A framework for an open source economic model of the systems shaping the mental health of young people

Matthew P Hamilton[1,*] Caroline X Gao[1,2,3] Glen Wiesner[4] John Gillam[2]
Kate M Filia[1,2] Jana M Menssink[1,2] Petra Plencnerova[5] David Baker[1,2]
Patrick D McGorry[1,2] Alexandra Parker[6] Jonathan Karnon[7] Sue M Cotton[1,2]
Cathrine Mihalopoulos[3]

Abstract

Summary: There is strong in principle support for open source health economic models, but practical barriers limit their availability. We propose a set of principles and standards for the implementation of open source health economic models that are TIMELY - Transparent, Iterative, Modular, Epitomised and Yielding. We then describe a software framework that we have developed for developing TIMELY models in youth mental health and illustrate this framework with an open source utility mapping project.

Data: Data

[1] Orygen, Parkville, Australia
[2] Centre for Youth Mental Health; University of Melbourne, Parkville, Australia
[3] School of Public Health and Preventive Medicine, Monash University, Clayton, Australia
[4] Heart Foundation, Melbourne, Australia
[5] headspace National Youth Mental Health Foundation, Melbourne, Australia
[6] Victoria University, Footscray, Australia
[7] Flinders University, Adelaide, Australia

[*] Correspondence: Matthew P Hamilton <matthew.hamilton@orygen.org.au>

1 Introduction

Computational models have become essential tools for health policy development [1]. Although influential and widely used, these models routinely contain errors [2], are rarely adequately validated [3], can be difficult to reproduce [4–6] and are likely to be infrequently updated or revised [7]. To help address these issues, there is growing support for greater use of open source health economics models (OSHEMs) that grant liberal permissions to access and re-use model source code [8]. However, to date actual implementations of OSHEMs are rare [9–11]. Barriers to adoption include concerns about intellectual property, confidentiality, model misuse and the resources required to support open source implementations [8,12]. As many health economic models are owned by pharmaceutical companies and consultancies, commercial considerations may also limit the uptake of OSHEMs [11].

There is also a need to develop good practice recommendations for OSHEMs [13]. Adherence to explicit standards is as essential requirement for quality health economic model implementation [1], but current guidance for OSHEMs is scarce and piecemeal. Guidelines on health economic model transparency were published ten years ago [14] and made recommendations on documenting models but notably not on the sharing of model code and data. More recent and more general modelling guidance [1] recommends the sharing of code and data through platforms such as GitHub [15] and Zenodo [16] and the use of version control systems such as Git [17]. A coding framework for OSHEMs developed in the language R includes standardised approaches to directory structure and naming conventions [18].

We have consolidated and refined these and other recommended standards for OSHEMs as part of a framework for developing an open source model of youth mental health. In this paper, we describe our motivation for developing the framework, the rationale for each included standard, the software toolkits we have developed to help meet each standard and a worked example of a modelling project developed with the framework.

2 Motivation

2.1 Why develop OSHEMs in mental health

Mental disorders impose high health, social and economic burdens worldwide [19,20]. Much of this burden is potentially avertable [21], but poorly financed and organised mental health systems are ill-equipped for this challenge[22,23]. The large and widespread additional mental health burdens recently observed during the COVID pandemic[24] and predicted as a potential future consequence of global heating [25], 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 disorder[26].

Computational modelling could play an important role in developing policies to improve population mental health but this may require significant changes in the way mental health modelling projects are funded, conceptualised and implemented.

Major mental health reform programs will require the identification, prioritisation, sequencing, targeting and monitoring of multiple interdependent initiatives. Single purpose models that assume static systems may be inadequate for the decision support needs of policymakers and service planners [27]. Currently, mental health economic models predominantly address issues relating to the affordability and value for money of individual programs [28] with mental health simulation studies rarely modelling complex systems [29]. Greater use of dynamic systems modelling approaches could provide new insights about inter-dependencies between candidate policies and the evolution of the mental health systems planning context [30]. These types of models might also be the basis for developing reference models [31] of mental health systems that are intended for multiple-applications and re-use by different modelling teams. However, as they are intended for multiple-purposes and because propagation errors may be more likely with more complex models [32] such models require greater investments in model transparency and validation [11,14].

