

Report 2: Estimating the potential total number of novel Coronavirus cases in Wuhan City, China

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1. Background

On the 31st December 2019, the World Health Organization (WHO) China Country Office was informed of cases of pneumonia of unknown aetiology in Wuhan City, Hubei Province, China [1]. A novel Coronavirus (2019-nCoV) related to the Middle Eastern Respiratory Syndrome virus (MERS-CoV) and the Severe Acute Respiratory Syndrome virus (SARS-CoV) has since been implicated [2].

As of 4am 21st January (Beijing Time) 2020, 440 cases (including nine deaths) have been confirmed across 13 provinces in China, plus suspected cases in multiple other provinces [3]. As of 9:00 GMT 22nd January 7 confirmed cases in travellers from Wuhan with symptom onset on or before the 18th January were detected outside mainland China in Thailand (3 cases), Japan (1 case), South Korea (1 case), Taiwan (1 case) and the United States (1 case) [4–10]. Chinese authorities have also confirmed evidence of human-to-human transmission, as well as 15 cases in healthcare workers [11,12]. Of these cases, four travelled before exit screening in Wuhan International Airport was introduced on 15th January [13], three (South Korea, Taiwan, USA) on or after.

Using the number of cases detected outside mainland China with who had disease onset by 18th January, it is possible (see Report 1 [14]) to infer the number of clinically comparable cases within Wuhan City that may have occurred thus far. Here we update our estimates to account for the additional international exported cases (7 cases).

Summary

We estimate that a total of 4,000 cases of 2019-nCoV in Wuhan City (uncertainty range: 1,000 – 9,700) had onset of symptoms by 18th January 2020 (the last reported onset date of any case) [15].

Our estimates should not be interpreted as implying the outbreak has doubled in size in the period 12th January to 18th January – delays in confirming and reporting exported cases and incomplete information about dates of symptom onset together with the still very small numbers of exported cases mean we are unable to estimate the epidemic growth rate at the current time.

This estimate is based on the following assumptions:

- Wuhan International Airport has a catchment population of 19 million individuals [1].
- There is a mean 10-day delay between infection and detection, comprising a 5-6 day incubation period [16,17] and a 4-5 day delay from symptom onset to detection/hospitalisation of a case (the cases detected in Thailand and Japan were hospitalised 3 and 7 days after onset, respectively) [4,18].
- Total volume of international travel from Wuhan over the last two months has been 3,301 passengers per day. This estimate is derived from the 3,418 foreign passengers per day in the top 20 country destinations based on 2018 IATA data [19], and uses 2016 IATA data held by Imperial College London to correct for the travel surge at Chinese New Year present in the

latter data (which has not happened yet this year) and for travel to countries outside the top 20 destination list.

- Exit screening (which reportedly came into force on the 15th January [13]) had no impact on exported cases reported up to 16th January. *Exit screening may have reduced exports in recent days, in which case our baseline prediction may be an underestimate of the true number of cases in Wuhan.*
- We assume all cases in travellers flying to destinations outside mainland China are being detected at those destinations. This may well not be the case. *If cases are being missed in other countries, our baseline prediction will underestimate the true number of cases in Wuhan.*
- We now report uncertainty as the range spanned by the 95% confidence intervals of the first three scenarios in Table 1. Thus, our uncertainty range represents uncertainty in key assumptions as well as statistical assumptions.

2. Additional caveats

1. We assume that outbound trip durations are long enough that an infected Wuhan resident travelling internationally will develop symptoms and be detected overseas, rather than being detected after returning to Wuhan. We also do not account for the fact that international visitors to Wuhan (such as the case who was detected in Japan) might be expected to have a shorter duration of exposure and thus a lower infection risk than residents. *Accounting for either factor correctly requires additional data but would increase our estimate of the total number of cases.*
2. We estimate the potential number of symptomatic cases with disease severity of a level requiring hospitalisation (both the cases detected in Thailand and Japan were moderately severe). Our estimates do not include cases with mild or no symptoms.
3. The incubation period of 2019-nCoV is not known and has been approximated with the estimates obtained for MERS-CoV and SARS [16,17].
4. We assume that international travel is independent of the risk of exposure to 2019n-CoV and of infection status. If zoonotic exposure were biased towards wealthier people, travel frequency may be correlated with exposure. Also, some travel might be causally linked to infection status (to seek healthcare overseas) or the infection status of contacts in Wuhan (this may apply to the case detected in Japan) [18]. *Accounting for either association would increase the probability of a case travelling and therefore reduce our estimates of the total number of cases.*

3. Sensitivity analysis

We explore the sensitivity of estimates of total cases to our assumptions about: i) the catchment population size of Wuhan International Airport (restricting to the population of Wuhan City of 11 million individuals [20], rather than the population of the entire metropolitan area [1]), ii) the duration of the detection window (exploring a lower value of 8 days representing the uncertainty in the detection window or the potential effect of exit screening), and iii) the number of exportations reported internationally (8 cases). Table 1 summarises the baseline assumptions and alternative scenarios explored.

