HB-165_JaimeKDevine_UNF

02/15/2023

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**<u>TESTIMONY ON HB-165 - UNFAVORABLE</u>**
**General Provisions - Standard Time - Year-Round Daylight Savings Time**

**TO**: Chair Pena-Melnyk, Vice Chair Kelly, and members of the Health and Government Operations Committee
**FROM**: Jaime Knudsen Devine, PhD

My name is Jaime Devine. I am a resident of Silver Spring, Maryland Congressional District 8. I work in Baltimore City, Maryland Congressional District 7. I am an operational fatigue scientist with a doctorate in Neuroscience from Brandeis University and a Certificate of Sleep Medicine from Harvard Medical School. I am submitting this testimony **<u>against</u>** HB-165, Year-Round Daylight Savings Time.

The scientific community in general opposes permanent daylight savings time. Sleep experts agree that standard time (which shifts daylight hours earlier in the morning) aligns best with human circadian biology while permanent daylight savings time will result in dark mornings for the majority of the year. Proponents of permanent daylight savings time posit that more sunlight in the afternoons will reduce traffic accidents since darkness is a risk factor for crashes.

I personally conducted a computer simulation to examine the impact of permanent daylight savings time on available sunlight and operator alertness during rush hours using the biomathematical modeling software SAFTE-FAST. The analysis clearly shows that permanent daylight savings time does not result in more sunlight during evening commutes. In fact, permanent daylight savings time results in significantly less sunlight available during morning commutes. Additionally, the results indicate that there is greater traffic congestion in the morning due to children commuting to school. Darkness during morning commutes may increase the risk of traffic accidents that involve children or student drivers.

I have attached the full scientific article from this biomathematical prediction of risk related to permanent daylight savings time for the committee's review. The scientific evidence overwhelmingly opposes permanent daylight savings time. There is no strong evidence that permanent daylight savings time helps the economy, reduces energy expenditure, increases physical activity, or improves the safety of our roads. **I respectfully urge the Health and Government Operations Committee to return an unfavorable report on bill HB-165.**

Very Respectfully,

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# Predicting the Effects of Permanent Daylight Savings Time on Light Exposure and Risk Using a Biomathematical Model of Fatigue

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# Abstract

Permanent Daylight Savings Time (DST) may improve road safety by providing more daylight in the evening when crash risks are higher. However, dark mornings could merely shift risk from evening to morning commutes or increase risk due to fatigue and circadian misalignment. In order to identify how light exposure and fatigue risk could differ between permanent DST versus permanent Standard Time (ST) or current time arrangements (CTA), the biomathematical modeling software Sleep , Activity, Fatigue, and Task Effectiveness Fatigue Avoidance Scheduling Tool (SAFTE-FAST) was used to generate predictions of sleep, activity, and Effectiveness across three shift work schedules (morning, evening, night) during autumn, winter, spring, and summer months as well as school schedules in autumn, winter, and spring in five United States cities with different latitudes and time zones for total waking day, work day, sleep periods, and commute times. Percent darkness was greater under permanent DST conditions compared to ST during the total waking day ($t=2.59$, $p=0.03$) and sleep periods ($t=2.46$, $p=0.045$). Waketimes occurred before sunrise a greater percent of the time for modeled schedules under DST (63%±41%) compared to CTA (42%±37%) or permanent ST (33%±38%; $F_{(2, 74)}=76.37$; $p<0.001$). Waketimes would need to occur, on average, 15 minutes before sunrise in preparation for work or school start times under permanent DST, 19 minutes after sunrise under CTA, and 44 minutes after sunrise under permanent ST. Commute data were further categorized by time to provide estimates of Effectiveness and light during morning (0700-0900) and evening (1600-1800) rush hours. Average Effectiveness scores were nominally different for morning rush hour (CTA: 87.89±14.37, DST: 88.05±14.15; ST: 88.07±14.16; $F_{(2, 54)}= 3.14$; $p=0.05$) and not significantly different for evening rush hour (CTA: 97.48±0.92; DST: 97.50±0.90; ST: 97.49±0.91; $F_{(2, 39)}= 0.54$, $p=0.58$). Percent darkness was greater during morning rush hour (16%±31%) and lower in evening rush hour (0%±0%) in DST compare to either CTA (morning: 7%±23%; evening: 7%±14%) or ST (morning: 7%±23%; evening: 7%±15%; all $p<0.001$). When taking into account commute times for shift work schedules, average Effectiveness was lower during morning rush hour compared to evening rush hour. Morning rush hour also overlapped with students' morning commutes, which may increase traffic congestion and risk compared to evening rush hour, which occurs after students are already home. Switching to permanent DST may be more disruptive than either switching to permanent ST or keeping CTA without any noticeable benefit to fatigue risk or overall increase in light exposure.

Keywords: daylight savings time, road lighting conditions, light exposure, fatigue risk, scheduling, biomathematical modeling

## 1. Introduction

Daylight Saving Time (DST) is a period of the year between March and November when clocks in most parts of the United States are set one hour ahead of Standard Time (ST), leading to more sunlight during evening hours. The United States first established DST in 1918 and federal regulations regarding DST have been unchanged since 1966 (Clark 2020). In recent years, however, 29 states have introduced legislation to abolish the twice-yearly changing of clocks, and in March 2022, the United States Senate passed legislation, called the Sunshine Protection Act, to make DST permanent starting in 2023 (Congress 2022).

Proponents of permanent DST argue that more daylight in the evenings would increase physical and economic activity, reduce energy costs, and improve road safety. Opponents of permanent DST argue that shifting the clock permanently forward may result in circadian misalignment and negative health effects as individuals will be forced to start their days before dawn during the winter months (Roenneberg *et al.* 2019a, Roenneberg *et al.* 2019b, Rishi *et al.* 2020). The body of research looking into the potential effects of DST on the economy, exercise, or energy costs have produced mixed results (Filliben *et al.* 1976, Kamstra *et al.* 2000, Belzer *et al.* 2008, Calandrillo and Buehler 2008, Hill *et al.* 2010, Rosenberg and Wood 2010, Kotchen and Grant 2011, Goodman *et al.* 2014, Zick 2014). While some findings indicate a benefit of permanent DST in these areas, other studies suggest little or even a detrimental effect. Road safety is another area of contention within the debate surrounding permanent DST. Abolishing the twice-yearly transition between standard time and DST has been recommended for improving safety through a reduction of motor vehicle accidents (Fritz *et al.* 2020). Some studies argue that permanent DST would have beneficial effects on road safety by shifting more daylight to the evening hours, when crash risk is highest (Bünnings and Schiele 2021). Darkness is a major contributor to motor vehicle accident risk during evening rush hours (Herd *et al.* 1980, Carey and Sarma 2017, Laliotis *et al.* 2019, Fritz *et al.* 2020, Bünnings and Schiele 2021). However, shifting light to the evening hours comes at the cost of light during early morning commutes (Carey and Sarma 2017).

A lack of natural sunlight in the morning could not only increase the risk of vehicular accidents during these times, but could result in circadian misalignment as individuals are forced to start their day prior to sunrise (Roenneberg *et al.* 2019a, Roenneberg *et al.* 2019b, Rishi *et al.* 2020). Circadian misalignment is associated with increased cardiovascular disease risk, metabolic syndrome, and other health risks (Rishi *et al.* 2020). Light is the body's strongest *zeitgieber*, or environmental cue about time. Natural daylight is usually 100 to 1000 times brighter than artificial light and a lack of exposure to natural sunlight, even with the use of electrical lighting, has been shown to alter circadian physiology and sleep behavior (Wright Jr *et al.* 2013). Time of awakening is additionally correlated with sunrise and tends to be later in the winter (Hashizaki *et al.* 2018). Establishing year-round DST could therefore result in population-level sleep disruption and fatigue, particularly during winter months (Harrison 2013, Hashizaki *et al.* 2018, Roenneberg *et al.* 2019b, Rishi *et al.* 2020).

Increased fatigue due to waking before sunrise is important for not only for health reasons, but also for road safety. Importantly, if drivers are fatigued, the benefit of better lighting conditions may not translate to a reduction in crash risk. This impact could be especially deleterious for school children.