The development, validation and maintenance of these more complex models may be simply too onerous a burden for a single modelling team. Developing networks of modellers working on common health conditions [13] and collaborations across multiple modelling teams that include the ability to re-use and extend each others work, can make complex modelling projects more tractable [33]. Similarly, more attention to developing partnerships between modellers and decision-makers across the life-cycle of a modelling project can help ensure models are appropriately conceptualised and implemented and improve their practical utility as decision aids [34].

Modelling projects should be resourced to be routinely updated and refined as new evidence emerges and decision contexts change [35]. There are significant deficits in our understanding of the systems in which mental disorder emerges and is treated [36] and longer term project horizons could allow mental health models to progressively improve validity as these gaps are addressed. Currently, the theoretical basis for understanding complex mental health systems is weak [37]. Strikingly, it remains unclear why increased investments in mental health care have yet to discernibly reduce the prevalence and burden of mental disorders[38]. The literature about how the requirements, characteristics and performance of mental health services are shaped by spatiotemporal context is underdeveloped [39]. There is insufficient 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 [40].

Open source frameworks have been previously recommended for the development of mental health modelling field [29] but, as with health economics more generally, OSHEMs remain rare. Currently there is only one mental health related model (in Alcohol Use Disorder [41]) that is indexed in the Open Source Models Clearinghouse [9,42]. A Major Depressive Disorder reference model for the United States [43] is also being developed as part of the Open Value Initiative [44]. We believe greater support for open source approaches have the potential to provide more transparent, collaborative and sustained approaches to mental health system model development.

2.2 readyforwhatsnext

We are currently developing an open source model of the systems shaping the mental health of young people in Victoria, Australia. The model is called readyforwhatsnext and development progress is reported on a project website [45]. The project aims to produce a reference model that can examine multiple potential population level strategies for prevention (in 0-25 year olds) and treatment (in 12-25 year olds) of mental disorders.

Our approach to model development is to undertake a number of discrete modelling projects and progressively link them together by means of a common framework. Sub-projects we are currently engaged in include those to develop models of people (synthetic populations of interest describing relevant individual characteristics and their household relationships, choice models for predicting helpseeking behaviour and models to map psychological measures to health utility), places (synthesising geometry and spatial attribute data to characterise the geographic distribution of relevant demographic, environmental, epidemiological and service infrastructure features) and platforms (representing the processes and operations of a complex primary youth mental health service). We have also previously undertaken scoping work reviewing economic evidence relating to youth mental health programs [46] and plan to integrate this with the model at a future date.

3 Framework

The framework we have developed consists of a set of standards for OSHEMs and tools for implementing those standards.

3.1 Standards

We have identified 20 standards that we believe are important for quality implementations of OSHEMs, each described under one of following six principles for making models TIMELY:

- **Transparent**: people can easily see how a model has been implemented and tested;
- **Iterative**: a model is routinely updated to maintain and improve validity;
- **Modular**: models and their components can be combined to extend their scope;
- **Epitomized**: models can be used in multiple decision contexts;
- **Licensed**: a model and its derivatives are persistently re-usable by other modellers; and
- **Yielding**: a model can be deployed as a simple, flexible and reliable decision aid.

3.1.1 Transparent Models

A range of tools and practices are available to help make model code and data accessible, citable and comprehensible. The most efficient way to widely disseminate code and data may be to use existing open science infrastructure [1]. Repositories such as Zenodo [16] and Dataverse [47] provide persistent storage solutions that generate a Digital Object Identifier (DOI) for each unique item. These repositories are a preferable solution for sharing citable code and data than transitory repositories such as corporate websites or GitHub where items can be deleted or relocated at any time [48]. Zenodo includes tools that automate integration with GitHub, which makes it easy for developers to maintain parallel code repositories - one for disseminating the most up to date development code and the other for archiving citable code releases.