Table 1: Estimated case numbers based on the baseline assumptions and alternative scenarios explored.

	Baseline ¹	Smaller catchment ¹	Shorter detection window ¹	6 exported cases	8 exported cases
Exported number of confirmed cases ²	7	7	7	6	8
Daily international passengers travelling out of Wuhan International Airport ³	3,301	3,301	3,301	3,301	3,301
Effective catchment population of Wuhan International Airport	19 million	11 million	19 million	19 million	19 million
Detection window (days)	10 days	10 days	8 days	10 days	10 days
Estimated total number of cases (95% CI)	4,000 (1,700 – 7,800)	2,300 (1,000 – 4,500)	5,000 (2,200 – 9,700)	3,400 (1,400 – 7,000)	4,600 (2,100 – 8,600)

¹We now report uncertainty around our central estimate as the range spanned by the 95% confidence intervals of these three scenarios. ²reported number of confirmed cases detected internationally. ³calculated from the 3-month totals reported by [19] corrected for the travel surge during Chinese New Year (see Summary).

4. Conclusions

Our estimates of the size of the outbreak in Wuhan have more than doubled since our first report. This is a result of the number of cases detected outside mainland China having increased from 3 to 7. Our analysis does not allow the growth rate of the epidemic to be determined however. *Our estimates should not be interpreted as implying the outbreak has doubled in size in the period 12th January to 18th January* – delays in confirming and reporting exported cases and incomplete information about dates of symptom onset together with the still very small numbers of exported cases mean we are unable to estimate the epidemic growth rate at the current time.

It is likely that the outbreak of a novel coronavirus in Wuhan has caused substantially more cases of moderate or severe respiratory illness than have currently been detected and reported. However, recent rapid increases in officially reported confirmed case numbers in China suggest that case detection and reporting has been substantially enhanced in recent days. With further refinements to case definitions and testing and further expansion of surveillance (for instance, to primary care providers) it is to be hoped that the differences between our estimates and official case numbers will lessen further.

This analysis does not directly address transmission routes, but recent reports [11,21,22] and past experience with SARS and MERS-CoV outbreaks of similar scale suggests currently self-sustaining human-to-human transmission should not be ruled out. Given this evidence for human-to-human transmission, enhancing rapid case detection will be essential if the outbreak is to be controlled.

5. References

1. World Health Organization. WHO | Pneumonia of unknown cause – China. WHO. 2020.
2. World Health Organization. WHO | Novel Coronavirus – China. WHO. 2020.
3. Sina China News. 440 new cases of coronavirus pneumonia confirmed in China as of 21st. [cited 22 Jan 2020]. Available: <https://news.sina.cn/2020-01-22/detail-iihnzhha4145411.d.html>
4. World Health Organization. WHO | Novel Coronavirus – Thailand (ex-China). WHO. 2020.
5. NHK WORLD-JAPAN. Japan confirms 1st case of new coronavirus | NHK WORLD-JAPAN News. [cited 16 Jan 2020]. Available: https://www3.nhk.or.jp/nhkworld/en/news/20200116_23/
6. New York Times. Japan and Thailand Confirm New Cases of Chinese Coronavirus - The New York Times. [cited 17 Jan 2020]. Available: <https://www.nytimes.com/2020/01/15/world/asia/coronavirus-japan-china.html>
7. Today Online. Thailand finds second case of new Chinese virus, says no outbreak - TODAYonline. [cited 17 Jan 2020]. Available: <https://www.todayonline.com/world/thailand-finds-second-case-new-chinese-virus-says-no-outbreak-1>
8. Taiwan Centers for Disease Control. 我國藉由登機檢疫即時發現首例中國大陸武漢移入之嚴重特殊傳染性肺炎個案，指揮中心提升中國大陸武漢之旅遊疫情建議至第三級警告-衛生福利部疾病管制署。 [cited 21 Jan 2020]. Available: https://www.cdc.gov.tw/Bulletin/Detail/6oHuoqzW9e_onW0AaMEemg?typeid=9
9. US Centers for Disease Control and Prevention. First Travel-related Case of 2019 Novel Coronavirus Detected in United States | CDC Online Newsroom | CDC. [cited 21 Jan 2020]. Available: <https://www.cdc.gov/media/releases/2020/p0121-novel-coronavirus-travel-case.html>
10. Ministry of Public Health of Thailand. Department of Disease Control reveals Chinese tourists infected with the second new strain of coronary pneumonia 2019 in Thailand Got well and returned to the country. [cited 22 Jan 2020]. Available: <https://pr.moph.go.th/?url=pr/detail/2/02/137474>
11. Xinhua News. China confirms human-to-human transmission of 2019-nCoV, infection of medical staff - Xinhua | English.news.cn. [cited 21 Jan 2020]. Available: http://www.xinhuanet.com/english/2020-01/20/c_138721762.htm
12. NHK News. 新型ウイルス肺炎 中国 死者6人に 患者は291人 拡大防止を強化 | NHKニュース。 [cited 21 Jan 2020]. Available: <https://www3.nhk.or.jp/news/html/20200121/k10012253721000.html>
13. Leung K, Wu JT, Leung GM. Nowcasting and forecasting the Wuhan 2019-nCoV outbreak. Available: <http://www.nhc.gov.cn/>.
14. Imai N, Dorigatti I, Cori A, Riley S, Ferguson NM. News / Wuhan Coronavirus | Faculty of Medicine | Imperial College London. [cited 20 Jan 2020]. Available: <https://www.imperial.ac.uk/mrc-global-infectious-disease-analysis/news--wuhan-coronavirus/>
15. Korea Centers for Disease Control. The first imported case of the novel coronavirus (2019-nCoV) in Korea | Press Release | News Room : KCDC. [cited 21 Jan 2020]. Available:

