# AP3. Sensitivity Test and Calibration

## S3.1. PM10 Levels by Non-Emission Factors

We tested how the variability of non-emission factors affect the levels of PM10 in the study area. Each line represents 5 sample points of Jongno, Sejong, Yulgok, Samil, and Pirun roads. The baseline emission factor was 5, and the alternates were 1, 10, and 20.

Figure 4 shows that the levels of PM10 increased linearly as the emission factors increased. Throughout the test period, the mean PM10 of Jongno for emission factors 1, 5, 10, and 20 was 43.4µg/m3, 60µg/m3, 81.4µg/m3, and 123µg/m3 respectively (see Table 1). The difference between each factor was 16.6µg/m3, 21.4µg/m3, and 41.6µg/m3, which increased proportionally as the factors increased. This linear increase was not only was seen in the mean figure but also seen on any of the dates, including the peak value on January the 20th where the levels sat near 150µg/m3 in factor 5 but showed an increase to around 200µg/m3 and 250µg/m3 from factors 10 and 20.

PM10 between roads varied greatly when the emission parameter was high. Although the model did not give any direction to the vehicles nor the hierarchy of roads, PM10 levels varied by 12µg/m3 in *Emission 20*, where the lowest was 122.6µg/m3 at Sejong and the highest was 134.1µg/m3 at Yulgok. This implies that although the number of road lanes was not specified, the high parameter value can measure the variability of PM10 by road.

Table S3.1 PM10 concentrations in five CBD roads based on emission factors of 1, 5, 10, and 20 (Unit: µg/m3)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Date | Emission factor | Jongno | Sejong | Yulgok | Samil | Pirun |
| Overall | 1 | 43.4 | 43.2 | 42.8 | 42.8 | 42.9 |
| 5 | 60.0 | 60.1 | 62.0 | 61.6 | 61.7 |
| 10 | 81.4 | 81.2 | 85.6 | 85.3 | 85.2 |
| 20 | 123.3 | 122.6 | 134.1 | 132.7 | 133.4 |
| Jan 8th | 1 | 49.2 | 48.6 | 48.1 | 47.8 | 48.4 |
| 5 | 65.5 | 66.7 | 67.8 | 67.9 | 66.9 |
| 10 | 85.3 | 86.4 | 90.3 | 91.9 | 90.5 |
| 20 | 129.6 | 115.3 | 141.1 | 150.1 | 128.7 |
| Jan 15th | 1 | 58.1 | 57.6 | 57.1 | 56.9 | 57.5 |
| 5 | 75.0 | 75.2 | 77.0 | 76.9 | 75.1 |
| 10 | 93.8 | 104.3 | 100.8 | 101.6 | 97.1 |
| 20 | 136.1 | 133.3 | 147.8 | 154.4 | 148.6 |
| Jan 22nd | 1 | 37.7 | 37.4 | 37.1 | 37.0 | 37.2 |
| 5 | 53.9 | 52.5 | 55.1 | 57.3 | 55.4 |
| 10 | 75.9 | 78.4 | 78.5 | 85.0 | 76.9 |
| 20 | 114.6 | 117.6 | 127.6 | 127.6 | 124.3 |

Chart, histogram

Description automatically generated

Figure 4 PM10 levels by emission factors of 1, 5, 10, and 20, each showing the N of vehicles that generate non-exhaust PM10 emissions. Each line represents 5 sample points of Jongno, Sejong, Yulgok, Samil, and Pirun roads. The variability at any station increases as the emission factor is increased

## S3.2. Dispersion and Dilution

This section examines the sensitivity of dispersion and dilution parameters that affect roadside PM10. As a baseline parameter, each vehicle disperses the NEE at an angle of 60° and dilute within 0-3 minutes. Initially, we adjusted the range of dispersion by 45° and 90° and the emission factor by 1, 5, 10, and 20, while keeping the dilution at 3 ticks. Then, controlling the dispersion to 60°, we adjusted the dilution by 5 ticks and 10 ticks and emission factor by 1, 5, 10, and 20.

Results showed that dispersion range displayed less sensitivity on roadside PM10, except for Jongno, where the difference of cone width between 45° and 90° was around 3µg/m3 in *Emission 5* and *Emission 10*, and further increased to 14µg/m3 in *Emission 20* (see Table 2). This implies that the range of dispersion might not be sensitive to the PM10 on-roads, such as Sejong and Pirun stations, but from the evidence of Jongno, a distant station, it may deliver higher PM10 to people walking near roads.