Model code and data also need to be clearly documented, potentially with different versions for technical and non-technical users [14]. Developers storing data in a Dataverse installation have access to multiple meta-data fields to document both a data collection and its constituent individual files. In R, code manuals and websites can be created with the aid of tools such as devtools [49], sinew [50], roxygen2 [51] and pkgdown [52].

Consistent use of meaningful naming conventions when authoring code is recommended [18,53]. The main logic of a program can be made comprehensible to even non-technical users though the use of the common practices of abstraction [54], where only simple, high level commands are routinely exposed to reviewers, and polymorphsim [55], where the same command (e.g. "simulate") can be reused to implement different algorithms of the same broad type. Literate programming, where tools like RMarkdown [56] are used to render documents that integrate computer code with plain English descriptions of each step in an analysis workflow, can make code easier to follow by both technical and non-technical users.

An essential component of quality assuring health economic models is verification - ensuring that calculations are correct and consistent with model specifications [57]. One useful concept for informing model users about the extensiveness of verification checks is code coverage [58] - the proportion of model code that has been explicitly tested. In R, the testthat [59] and covr [60] tools can be used in conjunction with GitHub to define tests and report coverage metrics.

Finally, transcription errors - mistakes introduced when transferring data between sources, models and reports - are very common in health economic models [2]. 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 [53].

Standards:

- **T1: Uniquely identified copies of model code and data are permanently archived in open online repositories**
- **T2: Model code and data are documented**
- **T3: Model code uses a simple and consistent syntax**
- **T4: Model analyses and reporting are implemented using literate programming**
- **T5: Code coverage is reported**
- **T6: All parts of a study analysis and reporting workflow can be reproduced and/or replicated**

3.1.2 Iterative Models

To avoid OSHEMs going stale - losing validity and usefulness with time - they should be routinely updated. A number of tools and approaches can make the process of implementing and curating changes to model code and data more coherent and efficient. Repositories such as Zenodo [16] and Dataverse [47] provide persistent access to all published versions of a dataset, each uniquely identifiable. For code, use of version control tools like Git [17] can ensure that the entire development history of a project is organised so that each version is distinguishable and retrievable by developers. The online platform GitHub [15] can make this version history accessible to anyone.

Adopting semantic versioning [61] conventions can be an efficient way to provide users of model code and data with information about the potential importance of an update. For R code, the usethis [62] package can be used to partially automate version number increments using the convention Major.Minor.Patch.Development. Datasets stored on the Harvard Dataverse use the simpler Major.Minor convention.

Continuous integration [63] tools can help verify that each code update passes multiple quality tests. OSHEMs developed in R can take advantage of templates provided by devtools [49] and pkgdown [52] to run continuous integration checks on GitHub. These tests can include those of units (do individual functions produce expected output?), documentation (does documentation render correctly?, can all example workflows be executed?) and installation (can the software be successfully deployed on multiple types of operating system?).

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. The package lifeycle [64] provides tools for R developers to consistently deprecate their code.

Standards:

- **I1: Model code is version controlled**
- **I2: Model code and data use semantic versioning**
- **I3: Continuous integration is used to verify model code updates**
- **I4: Deprecation conventions are used to retire model code and data**

3.1.3 Modular Models

Modular health economic models link multiple self-contained components that can be independently reused and extended by other projects [65,66].

Many types of mental health data are highly sensitive with strict confidentiality requirements. For this reason, not all data included in some mental health models can be made widely available for others to re-use. A modular approach that ensures that model code and data are decoupled (stored in different files) can help model developers to restrict access to confidential model data, while providing open access to all other model components.

An important consideration when combining model components (or modules) is to ensure that interactions between two modules do not compromise the validity of either. Using the coding practice of encapsulation [54] can help ensure that model modules can be safely combined [ready4oop2022].

Standards:

- **M1: Model code and data are stored and managed separately**
- **M2: Model code defines encapsulating data structures**

3.1.4 Epitomised Models

A key challenge to generalising health economic models is that they are typically developed to inform a decision problem with a highly specific jurisdictional context. However, Modular code is also recommended as good practice for scientific computing more generally [53].