Research shows that delaying school start times benefits students' sleep and daytime function, as well as reducing adolescent motor vehicle crash risk (Collins *et al.* 2017, Bin-Hasan *et al.* 2020, Meltzer *et al.* 2021, Meltzer *et al.* 2022, Ziporyn *et al.* 2022). If DST becomes permanent, the benefit of legislature to delay school start times could essentially be nullified.

Many of the arguments for or against permanent DST hinge on the assumption that individuals' work or school activities start between the hours of 0700 and 0900. These types of schedules would be affected by a one-hour shift in the timing of sunrise. In fact, both proponents of permanent DST and proponents of permanent standard time argue that darkness either in the mornings or the evenings, respectively, could be avoided by adjusting schedules to avoid activities during these times (Carey and Sarma 2017, Roenneberg *et al.* 2019a). However, the 16% of the United States population who currently follow shift work schedules (Statistics 2019) would also be affected by changes to sunrise and sunset. Shift workers are at an increased risk of fatigue and sleep problems that may affect their safety and ability to perform (Åkerstedt and Wright 2009, Lerman *et al.* 2012). While it is known that both DST and shiftwork impact the health and safety of workers (Kantermann 2008), the direct impact of time change arrangements on shift workers has not been thoroughly investigated.

A biomathematical model could effectively predict the impact of permanent DST or permanent ST on fatigue risk and light exposure across seasons, time zones, and activity schedules compared against current time arrangements (CTA). The Sleep, Activity, Fatigue, and Task Effectiveness Fatigue Avoidance Scheduling Tool (SAFTE-FAST) is a two-step, three-process model that estimates sleep patterns around work duties using a function called AutoSleep and then provides a continuous prediction of Effectiveness as a function of performance on the Psychomotor Vigilance Task (PVT) (Hursh, Hursh *et al.* 2004). Effectiveness is expressed as a percentage scaled to a fully rested person's normal best performance on the PVT (e.g. 100%). The higher the score, the lower the fatigue risk. The ability of AutoSleep to predict average sleep behavior (i.e., sleep timing and duration) has been successfully evaluated in shift-working operational populations (Gertler *et al.* 2012, Roma *et al.* 2012, Schwartz *et al.* 2021, Devine *et al.* 2022). SAFTE-FAST solutions are used in transportation and shiftwork environments as part of a fatigue risk management system (FRMS). SAFTE-FAST has previously been used to evaluate accident risk in railroad engineers (Hursh 2011). Regulators for the Federal Rail Administration (FRA) consider Effectiveness scores at or below 70 to constitute an area of high fatigue risk (Register 2011).

SAFTE-FAST also has the capability to model a buffer around work events to indicate time during which individuals would reasonably be expected to be commuting to or from a work location. SAFTE-FAST also contains a NASA-provided algorithm for determining the available sunlight for any location on the globe for any date and time. SAFTE-FAST can use this light information to indicate the degree of concordance between the sleep-wake pattern and the rising and setting of the sun and, by implication, determine the phase shift effects associated with the onset and offset of DST time changes, or to extrapolate information about light exposure during sleep, commute times, working hours, and across the entire day. While this information is not a standard output in the software, the software parameters were adapted to allow extraction of light data in addition to predicted performances for the analyses described herein.

If enacted, the Sunshine Protection Act would result in permanent DST in most states beginning in November 2023 (Congress 2022). Alternatively, the bill could be amended to enact permanent ST, or overruled entirely, allowing the twice-yearly clock changes to continue. Time change arrangements in the United States may have different effects depending on time zone, seasonality, or working arrangements. This analysis utilizes the biomathematical modeling software SAFTE-FAST to predict sleep timing, sleep duration, task effectiveness, and light exposure in permanent DST conditions compared against permanent ST or CTA between day, evening, and night shift work schedules as well as school schedules and daily commutes in five major United States cities during autumn, winter, spring, and summer conditions for year 2023-2024. The goal of this analysis is to provide objective, computational data on the impact of time change arrangements in 2023 and beyond for the benefit of transportation safety officials, policy makers, and circadian researchers.

# 2. Material and methods

## 2.1 City Selection Criteria

### 2.1.1 Location and Observation of DST

SAFTE-FAST predicts sunrise and sunset as a function of location and date. Locations were selected based on their ability to model the range of effects that time change arrangements may have on light and risk across regions that would be affected by the Sunshine Protection Act (Congress 2022), i.e., states within the United States (U.S.) that currently use temporary DST rather than permanent ST. U.S. states Arizona and Hawaii, and the U.S. territories of American Samoa, Guam, the Northern Mariana Islands, Puerto Rico, and the Virgin Islands observe permanent ST and were not eligible for inclusion (NCSL 2022).

Calculating sunrise and sunset for any given day and year requires latitude and longitude in degrees as input (Woolf 1968, Brock 1981, Forsythe *et al.* 1995). Day length is fairly consistent across the seasons in latitudes close to the Equator (~0°-23°), and vary to an extreme degree in the Artic circle (~66°-90°). In order to select locations that would experience seasonal variation, locations needed to be between 23°N and 66°N, as well as at least 2° different from the other selected locations.

There are five time zones within the U.S. that observe DST—Eastern Time, Central Time, Mountain Time, Pacific Time, and Alaska Time (Roenneberg *et al.* 2019a, NIST 2022). While time zones are not strictly determined by longitude, the U.S. time zones are defined in the Uniform Time Act roughly by degree of longitude west from Greenwich (UTA 1966) (see Figure 1). In order to model a range of locations with different sunrise times, each location needed to be in a different U.S. time zone and thus, have a different longitude relative to the other selected locations.

#### 2.1.2 Population and Traffic Congestion

Since a goal of this computational analysis was to evaluate risk in relation to road safety, selection criteria included risk due to traffic based on highway fatality rates and population size. Inclusion criteria for cities required a highway fatality rate for the county that was greater than 1.0 per 100,000 inhabitants as reported by the National Highway Traffic Safety Administration's (NHTSA) State Traffic Safety Information (STSI) report (NHTSA 2020). Locations furthermore needed to meet the U.S. Census Bureau criteria for metropolitan statistical area by having at least one urbanized area of 50,000 or more inhabitants (Management and Budget 2010). The largest metropolitan statistical area in a given time zone that met all inclusion criteria was selected for subsequent analysis. The five selected city locations were: 1) New York City, New York; 2) Chicago, Illinois; 3) El Paso, Texas; 4) Los Angeles, California; and 5) Anchorage, Alaska.

### 2.2 Selection of Time Periods

Four 30-day time periods were selected for modeling based on seasonal variation in day length based on solstices and DST changeover. Dates were selected to represent time periods after the potential enactment of the Sunshine Protection Act (Congress 2022) in November 2023. The winter solstice is scheduled to occur on December 21, 2023 and the summer solstice is scheduled to occur on June 20, 2024. DST ends on the first Sunday in November and starts on the second Sunday in March (UTA 1966, Congress 2022). This corresponds to November $5^{th}$, 2023 and March $10^{th}$, 2024. Autumn schedules were generated for November 1-30, 2023; winter schedules were generated from December 15, 2023 to Jan 15, 2024; spring schedules were generated for March 1-31, 2024 and summer schedules were generated for June 15-July 15, 2024.

## 2.3 Generation of Work Schedule Data

Three work schedules were selected for modeling on the basis of start and end times relative to sunrise and sunset under different time change arrangements—a typical day shift (0900-1700), an evening shift beginning around sunset (1700-0100), and an overnight shift ending around sunrise (2300-0700). Each schedule included a 40-hour work week with 8-hour shifts occurring during weekdays. An exception was that overnight shifts began at 2300 on Sundays in order to end on Monday mornings. A month's worth of schedules for each shift was generated as described above in section 2.3 in order to produce a monthly average prediction of Effectiveness and light exposure.

## 2.4 Generation of School Schedule Data

School schedules for each location were based on average start times and hours of school per day by state using data from the U.S. Department of Education, National Center for Education Statistics, Schools and Staffing Survey (SASS) (Wheaton, Anon 2008). A generic school schedule was generated for each selected location for autumn, winter, and spring as described in Section 2.3. Summer schedules were not modeled since most schools are out of session during this time. For the purposes of this model, school was assumed to be out of session for Thanksgiving break (November 23-24, 2023), winter break (December 25, 2023-January 1, 2024), and spring break (March 25-29, 2024).

