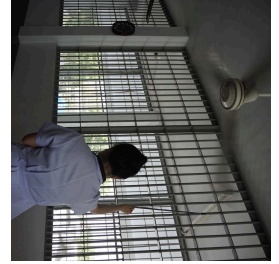


Jun 25, 2024

## Assessment of tuberculosis transmission probability in three Thai prisons based on five dynamic models

DOI

<https://dx.doi.org/10.17504/protocols.io.6qpvr868zlmk/v1>



Nithinan Mahawan<sup>1</sup>, Thanapoom Rattananupong<sup>1</sup>, Puchong Sri-Uam<sup>2</sup>, Wiroj Jiamjarasrangi<sup>1</sup>

<sup>1</sup>Faculty of Medicine, Chulalongkorn University;

<sup>2</sup>Center for Safety, Health and Environment of Chulalongkorn University

Wiroj Jiamjarasrangi: Corresponding author;



**Nithinan Mahawan**

School of Nursing, Walailak University, Nakhon Si Thammarat,...

### Create & collaborate more with a free account

Edit and publish protocols, collaborate in communities, share insights through comments, and track progress with run records.

Create free account

OPEN  ACCESS



**DOI:** <https://dx.doi.org/10.17504/protocols.io.6qpvr868zlmk/v1>

**Protocol Citation:** Nithinan Mahawan, Thanapoom Rattananupong, Puchong Sri-Uam, Wiroj Jiamjarasrangi 2024. Assessment of tuberculosis transmission probability in three Thai prisons based on five dynamic models. **protocols.io**

<https://dx.doi.org/10.17504/protocols.io.6qpvr868zlmk/v1>

**License:** This is an open access protocol distributed under the terms of the [Creative Commons Attribution License](#), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited

**Protocol status:** Working

**We use this protocol and it's working**

**Created:** May 04, 2024

**Last Modified:** June 25, 2024

**Protocol Integer ID:** 99258

**Keywords:** the probability of tuberculosis transmission, five dynamic models, the impact of model parameters, Prisons, assessment of tuberculosis transmission probability, tb transmission probability in most model, tuberculosis transmission probability, estimated tb transmission probability, tb transmission probability, tb transmission probability among these cell, tb transmission in prison, probability of tuberculosis, discrepant tb transmission probability, tb transmission model, number of infectious tb patient, infectious tb patient, tb transmission, dynamic models this study, ventilation rate, proposed model, thai prison, tuberculosis, dynamic model, tb, model parameter, applied seir model, impact of model parameter

**Funders Acknowledgements:**

The 90th Anniversary of Chulalongkorn University Fund

Grant ID: no. 035, 1/2021

the FY2021 Thesis Grant for Doctoral Degree Study of the National Research Council of Thailand

Grant ID: N41D640002, 2021

## Abstract

This study aimed to assess and compare the probability of tuberculosis (TB) transmission based on five dynamic models: the Wells–Riley equation, two Rudnick & Milton-proposed models based on air changes per hour (ACH) and liters per second per person (L/s/p), the model proposed by Issarow *et al*, and the Applied Susceptible-Exposed-Infected-Recovered (SEIR) TB transmission model. The study also aimed to determine the impact of model parameters on such probabilities in three Thai prisons.

The results revealed that the median (Quartiles 1 and 3) of TB transmission probability among these cells was 0.052 (0.017, 0.180). Compared with the pioneered Wells–Riley's model, the remaining models projected discrepant TB transmission probability from less to more commensurate to the degree of model modification from the pioneered model as follows: Rudnick & Milton (ACH), Issarow *et al*, and Rudnick & Milton (L/s/p), and the applied SEIR models. The ventilation rate and the number of infectious TB patients in each cell or zone had the greatest impact on the estimated TB transmission probability in most models. All stakeholders must urgently address these influential parameters to reduce TB transmission in prisons.

## Attachments



[assessment-of-tuberc...](#)

4.6MB

## Guidelines

1. The literature review.
2. A walk through survey to assess the suitability of prisons.

## Materials

1. The absolute ventilation rate, always used as a surrogate for exhaled air, was assessed by steady-state carbon dioxide (CO<sub>2</sub>) in parts per million using the Kimo HQ210 with SCOH 112 probe (Sauermann Industries, ZA Bernard Moulinet, Montpon, France).
2. ACH (Q; ACH), as a rule of thumb, is classically used as a metric for assessing infection control risk. It is the total air volume in a room or space that is completely removed and replaced in an hour. In this method, the wind speed (meters/second) in each cell was measured at the location of the opening facing prevailing winds using a hot wire thermo-anemometer and datalogger (Model SDL350, Extech Instruments, Waltham, MA).