[model functions - compare to analysis and reporting]

Standards:

- **E1: Model code is distributed as libraries of functions**

- **E2: Model code defines inheriting data-structures**
- **E3: Test data is available to demonstrate generalised model applications**

3.1.5 Licensed Models

copyleft licensing [67] is used to ensure that

Standards:

- **L1: Model code is made available for re-use under copyleft licenses**
- **L2: Non-confidential model data is available for liberal re-use, subject to adherence clearly specified ethical standards**
- **L3: Model code and data are distributed with citation tools**

3.1.6 Yielding Models

Shiny tutorial [68]

- **Y1: Non- technical users can configure and run models via simple user-interfaces**
- **Y2: Statistical models can be safely, consistently and flexibly deployed using standardised tools**

3.2 Toolkits

3.2.1 Technical platforms

3.2.2 Software Development Kit

4 Application

Worked example

5 Discussion

MH systems design is not a pharma led project - less concerns about commercial ownership

greater use of these types of models may require adaptation on the part of funders, modellers and decision-makers. T

Availability of data and materials

Ethics approval

Details on ethics approvals go here.

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Conflict of Interest

None declared.

References

1. Erdemir A, Mulugeta L, Ku JP, Drach A, Horner M, Morrison TM, et al. Credible practice of modeling and simulation in healthcare: Ten rules from a multidisciplinary perspective. Journal of translational medicine. 2020;18: 369. doi:10.1186/s12967-020-02540-4
2. Radeva D, Hopkin G, Mossialos E, Borrill J, Osipenko L, Naci H. Assessment of technical errors and validation processes in economic models submitted by the company for NICE technology appraisals. International Journal of Technology Assessment in Health Care. 2020;36: 311–316. doi:10.1017/S0266462320000422
3. Ghabri S, Stevenson M, Möller J, Caro JJ. Trusting the results of model-based economic analyses: Is there a pragmatic validation solution? Pharmacoeconomics. 2019;37: 1–6. doi:10.1007/s40273-018-0711-9
4. Jalali MS, DiGennaro C, Guitar A, Lew K, Rahmandad H. Evolution and reproducibility of simulation modeling in epidemiology and health policy over half a century. Epidemiologic Reviews. 2021;43: 166–175. doi:10.1093/epirev/mxab006
5. McManus E, Turner D, Sach T. Can you repeat that? Exploring the definition of a successful model replication in health economics. Pharmacoeconomics. 2019;37: 1371–1381. doi:10.1007/s40273-019-00836-y
6. Bermejo I, Tappenden P, Youn J-H. Replicating health economic models: Firm foundations or a house of cards? PharmacoEconomics. 2017;35: 1113–1121. doi:10.1007/s40273-017-0553-x
7. Sampson CJ, Wrightson T. Model registration: A call to action. PharmacoEconomics - Open. 2017;1: 73–77. doi:10.1007/s41669-017-0019-2
8. Pouwels X, Sampson CJ, Arnold RJG. Opportunities and barriers to the development and use of open source health economic models: A survey. Value Health. 2022;25: 473–479. doi:10.1016/j.jval.2021.10.001
9. Emerson J, Bacon R, Kent A, Neumann PJ, Cohen JT. Publication of decision model source code: Attitudes of health economics authors. PharmacoEconomics. 2019;37: 1409–1410. doi:10.1007/s40273-019-00796-3
10. Michalczyk J, Clay E, Pochopien M, Aballea S. PRM123 - AN OVERVIEW OF OPEN-SOURCE MODELS IN HEALTH ECONOMICS. Value in Health. 2018;21: S377. doi:10.1016/j.jval.2018.09.2243
11. Feenstra T, Corro-Ramos I, Hamerlijnck D, Voorn G van, Ghabri S. Four aspects affecting health economic decision models and their validation. PharmacoEconomics. 2022;40: 241–248. doi:10.1007/s40273-021-01110-w
12. Wu EQ, Zhou Z-Y, Xie J, Metallo C, Thokala P. Transparency in health economic modeling: Options, issues and potential solutions. PharmacoEconomics. 2019;37: 1349–1354. doi:10.1007/s40273-019-00842-0
13. Sampson CJ, Arnold R, Bryan S, Clarke P, Ekins S, Hatswell A, et al. Transparency in decision modelling: What, why, who and how? PharmacoEconomics. 2019;37: 1355–1369. doi:10.1007/s40273-019-00819-z
14. Eddy DM, Hollingworth W, Caro JJ, Tsevat J, McDonald KM, Wong JB. Model transparency and validation: A report of the ISPOR-SMDM modeling good research practices task force-7. Med Decis Making. 2012;32: 733–43. doi:10.1177/0272989x12454579
15. github. GitHub [Internet]. 2007. Available: https://github.com/
16. European Organization For Nuclear Research, OpenAIRE. Zenodo [Internet]. CERN; 2013. doi:10.25495/7GXK-RD71
17. git. Git [Internet]. Available: https://git-scm.com/

