

Summary Sheet

Team Control Number 2017057

Anyone that has flown across timezones for business meetings, conferences, or vacations knows that many days of this extended visit are dedicated to simply recovering from fatigue and jet lag caused by traveling over multiple time zones. Companies that organize international events, such as the International Meeting Management Corporation (IMMC), are faced with the issue of sub-optimal productivity from their participants due to the fatigue associated with jet lag. In this paper, we aim to define the relationship between jet lag and productivity as well as find the best location to hold an international event with participants from all across the globe.

The first part of our model deals with quantifying the amount of productive hours that the participants lose traveling across multiple time zones. We used the fact that human circadian rhythms are sinusoidal to predict the degree by which a conference member was disjoint from the real time at the location of the conference, thus calculating the amount of hours in a day that they would be productive.

Next, we developed a productivity metric κ that takes into account the number of productive hours an individual can contribute given by the first part of the model, the fatigue caused by distance traveled calculated using the Vincenty formula, and the root mean square of the individual distances traveled. The productivity metric is calculated using a root mean square function of the individual productive hours. In addition, we created a cost metric M that combined together the costs of lodging and air-travel using empirical data.

Using these metrics, we created a Python script that derived data from the GeoPy and PyTZ libraries in addition to the TimezoneDB database to implement our algorithm using real-time data. For 282 predetermined locations around the world, we calculated the ratio between our two metrics ($\frac{M}{\kappa}$) and ranked the locations from least to greatest ratio. **We found that for the small conference in mid-June, IMMC should host a conference in Irkutsk, Russia. In the case of the larger conference in January, IMMC should host it in Samara, Russia.** In addition, we investigated the case that IMMC may not have data on the location of the members attending the conference, we used ran our algorithm and 1000 times with 10 participants from randomly chosen locations. The sampling was weighted by Gross Domestic Product so as to simulate the distribution of conference members from each country. **We found that when the location of members in a conference is not known, Dublin, Ireland is the ideal location to hold a conference.**

Though our model does not account for effects of climate on productivity or variable lodging costs and flight availabilities, it is robust against changes to the various parameters that control the metrics, thus making it an effective in pinpointing the optimal location to hold such international conferences.

Introduction

Every day, millions of airline passengers are affected by the phenomenon of jet lag, a common sleeping disorder caused by traveling through multiple time zones. The International Meeting Management Corporation (IMMC) is sponsoring a three-day long event with participants from all across the globe and wants to ensure that the participants are well-rested at the start of the event. In this study, we aim to model the presence of jet lag as well as its effect on the productivity of international participants doing intense intellectual work.

Originally thought to be an issue of the conscious state of mind, jet lag is now considered to be a biological disruption of our “internal clock”, otherwise known as the circadian rhythm [1]. Previous attempts at modeling jet lag include using differential equations to describe the oscillatory change of the circadian rhythm and using experimental data from biological studies to determine the values of constants [2]. In addition to addressing these characteristics, our work directly parametrizes the effect of jet lag on productivity, and thus can be applied more realistically to organize and schedule global conferences.

To determine the optimal location for an international event, we developed a reproducible algorithm suitable to the needs of IMMC. In addition, we have conducted test cases to assess the viability and sensitivity of our model. In the case that the locations of members attending a conference are unknown, we have also used the algorithm to identify an ideal location to hold the global conference.

Restatement of Problem

The International Meeting Management Corporation requests us to develop an algorithm to find the best location for an international event that will last three days and test the effectiveness of our algorithm with the following scenarios:

Scenario 1 - Small Meeting in mid-June

- Six individual participants from: Monterey CA, USA; Zutphen, Netherlands; Melbourne, Australia; Shanghai, China; Hong Kong (SAR), China; Moscow, Russia.

Scenario 2 - Big Meeting in January

- Eleven individual participants from: Boston MA, USA (2 people); Singapore; Beijing, China; Hong Kong (SAR), China (2 people); Moscow, Russia; Utrecht, Netherlands; Warsaw, Poland; Copenhagen, Denmark; Melbourne, Australia.

In essence, this problem requires us to do 4 tasks:

1. Calculate the amount of jet lag a participant experiences travelling to the destination of the event.
2. Quantify the effects that jet lag has on productivity for each participant.
3. Find the airfare and lodging cost associated with the travel.
4. Considering the above factors, determine the optimal location to hold the event.

General Assumptions

- Seasonal variations in productivity and seasonal changes to airfares are difficult to quantify.
 - The effect of seasonal variance on productivity, such as fatigue caused by cultural or socioeconomic factors, is hard to quantify. Seasonal trends in airfare is a socioeconomic variable that is dependent on the cultural variance around the world.
- Conference members will be most productive in a climate that mirrors their climate of origin.
 - It is difficult to characterize the effects of climate, weather, and geography on productivity. Therefore, we postulated that conference members would be most productive and comfortable in a climate similar to their climate of origin. Our model is designed to average the latitudes of the conference members because the productivity metric is dependent on distance.
- Business travellers do not prepare to correct jet lag and follow their internal circadian clock until arrival.
 - Remedies to combat jet lag, such as sleeping at certain times or not sleeping at all, are difficult to parametrize. Instead, we assume that travellers sleep according to their circadian rhythms until they arrive at their destination.
- Participants only work when they are together, i.e. there is no individual work involved.
 - We assume that the purpose of this international conference is to have a diverse group of intellectuals to work collectively on an issue. Thus, we assume that they can only work when every participant is present at the event.
- There are flights available to fly to any given location at the times we specify.
 - Our model does not consider the availability of flights in different locations. To schedule the conference, we try to maximize the amount of communal productive time for each conference member, which requires scheduling flights at exact times for each member.

