**Impact of continued closure of red-light areas on COVID-19 transmission in India**

**Introduction**

The COVID-19 pandemic is a major threat to India [[1]](https://paperpile.com/c/dN8otS/91GbA), **one** of the most populous nations in the world. **One** measure to address the potential threat is the targeting of prevention measures within vulnerable communities that may be the first to experience widespread transmission and propagate transmission to the general population. One such community is that of red-light areas, within which the difficulty of social distancing, contact patterns, population density, and the potential transmission to and from diverse geographies may combine to make red-light communities key populations at high risk of COVID-19 COVID-19 is contagious and transmitted by respiratory droplets [[2]](https://paperpile.com/c/dN8otS/JK7m). As a primary intervention measure, social distancing involves staying at least one meter away from other individuals to prevent transmission [[3]](https://paperpile.com/c/dN8otS/2jwO) However, both typical living conditions and sexual interactions in red-light areas make these measures .

Here we evaluate the impact of continued closure of red-light areas to COVID-19 incidence both in those areas and to the broader population. We find that maintenance of closure will have a disporportionate impact in slowing epidemic growth. To make the prolonged closure of red light districts feasible, it is essential that the governement provide sex workers with alternative means to survive the closure.

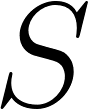
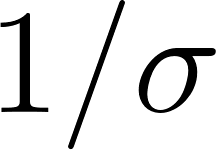
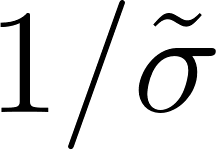
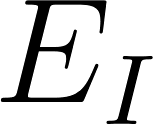
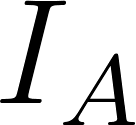
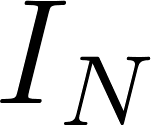
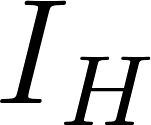
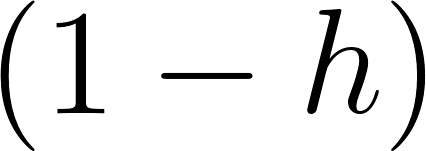
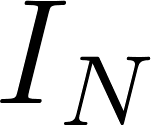
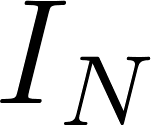
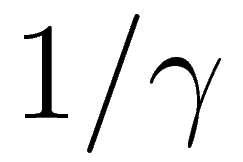
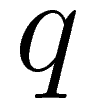
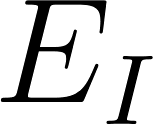
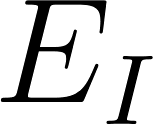
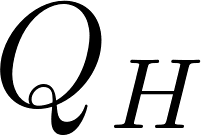
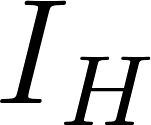
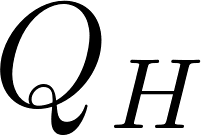
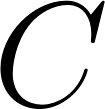
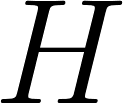
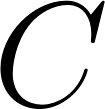
**Methods**

We developed an age-structured SEIR-type dynamic model for COVID-19 transmission to understand the impact of continued closure of red-light areas in five cities of India (Mumbai, Nagpur, Delhi, Kolkata, and Pune) as well as nationally after the initial country-wide lockdown of 40 days from 24 March 2020 to 3 May 2020 and subsequent continuation to 17 May 2020. The population of each location considered was compartmentalized into red-light area residents and the general population. Red-light area residents included sex workers as well as non-sex workers such as pimps, brothel managers, security, servants, and others performing miscellaneous roles in the area. Both populations were stratified into four age groups: 0–19 y, 20–49 y, 50–64 y, and ≥65 y. Age-distribution of each location was based on the most recent census[[4]](https://paperpile.com/c/dN8otS/A429) , adjusted to current population estimates for five major cities and the red-light areas within them, as well as the country of India. The general population and red-light areas were further compartmentalized (**Table 1; Fig. 1**) based on the known natural history of COVID-19 disease as well as interventions of hospitalization and provision of intensive care units (ICUs).

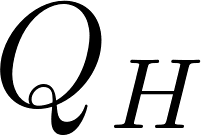
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| **Table 1**. Model compartments | |
| Compartment | Definition |
|  | Susceptible |
|  | Incubation |
|  | Presymptomatic infections |
|  | Asymptomatic infections |
|  | Symptomatic severe infections (not isolated) |
|  | Symptomatic mild infections (not isolated) |
|  | Symptomatic severe infections (isolated) |
|  | Symptomatic mild infections (not isolated) |
|  | Hospitalization |
|  | Intensive care units |
|  | Deaths |

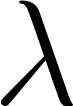
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| **Figure 1**. Model schematic. |

