# IMMC 2017: International Round

Team Control Number: 2017054

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## Contents

# 1 Summary

The development of communication technology has allowed us to see and talk to each other instantaneously, even from opposite sides of the globe. But as useful as video conferences are, sometimes they just don't cut it for some of the more formal meetings, and participants are required to show up in person. This gives rise to the question of *where* to hold the meeting.

A company generally wants to have the most productive meeting at the lowest possible cost. The productivity of a meeting depends on different factors, of which, especially for international meetings, jet lag is definitely one: a medical condition where one's circadian rhythm is disrupted by rapid transmeridian travel, lowering one's productivity significantly by triggering fatigue, headaches and irritability. Another factor is climate and weather: transitioning from a tropical archipelago to a wintry wasteland would be definitely jarring for many people. Other minor factors such as quality of accommodation, quality of food and availability of services can also play apart.

The total cost of the meeting also depends on many factors: tickets, accommodation, et cetera. Plane tickets can vary in price depending on the airline, the destination and origin, the presence of transfers and many others. The price of hotels or other accommodation fluctuates with the location as well as the amount the company is willing to fork out. Purchasing food, local transport and other commodities is also highly dependent on where the meeting is held.

In this paper, we will be attempting to develop an algorithm to determine the best meeting places based on these criteria. Obviously, it would be difficult to accommodate all of these factors. As a result, we will only be considering several key factors.

First, we will consider the impact of jet lag on productivity. We will be determining the best way of measuring this impact as a function of the time difference between the origin and destination cities of each individual. The cities with an overly large productivity loss can then be filtered out, and the best possible region isolated.

The region will then be further narrowed by considering cost. We will attempt to develop a way of estimating the cost based on the origin and destination cities, and the final search region will be determined by optimizing for the lowest possible cost.

Finally, within the region, other factors such as climate and service availability will be used to filter out the unnacceptable cities, producing the final list of feasible meeting places.

This algorithm will be tested on two test cases, and the result reported.

# 2 Introduction

Organizing a meeting is always a demanding job, especially when it involves people from all corners of the world. Problems anticipated in organizing one include productivity, which is affected by jet lag and comfort, as well as cost, including accommodation and plane tickets.

To locate an appropriate venue for the meeting, an algorithm is to be designed to compare locations all around the world and determine the best ones. The model must be closely aligned to the data available to the algorithm, while at the same time having the flexibility to accommodate different data sets.

Before constructing the algorithm, we will first begin by defining the problem.

# 3 Defining the problem

## 3.1 Question restatement

This question requires us to:

1. Create an algorithm that generates a list of suggestions of the best places to hold the meeting given the details of the event, including the number of participants, their home cities and the approximate time of the year it is held.

2. Test the algorithm on two given data sets.

Given these objectives, we can begin laying out the assumptions and variables we need to account for and define.

## 3.2 Assumptions

In designing our model, we decided on several basic assumptions. Listed in the table are the assumptions and our justifications for them.

| Assumption | Justification |
|---|---|
| No delay is caused by weather, air traffic, accidents or other reasons. | These factors are extremely difficult to model, and thus the uncertainty is unavoidable. |
| All flights and aircraft fly at the same constant speed and in the shortest path to their destinations. | Otherwise, the flight behaviour would be too difficult to model. |
| All airlines provide flights at the same price, and direct flights are available and used every time. | Crunching airline prices and routes is beyond the scope of this project, given the time and information provided. |
| The effect of rotation of the Earth on the flights is negligible. | The Coriolis and centrifugal forces are tiny compared to air resistance, lift and engine thrust. |
| The decrease in productivity and impact on health of jet lag is same for all individuals. | Insufficient information is given for more specific predictions to be made |
| Time zones are perfectly divided by unbroken lines of longitude. | This vastly simplifies the searching, and better reflects the day/night cycles, which is the real determinant of productivity. |

How these assumptions affect the accuracy and precision of the algorithm will be discusses in the **Limitations** and **Weaknesses** sections.

### 3.3 Variables

Listed are all the variables we handled in our investigation.

| Symbol | Variable | Definition | References |
|---|---|---|---|
| $t(X)$ | Time offset (hr) | The offset of the local time of a location X relative to UTC. | **4.2** |
| N/A | Timezone | A region in which the time offset is the same | |
| N/A | Timezone difference (hr) | The difference in local time between two timezones, $t(A) - t(B)$ | **4.1, 4.2** |
| $l$ | Jet lag (hr) | The absolute amount of offset of your body clock relative to local time. | **4.1, 4.2** |
| $L$ | Overall productivity loss (hr) | $\int l\,dt$, the total impact of jet lag $l$ over the course of the meeting | **4.2** |
| $L_{\text{total}}$ | Total overall productivity loss (hr) | $\sum L$, the total of the overall productivity losses of all the participants in the meeting | **4.2** |
| $t$ | Time (day) | Days since the start of the meeting. | **4.2** |
| $d$ | Distance of flight (km) | The length of the arc of a great circle connecting the origin and destination of the flight. | **4.1, 4.3** |
| N/A | Latitude (°) | The north-south coordinate of a point relative to the equator. | **4.1, 4.2** |
| N/A | Longitude (°) | The east-west coordinate of a point relative to the prime meridian. | **4.1, 4.3** |

When fleshing out the algorithm, some of these variables will be further defined and elaborated on. The sections that reference these variables can be seen in the fourth column above.

## 4 The Algorithm

### 4.1 Overview

The first priority of the algorithm is to maximize productivity, and the second priority is to minimize cost. The former is correlated with *jet lag*, which will be represented and minimized first with the input of *timezone difference*. The latter is approximated with the input of *distance of flight*, which will serve as the criterion for a second stage of selection.

The output of the algorithm requests a list of recommended places, which we interpret as cities. To obtain this list, a region defined by longitude and latitude will be found, and the major cities within picked out.

To transform the input variables into the output list, there are three main steps:

1. Jet lag is minimized across 24 time zones to narrow the search region to a longitude range.
2. Cost is minimized across 12 latitude regions to narrow the search to a specific latitude/longitude-bounded area.
3. The cities in the area are filtered for size, accessibility and environmental hostility.

## 4.2 Selecting the time zone

Let us consider a specific person experiencing jet lag. While the impact on productivity definitely increases with the timezone difference, it may not necessarily be a direct linear relationship.

Studies show[1] that our body clock adjusts to time differences at a linear rate, and that this rate varies depending on whether the offset is positive or negative. This gives a graph like below.

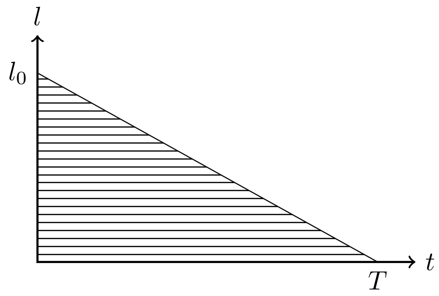


Figure 2: Plotting jet lag ($l$) against time ($t$)

Jet lag reflects loss in instantaneous productivity, i.e. the rate at which work is done. Loss of overall productivity, or total work done, would instead correspond to $\int l\,dt$, or the shaded triangle,

$$L = \frac{1}{2} l_0 T.$$

The rate of recovery in hours readjusted per day, $r$, is modeled as a constant. Therefore, it can be trivially shown that $r = \frac{l_0}{T}$. So,

$$L = \frac{{l_0}^2}{2r}.$$

$r$ is 1 hour per day and 1.5 hours per day for positive and negative time displacements respectively[1]. However, how is $l$ calculated? Simply deducting the time offsets to obtain the timezone difference would not work, as that would imply that UTC+11 and UTC-11 would give 22-hour jet lag, while in reality it should be 2 hours.

To account for this, we can do a simple test: if the initial jet lag $l_0$ is greater than 12, then we deduct 24. If it is less than $-12$, then we add 24. This means that an eastward 22 hour lag will become a westward 2 hour lag, and vice versa.

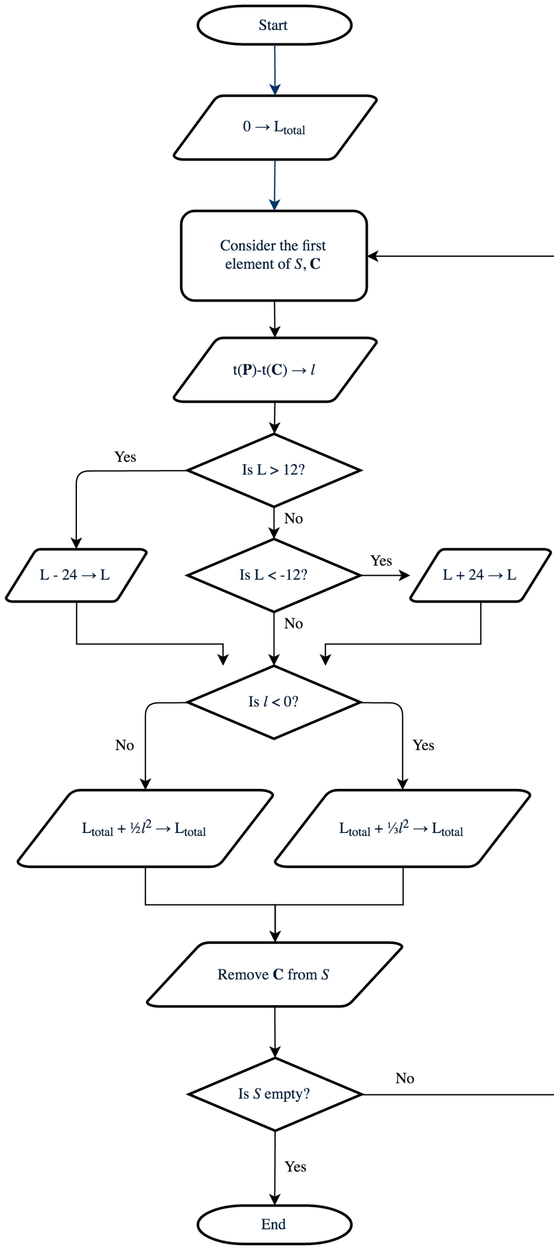


Figure 1: The procedure for calculating $L_{\text{total}}$ for timezone $P$ with a set of origin cities $S$. $t(X)$ is the time offset from UTC at location $X$.