## 2.5 Modeling Time Change Arrangements in SAFTE-FAST

A modified version of SAFTE-FAST software (Version 5.8.028) that reports light exposure by event was used to model work and school schedules by season, city, and time change condition. A separate SAFTE-FAST project file was created for each time change condition (CTA, Permanent DST, and Permanent ST). Identical work and school schedule data were uploaded into each scenario. The only difference between scenarios were time change conditions. AutoSleep is the sleep estimator in SAFTE-FAST that uses information about work events, time of day, and prior sleep to predict average sleep decisions under operational constraints. AutoSleep predicted sleep episodes around school or work events using default settings. No sleep was assumed to occur during work hours for these analyses, and no napping was assumed to occur. A 60-minute commute time buffer was assumed for the hour before work/school start and the hour after the conclusion of work/school. Events were categorized as sleep, wake, work, or commute using the SAFTE-FAST Activity and Description output columns. Event timing, average and minimum Effectiveness, and light exposure (measured as minutes of daylight, minutes of twilight, and minutes of darkness) were exported to .csv files.

## 2.6 Statistical Analysis

SAFTE-FAST csv files were compiled in Excel 2013. Average and minimum Effectiveness scores were averaged across all days within each season (autumn, winter, spring, summer) to create a seasonal mean prediction of Effectiveness for each schedule and condition. Average AutoSleep duration and waketime provided predicted values of expected sleep duration and morning waketime for each schedule. AutoSleep predicts split sleep schedules for evening and night workers; the first waketime occurring during any modeled day served as the expected morning waketime in these subgroups.

Light exposure was estimated as percent of darkness (minutes of darkness/total minutes of event * 100) for sleep, work, commute, and overall wake events. For the purposes of these analyses, minutes of twilight and minutes of daylight were aggregated to reflect time periods with any amount of ambient light exposure. Prediction of sunrise and sunset times for 2023-2024 were extracted from the sunearthtools.com Sunrise Sunset Calculator (SunEarthTools.com). Distance between AutoSleep expected morning waketimes and sunrise, in minutes, were computed for each modeled day by subtracting sunrise from waketime, and averaged across all days by season for each schedule and condition. Positive values indicate waketimes occurring after sunrise, while negative values indicate wake times occurring before sunrise. AutoSleep events were assigned a binary distinction to indicate waketimes occurring before sunrise (1) versus waketimes occurring after sunrise (0). The percentage of waketimes occurring before sunrise for each condition was computed as the total number of waketimes occurring before sunrise over the total number of waketimes for all major sleeps by season for each schedule and condition.

Schedules were identified by numeric codes containing information about location (New York City, Chicago, El Paso, Los Angeles, or Anchorage), shift type (day, evening, night, or school) and season (autumn, winter, spring, summer). Repeated measures analysis of variance (ANOVA) was used to compare differences between time change conditions (CTA, Permanent DST, and Permanent ST) for sunrise time, waketime, and expected sleep duration controlling for schedule specifics (location, shift, and season). Repeated measures ANOVA was further used to compared differences between time change conditions for average and minimum Effectiveness and percent darkness for the total waking day, commute-to-work, work day, and commute-home.

Commute times differed by schedule, and so, did not reflect Effectiveness during rush hours for all schedules. To estimate the risk associated with morning and evening rush hours, Effectiveness and percent darkness during commute times were additionally categorized by time of commute. Morning rush hour was defined as any commute times occurring between 0700-0900 and evening rush hour was defined as any commute times occurring between 1600-1800. Morning rush hour Effectiveness and percent darkness thereby corresponded to commute-to-work values for day and school schedules, and commute-home values for night schedules. Evening rush hour Effectiveness and percent darkness corresponded to commute-home values for day schedules and commute-to-work values for evening schedules. Differences in average and minimum Effectiveness and percent darkness for morning and evening rush hours were compared using repeated measures ANOVA, controlling for schedule. Time change condition were treated as a repeated measure for all evaluated variables. All statistical analyses were performed in Stata MP 15.

# 3. Results

## 3.1 Schedule Descriptive Statistics

Figure 1 depicts the selected locations by time zone, population, traffic fatality rate and average school start time. Three separate time change condition scenarios were constructed in SAFTE-FAST to model four different work schedules across five cities during four seasons for work schedules or three seasons for school schedules for a total of 75 schedules per scenario and 225 total schedules. Time change conditions (CTA, permanent DST, and permanent ST) were the only differences between SAFTE-FAST scenarios. Shift start time, shift end time, expected morning waketime, and expected sleep duration did not differ between scenarios (all $p>0.2$) and are summarized in Table 1. School start times varied by state as depicted in Figure 1.

Figure 1.

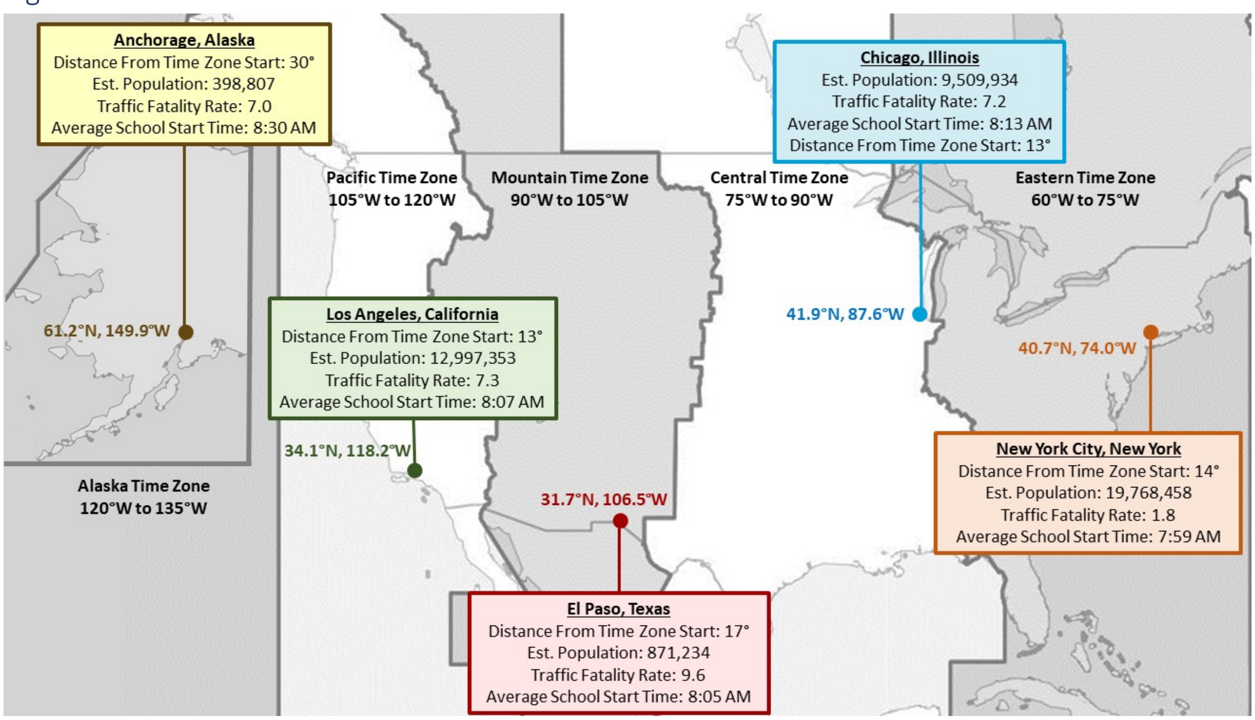



*Figure 1. City Locations Selected for Modeling. Map of the five metropolitan statistical areas selected for modeling based on time zone by longitude range (in black), with city and state names, latitude, longitude, distance of the city in degrees west from the start of the time zone, estimated population, and traffic fatality rates (listed in box). Average school start time for each selected city's state is additionally listed in box.*

Table 1. Waketimes and Sleep Duration by Schedule

| Shift Type | Shift Start Time | Shift End Time | Expected Morning Waketime | Average Expected Sleep Duration per 24 hours (in mins) |
|---|---|---|---|---|
| Day | 09:00 | 17:00 | 07:16±00:04 | 482±45 |
| Evening | 17:00 | 01:00 | 07:25±00:04 | 363±60 |
| Night | 23:00 | 07:00 | 07:53±00:06 | 338±43 |
| School | 08:10±00:17 | 14:45±00:27 | 07:14±00:04 | 460±67 |

## 3.2 Time Change Arrangements and Exposure to Daylight

Figure 2 depicts differences in hours of daylight by season, shift, and city location between time change conditions. There were expected main effects of city location, shift type, and season on exposure to daylight; these results are included in Supplementary Data Table 1.