18. Alarid-Escudero F, Krijkamp EM, Pechlivanoglou P, Jalal H, Kao S-YZ, Yang A, et al. A need for change! A coding framework for improving transparency in decision modeling. PharmacoEconomics. 2019;37: 1329–1339. doi:10.1007/s40273-019-00837-x

19. Bloom DE, Cafiero ET, Jané-Llopis E, Abrahams-Gessel S, Bloom LR, Fathima S, et al. The global economic burden of noncommunicable diseases. 91-93 route de la Capite,CH-1223 Cologny/Geneva,Switzerland: World Economic Forum.; 2011.

20. Global, regional, and national burden of 12 mental disorders in 204 countries and territories, 1990–2019: A systematic analysis for the global burden of disease study 2019. The Lancet Psychiatry. 2022;9: 137–150. doi:10.1016/S2215-0366(21)00395-3

21. Chisholm D, Sweeny K, Sheehan P, Rasmussen B, Smit F, Cuijpers P, et al. Scaling-up treatment of depression and anxiety: A global return on investment analysis. The Lancet Psychiatry. 2016; doi:10.1016/s2215-0366(16)30024-4

22. Saxena S, Thornicroft G, Knapp M, Whiteford H. Resources for mental health: Scarcity, inequity, and inefficiency. The Lancet. 370: 878–889. doi:10.1016/S0140-6736(07)61239-2

23. Whiteford H, Ferrari A, Degenhardt L. Global burden of disease studies: Implications for mental and substance use disorders. Health Affairs. 2016;35: 1114–1120. doi:10.1377/hlthaff.2016.0082

24. Santomauro DF, Mantilla Herrera AM, Shadid J, Zheng P, Ashbaugh C, Pigott DM, et al. Global prevalence and burden of depressive and anxiety disorders in 204 countries and territories in 2020 due to the COVID-19 pandemic. The Lancet. 2021;398: 1700–1712. doi:https://doi.org/10.1016/S0140-6736(21)02143-7

25. Page LA, Howard LM. The impact of climate change on mental health (but will mental health be discussed at copenhagen?). Psychological Medicine. Cambridge University Press; 2010;40: 177–180. doi:10.1017/S0033291709992169

26. Organization WH, Foundation CG. Social determinants of mental health. Geneva: World Health Organization; 2014.

27. Commission P. Mental health: Productivity commission inquiry report [Internet]. Productivity Commission; 2020. Available: https://apo.org.au/node/309475

28. Knapp M, Wong G. Economics and mental health: The current scenario. World Psychiatry. 2020;19: 3–14. doi:10.1002/wps.20692

29. Long KM, Meadows GN. Simulation modelling in mental health: A systematic review. Journal of Simulation. 2017; doi:10.1057/s41273-017-0062-0

30. Occhipinti JA, Skinner A, Doraiswamy PM, Fox C, Herrman H, Saxena S, et al. Mental health: Build predictive models to steer policy. Nature. 2021;597: 633–636. doi:10.1038/d41586-021-02581-9