There is the possibility that adjusting the direction of travel would actually increase the overall productivity loss $L$ due to the different coefficients. However, this is not a concern as the biological clock adjusts towards the nearest day/night cycle, not the one that will be achieved faster, so this would actually reflect reality better.

Therefore, for any given origin city and destination timezone, the overall productivity loss $L$ of the individual can be computed. Then, for each hypothetical timezone, the total overall productivity loss $L_{\text{total}}$ can be determined by summing the individual overall productivity losses of each participant. The whole process is illustrated in **Figure 1**.

After the losses are evaluated for every timezone, the timezone with the lowest $L_{\text{total}}$ can be selected. As timezones are discrete, it is impossible (or rather, meaningless) to further narrow down the longitude with this criterion, and we can move on to the second part.

### 4.3 Selecting the latitude range

The distances of flight impacts our choice in two ways: for one, a long flight creates stress on the traveler which decreases productivity. But more importantly, it is positively correlated the cost of flight. As a result, it will be used in the second stage of selection to determine the best latitudes.

The timezone will be divided into 12 regions, each spanning 15° of latitude and longitude. A phantom city will be placed at the center of each region (coordinates being the average of the latitude and longitude bounds).

The flight distance ($d$) from a city to a region will be defined as the shortest distance from the city to the phantom city, i.e. the length of the arc of a great circle joining the two points. From the latitudes and longitudes of these points, geometry can be then used to determine $d$ for any particular flight.

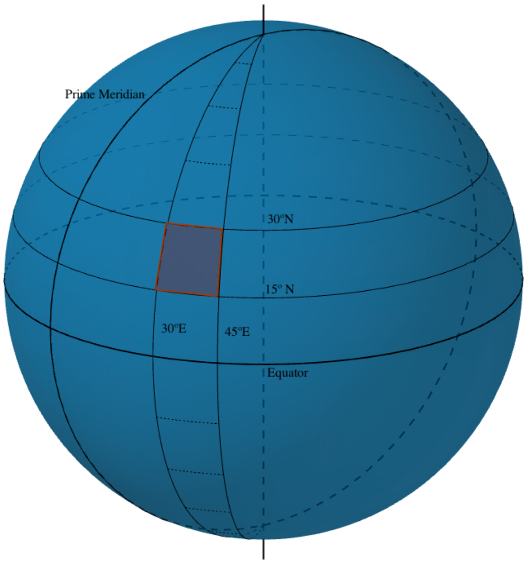


Figure 3: The division of latitude into regions

Let $\lambda$ and $\phi$ be latitude and longitude respectively, and $\theta$ be the angle subtended by the arc between the two points. First, project Earth onto a unit sphere in a Cartesian coordinate plane. If the geographical coordinates (0, 0) correspond to Cartesian coordinates $\begin{pmatrix}0\\0\\1\end{pmatrix}$, then latitude and longitude represent the rotation of the vector $\begin{pmatrix}0\\0\\1\end{pmatrix}$ around the $x$- and $y$-axes respectively, in that order. In other words,

$$P = \begin{pmatrix} \cos\phi & 0 & -\sin\phi \\ 0 & 1 & 0 \\ \sin\phi & 0 & \cos\phi \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\lambda & -\sin\lambda \\ 0 & \sin\lambda & \cos\lambda \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = \begin{pmatrix} -\cos\lambda\sin\phi \\ -\sin\lambda \\ \cos\lambda\cos\phi \end{pmatrix}. \tag{1}$$

The angle between the two position vectors, i.e. $\theta$, is the cosine by their dot product (divided by the product of their magnitudes, which is 1). So,

$$\begin{aligned} \cos\theta &= \begin{pmatrix} -\cos\lambda_1\sin\phi_1 \\ -\sin\lambda_1 \\ \cos\lambda_1\cos\phi_1 \end{pmatrix} \cdot \begin{pmatrix} -\cos\lambda_2\sin\phi_2 \\ -\sin\lambda_2 \\ \cos\lambda_2\cos\phi_2 \end{pmatrix} \\ &= \cos\lambda_1\sin\phi_1\cos\lambda_2\sin\phi_2 + \sin\lambda_1\sin\lambda_2 + \cos\lambda_1\cos\phi_1\cos\lambda_2\cos\phi_2 \\ &= \cos\lambda_1\cos\lambda_2(\sin\phi_1\sin\phi_2 + \cos\phi_1\cos\phi_2) + \sin\lambda_1\sin\lambda_2 \\ &= \cos\lambda_1\cos\lambda_2\cos(\phi_1 - \phi_2) + \sin\lambda_1\sin\lambda_2. \end{aligned} \tag{2}$$

Thus, as arc length $= r\theta$,

$$d = R_E * \cos^{-1}(\cos\lambda_1\cos\lambda_2\cos(\phi_1 - \phi_2) + \sin\lambda_1\sin\lambda_2) \tag{3}$$

where $R_E$ is the radius of the Earth.

Then, we have to attempt to relate distance to cost. According to a study by Rome2Rio[2], cost has an approximate linear correlation with flight distance:

$$\text{Cost} = \$50 + \text{Distance} * \$0.11 \tag{4}$$

Due to the linear nature of the relationship, the distances can simply be summed to obtain the sort key (in the case of other relationships, the individual *costs* would have to be summed, as the distribution of flight distance among individuals would influence the total cost).

By calculating the $d_{\text{total}}$ for each latitude region, the one with the minimum $d_{\text{total}}$ can simply be selected. The corresponding area will be the new search region. Then, we can move on to the third part.

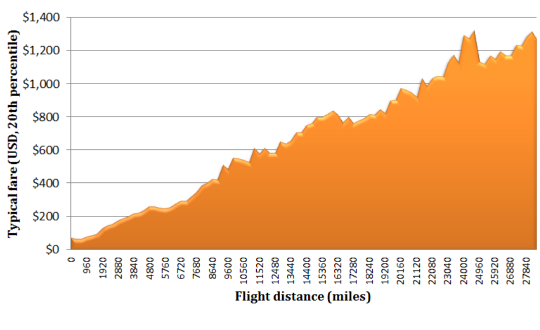


Figure 4: Ticket price against flight distance [2]

## 4.4 Filtering the results

Within the region obtained, viable cities have to be picked out. There are two main criteria for this:

1. The city must have an airport
2. The city must have a mean temperature at that time of the year between 0°C and 35°C.

The reason for the first criterion is clear: there needs to be an airport for the meeting individuals to fly there. Furthermore, the location needs to have a certain level of services, of which having an airport is strongly indicative.

For obvious reasons, airports reserved for military or private use are excluded, as they do not allow commercial flights to land.

The second criteron is concerned with the comfort and therefore productivity of the individuals. A too-cold or too-hot location would adversely impact their productivity, and so this is to be avoided.

As it is difficult to quantify discomfort due to climate differences, we have simply defined a range beyond which temperature is deemed unacceptable.

It is possible that no viable cities are found. There may be two reasons for this:

1. The area is too remote and has no airports.
2. The area is in polar or tropical desert regions, where the temperature criterion disqualifies all cities.
3. The region is over the ocean, where there are no cities.

In such a case, we refer back to the second stage and take the next best latitude region, then repeat the search. If all latitudes are exhausted, then we refer back to the first stage and take the next best longitude range, and repeat.

The entire filtration procedure is detailed in **Figure 5**. The final generated list of cities is the list submitted as the output.

In the next section, we will summarize all three stages of the algorithm.

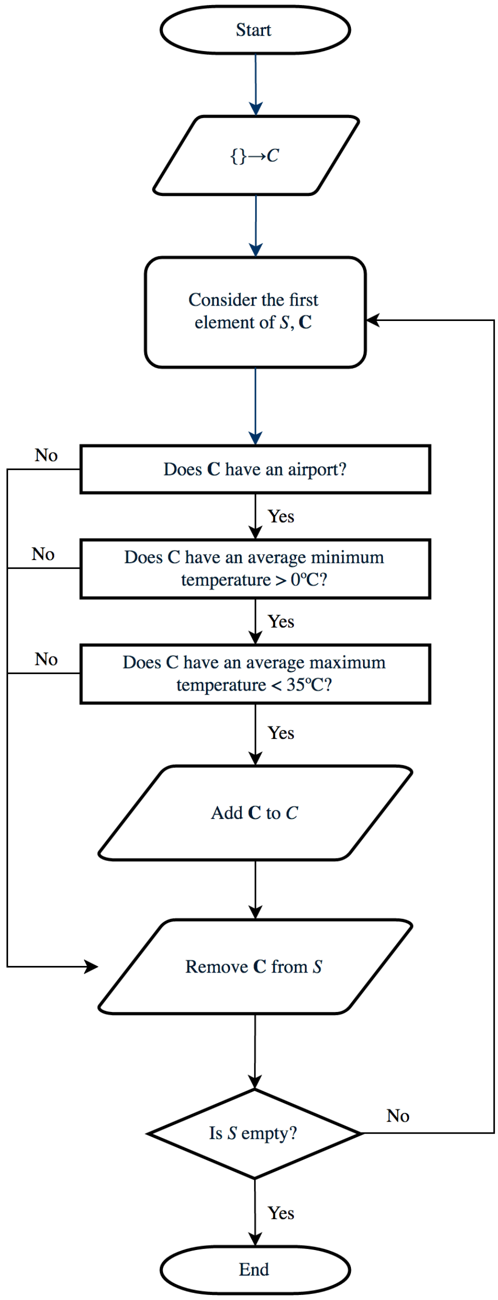


Figure 5: The procedure of filtering out invalid cities. S is the set of cities within the considered area.