Figure 2A) New York City, New York

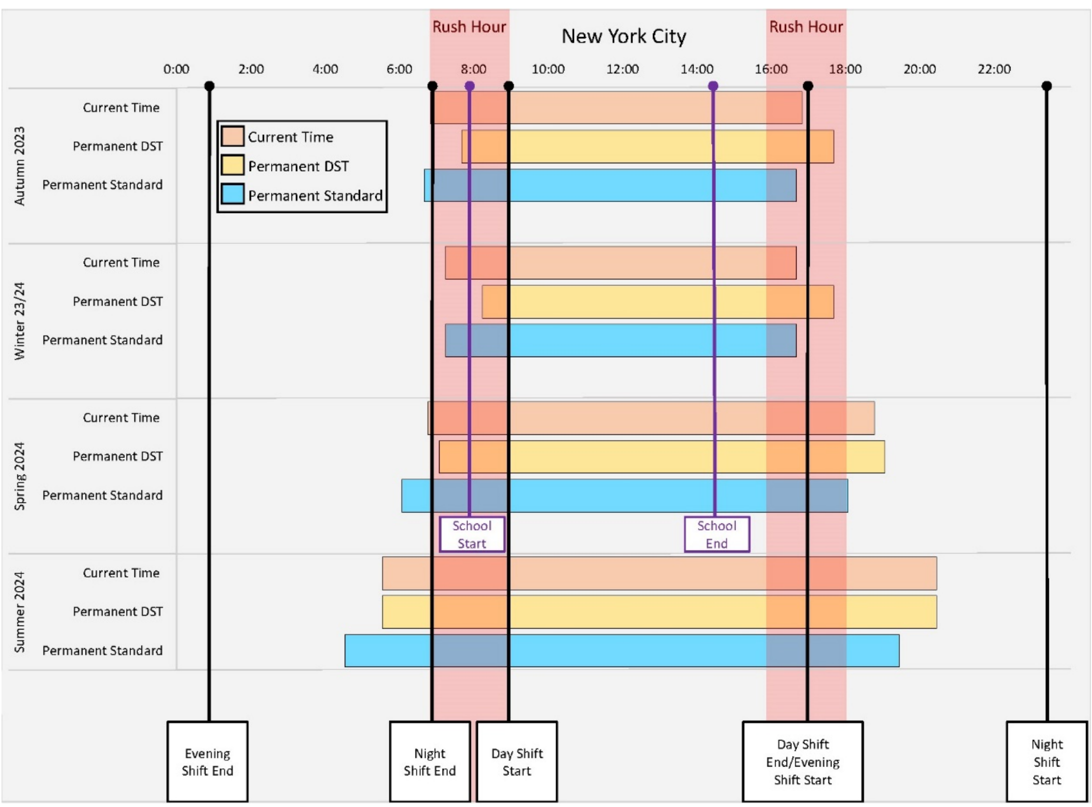


Figure 2B) Chicago, Illinois

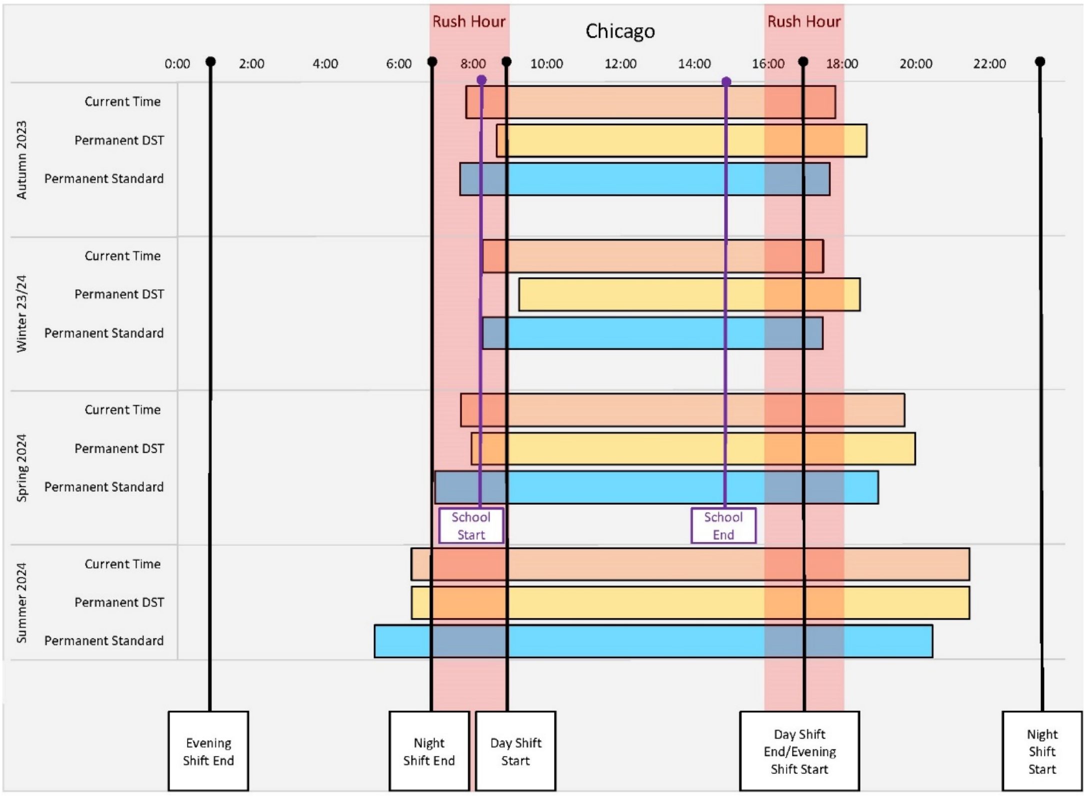
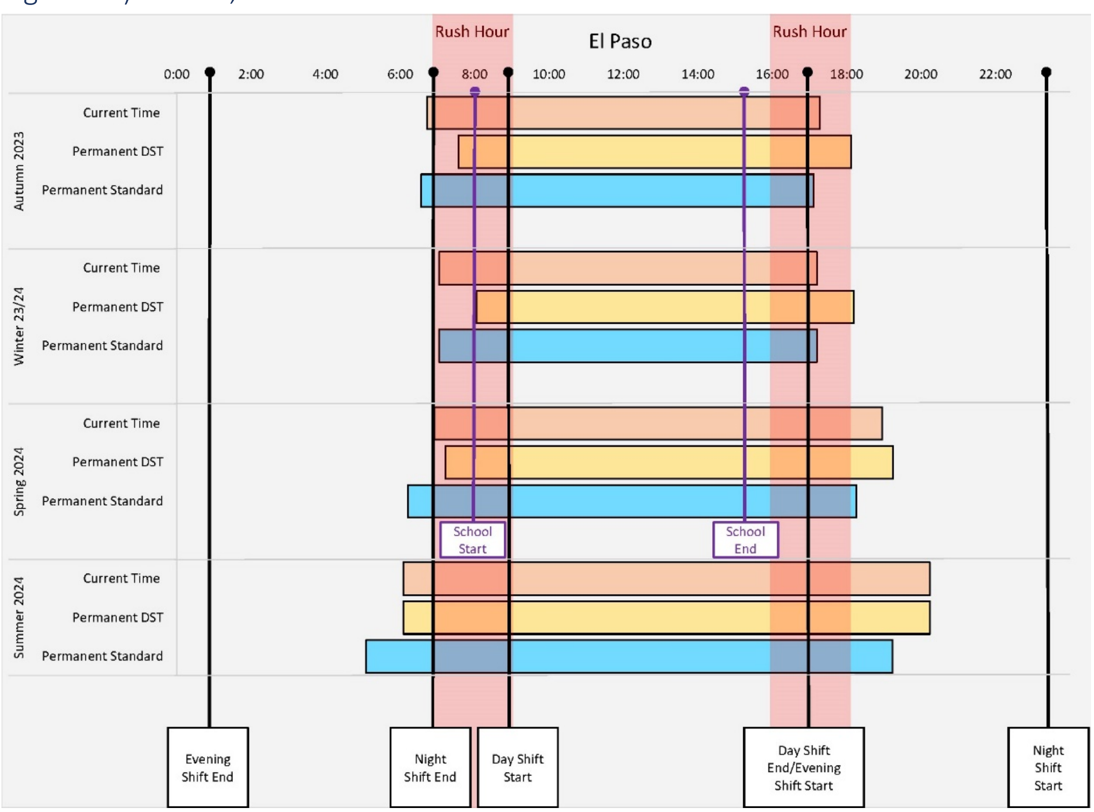
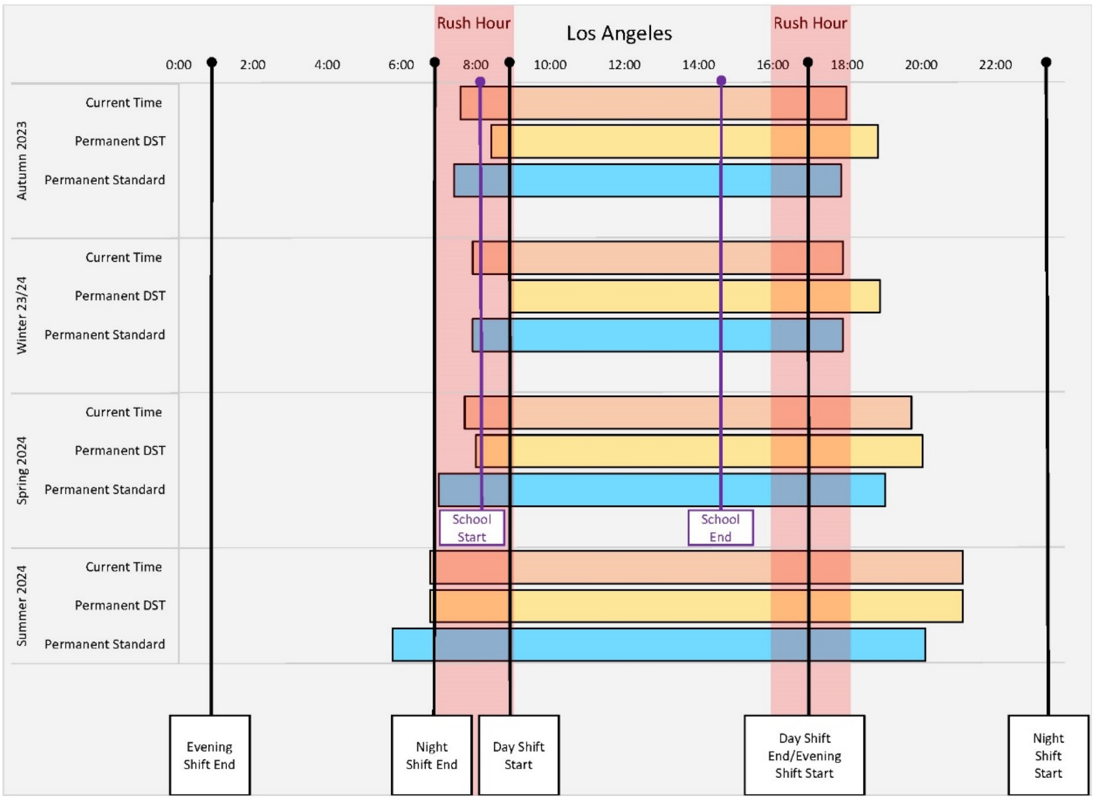