General Definitions

Circadian Rhythm: The circadian rhythm is a cyclic biological process that allows organisms to perform daily processes without external day-night cues. The circadian rhythm for a human, on average, is 24.5 hours.

External Clock: The external clock, ξ_e is the time at the given location given by physical time-keeping devices.

Internal Clock: The internal clock, ξ_i , is the internal state of any given member at the conference. That is, ξ_i describes what each member believes the time is, according to the circadian rhythm and level of fatigue. For instance, for a member that travels to a timezone 5 hours eastwards, $\xi_i = 12:00\text{PM}$ when the time is 5:00PM in the new time zone.

Jet Lag: Jet lag occurs when the internal clock and external clock are incongruous. The amount of jet lag is defined and calculated as the difference between the initial and final time zones of travel. That is, $\Delta J = Z_i - Z_f$.

Productivity (κ): A measure of the restfulness of the participant. This value decreases as jet lag increases.

UTC Offset: The amount of hours (forward or backward) from Greenwich Mean Time (Universal Time).

Model Design and Justification

Calculating Jet Lag

Since IMMC wants to organize an international event that consists of intense work over a course of three days, it is imperative that the penalty of jet lag is minimized for each participant.

This part of the model serves to find the amount of jet lag a participant will experience as he or she travels through different time zones. The objectives of this part of the model are to quantify the amount of productive hours lost for the participants as a function of jet lag and, secondly, to investigate the implications of jet lag on productivity.

Specific Assumptions

- Business hours occur between 8:00 AM and 6:00 PM in the location's timezone. Buildings are closed between midnight and 8:00AM.
 - Business hours typically follow a 9-5 schedule, and as this conference is an intensive work session, it is safe to assume that proceedings may extend 1 hour in either direction. In addition, nighttime for most locations is between midnight and 8AM, so it is safe to assume that most buildings are closed during this time.
- We assume that the circadian rhythms of all participants are oscillatory with an average period of 24.5 hours.
 - Antonsen *et al* discovered that the neurons responsible for managing the circadian rhythm behave in an oscillatory fashion. In addition they found that without any light cues, the normal human circadian rhythm is around 24.5 hours. This is why the jet lag experienced by travelling eastwards is often worse than traveling a commensurate distance westwards [\[2\]](#).

Specific Definitions

Productive Hours: The hours between 8AM and 6PM in which the participants are able to do intensive work.

S : The amount of productive hours lost due to jet lag.

Quantifying the Loss of Productive Hours

We assume that the participants will work during the business hours of 8AM to 6PM. Ideally, every participant will arrive to the event with their internal clocks in sync with the external clocks. However, jet lag imposes a phase shift in the circadian rhythm, and thus there is an inevitable loss of productive hours since the participants will not “feel” like their productive hours vary from those of their location. To quantify the exact loss in productive hours, S , we have to consider the effects of jet lag.

In regards to constructing the function $S(\Delta J)$, we know that the function must be sinusoidal, since the oscillatory behavior of the participants' circadian rhythms causes a periodic fall and rise in the perception of productive hours lost. Initial jet lag should cause a small loss in productive hours, while a ΔJ of 10 and ΔJ of 11 should cause a large loss in productive hours but not have a noticeable difference between them. Additionally the function will be bounded by $S = 0$ (since there can never be a negative amount of hours) and $S = 12$ which represents a complete reversal in the perception of night and day. Thus far, we have the following components:

$$S = 6 - 6 \cos(\omega \Delta J - \phi)$$

Finally, we know that S should repeat every day ($\frac{2\pi}{\omega} = 24$ hours) and that the phase shift ϕ should be 0.5 hours. This has been found to be a result of the circadian cycles of humans being equal to 24.5 hours instead of the expected 24 hours. Thus when a person experiences a day of 24 hours, that person is $24.5 - 24$ hours off their circadian cycle. Including all of these elements, we can predict the amount of productive hours lost as a function of jet lag.

$$S = 6 - 6 \cos\left(\frac{\pi \Delta J_m}{12} - \frac{\pi}{24}\right)$$

Implications on Productivity

Because a typical working environment is typically closed for 8 hours during the night, we have a total of 16 hours that the participants are awake. During those active hours, we can represent the additional time an individual is unable to work during the day as S . Thus, the remaining $16 - S$ hours are available for the individual to use towards the group effort up to a maximum of 10 hours which is the length of our business day. The figure below summarizes the typical breakdown of the participants' day.



Figure 1: Jet lag causes a shift S of 4 hours

In the example above, the participant loses 4 productive hours due to jet lag ($S = 4$), and therefore is still able to find 10 hours in the day to do productive work, with an excess of 2 hours for non-work related activities. However the worst case would be a 12 loss of productive hours due to jet lag (when the internal and external clocks are 180° out of phase), and the participant will only be able to work 4 hours as a result. Therefore, the amount of productive hours of an individual—the quantity we seek to maximize—is $\min(10, 16 - S)$.