## 4.5 Summary

The overarching structure can be restated as such:

1. Find the optimum longitude range by minimizing productivity loss due to jet lag.
2. Find the optimum latitude range by minimizing the cost of flight tickets.
3. Construct a list of cities in the latitude/longitude-bounded region that satisfies temperature and accessibility requirements.
4. If no cities are found, return to Step 2 and try the next best latitude range. If no cities are found in all latitude ranges, return to Step 1 and try the next best longitude range.

The flowchart below summarizes this.

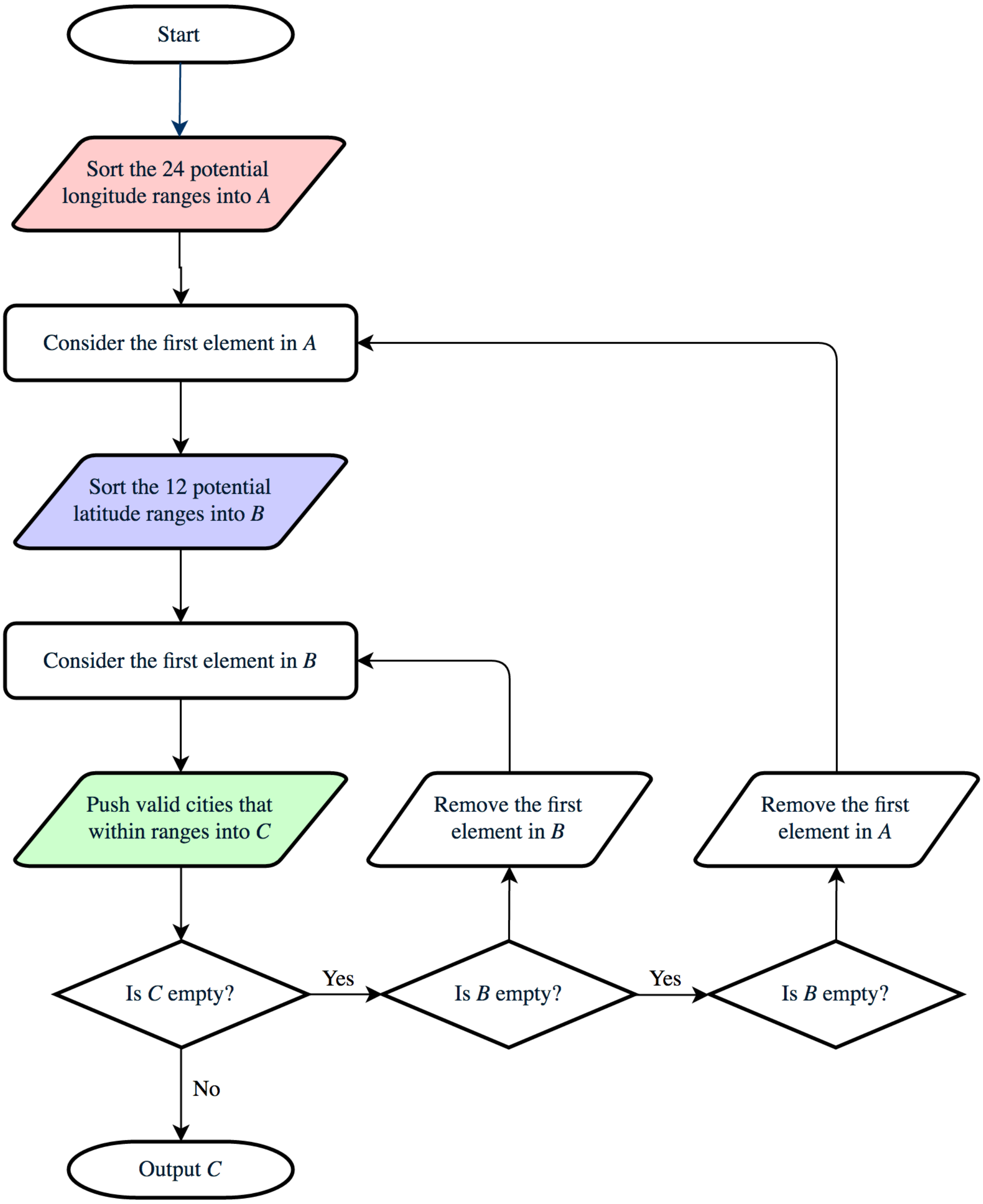


Figure 6: The overall logic of the algorithm

The red, blue and green processes require the evaluation of the sort keys of Stages 1 and 2, and the validation process for stage 3. They are laid out below in the corresponding colors.

Note that some charts are duplicates of smaller versions in the last 3 sections.

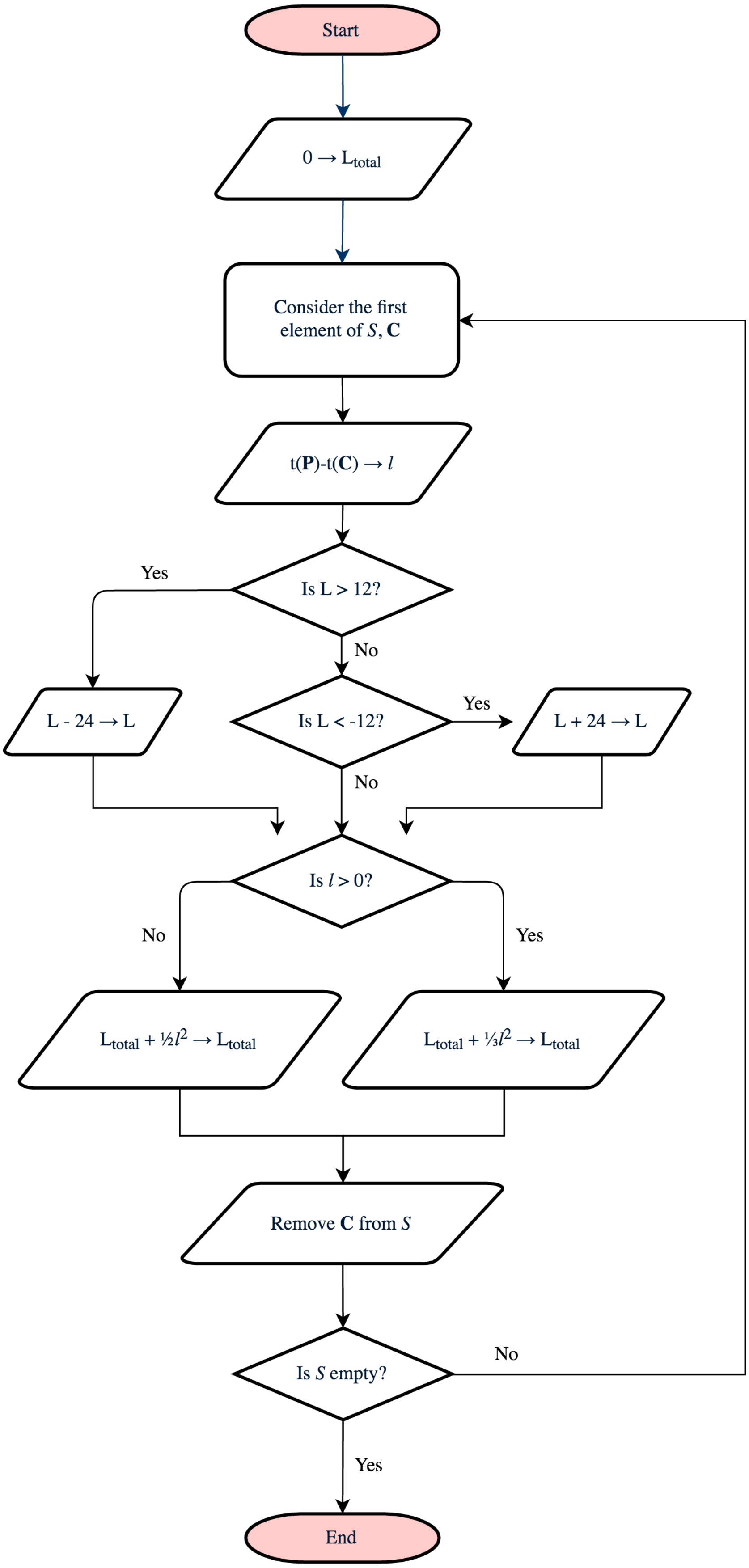


Figure 7: The sort key for Stage 1.