Table 2 PM10 concentrations by emission factors and dispersion range (Unit: µg/m3)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Emission | Range | Jongno | Sejong | Yulgok | Samil | Pirun |
| 1 | 45° | 50 | 49.6 | 50.5 | 50.3 | 50.9 |
| 60° | 50.3 | 49.8 | 50.5 | 50.4 | 51.1 |
| 90° | 50.7 | 49.9 | 50.6 | 50.5 | 51.1 |
| 5 | 45° | 58.4 | 55.7 | 58.7 | 58.9 | 60.1 |
| 60° | 59.3 | 56.3 | 59 | 59.5 | 60.4 |
| 90° | 60.4 | 56.6 | 59.1 | 59.5 | 60.8 |
| 10 | 45° | 73.2 | 71.2 | 77.3 | 77 | 80.5 |
| 60° | 76.6 | 72.3 | 77.9 | 77.4 | 81 |
| 90° | 79.6 | 73.1 | 78.5 | 78.1 | 81.8 |
| 20 | 45° | 102 | 100 | 112 | 113 | 118 |
| 60° | 109 | 102 | 114 | 115 | 120 |
| 90° | 116 | 104 | 115 | 118 | 120 |

Unlike the dispersion results, all roads were very sensitive to the dilution period except for *Emission 1* (see Table 3). In *Emission 5*, the default period of less than 3 minutes indicated an average figure of 60-62µg/m3, however, extending the period to 10 minutes increased PM10 to 67-69µg/m3, which was 10% higher than the default.

The difference between dilution periods increased proportionately to emission factors where the quickest (3 mins) was 14-18µg/m3 higher than the slowest (10 mins) in *Emission 10* and 31-41µg/m3 in *Emission 20*. If this analysis was to represent the length of dust resuspension in the real world, say 3 minutes of dust floating until dilution, the deterioration of PM10 can be explained by the floating particles from the vehicles that mixed well with the atmosphere. A disclaimer is that the dilution is only affected by the duration of ticks (zero wind), and no other components (e.g. wind, rain) that change dilution time.

Table 3 PM10 concentrations by emission factors and (the duration until) dilution (Unit: µg/m3)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Emission | Dilution | Jongno | Sejong | Yulgok | Samil | Pirun |
| 1 | 3 | 45.5 | 45.8 | 45.8 | 46 | 46.1 |
| 5 | 46.1 | 46 | 46.5 | 46.2 | 46.4 |
| 10 | 46.7 | 46.5 | 46.8 | 46.7 | 47 |
| 5 | 3 | 60 | 60 | 62 | 62 | 62 |
| 5 | 66 | 66 | 66 | 66 | 67 |
| 10 | 67 | 67 | 68 | 68 | 69 |
| 10 | 3 | 81 | 81 | 86 | 85 | 85 |
| 5 | 94 | 95 | 96 | 96 | 99 |
| 10 | 99 | 99 | 100 | 100 | 102 |
| 20 | 3 | 123 | 123 | 134 | 133 | 133 |
| 5 | 153 | 150 | 155 | 155 | 159 |
| 10 | 164 | 160 | 165 | 164 | 167 |

## S3.3. PM10 Levels by Car Ratio

We investigated how PM10 can be sensitive to changes in car sampling (see Figure 2). Resident vehicles were not included in this experiment as short-term journeys from the resident vehicles hardly contributed emission levels to the result. To summarise, car ratios of 0%, 2.5%, 5%, 10%, and 20% mean sample rates of traffic counts by each minute were taken from the traffic monitoring statistics.

In the 0% run, assuming no other vehicles, the roadside PM10 ranged between 47-50µg/m3 (which is equal to the background level), which was at least 10µg/m3 lower than the concentrations from other ratios. However, different sample sizes merely showed a small difference. For example, a 10% sample in Jongno only contributed 1.8µg/m3 more than that of 2.5%.

Surprisingly, all roads showed less pollution in the 20% sample because a massive number of vehicles failed to enter the study area. The queues were particularly long in Samil and Yulgok roads because Samil had fewer traffic signals at the entrance of the road which enabled vehicles to accelerate up to the core area with a few ticks but soon met several junctions, which can be depicted as a bottleneck effect; Yulgok has a roundabout that reduces the speed.

Table 4 Car ratio and PM10 concentration (µg/m3)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Ratio | Jongno | Sejong | Yulgok | Samil | Pirun |
| 0% | 50.5 | 49.5 | 48.0 | 50.2 | 47.8 |
| 2.5% | 59.5 | 60.0 | 60.3 | 60.9 | 61.4 |
| 5% | 61.9 | 61.6 | 62.7 | 64.2 | 64.2 |
| 10% | 62.3 | 61.8 | 63.4 | 64.4 | 64.4 |
| 20% | 60.8 | 61.5 | 63.6 | 64.0 | 64.0 |

Chart, histogram

Description automatically generated

Figure 2 PM10 levels by car ratios of 0%, 2.5%, 5%, 10%, and 20%. The average values (smooth curve) of PM10 are similar across roads but was different between 0% (no extra cars in the CBD) and the rest of the samples.