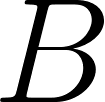
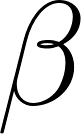
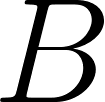
In our model, a susceptible individual ([](https://www.codecogs.com/eqnedit.php?latex=S#0)) after acquiring infection remained in an non-infectious incubation period ([](https://www.codecogs.com/eqnedit.php?latex=E#0)) for an average of [](https://www.codecogs.com/eqnedit.php?latex=1%2F%5Csigma#0) = 5.2 days (**Table 2**). As infected individuals become infectious [](https://www.codecogs.com/eqnedit.php?latex=1%2F%5Ctilde%7B%5Csigma%7D#0) = 2.3 days prior to symptom onset [[5]](https://paperpile.com/c/dN8otS/Bkwc), individuals move to a pre-symptomatic infectious compartment ([](https://www.codecogs.com/eqnedit.php?latex=E_I#0)) for the last 2.3 days of the incubation period. Following the incubation period, an infected individual either remained asymptomatic ([](https://www.codecogs.com/eqnedit.php?latex=I_A#0)) or developed symptoms ([](https://www.codecogs.com/eqnedit.php?latex=I_N#0),[](https://www.codecogs.com/eqnedit.php?latex=I_H#0)). A proportion of symptomatic individuals ([](https://www.codecogs.com/eqnedit.php?latex=(1-h)#0)) developed only mild symptoms ([](https://www.codecogs.com/eqnedit.php?latex=I_N#0)). Symptomatic individuals with mild symptoms ([](https://www.codecogs.com/eqnedit.php?latex=I_N#0),[](https://www.codecogs.com/eqnedit.php?latex=Q_N#0)) did not need hospitalization, and recovered in an average of [](http://www.sciweavers.org/tex2img.php?bc=Transparent&fc=Black&im=jpg&fs=100&ff=modern&edit=0&eq=1%2F%5Cgamma#0) = 4.6 days **(Table 2)**. A proportion of individuals ([](http://www.sciweavers.org/tex2img.php?bc=Transparent&fc=Black&im=jpg&fs=100&ff=modern&edit=0&eq=q#0)=0.05) with mild or severe symptoms were isolated ([](https://www.codecogs.com/eqnedit.php?latex=E_I#0) → [](https://www.codecogs.com/eqnedit.php?latex=Q_N#0), [](https://www.codecogs.com/eqnedit.php?latex=E_I#0) → [](https://www.codecogs.com/eqnedit.php?latex=Q_H#0)). Symptomatic individuals with severe symptoms ([](https://www.codecogs.com/eqnedit.php?latex=I_H#0),[](https://www.codecogs.com/eqnedit.php?latex=Q_H#0)) were either hospitalized ([](https://www.codecogs.com/eqnedit.php?latex=H#0)), or required an ICU admission within a hospital ([](https://www.codecogs.com/eqnedit.php?latex=C#0)). Those hospitalized patients ([](https://www.codecogs.com/eqnedit.php?latex=H#0),[](https://www.codecogs.com/eqnedit.php?latex=C#0)) either recovered or died.

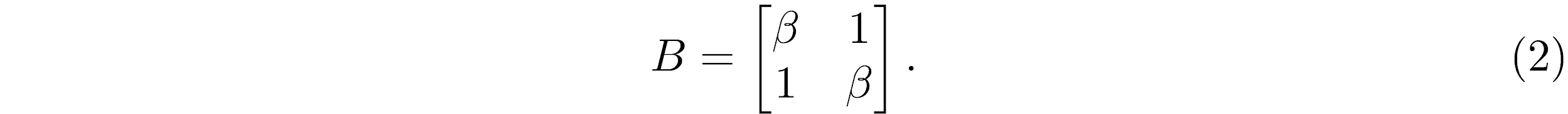
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| **Table 2.** Model parameters | | | |
| Parameter | Definition | Value | Reference |
|  | Reproduction number | 1.75–2.25 | [[6,7]](https://paperpile.com/c/dN8otS/38yW+k1rM) |
|  | Probability of infection | Calibrated to | |
|  | Relative infectivity of asymptomatic infections | 0.5 | [[8]](https://paperpile.com/c/dN8otS/lLL3) |
|  | Relative infectivity of mild cases | 0.5 | [[8]](https://paperpile.com/c/dN8otS/lLL3) |
|  | Duration of incubation period | 5.2 | [[9]](https://paperpile.com/c/dN8otS/OWam) |
|  | Duration of pre-symptomatic infectious period | 2.3 | [[5]](https://paperpile.com/c/dN8otS/Bkwc) |
|  | Duration of pre-symptomatic non-infectious period |  | |
|  | Proportion of asymptomatic cases | 0.28 | [[10]](https://paperpile.com/c/dN8otS/tohb) |
|  | Proportion of severe symptomatic cases, age group 0–19 | 0.025 | [[11]](https://paperpile.com/c/dN8otS/ORd7) |
| age group 20–49 | 0.32 |
| age group 50–64 | 0.32 |
| age group ≥65 | 0.64 |
|  | Proportion of symptomatic cases being isolated | 0.05 | [[11]](https://paperpile.com/c/dN8otS/ORd7) |
|  | Recovery period of mild and asymptomatic cases | 4.6 | [[11]](https://paperpile.com/c/dN8otS/ORd7) |
|  | Hospitalization rate | 1/3.5 | [[12]](https://paperpile.com/c/dN8otS/fwfy) |
|  | Proportion of symptomatic cases needing ICU in hospitals, age group 0–19 | 0.014 | [[11]](https://paperpile.com/c/dN8otS/ORd7) |
| age group 20–49 | 0.042 |
| age group 50–64 | 0.075 |
| age group ≥65 | 0.15 |
|  | Weight associated with the model death rate among among hospitalized (non-ICU) patients | 0.2296 | [[11]](https://paperpile.com/c/dN8otS/ORd7) |
|  | Weight associated with the model death rate among ICU patients | 0.1396 | [[11]](https://paperpile.com/c/dN8otS/ORd7) |
|  | Recovery rate of hospitalized cases | 1/10 | [[13]](https://paperpile.com/c/dN8otS/PFuL) |
|  | Recovery rate of hospitalized cases needing ICU | 1/13.25 | [[12]](https://paperpile.com/c/dN8otS/fwfy) |
|  | Mortality rate of hospitalized cases | 1/9.7 | [[12]](https://paperpile.com/c/dN8otS/fwfy) |
|  | Mortality rate of hospitalized cases needing ICU | 1/7 | [[14]](https://paperpile.com/c/dN8otS/SpsH) |

The spread of infection within each population depended on the prevalence of infections at the given time, age-specific contact patterns and per contact transmission rate of the virus. Prem et. al [[15]](https://paperpile.com/c/dN8otS/Kwwz) estimated contact patterns between different age-groups in India overall and within specific locations such as households. We use estimates of overall contact patterns to parameterize contact rate between different age groups in our model. Contact rate of individuals who are isolated ([](https://www.codecogs.com/eqnedit.php?latex=Q_N#0),[](https://www.codecogs.com/eqnedit.php?latex=Q_H#0)) is parameterized by the data on household contact patterns .