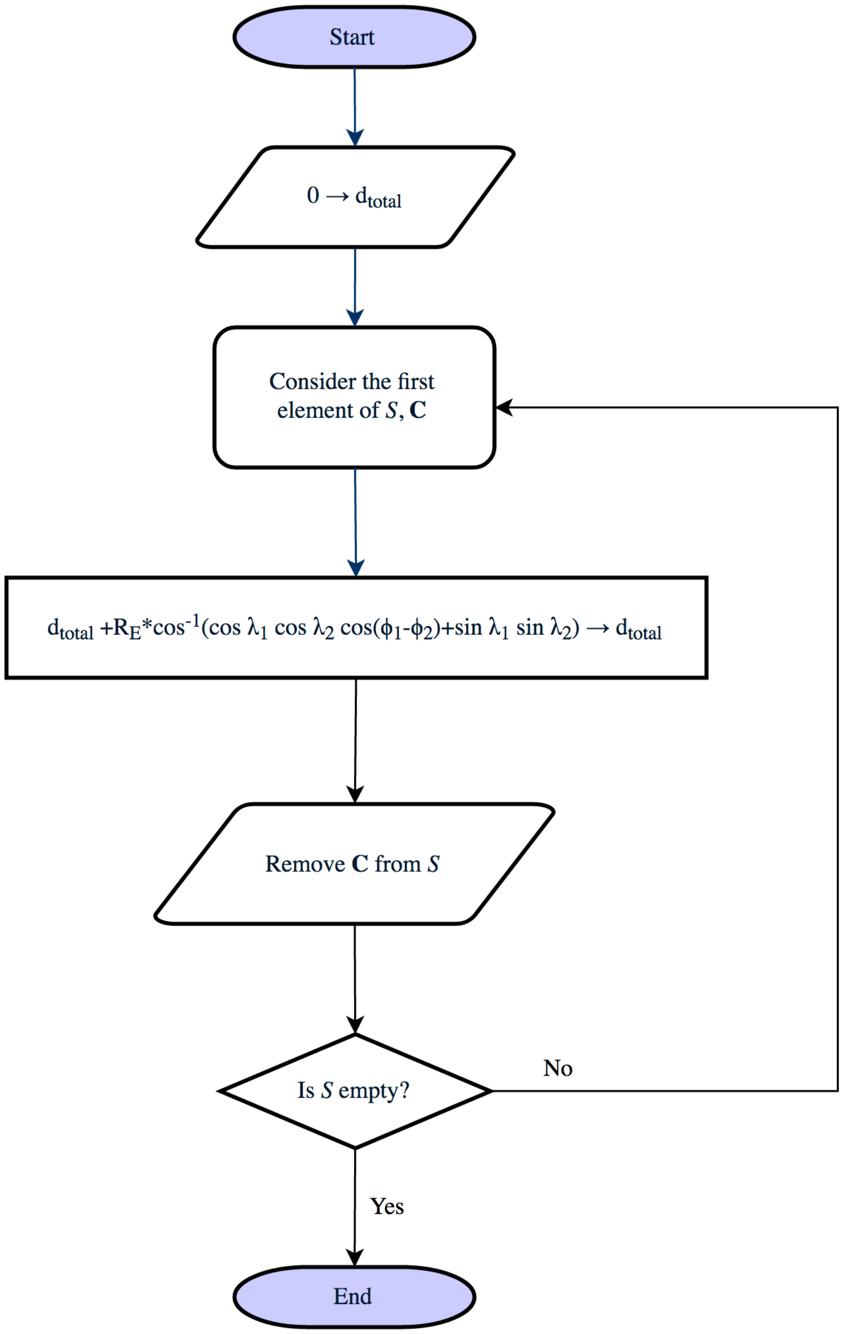


Figure 8: The sort key for Stage 2.

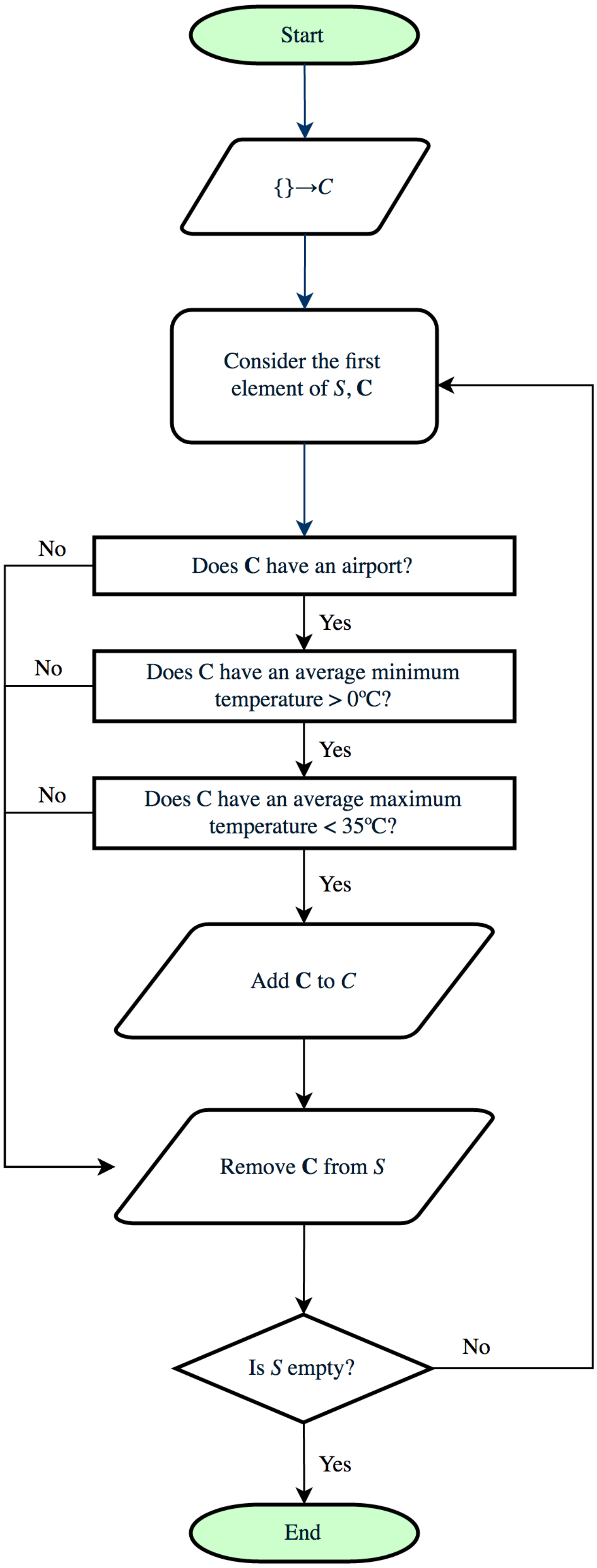


Figure 9: The validation process for Stage 3.

# 5 Applying the Algorithm

## 5.1 "Small Meeting"

The individuals we had to consider are listed in the table below, along with the cities' timezones and coordinates.

| | | |
|---|---|---|
| Monterey CA, USA<br>UTC-7 | Zutphen, Netherlands<br>UTC+2 | Moscow, Russia<br>UTC+3 |
| Shanghai, China<br>UTC+8 | Hong Kong (SAR), China<br>UTC+8 | Melbourne, Australia<br>UTC+11 |

Table 1: The cities and timezones of the individuals

| City | Monterey CA, USA | Zutphen, Netherlands | Moscow, Russia |
|---|---|---|---|
| Lat.<br>Long. | 36°36'14.2344"N<br>121°53'54.4560"W | 52°8'33.85"N<br>6°11'45.81"E | 55°45'8"N<br>37°36'56"E |
| City | Shanghai, China | Hong Kong (SAR), China | Melbourne, Australia |
| Lat.<br>Long. | 31°0'18"N<br>121°24'31"E | 22°15'0"N<br>114°10'0"E | 37°49'0"S<br>144°58'0"E |

Table 2: The coordinates of the cities

In Stage 1, Excel was used to calculate the overall productivity losses $L$ of each city in each timezone, and therefore the total overall productivity losses $L_{\text{total}}$ of each timezone. This is shown in **Figure 10**.

| | Monterey CA, USA | Zutphen, Netherlands | Moscow, Russia | Shanghai, China | Hong Kong (SAR), China | Melbourne, Australia | | |
|---|---|---|---|---|---|---|---|---|
| | -7 | 2 | 3 | 8 | 8 | 11 | | L_total |
| -12 | 8.333333333 | 50 | 40.5 | 8 | 8 | 0.5 | | 115.333333 |
| -11 | 5.333333333 | 60.5 | 50 | 12.5 | 12.5 | 2 | | 142.833333 |
| -10 | 3 | 48 | 60.5 | 18 | 18 | 4.5 | | 152 |
| -9 | 1.333333333 | 40.3333333 | 48 | 24.5 | 24.5 | 8 | | 146.666667 |
| -8 | 0.333333333 | 33.3333333 | 40.33333333 | 32 | 32 | 12.5 | | 150.5 |
| -7 | 0 | 27 | 33.33333333 | 40.5 | 40.5 | 18 | | 159.333333 |
| -6 | 0.5 | 21.3333333 | 27 | 50 | 50 | 24.5 | | 173.333333 |
| -5 | 2 | 16.3333333 | 21.33333333 | 60.5 | 60.5 | 32 | | 192.666667 |
| -4 | 4.5 | 12 | 16.33333333 | 48 | 48 | 40.5 | | 169.333333 |
| -3 | 8 | 8.33333333 | 12 | 40.33333333 | 40.33333333 | 50 | | 159 |
| -2 | 12.5 | 5.33333333 | 8.333333333 | 33.33333333 | 33.33333333 | 60.5 | | 153.333333 |
| -1 | 18 | 3 | 5.333333333 | 27 | 27 | 48 | | 128.333333 |
| 0 | 24.5 | 1.33333333 | 3 | 21.33333333 | 21.33333333 | 40.3333333 | | 111.833333 |
| 1 | 32 | 0.33333333 | 1.333333333 | 16.33333333 | 16.33333333 | 33.3333333 | | 99.6666667 |
| 2 | 40.5 | 0 | 0.333333333 | 12 | 12 | 27 | | 91.8333333 |
| 3 | 50 | 0.5 | 0 | 8.333333333 | 8.333333333 | 21.3333333 | | 88.5 |
| 4 | 60.5 | 2 | 0.5 | 5.333333333 | 5.333333333 | 16.3333333 | | 90 |
| 5 | 72 | 4.5 | 2 | 3 | 3 | 12 | | 96.5 |
| 6 | 40.33333333 | 8 | 4.5 | 1.333333333 | 1.333333333 | 8.33333333 | | 63.8333333 |
| 7 | 33.33333333 | 12.5 | 8 | 0.333333333 | 0.333333333 | 5.33333333 | | 59.8333333 |
| 8 | 27 | 18 | 12.5 | 0 | 0 | 3 | | 60.5 |
| 9 | 21.33333333 | 24.5 | 18 | 0.5 | 0.5 | 1.33333333 | | 66.1666667 |
| 10 | 16.33333333 | 32 | 24.5 | 2 | 2 | 0.33333333 | | 77.1666667 |
| 11 | 12 | 40.5 | 32 | 4.5 | 4.5 | 0 | | 93.5 |
| 12 | 8.333333333 | 50 | 40.5 | 8 | 8 | 0.5 | | 115.333333 |
| | | | | | | | | |
| | | | | | | | Lowest L_total | 59.8333333 |
| | | | | | | | Timezone | 7 |

Figure 10: The Excel setup for finding the best timezone (Small Meeting).