## Before start

1. The literature review comprises the following topics
  - 1.1 The incidence and prevalence of tuberculosis in prisons globally and specifically in Thailand.
  - 1.2 Evidence indicating that tuberculosis in prisons may serve as a reservoir for tuberculosis in the general population.
  - 1.3 Humanitarian issues concerning prisoners related to tuberculosis or overall health problems.
  - 1.4 Factors associated with the transmission of tuberculosis/drug-resistant tuberculosis in prisons
  - 1.5 Current dynamic models of tuberculosis transmission in prisons, including (1) the Wells-Riley equation (2) Rudnick & Milton-proposed (air change per hour: ACH) model (3) Rudnick & Milton-proposed (litre/second/person: l/s/p) model (4) the Applied Susceptible-Exposed-Infected-Recovered (SEIR) tuberculosis transmission model and (5) Issarow *et al* model.
2. Contact the academic department of the Department of Corrections for a walk through survey to assess the suitability of three sample prisons for research study (June, 2019).
  - (1) Cell architectural and environmental characteristics. (2) The number of TB infections.

## Research ethics

- 1 The study received ethical approval from the Ethical Review Board of Chulalongkorn University Faculty of Medicine, with reference number 610/63.
- 2 Contact the academic department of the Department of Corrections to gained permission from the Department of Corrections at the Ministry of Justice before being conducted.
- 3 Present all the details of the research study to the relevant stakeholders of all three sample prisons, ensuring they are informed and given the opportunity to inquire about any concerns. Additionally, the superintendent of each correctional facility reviewed the "Information Sheet for Participants" and signed the "Submission Agreement for Volunteers" before initiating the study. No personal information was collected during the study that could identify inmates; thus, individual inmate consent was not required.

## Data Collection

- 4 Our research team receives training on regulations, rules, and protocols for conducting research in each of the sample prisons and adheres strictly to them.
- 5 The inmate teams were trained by the principal investigator (NM) and a coinvestigator (PS, who is also an industrial hygienist) for collecting the CO<sub>2</sub> concentrations in the morning after at least 13 hours of lockup time using the Kimo HQ210 with SCOH 112 probe (Sauermann Industries, ZA BernardMoulinet, Montpon, France) within and outside each cell (985 cells in the winter; October 2020 to January 2021). These data use for calculating Germ-free ventilationrate,  $Q$  in liters/second/person (See S1 Table of PONE-D-24-02877R1 data Folder for more detail).
- 6 The wind speed (meters/second) in each cell was measured at the location of the opening facing prevailing winds using a hot wire thermo-anemometer and datalogger (Model SDL350, Extech Instruments, Waltham, MA). The credibility of the data was cooperatively ensured by the principal investigator (NM) and a coinvestigator (PS)(985 cells in the winter). These data use for calculating Germ-free ventilationrate,  $Q$  in air changes per hour (See S1 Table of PONE-D-24-02877R1 data Folder for more detail).
- 7 Working with HCW and Prison Health Volunteer for collecting the number of tuberculosis-infected patients in each cell and zone, which served as an indication of the prevalence at both the cell and zonal levels. These data were considered secondary data, comprising documents and computer databases sourced from the respective zonal and central administrative and medical facilities within the prisons. We cross-checked

the data obtained from central administrative and medical facilities with the data from each zone to ensure consistency for all PTB cases. The data was recorded as a percentage for a period of 6 months, from July to December 2020, for Prisons A and B, and from October 2020 to March 2021 for Prison C.

- 8 Five inmates from each zone were recruited and trained by the principal investigator (NM) and a coinvestigator (PS) to survey the architectural and environmental characteristics of each cell within the zone. The researchers verified the collected data against the prison blueprints and randomly measured the dimensions of the cells themselves.
- 9 However, since March 2021, there has been a COVID-19 outbreak in Thai prisons, leading to measures that prohibit outsiders from entering without valid reasons. This has prevented researchers from collecting data continuously according to the planned schedule. Once the COVID-19 situation in the sample prisons improved, the prisons relaxed their measures, allowing researchers to enter under strict adherence to the prison's protocols. Consequently, the researchers resumed collecting the data including (1) the architectural and environmental characteristics of each cell such as room volume, opening facing prevailing winds, opening into the building, and number of cells per courtyard; and (2) the demographic and health status composition of inmates, including the number of total and susceptible inmates per cell, residence time per day, and inmate turnover and (3) treatment effectiveness parameters, including period of infectiousness, number of recovered patients, and TB-related, natural, and other mortality rates (secondary data). These variables and parameters were collected or obtained as shown in S1 & S2 Table of the manuscript [Assessment of tuberculosis transmission probability in three Thai prisons based on five dynamic models PONE-D-24-02877R1]
- 10 Review literature related to the model parameters additionally