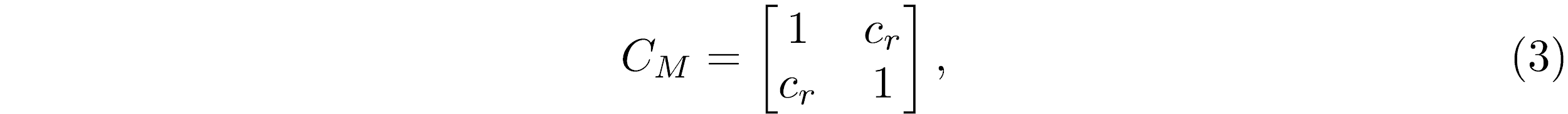
The force of infection [](https://www.codecogs.com/eqnedit.php?latex=%5Clambda#0) is given by

[](https://docs.google.com/document/d/1RB89W7IV-bzgNyQE8EzFCW16SUqMMxUO37JDAzKdf-Y/edit#D2L_code_render_%20%5Cbegin%7Bequation%7D%0A%5Clambda%20=%20%5Cfrac%7BB%20C_%7BM%7D%20%5B%20M_%7BA%7D(E_%7BI%7D%20+%20k_%7BA%7D%20I_%7BA%7D+k_%7BM%7D%20I_%7BN%7D+I_%7BH%7D)+M_%7BH%7D(k_%7BM%7DQ_%7BN%7D+Q_%7BH%7D)%5D%7D%7BP%7D,%0A%5Cend%7Bequation%7D)

where [](https://www.codecogs.com/eqnedit.php?latex=B#0) is a matrix representing the probability of infection given contact within the general population and the red-light area as well as the probability of infection given contact between the two subpopulations. Interaction between the general population and the red-light area occurred through customers from the general population. The probability of infection given a contact between a customer from the general population and a resident of the red-light area was assumed to be 1. Probability of infection within the red-light area or within in the general population [](https://www.codecogs.com/eqnedit.php?latex=%5Cbeta#0), was calibrated to the basic reproduction number [](https://www.codecogs.com/eqnedit.php?latex=R_0#0) (**Table 2**). Thus, [](https://www.codecogs.com/eqnedit.php?latex=B#0) is given by

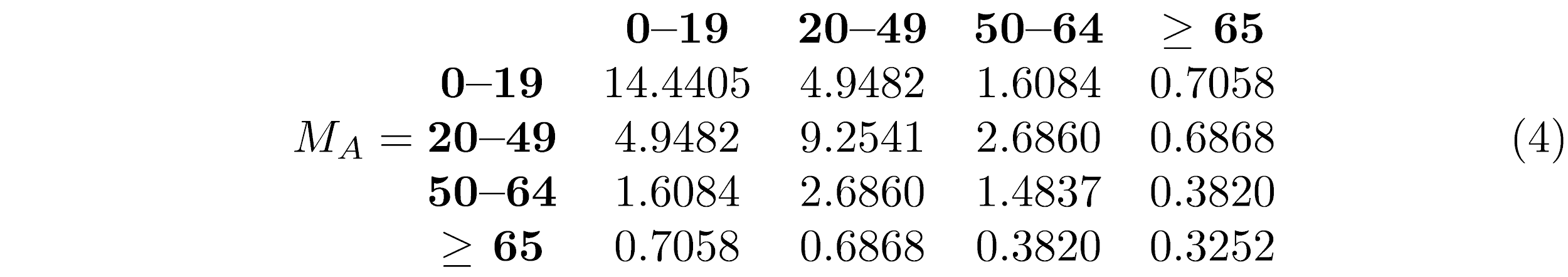
[](https://docs.google.com/document/d/1RB89W7IV-bzgNyQE8EzFCW16SUqMMxUO37JDAzKdf-Y/edit#D2L_code_render_%5Csetcounter%7Bequation%7D%7B1%7D%0A%5Cbegin%7Bequation%7D%20%0AB%20=%20%5Cbegin%7Bbmatrix%7D%20%5Cbeta%20&%201%20%5C%5C%201%20&%20%5Cbeta%20%5Cend%7Bbmatrix%7D.%0D%5Cend%7Bequation%7D)

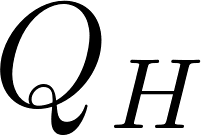
The interactions between the general population and the red-light area are defined by a connectivity matrix

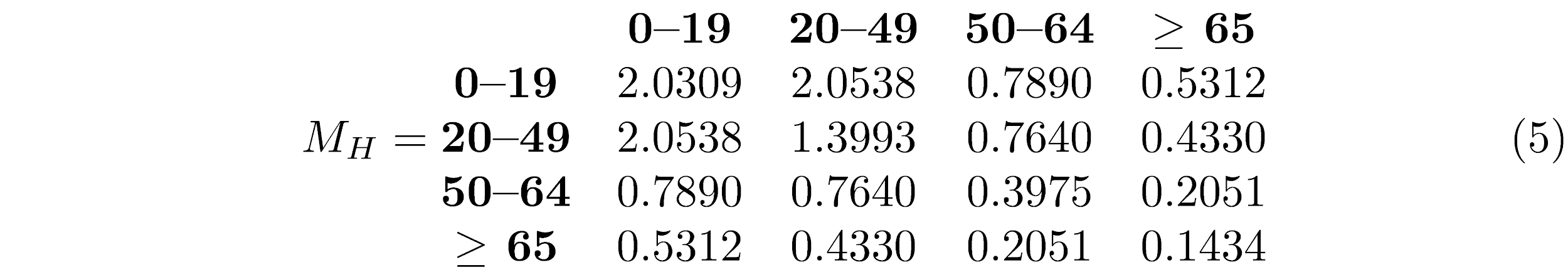
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where contact rate [](https://www.codecogs.com/eqnedit.php?latex=c_r#0) is calculated as the per-capita daily interactions between the customers from the general population and residents of the red-light area.