31. Afzali HH, Karnon J, Merlin T. Improving the accuracy and comparability of model-based economic evaluations of health technologies for reimbursement decisions: A methodological framework for the development of reference models. Med Decis Making. 2013;33: 325–32. doi:10.1177/0272989x12458160

32. Saltelli A. A short comment on statistical versus mathematical modelling. Nature Communications. 2019;10: 3870. doi:10.1038/s41467-019-11865-8

33. Arnold RJG, Ekins S. Time for cooperation in health economics among the modelling community. PharmacoEconomics. 2010;28: 609–613. doi:10.2165/11537580-000000000-00000

34. Zabell T, Long KM, Scott D, Hope J, McLoughlin I, Enticott J. Engaging healthcare staff and stakeholders in healthcare simulation modeling to better translate research into health impact: A systematic review. Frontiers in Health Services. 2021;1. doi:10.3389/frhs.2021.644831

35. Jenkins DA, Martin GP, Sperrin M, Riley RD, Debray TPA, Collins GS, et al. Continual updating and monitoring of clinical prediction models: Time for dynamic prediction systems? Diagnostic and Prognostic Research. 2021;5: 1. doi:10.1186/s41512-020-00090-3

36. Fried EI, Robinaugh DJ. Systems all the way down: Embracing complexity in mental health research. BMC Medicine. 2020;18: 205. doi:10.1186/s12916-020-01668-w

37. Langellier BA, Yang Y, Purtle J, Nelson KL, Stankov I, Diez Roux AV. Complex systems approaches to understand drivers of mental health and inform mental health policy: A systematic review. Administration And Policy In Mental Health. 2018; doi:10.1007/s10488-018-0887-5

38. Jorm AF, Patten SB, Brugha TS, Mojtabai R. Has increased provision of treatment reduced the prevalence of common mental disorders? Review of the evidence from four countries. World psychiatry : official journal of the World Psychiatric Association (WPA). 2017;16: 90–99. doi:10.1002/wps.20388

39. Furst MA, Gandré C, Romero López-Alberca C, Salvador-Carulla L. Healthcare ecosystems research in mental health: A scoping review of methods to describe the context of local care delivery. BMC Health Services Research. 2019;19: 173. doi:10.1186/s12913-019-4005-5

40. Alegría M, NeMoyer A, Falgàs Bagué I, Wang Y, Alvarez K. Social determinants of mental health: Where we are and where we need to go. Current Psychiatry Reports. 2018;20: 95–95. doi:10.1007/s11920-018-0969-9

41. Clearinghouse C. Basu, kim: Alcohol use disorder [Internet]. OSF; 2018. Available: osf.io/jvayu

42. Evaluation of Value C for the, Health R in. Open-source model clearinghouse [Internet]. Tufts Medical Center; Available: http://ghcearegistry.org/orchard/open-source-model-clearinghouse

43. Innovation T, Initiative V. IVI-MDD value model [Internet]. 2022. Available: https://www.thevalueinitiative.org/ivi-mdd-value-model/

44. Jansen JP, Incerti D, Linthicum MT. Developing open-source models for the US health system: Practical experiences and challenges to date with the open-source value project. PharmacoEconomics. 2019;37: 1313–1320. doi:10.1007/s40273-019-00827-z

45. Orygen. ready4-dev - documenting the development of an open souce youth mental health systems model [Internet]. Available: https://ready4-dev.com/

46. Hamilton MP, Hetrick SE, Mihalopoulos C, Baker D, Browne V, Chanen AM, et al. Identifying attributes of care that may improve cost-effectiveness in the youth mental health service system. Med J Aust. 2017;207: S27–S37. doi:10.5694/mja17.00972

47. Quantitative Social Science I for. Dataverse [Internet]. Harvard University; 2007. Available: https://dataverse.org

48. Data, Data Editors CG by. Frequently asked questions [Internet]. Available: https://social-science-data-editors.github.io/guidance/FAQ.html