Note that +12 and -12 are the same longitudes; they are included for symmetry only. These values give a graph of $L_{\text{total}}$ against timezone, shown in **Figure 11**.

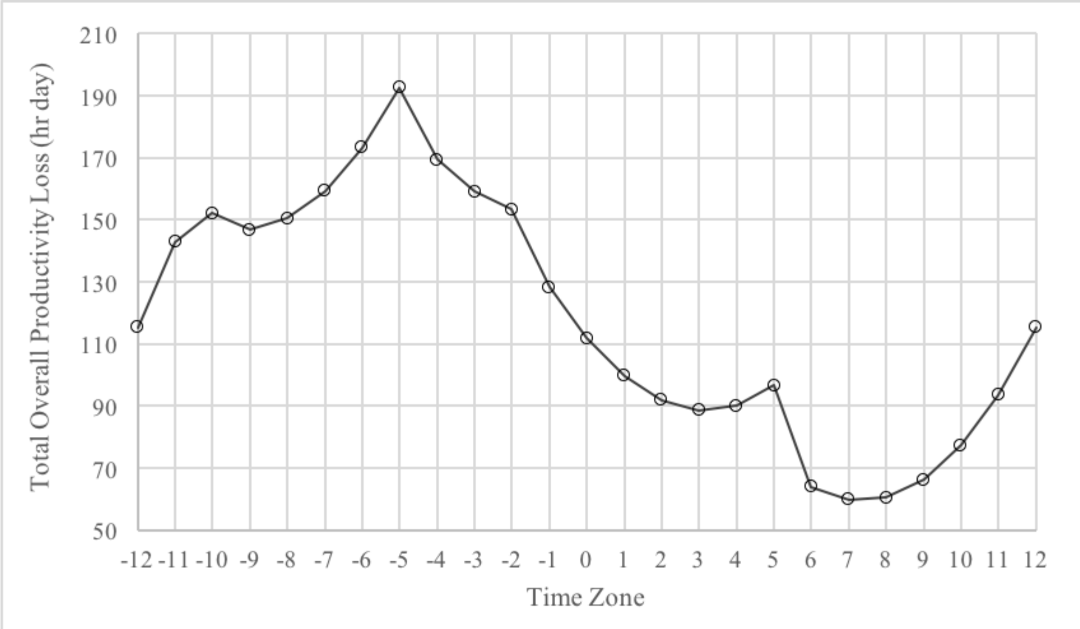


Figure 11: The graph of $L_{\text{total}}$ against timezone (Small Meeting).

There are several things to note about the graph. First, the smooth parabolic shape seen in several sections: this shape is expected as the formula to calculate $L_{\text{total}}$ involves the square of a linear function of the timezone. Therefore, when graphed against the timezone, a quadratic shape would naturally appear.

However, it can be seen that it is not a continuous quadratic. This is the second thing to note, which is explained by the timezone differences crossing the 12 hour mark and therefore 'flipping' in its $L$'s (overall productivity loss') direction of change. This thus causes 'jumps' and even changes in direction in the graph when multiple cities 'flip' at the same time.

Back to the task, as can be seen in the image, the timezone with the smallest $L_{\text{total}}$ is UTC+7. This corresponds to a longitude range of $97.5 - 112.5°$E.

Now, we can move to Stage 2. Excel was used to determine the $d_{\text{total}}$ for phantom cities in the $97.5 - 112.5°$E longitude band.

| Phantom City | | Degrees | latitude | -82.5 | -67.5 | -52.5 | -37.5 | -22.5 | -7.5 | 7.5 | 22.5 | 37.5 | 52.5 | 67.5 | 82.5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | longitude | 105 | 105 | 105 | 105 | 105 | 105 | 105 | 105 | 105 | 105 | 105 | 105 |
| | | Radians | latitude | -1.439897 | -1.178097 | -0.916298 | -0.654498 | -0.392699 | -0.1309 | 0.1309 | 0.392699 | 0.654498 | 0.916298 | 1.178097 | 1.439897 |
| | | | longitude | 1.832596 | 1.832596 | 1.832596 | 1.832596 | 1.832596 | 1.832596 | 1.832596 | 1.832596 | 1.832596 | 1.832596 | 1.832596 | 1.832596 |
| | | Degrees | Radians | | | | | | | | | | | | |
| Monterey | latitude | 36.60395 | 0.63886 | 14623.47 | 15515.61 | 15990.11 | 15895.97 | 15267.53 | 14281.67 | 13096.04 | 11806.24 | 10467.85 | 9118.223 | 7790.715 | 6526.679 |
| | longitude | -121.8985 | -2.127529 | | | | | | | | | | | | |
| Zutphen | latitude | 52.14274 | 0.910062 | 15863.04 | 15560.77 | 14802.59 | 13757.24 | 12552.52 | 11265.57 | 9944.273 | 8624.612 | 7343.136 | 6149.651 | 5125.246 | 4403.179 |
| | longitude | 6.196058 | 0.108142 | | | | | | | | | | | | |
| Melbourne | latitude | -37.81667 | -0.660025 | 5183.163 | 4119.23 | 3473.632 | 3491.018 | 4163.011 | 5240.912 | 6521.748 | 7900.501 | 9324.002 | 10760.17 | 12182.34 | 13557.86 |
| | longitude | 144.9667 | 2.530146 | | | | | | | | | | | | |
| Shanghai | latitude | 31.005 | 0.541139 | 12652.87 | 11039.4 | 9421.445 | 7805.974 | 6201.462 | 4624.316 | 3120.683 | 1880.566 | 1668.896 | 2735.976 | 4199.065 | 5762.994 |
| | longitude | 121.4086 | 2.11898 | | | | | | | | | | | | |
| Hong Kong | latitude | 22.25 | 0.388336 | 11657.83 | 10008.56 | 8359.289 | 6712.841 | 5074.038 | 3455.536 | 1911.503 | 942.8098 | 1909.717 | 3453.56 | 5072.022 | 6710.81 |
| | longitude | 114.1667 | 1.992584 | | | | | | | | | | | | |
| Moscow | latitude | 55.75222 | 0.97306 | 15823.76 | 14779.12 | 13521.8 | 12160.38 | 10750.76 | 9326.678 | 7915.804 | 6551.346 | 5287.717 | 4230.293 | 3576.725 | 3561.373 |
| | longitude | 37.61556 | 0.656515 | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | -82.5 | -67.5 | -52.5 | -37.5 | -22.5 | -7.5 | 7.5 | 22.5 | 37.5 | 52.5 | 67.5 | 82.5 |
| | | | | 6779.873 | 6155.78 | 5503.663 | 4882.02 | 4311.597 | 3780.432 | 3285.541 | 2898.982 | 2858.681 | 3056.261 | 3367.094 | 3789.583 |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | minimum distance: | 2858.681 |
| | | | | | | | | | | | | | | suggested latitude: | 37.5 |

Figure 12: The Excel setup for finding the best latitude (Small Meeting).

This can be graphically represented. See **Figure 13**.

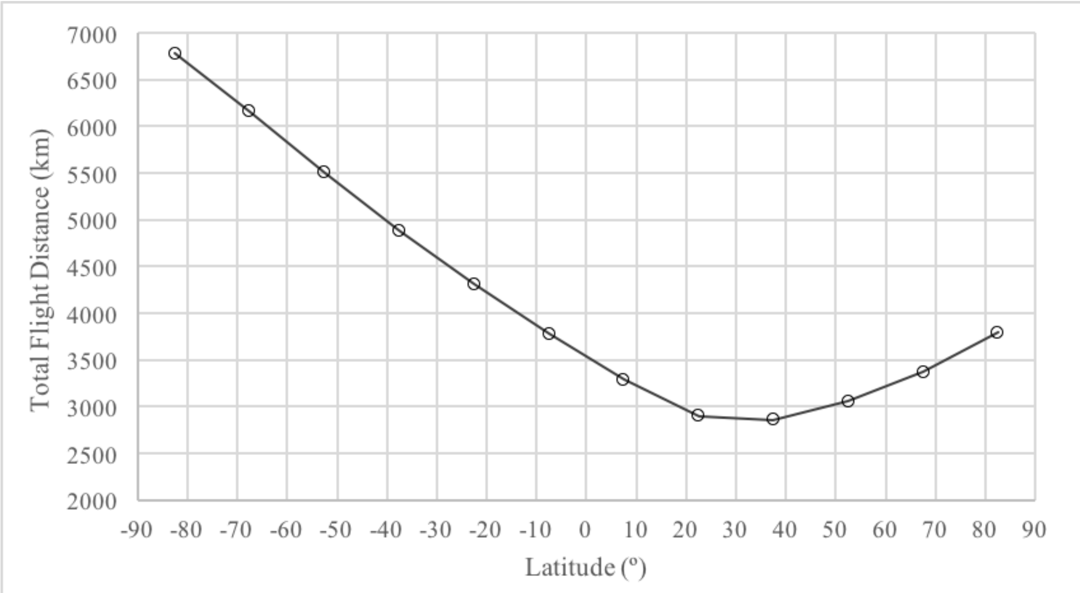


Figure 13: The graph of $d_{\text{total}}$ against latitude (Small Meeting).