## Statistical analysis

- 11 To calculate the estimated TB transmission probability within cells using five dynamic models (See excel data Folder)
- 12 Agreement among the TB transmission probability estimated using the different dynamic models was then assessed via Spearman's rank correlation ( $r$ ). The detailed pattern of agreement or difference was further investigated using Bland–Altman plots representing absolute and percent differences.

- 13 To investigate the influence of model parameters on TB transmission probability, two procedures were used separately for each TB transmission prediction model. First, cells were categorized into four subgroups based on the quartile of predicted TB transmission probability. Furthermore, subgroups of model parameters were then compared using the Wilcoxon rank-sum (Mann–Whitney) test since the cell-specific probabilities of TB transmission were non-normally distributed. Second, the magnitude and pattern of change in the predicted TB transmission probability along each model's parameter categories were investigated using a multiple linear regression incorporating all model parameters simultaneously for a specific prediction model. The adjusted beta (i.e., the magnitude of change in the predicted TB transmission probability) and its 95% confidence intervals were estimated. All statistical analyses were performed using Stata software, Version 13.0 (StataCorp. 2013, Stata Statistical Software: Release 13, College Station, TX: StataCorp LP).

## Results and Conclusion

- 14 This study showed that the variant models projected different values of TB transmission probability. Although the probability values differed, three models, i.e., the Wells–Riley model and the two Rudnick & Milton-proposed models, estimated similar patterns of TB transmission probability. Using the pioneered Wells–Riley's model as the reference, the remaining models projected discrepant TB transmission probability from less to more commensurate to the degree of model modification from the pioneered model as follows: Rudnick & Milton (ACH), Issarow *et al.* and Rudnick & Milton (L/s/p), and the applied SEIR models. In terms of risk factors, our study identified two parameters that significantly contribute to ongoing TB transmission risk in all models: low ventilation rates and a high number of existing TB inmates in the cell or zone. All stakeholders must urgently address these issues to reduce TB transmission in prisons. Furthermore, since these five models produced varying estimates of TB transmission probabilities, further studies are required to determine their relative validity in accurately predicting TB incidence in prison settings.