The contact patterns between different age-groups are informed by two matrices:

[](https://docs.google.com/document/d/1RB89W7IV-bzgNyQE8EzFCW16SUqMMxUO37JDAzKdf-Y/edit#D2L_code_render_%5Csetcounter%7Bequation%7D%7B3%7D%0A%5Cbegin%7Bequation%7D%0AM_A%20=%20%5Cbegin%7Bmatrix%7D%0A&%20%5Ctextbf%7B0--19%7D%20&%20%5Ctextbf%7B20--49%7D%20&%20%5Ctextbf%7B50--64%7D%20&%20%5Ctextbf%7B$%5Cge$%2065%7D%20%5C%5C%0A%5Ctextbf%7B0--19%7D%20&%2014.4405%20&%20%20%204.9482%20%20&%20%201.6084%20%20&%20%200.7058%20%5C%5C%0A%5Ctextbf%7B20--49%7D%20&%204.9482%20%20&%20%209.2541%20%20%20&%20%202.6860%20%20&%20%200.6868%20%5C%5C%0A%5Ctextbf%7B50--64%7D%20&%201.6084%20%20&%20%202.6860%20%20%20&%20%201.4837%20%20&%20%200.3820%20%5C%5C%0A%5Ctextbf%7B$%5Cge$%2065%7D%20&%200.7058%20%20&%20%200.6868%20%20%20&%20%200.3820%20%20&%20%200.3252%0A%5Cend%7Bmatrix%7D%0A%5Cend%7Bequation%7D)

when individuals are not isolated / quarantined in their home ([](https://www.codecogs.com/eqnedit.php?latex=Q_N#0),[](https://www.codecogs.com/eqnedit.php?latex=Q_H#0)), and

[](https://docs.google.com/document/d/1RB89W7IV-bzgNyQE8EzFCW16SUqMMxUO37JDAzKdf-Y/edit#D2L_code_render_%5Csetcounter%7Bequation%7D%7B4%7D%0A%5Cbegin%7Bequation%7D%0AM_H%20=%20%5Cbegin%7Bmatrix%7D%0A&%20%5Ctextbf%7B0--19%7D%20&%20%5Ctextbf%7B20--49%7D%20&%20%5Ctextbf%7B50--64%7D%20&%20%5Ctextbf%7B$%5Cge$%2065%7D%20%5C%5C%0A%5Ctextbf%7B0--19%7D%20&%202.0309%20&%20%20%202.0538%20&%20%200.7890%20&%20%20%200.5312%20%5C%5C%0A%5Ctextbf%7B20--49%7D%20&%202.0538%20&%20%20%201.3993%20&%20%200.7640%20&%20%20%200.4330%20%5C%5C%0A%5Ctextbf%7B50--64%7D%20&%200.7890%20&%20%20%200.7640%20&%20%200.3975%20&%20%20%200.2051%20%5C%5C%0A%5Ctextbf%7B$%5Cge$%2065%7D%20&%200.5312%20&%20%20%200.4330%20&%20%200.2051%20&%20%20%200.1434%0A%5Cend%7Bmatrix%7D%0A%5Cend%7Bequation%7D)

when they are (matching contact patterns at the household level) [[15]](https://paperpile.com/c/dN8otS/Kwwz).

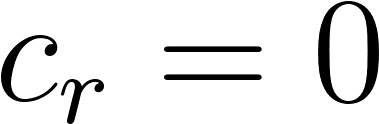
Red-light areas in India are much more densely populated as well as have substantially higher number of interactions when they are open. Therefore, we scaled the average number of interactions per day in the general population (4) by the total number of interactions that a customer has per visit to red-light areasfor interaction between the general population and red-light area.

We specified that individuals with asymptomatic and mild infections are only 50% infectious compared to severe infections (**Table 2**).

*Model fitting*

To generate projections, we first estimated the initial prevalence of COVID-19 at the beginning of lockdown by calibrating our model to the cumulative number of cases during the week of April 22 to 28, 2020 [[16,17]](https://paperpile.com/c/dN8otS/6xpC+CM8y) and a range of plausible reproduction numbers for India (**Table 2)** using the least-squares method**.** We projected our simulations using our calibrated model to generate results under scenarios of no initial lockdown, initial lockdown followed by return to status quo and initial lockdown followed by continued closure of the red-light area.

*Implementation of initial lockdown*To implement the 40 day national lockdown in our model, we specified that everyone remained at home, and their contact patterns were informed by the household matrix [](https://www.codecogs.com/eqnedit.php?latex=M_H#0) for the duration of lockdown. Moreover, set the interaction rate [](https://www.codecogs.com/eqnedit.php?latex=c_r#0) between the general population and the red-light area at zero during this period.

*Post-lockdown*After the initial lockdown period, contact patterns were informed by the overall contact matrix [](https://www.codecogs.com/eqnedit.php?latex=M_A#0), and it was assumed that as a result of improved contact-tracing capacity achieved during lockdown, 50% of symptomatic cases were isolated after the lockdown period [[18]](https://paperpile.com/c/dN8otS/6qtn). For the scenario of continued closure of the red-light area after lockdown, we maintained the contact rate [](https://www.codecogs.com/eqnedit.php?latex=c_r%20%3D%200#0); with no lockdown it was reset at its original value.