- https://www.cdc.go.kr/board/board.es?mid=a30402000000&bid=0030&act=view&list_no=365797&tag=&nPage=1
16. Cauchemez S, Fraser C, Van Kerkhove MD, Donnelly CA, Riley S, Rambaut A, et al. Middle East respiratory syndrome coronavirus: quantification of the extent of the epidemic, surveillance biases, and transmissibility. *LANCET Infect Dis.* 2014;14: 50–56. doi:10.1016/S1473-3099(13)70304-9
 17. Donnelly CA, Ghani AC, Leung GM, Hedley AJ, Fraser C, Riley S, et al. Epidemiological determinants of spread of causal agent of severe acute respiratory syndrome in Hong Kong. *Lancet.* 2003;361: 1761–1766. doi:10.1016/S0140-6736(03)13410-1
 18. Ministry of Health Japan. 新型コロナウイルスに関連した肺炎の患者の発生について. [cited 16 Jan 2020]. Available: https://www.mhlw.go.jp/stf/newpage_08906.html
 19. Bogoch II, Watts A, Thomas-Bachli A, Huber C, Kraemer MUG, Khan K. Pneumonia of Unknown Etiology in Wuhan, China: Potential for International Spread Via Commercial Air Travel. *J Travel Med.* 2020 [cited 16 Jan 2020]. doi:10.1093/jtm/taaa008
 20. Xinhua News. 武汉常住人口突破1100万 城市吸引力稳步提升_新华网. [cited 16 Jan 2020]. Available: http://www.hb.xinhuanet.com/2019-03/26/c_1124281764.htm
 21. The Guardian. China confirms human-to-human transmission of coronavirus | World news | The Guardian. [cited 21 Jan 2020]. Available: <https://www.theguardian.com/world/2020/jan/20/coronavirus-spreads-to-beijing-as-china-confirms-new-cases>
 22. Coronavirus battle at full-scale - Global Times. [cited 21 Jan 2020]. Available: <https://www.globaltimes.cn/content/1177666.shtml>

6. Methods

Using internationally reported cases, it is possible to infer the magnitude of comparable cases within Wuhan City that may have occurred thus far.

The total number of cases requiring healthcare is given by:

$$\text{Total number of cases} = \frac{\text{number of cases detected overseas}}{\text{probability any one case will be detected overseas}}$$

where the probability any one case will be detected overseas (p) is given by:

$$p = \text{daily probability of international travel} \times \text{mean time to detection of a case}$$

The daily probability of travel is calculated by:

$$\text{daily probability of international travel} = \frac{\text{daily outbound international travellers from Wuhan}}{\text{catchement population of Wuhan airport}}$$

Finally, the mean time to detection can be approximated by:

$$\begin{aligned} \text{mean time to detection} \\ = \text{incubation period} + \text{mean time from onset of symptoms to detection} \end{aligned}$$

Confidence intervals can be calculated from the observation that the *number of cases detected overseas*, X , is binomially distributed as $\text{Bin}(p, N)$, where p = *probability any one case will be detected overseas*, and N is the *total number of cases*. N is therefore a negative binomially distributed function of X . The results in Table 1 are maximum likelihood estimates obtained using this negative binomial likelihood function. We now report overall uncertainty as the range spanned by the 95% confidence intervals of the first three scenarios in Table 1.