As $d_{\text{total}}$ and its derivatives are continuous at all points, a smooth curve like this is expected. From this data, we can see that the optimal latitude is 37.5°. Therefore, the final search region is bounded by $30 \leq \lambda \leq 45$ and $97.5 \leq \phi \leq 112.5$.

In that region, there are 5 cities with airports. Noting that the meeting is held mid-June, let us look at their temperatures.

1. *Xi'an* has an average temperature range of $19 - 30$°C; it is valid.
2. *Cheng Du* has an average temperature range of $21 - 28$°C; it is valid.
3. *Nanchong* has an average temperature range of $24 - 32$°C; it is valid.
4. *Lanzhou* has an average temperature range of $14 - 27$°C; it is valid.
5. *Xining* has an average temperature range of $9 - 23$°C; it is valid.

As all of them have passed, the final list of recommendations can be generated:

| City | Latitude | Longitude |
|---|---|---|
| Xi'an | 35°15'44"N | 108°56'16"E |
| Cheng Du | 30°34'22"N | 104°4'00"E |
| Nanchong | 30°47'0"N | 106°8'0"E |
| Lanzhou | 36°3'23"N | 103°47'32"E |
| Xining | 36°37'0"N | 101°46'0"E |

Table 3: The list of recommended places for the 'Small Meeting'

## 5.2 "Big Meeting"

The individuals we had to consider are listed in the table below, along with the cities' timezones and coordinates.

| Boston MA, USA ×2<br>UTC-5 | Utrecht, Netherlands<br>UTC+1 | Warsaw, Poland<br>UTC+1 |
|---|---|---|
| Copenhagen, Denmark<br>UTC+1 | Moscow, Russia<br>UTC+3 | Singapore<br>UTC+8 |
| Beijing, China<br>UTC+8 | Hong Kong (SAR), China ×2<br>UTC+8 | Melbourne, Australia<br>UTC+10 |

Table 4: The cities and timezones of the individuals

| City | Boston MA, USA ×2 | Utrecht, Netherlands | Warsaw, Poland |
|---|---|---|---|
| Lat.<br>Long. | 42°21'29"N<br>71°3'37"W | 52°5'34.3534"N<br>5°6'16.1280"E | 52°15'0"N<br>21°0'0"E |
| City | Copenhagen, Denmark | Moscow, Russia | Singapore |
| Lat.<br>Long. | 55°40'0"N<br>12°35'0"E | 55°45'8"N<br>37°36'56"E | 1°22'0"N<br>103°48'0"E |
| City | Beijing, China | Hong Kong (SAR), China ×2 | Melbourne, Australia |
| Lat.<br>Long. | 39°55'44"N<br>116°23'18"E | 22°15'0"N<br>114°10'0"E | 37°49'0"S<br>144°58'0"E |

Table 5: The coordinates of the cities

Excel was used to calculate the overall productivity losses $L$ of each city in each timezone, and therefore the total overall productivity losses $L_{\text{total}}$ of each timezone. This is shown in **Figure 14**.

| | Boston MA, USA | Boston MA, USA | Utrecht, Netherlands | Warsaw, Poland | Copenhagen, Denmark | Moscow, Russia | Singapore | Beijing, China | Hong Kong (SAR), China | Hong Kong (SAR), China | Melbourne, Australia | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -5 | -5 | 1 | 1 | 1 | 3 | 8 | 8 | 8 | 8 | 10 | | L_total |
| -12 | 16.33333333 | 16.33333333 | 60.5 | 60.5 | 60.5 | 40.5 | 8 | 8 | 8 | 8 | 2 | | 288.6667 |
| -11 | 12 | 12 | 48 | 48 | 48 | 50 | 12.5 | 12.5 | 12.5 | 12.5 | 4.5 | | 272.5 |
| -10 | 8.333333333 | 8.333333333 | 40.33333333 | 40.33333333 | 40.33333333 | 60.5 | 18 | 18 | 18 | 18 | 8 | | 278.1667 |
| -9 | 5.333333333 | 5.333333333 | 33.33333333 | 33.33333333 | 33.33333333 | 48 | 24.5 | 24.5 | 24.5 | 24.5 | 12.5 | | 269.1667 |
| -8 | 3 | 3 | 27 | 27 | 27 | 40.33333333 | 32 | 32 | 32 | 32 | 18 | | 273.3333 |
| -7 | 1.333333333 | 1.333333333 | 21.33333333 | 21.33333333 | 21.33333333 | 33.33333333 | 40.5 | 40.5 | 40.5 | 40.5 | 24.5 | | 286.5 |
| -6 | 0.333333333 | 0.333333333 | 16.33333333 | 16.33333333 | 16.33333333 | 27 | 50 | 50 | 50 | 50 | 32 | | 308.6667 |
| -5 | 0 | 0 | 12 | 12 | 12 | 21.33333333 | 60.5 | 60.5 | 60.5 | 60.5 | 40.5 | | 339.8333 |
| -4 | 0.5 | 0.5 | 8.333333333 | 8.333333333 | 8.333333333 | 16.33333333 | 48 | 48 | 48 | 48 | 50 | | 284.3333 |
| -3 | 2 | 2 | 5.333333333 | 5.333333333 | 5.333333333 | 12 | 40.33333333 | 40.33333333 | 40.33333333 | 40.33333333 | 60.5 | | 253.8333 |
| -2 | 4.5 | 4.5 | 3 | 3 | 3 | 8.333333333 | 33.33333333 | 33.33333333 | 33.33333333 | 33.33333333 | 48 | | 207.6667 |
| -1 | 8 | 8 | 1.333333333 | 1.333333333 | 1.333333333 | 5.333333333 | 27 | 27 | 27 | 27 | 40.33333333 | | 173.6667 |
| 0 | 12.5 | 12.5 | 0.333333333 | 0.333333333 | 0.333333333 | 3 | 21.33333333 | 21.33333333 | 21.33333333 | 21.33333333 | 33.33333333 | | 147.6667 |
| 1 | 18 | 18 | 0 | 0 | 0 | 1.333333333 | 16.33333333 | 16.33333333 | 16.33333333 | 16.33333333 | 27 | | 129.6667 |
| 2 | 24.5 | 24.5 | 0.5 | 0.5 | 0.5 | 0.333333333 | 12 | 12 | 12 | 12 | 21.33333333 | | 120.1667 |
| 3 | 32 | 32 | 2 | 2 | 2 | 0 | 8.333333333 | 8.333333333 | 8.333333333 | 8.333333333 | 16.33333333 | | 119.6667 |
| 4 | 40.5 | 40.5 | 4.5 | 4.5 | 4.5 | 0.5 | 5.333333333 | 5.333333333 | 5.333333333 | 5.333333333 | 12 | | 128.3333 |
| 5 | 50 | 50 | 8 | 8 | 8 | 2 | 3 | 3 | 3 | 3 | 8.333333333 | | 146.3333 |
| 6 | 60.5 | 60.5 | 12.5 | 12.5 | 12.5 | 4.5 | 1.333333333 | 1.333333333 | 1.333333333 | 1.333333333 | 5.333333333 | | 173.6667 |
| 7 | 72 | 72 | 18 | 18 | 18 | 8 | 0.333333333 | 0.333333333 | 0.333333333 | 0.333333333 | 3 | | 210.3333 |
| 8 | 40.33333333 | 40.33333333 | 24.5 | 24.5 | 24.5 | 12.5 | 0 | 0 | 0 | 0 | 1.333333333 | | 168 |
| 9 | 33.33333333 | 33.33333333 | 32 | 32 | 32 | 18 | 0.5 | 0.5 | 0.5 | 0.5 | 0.333333333 | | 183 |
| 10 | 27 | 27 | 40.5 | 40.5 | 40.5 | 24.5 | 2 | 2 | 2 | 2 | 0 | | 208 |
| 11 | 21.33333333 | 21.33333333 | 50 | 50 | 50 | 32 | 4.5 | 4.5 | 4.5 | 4.5 | 0.5 | | 243.1667 |
| 12 | 16.33333333 | 16.33333333 | 60.5 | 60.5 | 60.5 | 40.5 | 8 | 8 | 8 | 8 | 2 | | 288.6667 |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | Lowest L_total | 119.6667 |
| | | | | | | | | | | | | Timezone | 3 |

Figure 14: The Excel setup for finding the best timezone (Big meeting).

These values give a graph of $L_{\text{total}}$ against timezone, shown in **Figure 15**.

Similar to the 'Small Meeting' scenario, the same 'broken parabolas' are seen. The optimal timezone is UTC+3, i.e. the longitude range $37.5 - 52.5°$E.

Then we move to Stage 2. Excel was used to determine the region with the lowest $d_{\text{total}}$. This is seen in **Figure 16**.

The graph is shown in **Figure 17**.