## Protocol references

1. World Health Organization. Global tuberculosis report 2023. Geneva: World Health Organization; 2023. 57 p.
2. United States Agency International Development. Tuberculosis in prisons: a growing public health challenge [Internet]. USAID; 2014[Cited 2021 August 8]. Available from: <https://www.usaid.gov/sites/default/files/documents/1864/USAID-TB-Brochure.pdf>.
3. World Health Organization [Internet]. Tuberculosis: Key facts. [cited 2021 August 8]. Available from: <https://www.who.int/news-room/fact-sheets/detail/tuberculosis>.
4. World Prison Brief, Institute for Crime & Justice Policy Research, Birkbeck University of London [Internet]. Highest to Lowest - Prison Population Total. [cited 2022 February 25]. Available from: [https://www.prisonstudies.org/highest-to-lowest/prison-population-total?field\\_region\\_taxonomy\\_tid=All](https://www.prisonstudies.org/highest-to-lowest/prison-population-total?field_region_taxonomy_tid=All).
5. Walter KS, Martinez L, Arakaki-Sanchez D, Sequera VG, Estigarribia Sanabria G, Cohen T, et al. The escalating tuberculosis crisis in central and South American prisons. *Lancet*. 2021; 397(10284):1591-6. PubMed PMID: 33838724; PubMed Central PMCID: PMC9393884.
6. Mabud TS, de Lourdes Delgado Alves M, Ko AI, Basu S, Walter KS, Cohen T, et al. Evaluating strategies for control of tuberculosis in prisons and prevention of spillover into communities: an observational and modeling study from Brazil. *PLoS Med*. 2019; 16(1):e1002737. PubMed PMID: 30677013; PubMed Central PMCID: PMC6345418.
7. Johnstone-Robertson S, Lawn SD, Welte A, Bekker LG, Wood R. Tuberculosis in a South African prison - a transmission modelling analysis. *S Afr Med J*. 2011;101(11):809-13. PubMed PMID: 22272961; PubMed Central PMC4538692.
8. Urrego J, Ko AI, da Silva Santos Carbone A, Paiao DS, Sgarbi RV, Yeckel CW, et al. The impact of ventilation and early diagnosis on tuberculosis transmission in Brazilian Prisons. *Am J Trop Med Hyg*. 2015;93(4):739-46. PubMed PMID: 26195459; PubMed Central PMC4596592.
9. Rudnick SN, Milton DK. Risk of indoor airborne infection transmission estimated from carbon dioxide concentration. *Indoor Air*. 2003;13(3):237-45. PubMed PMID: 12950586.
10. Issarow CM, Mulder N, Wood R. Modelling the risk of airborne infectious disease using exhaled air. *J Theor Biol*. 2015;372:100-6. PubMed PMID: 25702940.
11. Issarow CM, Mulder N, Wood R. Environmental and social factors impacting on epidemic and endemic tuberculosis: a modelling analysis. *R Soc Open Sci*. 2018;5(1):170726. PubMed PMID: PMC5792873; PubMed Central PMC5792873.
12. Naning H, Al-Darraj HAA, McDonald S, Ismail NA, Kamarulzaman A. Modelling the impact of different tuberculosis control interventions on the prevalence of tuberculosis in an Overcrowded Prison. *Asia Pac J Public Health*. 2018;30(3):235-43. PubMed PMID: 29502429.
13. Sze To GN, Chao CY. Review and comparison between the Wells-Riley and dose-response approaches to risk assessment of infectious respiratory diseases. *Indoor Air*. 2010;20(1):2-16. PubMed PMID: 19874402; PubMed Central PMC7202094.
14. Ozcaglar C, Shabbeer A, Vandenberg SL, Yener B, Bennett KP. Epidemiological models of Mycobacterium tuberculosis complex infections. *Math Biosci*. 2012;236(2):77-96. PubMed PMID: 22387570; PubMed Central PMC3330831.
15. Persily AK. Evaluating building IAQ and ventilation with indoor carbon dioxide ASHRAE [Preprint]. 1997 [cited 2022 April 3]: [12 p.]. Available from: [https://www.aivc.org/sites/default/files/airbase\\_10530.pdf](https://www.aivc.org/sites/default/files/airbase_10530.pdf).



16. Atkinson J, Chartier Y, PessoaSilva CL, Jensen P, Li Y, Seto WH, editors. Natural ventilation for infection control in Health-Care Settings. Geneva: World Health Organization; 2009.
17. Pinna GD, Maestri R, La Rovere MT, Gobbi E, Fanfulla F. Effect of paced breathing on ventilatory and cardiovascular variability parameters during short-term investigations of autonomic function. *Am J Physiol Heart Circ Physiol*. 2006;290(1):H424-33. PubMed PMID: 16155106.
18. Guo Y, Qian H, Sun Z, Cao J, Liu F, Luo X, et al. Assessing and controlling infection risk with Wells-Riley model and spatial flow impact factor (SFIF). *Sustain Cities Soc*. 2021;67:102719. PubMed PMID: 33520610; PubMed Central PMC7834120.
19. M Issarow C, Wood R. Seminal mycobacterium tuberculosis in vivo transmission studies: reanalysis using probabilistic modelling. *Mycobact Dis*. 2016;6(3):217.
20. Riley RL, Wells WF, Mills CC, Nyka W, McLean RL. Air hygiene in tuberculosis: quantitative studies of infectivity and control in a pilot ward. *Am Rev Tuberc*. 1957;75(3):420-31. PubMed PMID: 13403171.
21. Catanzaro A. Nosocomial tuberculosis. *Am Rev Respir Dis*. 1982;125(5):559-62. PubMed PMID: 7081816.
22. Noakes CJ, Sleigh PA. Mathematical models for assessing the role of airflow on the risk of airborne infection in hospital wards. *J R Soc Interface*. 2009;6 Suppl 6(Suppl 6):S791-800. PubMed PMID: 19812072; PubMed Central PMC2843948.
23. Nardell EA, Keegan J, Cheney SA, Etkind SC. Airborne infection. Theoretical limits of protection achievable by building ventilation. *Am Rev Respir Dis*. 1991;144(2):302-6. PubMed PMID: 1907115.
24. Riley RL, Mills CC, O'Grady F, Sultan LU, Wittstadt F, Shivpuri DN. Infectiousness of air from a tuberculosis ward. Ultraviolet irradiation of infected air: comparative infectiousness of different patients. *Am Rev Respir Dis*. 1962;85:511-25. PubMed PMID: 14492300.
25. Behr MA, Warren SA, Salamon H, Hopewell PC, Ponce de Leon A, Daley CL, et al. Transmission of mycobacterium tuberculosis from patients smear-negative for acid-fast bacilli. *Lancet*. 1999;353(9151):444-9. PubMed PMID: 9989714.
26. Vynnycky E, Fine PE. The natural history of tuberculosis: the implications of age-dependent risks of disease and the role of reinfection. *Epidemiol Infect*. 1997;119(2):183-201. PubMed PMID: 9363017; PubMed Central PMC2808840.
27. Dye C, Garnett GP, Sleeman K, Williams BG. Prospects for worldwide tuberculosis control under the WHO DOTS strategy. Directly observed short-course therapy. *Lancet*. 1998;352(9144):1886-91. PubMed PMID: 9863786.
28. Legrand J, Sanchez A, Le Pont F, Camacho L, Larouze B. Modeling the impact of tuberculosis control strategies in highly endemic overcrowded prisons. *PloS one*. 2008;3(5):e2100. PubMed PMID: 18461123; PubMedCentral PMC2324198.
29. Dowdy DW, Dye C, Cohen T. Data needs for evidence-based decisions: a tuberculosis modeler's 'wish list'. *Int J Tuberc Lung Dis*. 2013;17(7):866-77. PubMed PMID: 23743307; PubMed Central PMC4041555.
30. Blower SM, McLean AR, Porco TC, Small PM, Hopewell PC, Sanchez MA, et al. The intrinsic transmission dynamics of tuberculosis epidemics. *Nat Med*. 1995;1(8):815-21. PubMed PMID: 7585186.
31. Malaysian Health Technology Assessment Section, Medical Development Division, Ministry of Health Malaysia. Clinical Practice Guidelines: Management of Tuberculosis. 4th ed. Putrajaya: Federal Government Administrative Centre; 2021.106 p.
32. Grzybowski S, Enarson DA. The fate of cases of pulmonary tuberculosis under various treatment programmes. *Bull IUAT*. 1978;53(2):70-5.