Figure 2C) El Paso, Texas



## Figure 2D) Los Angeles, California




## Figure 2E) Anchorage, Alaska

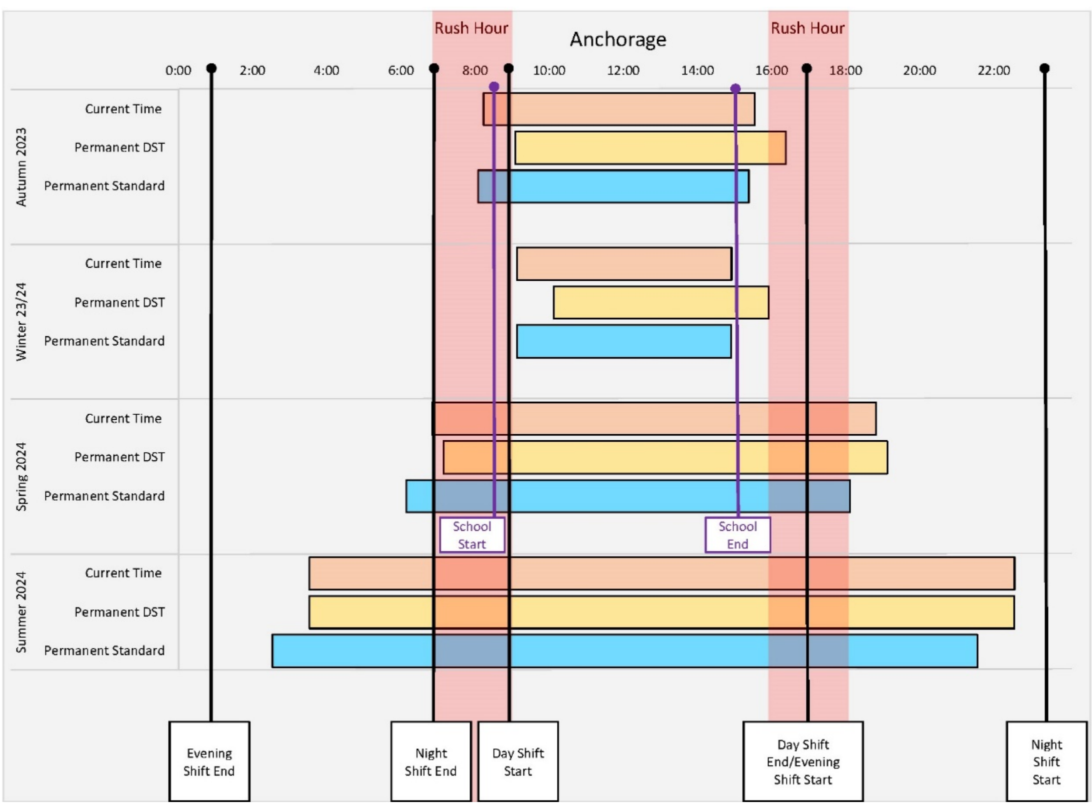


*Figure 2. Exposure to Daylight by Schedule and Time Change Conditions. Graphic depiction of hours of daylight across the 24-hour day (top x axis) by time change condition (CTA: orange bar, DST: yellow bar, ST: blue bar) and season on the y axis for A) New York City, B) Chicago, C) El Paso, D) Los Angeles, and E) Anchorage. Work schedule start and end times are indicated by black lines. School start and end times are indicated by purple lines. Morning and evening rush hours are indicated by red shading.*

Table 2 summarizes the repeated measures ANOVA results for exposure to daylight by time change conditions, controlling for city location, shift type, and season. Bonferroni post-hoc analysis revealed significant differences between all conditions for average sunrise, distance between sunrise and waketime, and percentage of waketimes occurring before sunrise (all $p \leq 0.001$). There were significant differences between DST and ST conditions for percent darkness during the total waking day ($t=2.59$, $p=0.03$) and percent darkness during sleep ($t=2.46$, $p=0.045$), but not between either DST or ST and CTA (all $p>0.3$). There were significant differences between DST and either CTA ($t=3.05$, $p=0.008$) or ST ($t=3.19$, $p=0.005$) for percent darkness during the commute-to-work, but not between CTA and ST ($t=0.14$, $p=1.0$). There were no significant differences between percent darkness during the work day or commute-home between conditions (all $p>0.6$).

