub organisation [51] and all archived releases are available in a Zenodo community [53]. All non-confidential data is stored in repositories within a Harvard Dataverse collection [54].
R4	Encapsulated, inheriting	Yes	Four [62–65] out of five libraries include encapsulating and inheriting modules. See: https://www.ready4-dev.com/docs/model/finding-modules/
R5	Functions	Yes	All code libraries include functions. The most complete list of functions for each library is available by clicking the 'Manual - Developer (PDF)' link on each package's documentation homepage (see item T2 above)
R6	Libraries	Yes	All module data-structures and algorithms are distributed as code libraries

	Standard	Met?	Description
R7	Test data	Yes	Two synthetic datasets and their data dictionaries are publicly available in a data repository [73]. One (ymh_clinical_tb.RDS) closely resembles the study dataset and was released so that the main study algorithm [67] can be rerun by those without access to the confidential study dataset. The other (eq5d_ds_dict.RDS) is deliberately different to the source dataset in both variable naming convention and the concepts used for predictors and outcome measures. It was created to demonstrate generalised applications of study algorithms.
R8	Prediction tools	Yes	Model catalogues (PDF files beginning with 'AAA_TTU_MDL_CTG') are available in the study results dataset [72] and describe the predictive performance of all models under a variety of usage regimes (including when the source dataset in the R model object is replaced with fake data). The youthu library [66] includes tools for searching for and applying models compatible with different types of input data. An example program to demonstrate this functionality is available in both RMarkdown [68] and rendered PDF formats (the 'Application.pdf' file in the study results dataset [72]).
R9	User interface	No	No Shiny app user interface has yet been developed.
U1	Version controlled	Yes	All code is version controlled using Git and GitHub. All source code is available in a GitHub organisation [51].
U2	Semanticly versioned	Yes	Semantic version is used in all code. As no code library has yet been submitted to CRAN, only the development version extensions of each version number have been incremented to date.
U3	Continuously integrated	Yes	All six libraries use continuous integration (CI). CI results for each library can be viewed at a URL that concatenates 'https://github.com/ready4-dev/', the package name and '/actions' (e.g. https://github.com/ready4-dev/youthvars/actions)
U4	Deprecation	Yes	Retired code is deprecated using lifecycle package tools (e.g. everything after "## DEPRECATED FNS" in https://github.com/ready4-dev/youthvars/blob/main/data-raw/fns/add.R). Package vignettes and datasets are also deprecated e.g. https://ready4-dev.github.io/youthvars/articles/Replication_DS.html)

3 Application

3.1 readyforwhatsnext

Our approach to model development is to undertake a number of discrete modelling projects of the people, places, platforms and programs that shape the mental health and wellbeing of young people and to progressively link them together by means of a common framework. To model people we are developing synthetic representations of populations of interest [73] that describe relevant individual characteristics and their relationships, algorithms that map psychological measures to health utility [74] and choice models for predicting the helpseeking behaviour of young people [75]. Our in-development model of places [76] has the aim of synthesising geometry and spatial attribute data to characterise the geographic distribution of relevant demographic, environmental, epidemiological and service infrastructure features. We are in the early stages of a multi-annual project to develop a service platform model that will represent the processes and operations of a complex primary youth mental health service. We also plan to extend and update our prior work reviewing economic evidence relating to youth mental health programs [77] so that it can be integrated with this model.

Our initial work on **readyforwhatsnext** is focused on Victoria, Australia but the framework we are using to develop it is designed to facilitate extension by ourselves and others to different jurisdictional decision contexts. Progress is reported on a project website [78].

3.2 Utility mapping

We used framework toolkits to develop model code and datasets for implementing a utility mapping study that has previously been described [74]. Table 3 assesses that study against each TIMELY standard, 18 of which the study was able to meet. The two current standards where the study falls short are in reporting code coverage and including a user-interface. Both these items are current development priorities for our team.

4 Discussion

Mental disorders impose high health, social and economic burdens worldwide [79,80]. Much of this burden is potentially avertable [81], but poorly financed and organised mental health systems are ill-equipped for this challenge[82,83]. The large and widespread additional mental health burdens recently observed during the COVID-19 pandemic[84] and predicted as a potential future consequence of climate change [85], highlight the need to improve the resilience and adaptability of these systems. To help stem growing demand for mental health services, policymakers have also been encouraged to place greater emphasis on tackling the social determinants of mental disorders [86].

Major mental health reform programs, can involve the identification, prioritisation, sequencing, targeting and monitoring of multiple interdependent initiatives.

The significant deficits in our understanding of the systems in which mental disorders emerge and are treated [87] suggest that there is ample scope for mental health systems models to progressively improve their validity over time. Prospective work could address the weak theoretical underpinnings for understanding complex mental health systems [88]. For example, it remains unclear why increased investments in mental health care have yet to discernibly reduce the prevalence and burden of mental disorders[89]. The literature, and evidence base, regarding how the requirements, characteristics and performance of mental health services are shaped by spatiotemporal context needs to be further developed [90]. There is also a need for better evidence to identify the social determinants of mental disorders most amenable to preventative interventions, and for which population sub-groups such interventions would be most effective [91].

The development, validation and updating of more complex mental health economic models implemented over longer time frames may be too onerous a burden for a single modelling team.

Developing networks of modellers working on common health conditions has been recommended as a strategy for improving model validity [28] and some of us are part of a nascent initiate of this type in mental health

[92]. Similarly, developing partnerships between modellers and decision-makers across the life-cycle of a modelling project can help ensure models are appropriately conceptualised, implemented and have practical utility as decision aids [93,94].

Output by health economists [95–97]

5 Conclusion

We have identified a number of standards that we believe are appropriate to implementing quality OSHEMs in youth mental health. Most of these standards are probably relevant to OSHEMs in other health conditions, though some such as the copyleft licensing may be less relevant to modellers using different tools. Our framework toolkits can help support standardised approaches to dynamic systems model development that are important for collaborative and interdependent projects.

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Availability of data and materials

Development versions of all code repositories referenced in this article are available in https://github.com/ready4-dev/ . Archived code releases are available in https://zenodo.org/communities/ready4 .

All data repositories referenced in this article are available in https://dataverse.harvard.edu/dataverse/ready4 .

Ethics approval

Framework development did not involve human subject research and was not ethically reviewed. The worked example of framework application is a previously reported study that was reviewed and granted approval by the University of Melbourne's Human Research Ethics Committee, and the local Human Ethics and Advisory Group (1645367.1).

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Conflict of Interest

None declared.

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