33. Noakes CJ, Beggs CB, Sleight PA, Kerr KG. Modelling the transmission of airborne infections in enclosed spaces. *Epidemiol Infect.* 2006;134(5):1082-91. PubMed PMID: 16476170; PubMed Central PMC2870476.
34. Carbone Ada S, Paiao DS, Sgarbi RV, Lemos EF, Cazanti RF, Ota MM, et al. Active and latent tuberculosis in Brazilian correctional facilities: a cross-sectional study. *BMC Infect Dis.* 2015;15:24. PubMed PMID: 25608746; PubMed Central PMC4307675.
35. Storla DG, Yimer S, Bjune GA. A systematic review of delay in the diagnosis and treatment of tuberculosis. *BMC Public Health.* 2008;8:15. PubMed PMID: 25608746; PubMed Central PMC4307675.
36. Tiemersma EW, van der Werf MJ, Borgdorff MW, Williams BG, Nagelkerke NJD. Natural history of tuberculosis: duration and fatality of untreated pulmonary tuberculosis in HIV negative patients a systematic review. *PLoS ONE.* 2011; 6(4): e17601. PubMed PMID: 21483732; PubMed Central PMC3070694.
37. Hinkle DE, Wiersma W, Jurs SG. *Applied statistics for the behavioral sciences.* 5th ed. Boston: Houghton Mifflin; 2003.
38. Giavarina D. Understanding Bland Altman analysis. *Biochem Med (Zagreb).* 2015;25(2):141-51. PubMed PMID: 26110027; PubMed Central PMC4470095.
39. Cooper-Arnold K, Morse T, Hodgson M, Pettigrew C, Wallace R, Clive J, et al. Occupational tuberculosis among deputy sheriffs in Connecticut: a risk model of transmission. *Appl Occup Environ Hyg.* 1999;14(11):768-76. PubMed PMID: 10590550.
40. Haeusler IL, Torres-Ortiz A, Grandjean L. A systematic review of tuberculosis detection and prevention studies in prisons. *Glob Public Health.* 2022;17(2):194-209. PubMed PMID: 33427099.
41. Ndeffo-Mbah ML, Vigliotti VS, Skrip LA, Dolan K, Galvani AP. Dynamic models of infectious disease transmission in prisons and the general population. *Epidemiol Rev.* 2018;40(1):40-57. PubMed PMID: 29566137; PubMed Central PMC5982711.
42. World Health Organization. *WHO policy on TB infection control in health-care facilities: congregate settings and households.* Geneva: World Health Organization; 2009. 62 p.