Table 2. Effects of Time Change Conditions on Exposure to Daylight

| | Current Time Arrangements | Permanent DST | Permanent ST | $F_{(2, 74)}$ value | P value |
|---|---|---|---|---|---|
| Average Sunrise | 07:08±02:48 | 07:35±03:18 | 06:42±03:18 | 387.24 | <0.001** |
| Distance between Sunrise and Waketime‡ | 19±69 minutes | -15±86 minutes | 44±86 minutes | 406.82 | <0.001** |
| Percentage of Waketimes Occurring Before Sunrise | 42%±37% | 63%±41% | 33%±38% | 76.37 | <0.001** |
| Percent Darkness During the Total Waking Day | 32%±13% | 29%±13% | 33%±12% | 94.69 | <0.001** |
| Percent Darkness During Commute-to-work | 28%±44% | 32%±45% | 28%±44% | 6.48 | 0.002* |
| Percent Darkness During Work Day | 41%±42% | 41%±42% | 41%±42% | 0.08 | 0.93 |

| | | | | | |
|---|---|---|---|---|---|
| Percent Darkness During Commute-home | 31%±44% | 30%±45% | 31%±44 | 0.37 | 0.68 |
| Percent Darkness During Sleep | 66%±24% | 71%±26% | 63%±24% | 103.11 | <0.001** |

‡*Negative values indicate waketimes occurring before sunrise. Positive values indicate waketimes occurring after sunrise. * indicates p values ≤0.05; ** indicates p values ≤0.001.*

## 3.3 Time Change Arrangements and Predicted Effectiveness

Table 3 summarizes differences in Effectiveness scores between time change conditions. Bonferroni post-hoc analysis revealed that average and minimum Effectiveness scores were significant higher under either permanent DST or ST conditions compared to CTA for commute-to-work, work day, commute-home, and total waking day (see Table 3; all p≤0.001). There were no significant differences between DST and ST (all p>0.9). There were no differences between time change conditions for minimum or average Effectiveness during the total waking day controlling for city location, shift type, and season (all p>0.9). There were expected differences in Effectiveness by shift and season. Effectiveness did not differ by city location. These results are summarized in Supplementary Data Table 2. Differences in Effectiveness during CTA were driven by dips during March and November related to clock changing (see Supplementary Data Table 2).

Table 3. Effects of Time Change Conditions on Average and Minimum Effectiveness

| | Current Time Arrangements | Permanent DST | Permanent ST | $F_{(2, 74)}$ value | P value |
|---|---|---|---|---|---|
| Commute-to-work Average Effectiveness | 96.02±3.27 | 96.12±3.12 | 96.12±3.14 | 9.50 | 0.001** |
| Commute-to-work Minimum Effectiveness | 94.94±3.87 | 95.04±3.73 | 95.04±3.75 | 8.24 | 0.004* |
| Work Day Average Effectiveness | 91.21±10.76 | 91.32±10.60 | 91.33±10.61 | 11.40 | <0.001** |
| Work Day Minimum Effectiveness | 86.70±12.32 | 86.84±12.13 | 86.83±12.13 | 4.82 | 0.009* |

| | | | | | |
|---|---|---|---|---|---|
| Commute-home Average Effectiveness | 87.36±11.83 | 87.50±11.64 | 87.49±11.63 | 3.37 | 0.04* |
| Commute-home Minimum Effectiveness | 86.31±11.93 | 86.45±11.75 | 86.44±11.75 | 3.23 | 0.04* |
| Total Waking Day Average Effectiveness | 93.60±5.99 | 93.63±5.98 | 93.63±5.98 | 9.19 | <0.001** |
| Total Waking Day Minimum Effectiveness | 89.45±5.91 | 89.48±5.90 | 89.48±5.89 | 24.26 | <0.001** |

** indicates p values ≤0.05; ** indicates p values ≤0.001.*

## 3.4 Time Change Arrangements and Rush Hour Commutes

Table 4 summarizes differences in Effectiveness scores and percent darkness during morning rush hour (0700-0900) and evening rush hour (1600-1800) between time change conditions. Morning rush hour included commute-to-work Effectiveness and percent darkness values for day and school shift schedules and commute-home Effectiveness and percent darkness values for night shift schedules for a total of 55 schedules. There was a trend for differences in average and minimum Effectiveness scores by time change conditions during morning rush hours. Bonferroni post-hoc analysis revealed lower minimum and average Effectiveness under CTA compared to either DST or ST (all p≤0.002). There were significant differences in percent darkness during morning rush hour. Bonferroni post-hoc analysis indicated that there was a greater percentage of darkness under DST conditions compared against either CTA (t=4.52, p<0.001) or permanent ST (t=4.75, p<0.001). There were no differences in percent darkness between CTA and ST (t=0.23, p=1.00).

Evening rush hour included commute-home Effectiveness and percent darkness values for day shift schedules and commute-to-work Effectiveness and percent darkness values for evening shift schedules for a total of 40 schedules. There were no significant differences in average and minimum Effectiveness scores by time change conditions during evening rush hours. There were significant differences in percent darkness during evening rush hours. Bonferroni post-hoc analysis indicated that there was a greater percentage of darkness under either CTA (t=5.04, p<0.001) or permanent ST (t=5.23, p<0.001) compared to permanent DST. There were no significant differences in percent darkness between CTA and ST (t=0.00, p=1.00). Breakdowns of average Effectiveness and percent darkness during morning and evening rush hours by city, season, and time change condition, with information about included schedules, are included in Supplementary Data Tables 3 and 4, respectively.

Table 4. Effects of Time Change Conditions on Rush Hour Effectiveness and Exposure to Light

| | Current Time Arrangements | Permanent DST | Permanent ST | F value | P value |
|---|---|---|---|---|---|
| Morning Rush Hour Average Effectiveness | 87.89±14.37 | 88.05±14.15 | 88.07±14.16 | $F_{(2, 54)}$= 3.14 | 0.05† |
| Morning Rush Hour Minimum Effectiveness | 86.92±14.22 | 87.06±14.00 | 87.09±14.00 | $F_{(2, 54)}$= 2.90 | 0.06† |
| Percent Darkness During Morning Rush Hour | 7%±23% | 16%±31% | 7%±23% | $F_{(2, 54)}$= 14.35 | <0.001** |
| Evening Rush Hour Average Effectiveness | 97.48±0.92 | 97.50±0.90 | 97.49±0.91 | $F_{(2, 39)}$= 0.54 | 0.58 |
| Evening Rush Hour Minimum Effectiveness | 97.11±0.68 | 97.12±0.66 | 97.12±0.67 | $F_{(2, 39)}$= 0.51 | 0.60 |
| Percent Darkness During Evening Rush Hour | 7%±14% | 0%±0% | 7%±15% | $F_{(2, 39)}$= 8.80 | <0.001** |

** indicates p values ≤0.05; ** indicates p values ≤0.001.*

## 4. Discussion

The purpose of this computational modeling project has been to evaluate the average potential impact that time change arrangements alone may have on cognitive alertness and exposure to daylight in United States locations under a variety of seasons and work or school schedules. To our knowledge, this is the first attempt to model the impact of time change arrangements using a biomathematical model of fatigue (SAFTE-FAST) with a sleep prediction algorithm (AutoSleep). Our findings suggest that under ideal hypothetical circumstances, abandoning the twice-yearly clock change may be nominally beneficial for Effectiveness. Permanent DST conditions resulted in less light at waketime, during morning rush hour, and less light exposure across the day than either CTA or ST. Given the similarities between CTA and ST in these analyses, it would seem that adjusting to permanent ST would be logistically easier than adapting to permanent DST time conditions.

With regards to Effectiveness, the computational analysis suggests that adopting either permanent DST or permanent ST may prevent cognitive alertness deficits related to the bi-annual transition between ST and DST in November and March (see Table 3). Although they are statistically significant, the observed differences in predicted Effectiveness are less than a full integer. Moreover, scores are above the FRA cut-off for fatigue risk (an Effectiveness score of 70) (Register 2011). Taken together, it is unlikely that fatigue risk would be noticeably different based on the time change conditions alone. Previous research investigating the contributing role of DST transitions on cognitive performance or accident risk have shown mixed results, with some studies indicating an increased risk due to clock changing and other studies showing no association (Lambe and Cummings 2000, Lahti *et al.* 2010, Robb and Barnes 2018, Fritz *et al.* 2020). The risk of fatigue due solely to the bi-annual clock change may be negligible under ideal conditions, such as fixed schedules that consistently allow for a sufficient amount of sleep, but could interact with other factors to produce higher risk in real-life situations.