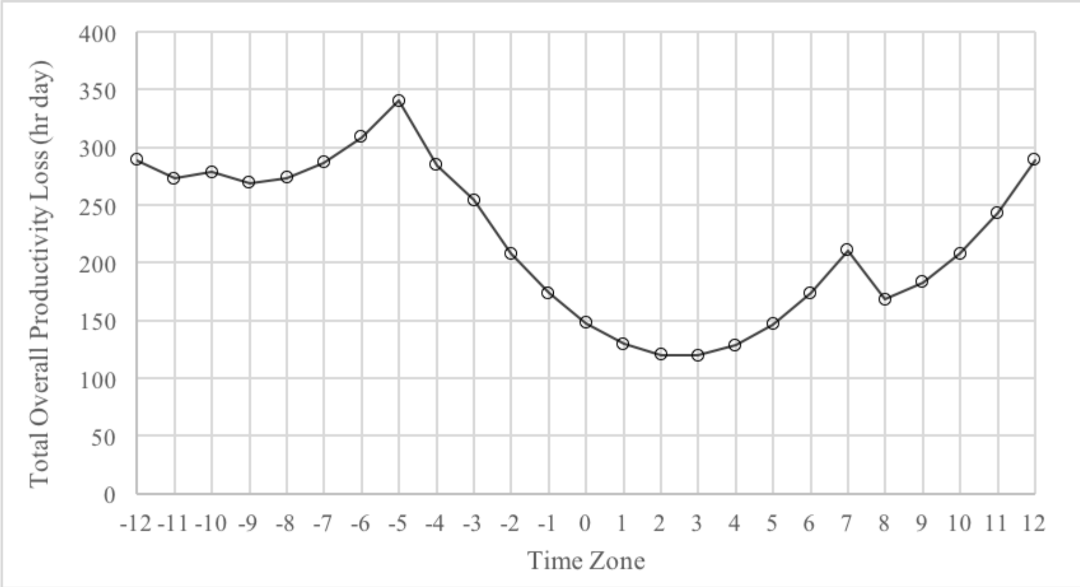


Figure 15: The graph of $L_{\text{total}}$ against timezone (Big meeting).

| Phantom City | | Degrees | latitude | -82.5 | -67.5 | -52.5 | -37.5 | -22.5 | -7.5 | 7.5 | 22.5 | 37.5 | 52.5 | 67.5 | 82.5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | longitude | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 |
| | | Radians | latitude | -1.4398966 | -1.1780972 | -0.9162979 | -0.6544985 | -0.3926991 | -0.1308997 | 0.1308997 | 0.3926991 | 0.6544985 | 0.9162979 | 1.1780972 | 1.4398966 |
| | | | longitude | 0.7853982 | 0.7853982 | 0.7853982 | 0.7853982 | 0.7853982 | 0.7853982 | 0.7853982 | 0.7853982 | 0.7853982 | 0.7853982 | 0.7853982 | 0.7853982 |
| | | Degrees | Radians | | | | | | | | | | | | |
| Boston | latitude | 42.35805556 | 0.739287534 | 15040.789 | 15378.908 | 15241.192 | 14665.547 | 13777.155 | 12697.592 | 11511.73 | 10275.738 | 9031.4387 | 7818.2749 | 6684.6127 | 5701.1823 |
| | longitude | -71.06027778 | -1.240235815 | | | | | | | | | | | | |
| Boston | latitude | 42.35805556 | 0.739287534 | 15040.789 | 15378.908 | 15241.192 | 14665.547 | 13777.155 | 12697.592 | 11511.73 | 10275.738 | 9031.4387 | 7818.2749 | 6684.6127 | 5701.1823 |
| | longitude | -71.06027778 | -1.240235815 | | | | | | | | | | | | |
| Singapore | latitude | 1.366666667 | 0.023852833 | 9727.4456 | 8879.4126 | 8090.7541 | 7411.1738 | 6895.0983 | 6595.3922 | 6549.1661 | 6762.6514 | 7208.2364 | 7836.6723 | 8592.933 | 9425.4222 |
| | longitude | 103.8 | 1.811651764 | | | | | | | | | | | | |
| Beijing | latitude | 39.92888889 | 0.696890578 | 14142.406 | 13338.403 | 12355.248 | 11268.038 | 10131.853 | 8991.082 | 7889.086 | 6877.7803 | 6027.2972 | 5430.5332 | 5185.6316 | 5344.5573 |
| | longitude | 116.3883333 | 2.031359628 | | | | | | | | | | | | |
| Hong Kong | latitude | 22.25 | 0.388335759 | 12166.636 | 11445.932 | 10645.817 | 9812.3003 | 8988.8809 | 8219.8587 | 7553.213 | 7040.805 | 6732.9238 | 6665.8997 | 6848.3827 | 7257.4704 |
| | longitude | 114.1666667 | 1.992584229 | | | | | | | | | | | | |
| Hong Kong | latitude | 22.25 | 0.388335759 | 12166.636 | 11445.932 | 10645.817 | 9812.3003 | 8988.8809 | 8219.8587 | 7553.213 | 7040.805 | 6732.9238 | 6665.8997 | 6848.3827 | 7257.4704 |
| | longitude | 114.1666667 | 1.992584229 | | | | | | | | | | | | |
| Moscow | latitude | 55.75222222 | 0.973059843 | 15378.778 | 13718.639 | 12056.169 | 10392.807 | 8729.2987 | 7066.2989 | 5404.8105 | 3747.2865 | 2103.5781 | 601.39557 | 1361.0548 | 2982.8299 |
| | longitude | 37.61555556 | 0.656515294 | | | | | | | | | | | | |
| Utrecht | latitude | 52.09287594 | 0.909192202 | 15135.294 | 13706.844 | 12211.069 | 10686.441 | 9154.1875 | 7631.6069 | 6141.0296 | 4724.4013 | 3482.6441 | 2678.61 | 2733.937 | 3609.1895 |
| | longitude | 5.10448 | 0.089089983 | | | | | | | | | | | | |
| Warsaw | latitude | 52.25 | 0.911934534 | 15045.796 | 13465.246 | 11860.924 | 10247.328 | 8632.6667 | 7024.5191 | 5434.6077 | 3890.1917 | 2482.2505 | 1621.9237 | 2131.92 | 3450.0155 |
| | longitude | 21 | 0.366519143 | | | | | | | | | | | | |
| Copenhagen | latitude | 55.66666667 | 0.971566617 | 15474.091 | 13955.015 | 12389.909 | 10805.794 | 9216.351 | 7632.1875 | 6066.9527 | 4547.5676 | 3147.4882 | 2123.4077 | 2120.5875 | 3141.7825 |
| | longitude | 12.58333333 | 0.219620598 | | | | | | | | | | | | |
| Melbourne | latitude | -37.81666667 | -0.660025345 | 5986.7112 | 6567.1582 | 7363.501 | 8300.253 | 9316.0829 | 10361.477 | 11391.911 | 12360.302 | 13209.753 | 13869.013 | 14258.261 | 14314.829 |
| | longitude | 144.9666667 | 2.530145639 | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| | | | | 16033.591 | 15150.844 | 14141.175 | 13037.428 | 11886.837 | 10735.121 | 9620.8194 | 8579.7594 | 7660.897 | 6994.2895 | 7029.5347 | 7550.4524 |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | minimum distance: | 6994.2895 |
| | | | | | | | | | | | | | | suggested latitude: | 52.5 |

Figure 16: The Excel setup for finding the best latitude (Big Meeting).

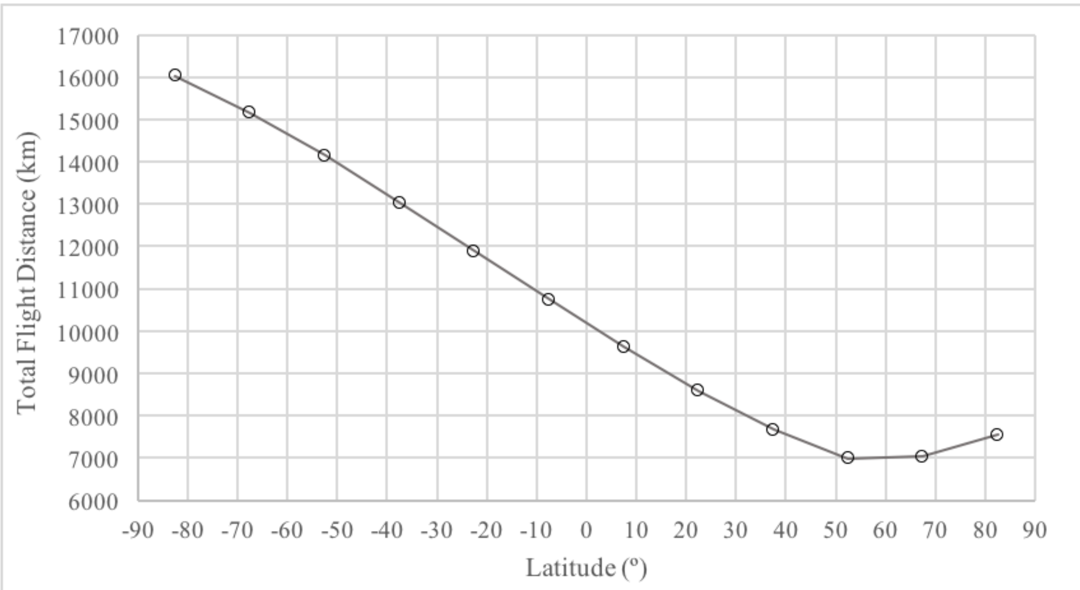


Figure 17: The graph of $d_{\text{total}}$ against latitude (Big Meeting).

Clearly, the latitude 52.5°N has the lowest $d_{\text{total}}$. This gives a search region of to $45 \leq \lambda \leq 60$ and $37.5 \leq \phi \leq 52.5$.

Here, we find 11 cities with airports. Noting that the meeting is in January, let us look at each one in turn.