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| **Table 2.** Model parameters | | | |
| Parameter | Definition | Value | Reference |
|  | Reproduction number | 1.75–2.25 | [[6,7]](https://paperpile.com/c/dN8otS/38yW+k1rM) |
|  | Probability of infection | Calibrated to | |
|  | Relative infectivity of asymptomatic infections | 0.5 | [[8]](https://paperpile.com/c/dN8otS/lLL3) |
|  | Relative infectivity of mild cases | 0.5 | [[8]](https://paperpile.com/c/dN8otS/lLL3) |
|  | Duration of incubation period | 5.2 | [[9]](https://paperpile.com/c/dN8otS/OWam) |
|  | Duration of pre-symptomatic infectious period | 2.3 | [[5]](https://paperpile.com/c/dN8otS/Bkwc) |
|  | Duration of pre-symptomatic non-infectious period |  | |
|  | Proportion of asymptomatic cases | 0.28 | [[10]](https://paperpile.com/c/dN8otS/tohb) |
|  | Proportion of severe symptomatic cases, age group 0–19 | 0.025 | [[11]](https://paperpile.com/c/dN8otS/ORd7) |
| age group 20–49 | 0.32 |
| age group 50–64 | 0.32 |
| age group ≥65 | 0.64 |
|  | Proportion of symptomatic cases being isolated | 0.05 | [[11]](https://paperpile.com/c/dN8otS/ORd7) |
|  | Recovery period of mild and asymptomatic cases | 4.6 | [[11]](https://paperpile.com/c/dN8otS/ORd7) |
|  | Hospitalization rate | 1/3.5 | [[12]](https://paperpile.com/c/dN8otS/fwfy) |
|  | Proportion of symptomatic cases needing ICU in hospitals, age group 0–19 | 0.014 | [[11]](https://paperpile.com/c/dN8otS/ORd7) |
| age group 20–49 | 0.042 |
| age group 50–64 | 0.075 |
| age group ≥65 | 0.15 |
|  | Probability of death for hospitalized cases | 0.2296 | [[11]](https://paperpile.com/c/dN8otS/ORd7) |
|  | Probability of death for hospitalized cases needing ICU | 0.1396 | [[11]](https://paperpile.com/c/dN8otS/ORd7) |
|  | Recovery period of hospitalized cases | 10 | [[13]](https://paperpile.com/c/dN8otS/PFuL) |
|  | Recovery period of hospitalized cases needing ICU | 13.25 | [[12]](https://paperpile.com/c/dN8otS/fwfy) |
|  | Mortality rate of hospitalized cases | 1/9.7 | [[12]](https://paperpile.com/c/dN8otS/fwfy) |
|  | Mortality rate of hospitalized cases needing ICU | 1/7 | [[14]](https://paperpile.com/c/dN8otS/SpsH) |

*Data collection*

To collect city-level population data, statistical analysis was conducted to estimate the year-on-year population growth rate based on the information reported by the the Department of Economic and Social Affairs, United Nations [[19]](https://paperpile.com/c/dN8otS/w1fb) and Govt. of India [[4]](https://paperpile.com/c/dN8otS/A429) for population size of City/District and Population Density.

To analyze data about RLAs, extensive review and evaluation of research articles (including published reports, books, journals, research papers, program agendas/assessments/summaries), press releases, and credible media reports was conducted for ascertaining accurate estimates for number of sex workers, number of brothels, and the number of sex workers per brothel.

For confirming the above data and getting the information on the number of non-sex workers per brothel, number of customers per sex worker per day, number of sex workers crossed on the way to brothel in the RL per visit, number of brothel workers met inside brothels on an average red-light visit by a customer per visit, total interaction with sex workers and staff by a customer per visit and sex worker interaction with other sex workers per day, primary data collection techniques were used as an additional measure to validate the data estimates suggested in preexisting literature [[20–24]](https://paperpile.com/c/dN8otS/H7Zg+2sse+omwI+J1vm+d1Z8).

The respondents were identified and selected based on their work experience in RLAs and continued access/exposure to the primary sampling units that comprised of active/former sex workers, brothel keepers, pimps and communities inhabiting in and around RLAs. The work experience/access/exposure to RLAs for the respondents ranged from minimum 1 year to up to 15 years. The respondents were identified based on their close engagement with RLA residents, police, the city’s municipal corporation, NGOs specifically working in the particular RLA, NGOs addressing broad issues relating to RLA, counsellors, health service providers, workers association active in RLA, local business, and shop owners.

Cumulatively, for 5 RLAs, 147 sex workers, 87 Pimps/Brothel Managers, 143 customers, 33 social workers/researchers, 103 community members, and 39 local business owners i.e. 552 individuals were approached. Among these, 180 completed follow-up in-depth face to face interviews at 5 RLAs conducted in local languages resulting in a 32.6% overall response rate. The primary sample units includes 48 sex workers, 31 Pimps/Brothel Managers, 43 customers, 14 social workers/researchers, 24 community members, 20 local business owners. The trained field data collectors conducted confidential in-depth interviews with the sex workers after obtaining consent to share information. To get an estimation of the population working in RLAs, non-sex-workers in RLAs were oriented to work as survey enumerators. The survey included demographic details, indicators of mobility, socio-economic vulnerability, engagement with customers, and routine activity patterns. The respondent’s identities are kept confidential for safety reasons.