The AutoSleep algorithm predicts sleep as a function of time available between work events and will assume an 8-hour, overnight sleep opportunity unless time is constrained by the work schedule. Effectiveness is calculated as a function of sleep history as well as circadian rhythm and sleep inertia in SAFTE-FAST. The schedules modeled in this analysis may be considered representative of ideal sleep and working conditions. Individual differences in sleep behavior or cognitive alertness cannot be predicted using generic fixed schedules and the AutoSleep function in SAFTE-FAST. Furthermore, AutoSleep has not be evaluated for the sleep prediction in student populations. The use of a sleep prediction algorithm rather than actual measures of sleep behavior under different time change conditions constitutes a limitation for the interpretability of the presented results.

Deficits in alertness due to the clock change may reasonably be compounded by individual differences in sleep behavior, work schedules, or resilience to fatigue that could be variable across populations. These differences could potentially account for the mixed findings with respect to the impact of time changes on accident risk seen in real-world data analyses (Lambe and Cummings 2000, Lahti *et al.* 2010, Robb and Barnes 2018, Fritz *et al.* 2020). It is possible to model objective measures of sleep in SAFTE-FAST to produce a more specific prediction of Effectiveness. However, since it is not possible to collect ecologically-valid sleep data across seasons in the future (year 2023-24) in multiple cities simultaneously under three different time change conditions, AutoSleep provides an adequate exploratory proxy for real-world sleep in this computational analysis.

Setting the clocks forward in the spring has been shown to disrupt sleep and impair cognitive performance as well as shift the amount of light available during morning commutes compared to evening commutes (Herd *et al.* 1980, Lambe and Cummings 2000, Lahti *et al.* 2010, Robb and Barnes 2018, Laliotis *et al.* 2019, Fritz *et al.* 2020, Bünnings and Schiele 2021). Decreasing the amount of darkness during evening rush hours to reduce crash risk is an argument for the adoption of permanent DST (Laliotis *et al.* 2019, Bünnings and Schiele 2021). Time change arrangements did not show a significant effect on rush hour Effectiveness in this analysis (see Table 4). Percent darkness during morning rush hour was greater under permanent DST conditions compared to CTA or permanent ST (16% vs. 7%; see Table 4) while percent darkness during evening rush hour was lower under permanent DST conditions compared to the other conditions (0% vs. 7%; see Table 4).

Interestingly, Effectiveness during morning rush hour was lower than Effectiveness during evening rush hour (see Table 4). This difference can be attributed to the inclusion of shiftwork schedule commute data. Morning rush hour coincided with commute-home data from night schedules, when workers are assumed to have lower Effectiveness following a full 8-hours of work, whereas evening rush hour included commute-to-work data from evening schedules, when workers are assumed to be well-rested. Shift workers are rarely considered in the discussion of the impact of time change arrangements on highway safety. Our computational model suggests that traffic congestion and diminished alertness could be a greater issue during morning rush hour than during evening rush hour in areas with a substantial number of overnight shift workers. Increased morning darkness in Permanent DST could exacerbate fatigue in shift workers (Kantermann 2008, Åkerstedt and Wright 2009, Watson 2019), though the effects of DST or DST transitions on shift workers has not been directly investigated. Since darkness is known to contribute to crash risk (Herd *et al.* 1980, Fritz *et al.* 2020, Raynham *et al.* 2020, Bünnings and Schiele 2021, Fotios *et al.* 2021), the safest option to prevent risk at a time when there are not only daytime workers on the road, but also fatigued shift workers returning home, student drivers, and buses full of school children would be any arrangements that allow morning rush hour under ambient light conditions. Work and school schedules could be modified to avoid dark morning commutes under any time change arrangements, but are most closely aligned to this goal under CTA or permanent ST conditions.

The data here suggest that permanent DST would result in darker mornings and darker waking days overall, as shown in Table 2. The scenario also confirms that permanent DST would be associated with an increase in waketimes occurring before sunrise. Under DST conditions, assuming that individuals plan their waketimes in relation to work start times, individuals will need to wake, on average, 15 minutes before sunrise as opposed to 19 minutes after sunrise under modeled CTA conditions, or 44 minutes after sunrise under permanent ST (see Table 2). In the current model, morning waketimes would occur before sunrise 63% of the time under DST conditions while under either other condition, the average percentage of waketimes before sunrise were less than 50%. The increase in waketimes before sunrise under DST conditions even affected evening and night shift schedules, as shown in Supplementary Data Table 1.

This increase in darkness around the time of morning awakening is a strong argument against permanent DST (Roenneberg *et al.* 2019a, Roenneberg *et al.* 2019b, Rishi *et al.* 2020). In the absence of schedule constraints or artificial light, humans naturally awake around or after sunrise (Wright Jr *et al.* 2013, Skeldon *et al.* 2017). A mismatch between the timing of sleep due to schedule constraints and human's natural circadian rhythmicity can result in recurrent symptoms of fatigue known as "social jet-lag" (Wittmann *et al.* 2006, Skeldon *et al.* 2017, McMahon *et al.* 2018). Adolescents may be affected in particular due to a natural propensity towards later waketimes (Owens *et al.* 2016). Early school start times have been known to disrupt student sleep and impair health and performance. Many states have introduced legislature to limit how early schools may start in the morning to curb this negative health effect (Watson *et al.* 2017, Anon 2021, Meltzer *et al.* 2021, Meltzer *et al.* 2022). Permanent DST would in effect undo the benefits of these efforts (Skeldon and Dijk 2019). SAFTE-FAST takes light exposure, circadian misalignment, and sleep inertia into account to estimate Effectiveness, but the model has not been examined in the context of social jet lag. This constitutes a limitation for the current analyses and an interesting concept to test in future investigations.

As expected, the effects of time change conditions on exposure to light differed by city location, season, and shift as depicted in Figure 2 and shown in Supplementary Data Table 1. A limitation of this analysis is that we compare averages for Effectiveness and light exposure based on data from generic hypothetical schedules and algorithmic predictions of sleep. This type of analysis cannot account for individual differences, rotating shift schedules, or behaviors specific to a certain population. The relationship between city selection criteria such as population, highway fatality rate, or distance relative to the start of the time zone on Effectiveness or light exposure could also not be examined in these analyses because the datasets are generic and hypothetical. In light of these limitations, it is important to note that if the Sunshine Protection Act is enacted, it will affect all people living in U.S. locations across the entire year regardless of their location, schedule, or individual differences. In this way, using hypothetical generic schedules may be a useful tool to evaluate the base level of risk associated with any time change arrangement.

Biomathematical models are frequently used in industry to prospectively investigate work schedules in order to avoid working during periods of high fatigue risk. Schedule adaptation has also been suggested for avoiding fatigue risk or circadian misalignment related to either permanent DST or ST (Carey and Sarma 2017, Roenneberg *et al.* 2019a). Our findings suggest that permanent ST is more similar to CTA, particularly in student populations since school is not in attendance over the summer. Logistically speaking, permanent ST may require fewer schedule changes than DST, and therefore make for an easier adjustment. An alternative interpretation is that neither permanent DST nor permanent ST offer a significant advantage over CTA. Adopting permanent ST would require fewer schedule changes than adopting permanent DST, but continuing to use CTA would require no schedule changes since the U.S. already uses this time change arrangement. According to a poll by The Associated Press-NORC Center for Public Affairs Research, only 25% of Americans support continuing to use CTA (AP-NORC 2021). Despite mixed evidence or a lack of direct evidence that adopting permanent time arrangements in either direction would improve traffic safety, energy use, light exposure, or health outcomes, Americans do not seem to like CTA (Kamstra *et al.* 2000, Belzer *et al.* 2008, Calandrillo and Buehler 2008, Hill *et al.* 2010, Zick 2014, Carey and Sarma 2017, Roenneberg *et al.* 2019a, Skeldon and Dijk 2019, Bin-Hasan *et al.* 2020, Fritz *et al.* 2020, AP-NORC 2021, Bünnings and Schiele 2021). Given that American voters want to stop the bi-annual clock changes, then the least disruptive permanent time option would appear to be permanent ST.