## S3.4. Health Loss

This section investigated the health risk of subway commuters and resident drivers who are sensitive to the health loss parameters. Here, individuals only lose health when PM10 exceeds 100µg/m3, and contribute to the population at risk when one’s health status falls below 100. Output A of each figure resulted from allowing extra inbound traffic in the CBD, whereas output B of each figure resulted from no other traffic than the resident vehicles.

For subway commuters, the population at risk appeared on January 20th-22nd, late February, early March, and late March (see Figure 3). The maximum risk rate was 10% in *0.03* and proportionately increased to 30% in *0.1*, but suddenly skyrocketed to 100% over *0.15*. Although a lot of uncertainty from other parameters has contributed towards the outcomes, the tipping point of the health loss parameter was somewhere between 0.1 and 0.15. Several oscillations were also discovered during the extreme PM10 events. This was because subway commuters have different commute hours that led them to be exposed to ambient PM10, and since health recovery activates when the individual arrives at home or the workplace, the risk rate oscillates frequently.

With a car-free experiment (output B), the results did not affect the health risks of subway commuters. This is because the trajectories of the commuters between stations and office locations were mostly distant from the road. However, the sensitivity between health loss parameters was comparable to the previous experiment: health risk proportionately rose until the parameter reached *0.1* but a sudden upsurge appeared when the parameter was over *0.15*.

Chart

Description automatically generated

Figure 3 Temporal change of risk rates for subway commuters (% of those with health under 100) with inbound cars (left), and without inbound cars (right)

Compared to subway commuters, resident drivers experienced fewer occurrences of health risk, but higher surges in extreme PM10 episodes particularly over the parameter value of *0.15* (see Figure 20 A). Throughout the whole period, the health risk of resident drivers emerged during January 22nd, February 12th, March 8th, and March 24-25th, where the majority was at risk at the last peak. The prominent difference by the health-loss adjustment was very clear at the first peak where it started from less than a per cent of risk at *0.03*, then rose to 2.5% and 6% in 0.05 and 0.1, then surged to 50% and 71% on 0.15 and *0.2*. In line with the subway commuters, a tipping point was also seen between *0.1* and *0.15*.

However, the first surge that happened in *0.15* and *0.2* experiments significantly reduced to 15% and 18% in a car-free condition (see Figure 4B). The other parameters only showed a less than 2% difference. This implies that the health risk of the drivers was not only sensitive to the health-loss parameters but also was affected by the emissions generated by non-resident traffic.

Graphical user interface

Description automatically generated with low confidence

Figure 4 Temporal change of risk rates for resident drivers (% of those with health under 100) with inbound cars (left) and without inbound cars (right)

The difference in health risk can differ by the time the individual has spent outdoors when the ambient PM10 is over the threshold of 100µg/m3, and how quickly that person recovered health. Even if 30% of subway commuters have experienced health risks, the short walking distance allowed them to recover promptly. By contrast, although drivers had fewer emergences of health risk, traffic congestion together with high background pollution had rapidly deteriorated the driver’s health, especially on extremely polluted days.

This study chose one subway commuter and one driver to understand how the nominal health changed over time (see Figure 5A). The light shaded colours shown in the background is the health status by each minute and the lines of turquoise and red are the moving averages. The health status of a subway commuter lost health earlier than the driver under the same condition. The driver might seem healthier than the pedestrian because the driver was never exposed to ambient PM10 which prevented multiple threats of major PM10 episodes. In Figure 5B, the selected driver experienced fewer health risks in the car-free experiment, which can support the result of the population outcomes in Figure 4B where a major fall in risk rate is for drivers in a car-free situation.

The rolling mean between the two groups converged as the parameters increased. The subway commuter’s health was almost the same in different patterns, but for the drivers, the high parameter settings might have caused higher health loss even from a single pollution episode. The difference exists between the two on January 23rd because of the indoor factor of 0.7 that benefited the vehicle drivers.

In short, signs of deterioration in health appeared continuously in long-distance commuters on days when PM10 was on the rise, while the resident drivers had a relatively short period of commute time that prevented frequent health risk, but the extreme levels of PM10 led most of the drivers to an acute health crisis.