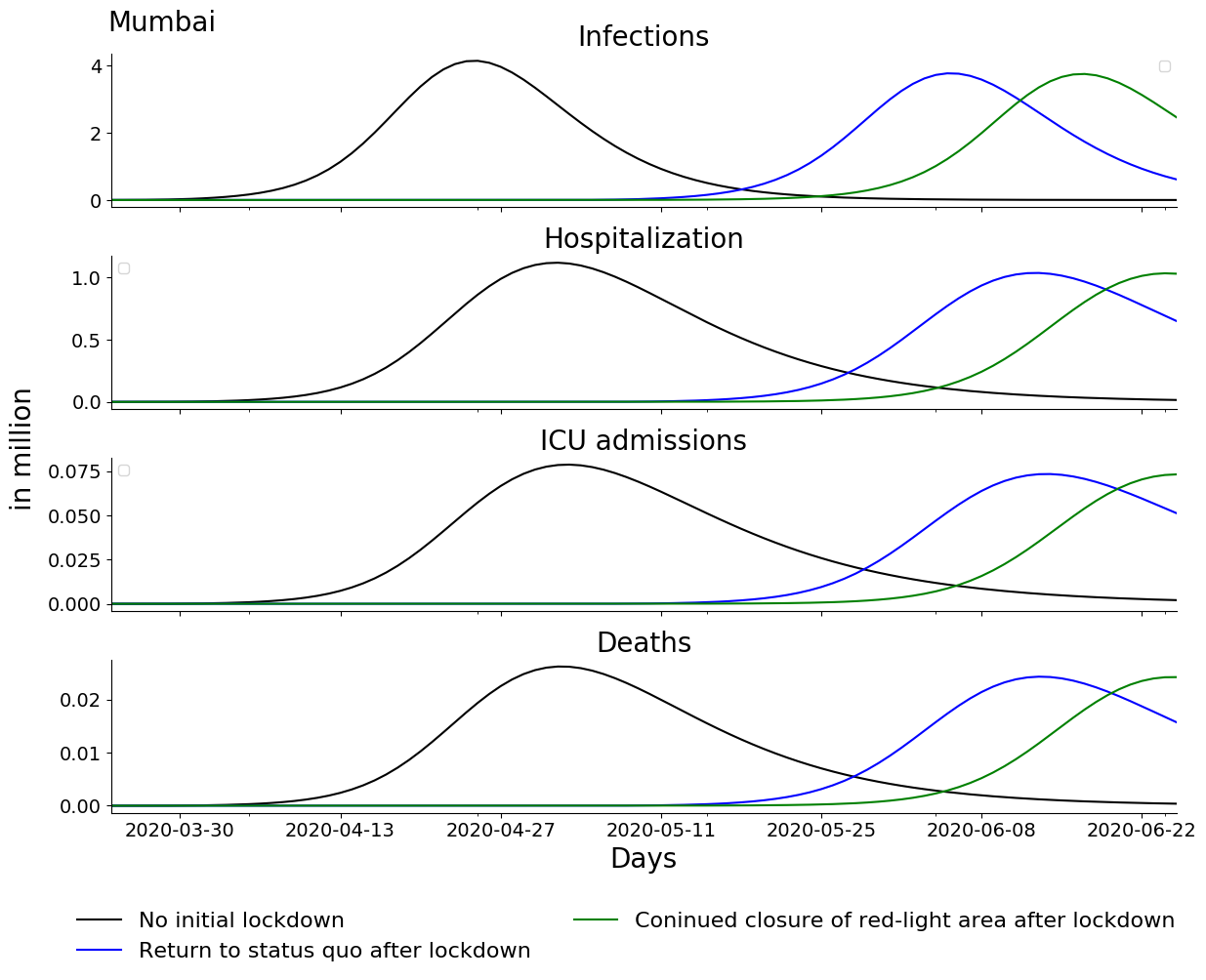
For all-India data, the number of sex workers, brothels, and customer visits was evaluated from secondary sources [[25,26]](https://paperpile.com/c/dN8otS/X3R2+LdAZ)]. Exhaustive face validation with subject experts was conducted for the dynamic data sets pertaining to the movement of sex / non-sex workers, customers, and their interaction within the brothels due to the high volatility of movement patterns of primary respondents at any given time-space in RLAs. Where more general secondary sources exhibited discrepancies with the specific RLA surveys, the more specific estimates from the five RLA surveys were used to compose final data at the national level.

**Results**

Data collected on the red-light area (**Table 3**) facilitated model parameterization. Closure of the red-light areas subsequent to lockdown significantly delayed spread of COVID-19 in all cities and in the country of India, including infections, hospitalizations, ICU admissions, and deaths (**Figs. 2–7; Table 4**). The delay in spread was accompanied by flattening of the curve; peak infection numbers decline in each locale as well. Cases, hospitalizations, ICUs required, and deaths all decreased as a function of continued closure of the red-light area (**Tables 5–8**). The magnitude of these effects varied with greater infectiousness (increasing *R*0; **Tables 4–8**) and increased with a greater resident population of the red-light area relative the general population of the city and with a greater contact rate between the general population of the city and residents of the red-light area (**Table 3**; **Tables 4–8**). The least delay in the peak of cases that was induced by continued closure of the red-light area in Mumbai with an *R*0 of 2.5 (a 40-day delay to a 47-day delay; **Table 4**, c.f. **Fig. 2** for an *R*0 of 2.0). The largest delay in the peak of cases that was induced by continued closure of the red-light area in Kolkata with an *R*0 of 1.75, leading to a delay of the peak that was more than double that produced by lockdown alone (a 41-day delay to an 85-day delay; **Fig. 4**, **Table 4**). Mumbai and Kolkata (and the two extremes of *R*0 considered) tended to produce the most extreme results across cities (**Tables 5–8**)—a difference that can be attributed to the resident populations of the red-light areas relative the general population of the city and to the contact rates between the general population of the city and residents of the red-light area (**Table 3**).

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| **Table 3**. Demography and red-light area data. | | | | | | |
| Location | Mumbai | Nagpur | Delhi | Kolkata | Pune | India |
| General population | 20,411,00 | 2,893,000 | 19,500,00 | 14,850,000 | 6,629,000 | 1,380,004,385 |
| Red-light area population | 5,471 | 2,310 | 4,048 | 16,000 | 6,345 | 637,500 |
| Total daily interaction between general population and red-light area | 441,000 | 252,000 | 777,000 | 2,112,000 | 820,000 | 20,475,000 |
| Contact rate between general population and red-light area () | 0.0216 | 0.0871 | 0.0398 | 0.1422 | 0.1237 | 0.01484 |
| Total interaction with sex workers and staff by a customer per visit | 49 | 60 | 74 | 64 | 82 | 35 |

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| **Figure 2:** Number of infections, hospitalization, ICU admissions, and deaths over time in Mumbai for  under three scenarios: no initial lockdown (black), initial lockdown of 40 days followed by return to status quo (blue), and initial lockdown of 40 days followed by continued closure of the red-light area (green). |

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| **Figure 3:** Number of infections, hospitalization, ICU admissions, and deaths over time in Delhi for  under three scenarios: no initial lockdown (black), initial lockdown of 40 days followed by return to status quo (blue), and initial lockdown of 40 days followed by continued closure of the red-light area (green). |

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| **Figure 4:** Number of infections, hospitalization, ICU admissions, and deaths over time in Kolkata for  under three scenarios: no initial lockdown (black), initial lockdown of 40 days followed by return to status quo (blue), and initial lockdown of 40 days followed by continued closure of the red-light area (green). |