49. Wickham H, Hester J, Chang W, Bryan J. Devtools: Tools to make developing r packages easier [Internet]. 2021. Available: https://CRAN.R-project.org/package=devtools

50. Sidi J. Sinew: Package development documentation and namespace management [Internet]. 2022. Available: https://CRAN.R-project.org/package=sinew

51. Wickham H, Danenberg P, Csárdi G, Eugster M. roxygen2: In-line documentation for r [Internet]. 2021. Available: https://CRAN.R-project.org/package=roxygen2

52. Wickham H, Hesselberth J, Salmon M. Pkgdown: Make static HTML documentation for a package [Internet]. 2022. Available: https://CRAN.R-project.org/package=pkgdown

53. Wilson JAC Greg AND Bryan. Good enough practices in scientific computing. PLOS Computational Biology. Public Library of Science; 2017;13: 1–20. doi:10.1371/journal.pcbi.1005510

54. Hourani H, Wasmi H, Alrawashdeh T. A code complexity model of object oriented programming (OOP). 2019 IEEE jordan international joint conference on electrical engineering and information technology (JEEIT). 2019. pp. 560–564. doi:10.1109/JEEIT.2019.8717448

55. Milojkovic N, Caracciolo A, Lungu MF, Nierstrasz O, Röthlisberger D, Robbes R. Polymorphism in the spotlight: Studying its prevalence in java and smalltalk. 2015 IEEE 23rd international conference on program comprehension. 2015. pp. 186–195. doi:10.1109/ICPC.2015.29

56. Xie Y, Allaire JJ, Grolemund G. R markdown: The definitive guide. Chapman; Hall/CRC; 2018.

57. Büyükkaramikli NC, Rutten-van Mölken MPMH, Severens JL, Al M. TECH-VER: A verification checklist to reduce errors in models and improve their credibility. PharmacoEconomics. 2019;37: 1391–1408. doi:10.1007/s40273-019-00844-y

58. Eric Wong W, Debroy V, Choi B. A family of code coverage-based heuristics for effective fault localization. Journal of Systems and Software. 2010;83: 188–208. doi:https://doi.org/10.1016/j.jss.2009.09.037

59. Wickham H. Testthat: Get started with testing. The R Journal. 2011;3: 5–10. Available: https://journal.r-project.org/archive/2011-1/RJournal_2011-1_Wickham.pdf

60. Hester J. Covr: Test coverage for packages [Internet]. 2020. Available: https://CRAN.R-project.org/package=covr

61. Preston-Werner T. Semantic versioning 2.0.0 [Internet]. 2022. Available: https://semver.org

62. Wickham H, Bryan J, Barrett M. Usethis: Automate package and project setup [Internet]. 2021. Available: https://CRAN.R-project.org/package=usethis

63. Shahin M, Ali Babar M, Zhu L. Continuous integration, delivery and deployment: A systematic review on approaches, tools, challenges and practices. IEEE Access. 2017;5: 3909–3943. doi:10.1109/ACCESS.2017.2685629

64. Henry L, Wickham H. Lifecycle: Manage the life cycle of your package functions [Internet]. 2021. Available: https://CRAN.R-project.org/package=lifecycle

65. Trauer JM, Ragonnet R, Doan TN, McBryde ES. Modular programming for tuberculosis control, the "AuTuMN" platform. BMC Infectious Diseases. 2017;17: 546. doi:10.1186/s12879-017-2648-6

66. Urach C, Zauner G, Endel G, Wilbacher I, Breitenecker F. A modular simulation model for assessing interventions for abdominal aortic aneurysms. 2013 winter simulations conference (WSC). 2013. pp. 66–76. doi:10.1109/WSC.2013.6721408

67. Foundation TFS. What is copyleft? [Internet]. Available: https://www.gnu.org/copyleft/

68. Smith R, Schneider P. Making health economic models shiny: A tutorial. Wellcome Open Res. 2020;5: 69. doi:10.12688/wellcomeopenres.15807.2

A Appendix