Chart

Description automatically generated

Figure 5 Health comparison between a randomly chosen subway commuter (e\_health) and a resident driver (d\_health) with the case of traffic (A) and traffic-free (B)

## S3.5. Walking Speed

To test how walking speed affects the change to risk population, this section adjusted various levels of walking speed for subway commuters. Given the default speed at 0.6-1.0, the section tested 1) 0.2-0.4 patch per minute, 2) 0.4-0.7 patch per minute, and 3) 1.6-1.8 patch per minute. The range was given under the assumption that people have different walking speeds. Walking speed over .5 might seem rather unrealistic, but this experiment intended to illustrate how speed affects exposure levels.

The time-series graph clearly showed that the onset and peak levels were very sensitive to walking speed (see Figure 22). When the pedestrian’s walking speed was "Extremely Slow" (0.2-0.4), more than 40% of the population was at risk on five different occasions with the highest peak of 47%. However, the risk rate declined by 10% when the walking speed increased to "Slow" (0.4-0.7) and further declined by 30% when the speed increased to 1.6-1.8. This corresponds to the previous sensitivity analyses because slowing down the walking speed can mean that the person is prolonging the exposure time, which in turn causes a further health loss.

Chart, bar chart

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Figure 6 **A**ssessing subway commuters’ health by different walking speed parameters

## S3.6. Calibration

This section calibrates emission factors with the observation values measured from the Jongno roadside station. From the sensitivity analysis, it was found that the emission parameters were not only sensitive to the increase in the parameter but also to the variation between roads when the parameter was over 10. Calibration in ABM is very common as it controls the errors and the uncertainty close to the acceptable level (Grimm et al., 2020).

This section did not calibrate PM10 across the study area because the background PM10, which covers most areas, was already generated by the station data. Simulation results of Jongno were averaged from 20 iterations to avoid any noise from a particular run, then compared with the observation value. The simulation ran from the 2nd to the 31st of January 2018. This study used mean squared errors (MSE) and regression to examine the robustness of the model. MSE, as it is known, as the average squared difference between the estimated values and the actual value, can be used to compare the results in positive numbers, understanding the values closer to zero are more accurate. R2 is useful because it is often easier to interpret since it doesn't depend on the scale of the data, and people are familiar with percentages. Note here that each method has its pros and cons and there is no ground rule in selecting a method.

On January the 8th, MSE varied largely by 25, 42, 419, and 2684 in parameters 1, 5, 10, and 20; they varied by 90, 6, 248, and 2087 on the 15th, and 26, 42, 481, and 2426 on the 22nd. Throughout the whole month, *Emission 1* and *Emission 5* had the lowest MSE values by 18 days and 12 days respectively. The line graph shows that low biases for high values are observed in *Emission 1*, whereas high biases for low values are observed in the other parameters, but all modelled parameters could not replicate the peak values introduced from the observed values.

Regression results are similar to the MSE results, where the R2 appeared to be highest in the lower two parameters and decreased significantly in the upper two parameters (see Figure 7B). In line with the MSE results, the scatter plot from *Emission 1* underestimated the observation values, in which most of the points were concentrated on the right side of the 1:1 line. *Emission 5*, on the other hand, slightly overestimated the results on the lower values but got most of the values, including the high values closer to the 1:1 line. Hence, although the overall MSE was lower and R2 was higher in *Emission 1*, the author selected *Emission 5* as the correct parameter. The reason being, that *Emission 5* effectively expresses the extreme values on a polluted day, while at the same time predicting closer values to the truth value. *Emission 1*, even on a minute-by-minute basis, does not articulate the peak of particulates that have possibly dispersed into the local atmosphere.

Table 24 Sum of standardized squared errors (SSSE) on January the 8th, 15th, and 22nd.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Date | Emission | Model | Observation | MSE |
| Jan 8th | 1 | 49.2 | 56.4 | 25 |
| 5 | 65.5 | 56.4 | 42 |
| 10 | 85.3 | 56.4 | 419 |
| 20 | 129.6 | 56.4 | 2684 |
| Jan 15th | 1 | 58.1 | 71.5 | 90 |
| 5 | 75 | 71.5 | 6 |
| 10 | 93.8 | 71.5 | 248 |
| 20 | 136.1 | 71.5 | 2087 |
| Jan 22nd | 1 | 37.7 | 44.9 | 26 |
| 5 | 53.9 | 44.9 | 41 |
| 10 | 75.9 | 44.9 | 482 |
| 20 | 114.6 | 44.9 | 2426 |

Graphical user interface, chart

Description automatically generated with medium confidence

Figure 7 Sensitivity output of adjusting the emission factor *N* from the equation of non-exhaust emissions (Figure A, Jongno: Modelled, pm10\_rd: Observation). Figure B correlates the modelled output against the observation of the Jongno roadside station. R2 of factors 1, 5, 10, and 20 returns .94, .91, .8, and .56.