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| **Figure 5:** Number of infections, hospitalization, ICU admissions, and deaths over time in Pune for  under three scenarios: no initial lockdown (black), initial lockdown of 40 days followed by return to status quo (blue), and initial lockdown of 40 days followed by continued closure of the red-light area (green). |

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| **Figure 6:** Number of infections, hospitalization, ICU admissions, and deaths over time in Nagpur for  under three scenarios: no initial lockdown (black), initial lockdown of 40 days followed by return to status quo (blue), and initial lockdown of 40 days followed by continued closure of the red-light area (green). |

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| **Figure 7:** Number of infections, hospitalization, ICU admissions, and deaths over time in India for  under three scenarios: no initial lockdown (black), initial lockdown of 40 days followed by a return to status quo (blue), initial lockdown of 40 days followed by continued closure of the red-light area (green). |

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| **Table 4:** Delay (in days) in the peak of outbreak for each location and  of 1.75, 2, 2.25, and 2.5 | | | | | | | | |
|  |  | |  | |  | |  | |
| **L** | **L + C** | **L** | **L + C** | **L** | **L + C** | **L** | **L + C** |
| **Mumbai** | 42 | 60 | 42 | 55 | 41 | 51 | 40 | 47 |
| **Delhi** | 42 | 67 | 41 | 60 | 41 | 56 | 40 | 52 |
| **Kolkata** | 41 | 88 | 40 | 78 | 40 | 72 | 40 | 66 |
| **Pune** | 40 | 80 | 41 | 72 | 40 | 65 | 40 | 62 |
| **Nagpur** | 40 | 81 | 40 | 73 | 40 | 67 | 40 | 62 |
| **India** | 43 | 69 | 42 | 61 | 41 | 56 | 40 | 51 |
| The number of days by which the peak of the outbreak is delayed as a result of initial lockdown in India from 24 March 2020 to 3 May 2020 **(L)** and continued closure of red-light areas after the initial lockdown (**L + C**). | | | | | | | | |

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| **Table 5:** Cases averted at peak of the COVID-19 pandemic for each location and  of 1.75, 2, 2.25, and 2.5. | | | | | | | | |
|  |  | |  | |  | |  | |
| **L** | **L + C** | **L** | **L + C** | **L** | **L + C** | **L** | **L + C** |
| **Mumbai** | 406382 | 430833 | 373786 | 391303 | 336690 | 355217 | 297533 | 309497 |
| **Delhi** | 392862 | 442815 | 351466 | 394864 | 327108 | 363467 | 282754 | 315053 |
| **Kolkata** | 280198 | 821236 | 254716 | 708907 | 235757 | 615728 | 210994 | 549790 |
| **Pune** | 126336 | 364320 | 113762 | 312827 | 103488 | 275905 | 93401 | 237451 |
| **Nagpur** | 56378 | 104360 | 50418 | 91980 | 46152 | 82115 | 42399 | 72839 |
| **India** | 27673902 | 29093347 | 24602292 | 25761200 | 22121167 | 22987948 | 20568259 | 21442155 |
| The number of cases averted at the peak of the outbreak as a result of initial lockdown in India from 24 March 2020 to 3 May 2020 **(L)** and continued closure of red-light areas after the initial lockdown (**L + C**). | | | | | | | | |

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| **Table 6:** Hospitalization averted at peak of the COVID-19 pandemic for each location and  of 1.75, 2, 2.25, and 2.5. | | | | | | | | |
|  |  | |  | |  | |  | |
| **L** | **L + C** | **L** | **L + C** | **L** | **L + C** | **L** | **L + C** |
| **Mumbai** | 95469 | 99713 | 81482 | 84836 | 69974 | 72435 | 60290 | 61360 |
| **Delhi** | 88713 | 98497 | 74531 | 81802 | 64583 | 69833 | 56204 | 60388 |
| **Kolkata** | 59423 | 158271 | 51375 | 128298 | 44974 | 105621 | 37729 | 86730 |
| **Pune** | 27462 | 71723 | 23454 | 57978 | 20202 | 48051 | 17752 | 40172 |
| **Nagpur** | 12794 | 22001 | 11013 | 18030 | 9292 | 15044 | 8050 | 12654 |
| **India** | 5854068 | 6040293 | 4899798 | 5083189 | 4161626 | 4313662 | 3520029 | 3604250 |
| The number of hospitalization averted at the peak of the outbreak as a result of initial lockdown in India from 24 March 2020 to 3 May 2020 **(L)** and continued closure of red-light areas after the initial lockdown (**L + C**). | | | | | | | | |

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| **Table 7:** ICU admissions averted at peak of the COVID-19 pandemic for each location and  of 1.75, 2, 2.25, and 2.5. | | | | | | | | |
|  |  | |  | |  | |  | |
| **L** | **L + C** | **L** | **L + C** | **L** | **L + C** | **L** | **L + C** |
| **Mumbai** | 6201 | 6499 | 5258 | 5490 | 4491 | 4669 | 3897 | 3947 |
| **Delhi** | 5113 | 5687 | 4363 | 4786 | 3633 | 3985 | 2985 | 3265 |
| **Kolkata** | 3690 | 10094 | 3094 | 8017 | 2678 | 6605 | 2311 | 5413 |
| **Pune** | 1772 | 4715 | 1509 | 3793 | 1289 | 3130 | 1130 | 2617 |
| **Nagpur** | 826 | 1442 | 706 | 1174 | 591 | 975 | 510 | 813 |
| **India** | 367033 | 382277 | 304784 | 316613 | 257205 | 268394 | 215280 | 223200 |
| The number of ICU admissions averted at the peak of the outbreak as a result of initial lockdown in India from 24 March 2020 to 3 May 2020 **(L)** and continued closure of red-light areas after the initial lockdown (**L + C**). | | | | | | | | |