1. *Atyrau* has an average minimum temperature of −13°C; it is disqualified.
2. *Astrakhan* has an average minimum temperature of −12°C; it is disqualified.
3. *Elista* has an average minimum temperature of −8°C; it is disqualified.
4. *Krasnodar* has an average minimum temperature of −2°C; it is disqualified.
5. *Rostov-On-Don* has an average minimum temperature of −5°C; it is disqualified.
6. *Donetsk* has an average minimum temperature of −7°C; it is disqualified.
7. *Uralsk* has an average minimum temperature of −14°C; it is disqualified.
8. *Voronezh* has an average minimum temperature of −11°C; it is disqualified.
9. *Samara* has an average minimum temperature of −15°C; it is disqualified.
10. *Kazan* has an average minimum temperture of −19°C; it is disqualified.
11. *Moscow* has an average minimum temperature of −9°C; it is disqualified.
12. *Nizhniy Novgorod* has an average minimum temperature of $-12\circ$C; it is disqualified.

Therefore, there are no valid cities in $45 \leq \lambda \leq 60$ and $37.5 \leq \phi \leq 52.5$. We move again to $30 \leq \lambda \leq 45$ and $37.5 \leq \phi \leq 52.5$. Here, we find 12 cities with airports. Let us look at their climates as well.

1. *Aktau* has an average minimum temperature of −2°C; it is disqualified.
2. *Ahvaz* has an average minimum temperature of 7.2°C; it is valid.
3. *Shahrekord* has an average minimum temperature of −8°C; it is disqualified.
4. *Esfahan* has an average minimum temperature of −2°C; it is disqualified.
5. *Tehran* has an average minimum temperature of −2°C; it is disqualified.
6. *Tabriz* has an average minimum temperature of −5.7°C; it is disqualified.
7. *Tbilisi* has an average minimum temperature of −1°C; it is disqualified.
8. *Batumi* has an average minimum temperature of 3°C; it is valid.
9. *Vladikavkaz* has an average minimum temperture of −6°C; it is disqualified.
10. *Nalchik* has an average minimum temperature of −7°C; it is disqualified.
11. *Sochi* has an average minimum temperature of 3.6°C; it is valid.
12. *Mineralnye Vody* has an average minimum temperature of −5.7°C; it is disqualified.

Therefore, the list of recommended cities can be generated:

| City | Latitude | Longitude |
|---|---|---|
| Ahvaz, Iran | 31°19'13"N | 48°40'09"E |
| Batumi, Georgia | 41°38'45"N | 41°38'30"E |
| Sochi, Russia | 43°35'07"N | 39°43'13"E |

Table 6: The list of recommended places for the 'Small Meeting'

# 6 Limitations

1. Flight delays

A study done by the Western Michigan University[3], divided flights into 11 distance groups, each 250 miles longer than the previous one. The delays encountered varied up to 2x the smallest one. After research, they found that the distance flown and the duration of delay has a positive relationship. That means the longer the flight, the longer the duration of delay.

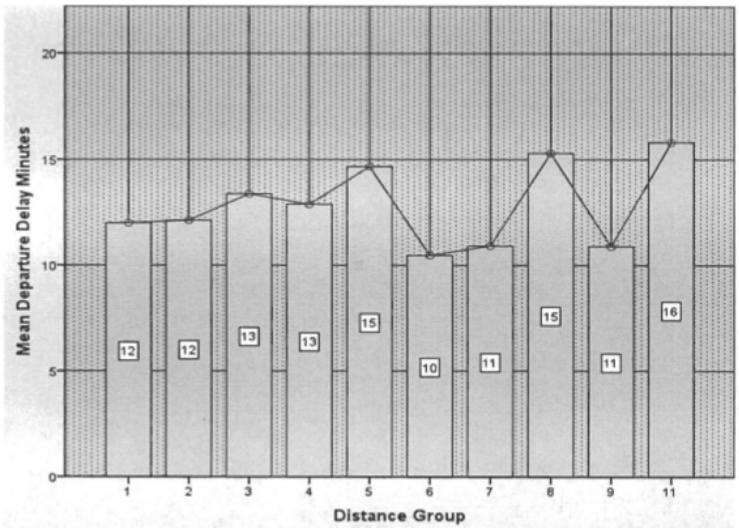


Figure 18: The relationship between delay time and flight length.

Since the meeting arrangement involves people from all corners of the world and the flight lengths are likely going to vary, the delays encountered will then also be large and varying. This means that the flight times may be heavily prolonged.

2. Neglection of climate and other factors

Jet lag was the main factor we considered with productivity. However, the influence of differences in climate, temperature and other factors can also be significant, and they were not accounted for apart from in the final filtering.

For example, for some participants, their home cities may still be in summer while the city we have chosen may be already in winter. That would result in an impact to productivity that we had not considered in our calculations. But admittedly, jet lag is still the major cause of almost all the biological/environmental stress exerted on our body, so the issues should not be too large.

3. Ticket prices and flight routes

So to make it simple, we just assumed the ticket price is directly proportional to the distance traveled. In order to minimize the cost of meeting, we chose the city for which the sum of the distances traveled by all the participants was the smallest.

However, in reality the price of the air tickets vary a lot. Time of purchase is one factor; The earlier it is bought, the cheaper it is. The airline chosen may also have a great impact on the price of the tickets. Taking transfer flights in another variable which we neglected; This would affect both the distance traveled and the cost.

4. Incomplete representation of timezones

Some time zones such as UTC+13 and those with fractional time offsets such as UTC+5.75 have not been considered, instead the 'regular' timezones absorbing them into their corresponding latitudes in fractions of 15°. UTC+13 was mapped to UTC-11, UTC+5.75 was UTC+6, etc.

Furthermore, timezones often wrap around country borders, and do not follow the lines of latitude. This was also neglected for convenience. As a result, some selected cities may not be actually in the timezones that were selected for.

Nevertheless, this is a reasonable concession, as the day/night cycle *does* follow the lines of latitude, and arguably even if the individuals sleep late/early relative to local clocks, can still synchronize to the day/night cycle. In addition, the clocks of UTC+13 *do* match those of UTC-11, making it logical to combine them. Therefore, productivity may not be truly be impacted. It was clear to us that the convenience of clean mapping to latitudes outweighed the possible inaccuracies caused.

# 7 Strengths

1. Flexibility

The whole model was built to stand alone without any given data, which means it can be applied to any case as long as the home cities of the participants are provided. In other words, this model is not limited to the two test cases only.

2. Minimalism

As said, the number of variables considered is small, and they are easy to access. By avoiding the use of other factors such as airline price differences, transfer flights and specific weather patterns, we have limited the amount of work necessary to obtain the necessary inputs.

This is important as for many smaller or less wealthy countries or airlines, information may not be as readily available. Complex algorithms may break down in these cases, and therefore the chance of issues as the number of participants increases will also rise. This also links to scalability.

3. Scalability

Productivity was maximized and cost minimized only by considering the total distance traveled by all the participants and the time zone differences. As all of this is quantitative and not qualitative data, all calculations can be left to the computer after the formulae for sort keys have been defined. Using a spreadsheet allows the same mathematical operations to be repeated across a large volume of data.

Furthermore, if fully automated, this algorithm runs in polynomial time. As a result, even for conventions with hundreds of people, the runtime will be minimal compared to more complex algorithms. This could be important for large companies that need to hold large events, but are unable to afford so much runtime.

# 8 Weaknesses

1. Inaccurate modeling of jet lag

For all models, imprecision must exist. The result we have got is a good one but not the best one. During the whole process of building this model, we have done a lot of research and collected data from different resources. Most majorly, our work on jet lag drew on previous studies regarding the impact of jet lag on athlete's performance.

However, mental work may not necessarily follow the same trends as physical performance. So, our simulations of the influence of jet lag may not be an accurate reflection of the true impact. Without actual scientific studies, our approximations will have to remain approximations.

2. Ocean areas

As the first two stages of selection do not involve specific cities, it is possible that with certain setups the final region will end up in the middle of an ocean. This is likely to occur if the cities involved are on opposite sides of an ocean: for example, cities on the East Coast of the USA and in Europe would give a final region somewhere in the Atlantic Ocean.

In that case, you would have to backtrack, and it might take a long time to locate a region with acceptable cities. This would waste computation time and introduce inefficiencies compared to an algorithm that started from a list of cities.

# 9 Conclusion

After preliminary literature review, data collection and some shallow research, we approached this question by building an algorithm involving two steps of filtering. We took into account the amount of jet lag and the distances traveled, corresponding to losses in productivity and the cost of the tickets respectively. These variables were used to determine the approximate longitude and latitude of the solution region, from which we selected cities that matched our criteria to produce the final list.

The algorithm was tested on two test cases.

The first test case, where there were individuals coming from Monterey, Zutphen, Hong Kong, Shanghai, Melbourne and Moscow, resulted in a recommendation list of one:

1. Xi'an
2. Cheng Du
3. Nanchong
4. Lanzhou
5. Xining

The second case, involving two people from Hong Kong, two from Boston, and one from each of Copenhagen, Utrecht, Moscow, Warsaw, Singapore, Beijing and Melbourne, resulted in a recommendation list of three:

1. Ahvaz, Iran
2. Batumi, Georgia
3. Sochi, Russia.

This model is of use to any international meeting organizer. The algorithm is quantitative, logical and requires minimal amounts of input. By processing the basic information of the home cities, it can quickly output a list of recommended cities.

There are some flaws to this model, such as the neglection of some minor productivity-impacting variables and the simplification of timezone divisions. However, they are compensated for the high efficiency, simplicity and flexibility of the model which makes it adaptable to a large number of cases, even with more obscure home cities or with very large numbers of participants.

# References

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