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| **Table 8:** Deaths averted at peak of the COVID-19 pandemic for each location and  of 1.75, 2, 2.25, and 2.5. | | | | | | | | |
|  |  | |  | |  | |  | |
| **L** | **L + C** | **L** | **L + C** | **L** | **L + C** | **L** | **L + C** |
| **Mumbai** | 2240 | 2338 | 1926 | 1987 | 1635 | 1681 | 1403 | 1465 |
| **Delhi** | 2063 | 2272 | 1795 | 1944 | 1519 | 1648 | 1282 | 1386 |
| **Kolkata** | 1415 | 3715 | 1216 | 3010 | 1018 | 2457 | 897 | 2061 |
| **Pune** | 637 | 1671 | 558 | 1366 | 486 | 1120 | 407 | 928 |
| **Nagpur** | 301 | 516 | 257 | 426 | 224 | 353 | 193 | 297 |
| **India** | 135897 | 141966 | 115246 | 118891 | 96042 | 98371 | 82736 | 86270 |
| The number of deaths averted at the peak of the outbreak as a result of initial lockdown in India from 24 March 2020 to 3 May 2020 **(L)** and continued closure of red-light areas after the initial lockdown (**L + C**). | | | | | | | | |

**Discussion**

Reopening red-light areas will accelerate the peak at the city level and national level and lead to large scale transmission and a large number of deaths. As task forces in India make plans for reopening the economy across states, districts, and cities, considering the impact of red-light areas will be important as they will significantly increase the number of COVID-19 cases in the city upon reopening. Red-light areas due to the high number of visitors and nature of business will likely become a major hotspot of COVID-19. This concentration of transmission within a high population-density area poses a threat to the general population of India as well as the people who interact most closely with the sex worker population and those that are in the immediate vicinity of red-light areas—iincluding workers in local businesses, police personnel, NGO workers, and the local community. The brothel-based children, senior citizens, and individuals living in adjacent housing are all put at risk by the reopening of red-light areas. The economic assessment shows the disproportionately higher cost for India to keep red-light areas open versus the decision to close down red-light areas. Keeping the red-light areas closed will prevent a substantial cost to be borne by the state and its citizens by markedly reducing the initial spread of the pandemic in India, preventing infection, hospitalization and death of its citizens and associated hospitalization costs.

Given the prevalence of co-morbidities in sex workers, this population is highly vulnerable to severe symptoms, hospitalization, and increased death rates from COVID-19 infection. Sex workers with lower immunity could more readily contract the infection, potentially leading to accelerated spread and worsening the pandemic. This factor has not been modeled but would be expected to increase the speed of transmission and the number of infections, therefore increasing the numbers of hospitalizations and fatalities in connection with red-light area reopening.

Red-light areas host a large volume of customers traveling from diverse geographic areas to visit them. Visitors to the red-light area will include infected individuals, often in the highly contagious, pre-symptomatic phase where they are unaware of their infection. While individuals are pre-symptomatic or in the 80% of cases that are asymptomatic (ICMR, April 2020) there is a high risk of transmission from customers to sex workers, sex workers to other sex workers, sex workers to customers, customers to other customers via sex workers, and finally post visit from customers to the general population, without these individuals realizing they are infected. The red-light area is a breeding ground for producing COVID-19 carriers. A single customer or sex worker can be party to a substantial number of transmissions as a visitor to the red-light area.

Infected customers will spread COVID-19 in the city they live in—including far beyond the red-light area. There is a significant percentage of customers of sex workers that are truck drivers (NACO report, 2017). This highly mobile population travels across substantial geographic areas due to their profession.\* They can spread the disease from red zones to green and orange zones. This means of spread can be a significant threat to rural populations and their healthcare systems. Migrant laborers are also a significant percentage of customers of red-light areas in India, and the negative impact of attracting movement of this population during the COVID-19 pandemic in 2020 can be worsened if red-light areas are open.

The lockdown, contact tracing, and other government interventions delay the infection rate and flatten the curve, however, the pandemic situation may not be resolved until there is a vaccine for the population (WHO, April 13, 2020). Social distancing norms and other safety measures are important to keep in place until a vaccine is developed and widely distributed throughout India, which could take 9–18 months or longer. As long as continued measures to delay widespread exposure are being applied, it will be important to the protection of sex workers, their customers, city populations, and the country of India to leave these areas closed. The burden on the healthcare system and the health, social, and economic cost of the number of cases and deaths is very large. To prevent this disproportionately large burden on the healthcare system, citizens, and economy, it will be important to not reopen them until the COVID-19 pandemic is curtailed. India has taken strong measures to close down the country to protect the population from COVID-19 and made significant progress on this front versus other worse-hit countries. Maintaining active interventions to keep sites of high transmission closed will make a significant impact in saving lives.

The additional time that is provided by keeping these areas closed and delaying the peak will give the Indian government more time to execute measures that will lower the overall peak and slow the growth rate of cases, reducing the negative impact of COVID-19 significantly. Because transmission is likely to be so high in sex work compared to nearly any other work, closure of red-light areas while the disease can spread within them should be a priority compared to other closures such as closures of cinema halls, shopping malls, and public gatherings.

The disruption caused to residents of red-light areas due to COVID-19 will likely last for a long time. Closure for a significant period of time will make sex workers vulnerable to financial exploitation, hence pushing them into debt cycles that can be extremely difficult to escape. In addition to providing essential support, the government can work on a plan for alternative livelihood for the long-term reintegration of sex workers into mainstream society. Therefore, alternative sustainable economic recovery programs for sex workers should be identified. The cost of reintegrating a sex worker in India to other occupations has been quantified at INR 48, 844/- ($644.12), enabling attendace at a 6-month residential course (MSED, 2018). The economic cost for rehabilitating a sex worker at the India level is INR --- ($---) per transmission avoided (MRD, 2013) and INR ---- per death avoided (Thacker & Rajagopal, 2020). The economic savings of reintegrating a sex worker is (sum total costs of hospitilizations caused per sex worker - INR . The economics of reintegration belie any long-term economic burden to the re-opening of red-light areas.

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