## 5. Conclusions

The effect of potential time change arrangements following the Sunshine Protection Act start date of November 2023 were compared using a biomathematical model of fatigue (SAFTE-FAST). Our findings suggest that permanent ST would result in fewer changes in terms of light exposure and Effectiveness relative to CTA compared to DST. Controlling for U.S. location, season, and shift type, permanent DST would result in greater morning darkness than CTA or ST with only nominal differences to Effectiveness. Under permanent DST, morning rush hour would have a greater percentage of darkness that could increase risk during a time period of reduced commuter Effectiveness and greater traffic congestion, including school children. Permanent ST would require less adaptation to new schedules, allow for better alignment with the circadian clock, and be the more beneficial choice for traffic safety for students and shift workers as well as the general working public.

**Author Contributions:** Conceptualization, J.K.D., and S.R.H., methodology, J.K.D., J.C., S.R.H.; formal analysis, J.K.D., J.C., S.R.H.; data curation, J.K.D., J.C.; writing—original draft preparation, J.K.D; writing—review and editing, J.K.D., J.C., S.R.H.; supervision, S.R.H.; All authors have read and agreed to the published version of the manuscript.

**Declarations of Interest:** The authors declare no direct conflicts of interest. The Institutes for Behavior Resources provides licensing of SAFTE-FAST. Authors J. K. Devine, and J. Choynowski are affiliated with the Institutes for Behavior Resources, but do not benefit financially or non-financially from licensing sales of SAFTE-FAST software. Author S. R. Hursh is the inventor of the SAFTE-FAST biomathematical model and a fraction of his compensation is based on sales of the software.

**Funding:** This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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## 7. Supplementary Data

**Supplementary Data Table 1. Percent Darkness During Total Waking Day and During Sleep by City, Season, and Shift by Time Change Condition**

| | | | Percent Darkness During Total Waking Day | | | Percent Darkness During Sleep | | | Percent Waketimes Before Sunrise | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **City** | Season | Shift | CTA | DST | ST | CTA | DST | ST | CTA | DST | ST |
| **New York City** | Autumn | Day | 33% | 28% | 34% | 86% | 96% | 84% | 13% | 75% | 0% |
| | | Evening | 41% | 37% | 42% | 62% | 72% | 60% | 12% | 61% | 0% |
| | | Night | 51% | 49% | 51% | 51% | 53% | 49% | 10% | 20% | 0% |
| | | School | 33% | 28% | 34% | 86% | 96% | 84% | 13% | 75% | 0% |
| | Winter | Day | 34% | 30% | 34% | 90% | 98% | 90% | 71% | 100% | 71% |
| | | Evening | 41% | 36% | 41% | 67% | 79% | 67% | 58% | 100% | 51% |
| | | Night | 53% | 51% | 53% | 52% | 56% | 52% | 10% | 100% | 10% |
| | | School | 33% | 30% | 33% | 91% | 98% | 91% | 76% | 100% | 76% |
| | Spring | Day | 21% | 19% | 25% | 85% | 89% | 77% | 23% | 45% | 0% |
| | | Evening | 30% | 29% | 34% | 61% | 65% | 53% | 16% | 34% | 0% |
| | | Night | 42% | 41% | 40% | 42% | 45% | 47% | 0% | 10% | 0% |
| | | School | 22% | 19% | 25% | 85% | 91% | 78% | 33% | 63% | 0% |
| | Summer | Day | 9% | 9% | 15% | 67% | 67% | 55% | 0% | 0% | 0% |
| | | Evening | 19% | 19% | 25% | 43% | 43% | 31% | 0% | 0% | 0% |
| | | Night | 30% | 30% | 28% | 26% | 26% | 29% | 0% | 0% | 0% |
| **Chicago** | Autumn | Day | 33% | 28% | 34% | 85% | 95% | 83% | 79% | 100% | 73% |
| | | Evening | 42% | 37% | 43% | 61% | 71% | 59% | 67% | 100% | 61% |
| | | Night | 51% | 49% | 51% | 51% | 53% | 49% | 40% | 100% | 20% |
| | | School | 33% | 28% | 34% | 86% | 95% | 84% | 81% | 100% | 75% |
| | Winter | Day | 34% | 30% | 34% | 90% | 98% | 90% | 100% | 100% | 100% |
| | | Evening | 41% | 36% | 41% | 67% | 79% | 67% | 100% | 100% | 100% |
| | | Night | 53% | 51% | 53% | 52% | 56% | 52% | 100% | 100% | 100% |
| | | School | 34% | 30% | 34% | 91% | 98% | 91% | 100% | 100% | 100% |
| | Spring | Day | 21% | 19% | 25% | 84% | 88% | 75% | 77% | 90% | 38% |
| | | Evening | 31% | 29% | 34% | 60% | 64% | 52% | 63% | 78% | 31% |
| | | Night | 42% | 40% | 40% | 41% | 45% | 46% | 20% | 40% | 10% |
| | | School | 22% | 19% | 25% | 84% | 90% | 77% | 79% | 96% | 50% |
| | Summer | Day | 8% | 8% | 15% | 65% | 65% | 53% | 0% | 0% | 0% |
| | | Evening | 19% | 19% | 25% | 41% | 41% | 29% | 0% | 0% | 0% |
| | | Night | 29% | 29% | 28% | 25% | 25% | 28% | 0% | 0% | 0% |
| **El Paso** | Autumn | Day | 30% | 25% | 31% | 85% | 95% | 83% | 12% | 70% | 0% |
| | | Evening | 39% | 34% | 40% | 61% | 71% | 59% | 12% | 58% | 0% |
| | | Night | 48% | 46% | 48% | 51% | 53% | 49% | 10% | 10% | 0% |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | School | 30% | 25% | 31% | 85% | 95% | 83% | 12% | 70% | 0% |
| | Winter | Day | 30% | 26% | 30% | 88% | 97% | 88% | 60% | 97% | 60% |
| | | Evening | 38% | 33% | 38% | 65% | 77% | 65% | 48% | 97% | 46% |
| | | Night | 49% | 48% | 49% | 51% | 54% | 51% | 10% | 100% | 10% |
| | | School | 30% | 26% | 30% | 89% | 98% | 89% | 71% | 97% | 71% |
| | Spring | Day | 20% | 18% | 24% | 87% | 91% | 79% | 41% | 63% | 0% |
| | | Evening | 30% | 28% | 34% | 64% | 68% | 56% | 31% | 50% | 0% |
| | | Night | 42% | 42% | 40% | 42% | 45% | 48% | 0% | 10% | 0% |
| | | School | 21% | 18% | 24% | 87% | 93% | 81% | 46% | 75% | 0% |
| | Summer | Day | 11% | 11% | 17% | 76% | 76% | 64% | 0% | 0% | 0% |
| | | Evening | 22% | 22% | 27% | 52% | 52% | 40% | 0% | 0% | 0% |
| | | Night | 34% | 34% | 32% | 32% | 32% | 35% | 0% | 0% | 0% |
| **Los Angeles** | Autumn | Day | 32% | 26% | 33% | 83% | 93% | 81% | 76% | 100% | 70% |
| | | Evening | 40% | 36% | 42% | 60% | 69% | 57% | 64% | 100% | 56% |
| | | Night | 49% | 47% | 49% | 50% | 53% | 49% | 30% | 100% | 10% |
| | | School | 31% | 26% | 33% | 84% | 94% | 82% | 81% | 100% | 75% |
| | Winter | Day | 32% | 27% | 32% | 87% | 97% | 87% | 71% | 100% | 71% |
| | | Evening | 40% | 34% | 40% | 64% | 76% | 64% | 66% | 100% | 59% |
| | | Night | 50% | 49% | 50% | 51% | 55% | 51% | 30% | 100% | 30% |
| | | School | 32% | 27% | 32% | 88% | 98% | 88% | 82% | 100% | 82% |
| | Spring | Day | 21% | 19% | 26% | 85% | 89% | 77% | 75% | 88% | 38% |
| | | Evening | 31% | 29% | 35% | 60% | 65% | 52% | 65% | 81% | 29% |
| | | Night | 42% | 41% | 40% | 42% | 45% | 47% | 30% | 50% | 10% |
| | | School | 22% | 20% | 26% | 85% | 91% | 78% | 83% | 100% | 50% |
| | Summer | Day | 12% | 12% | 18% | 72% | 72% | 60% | 0% | 0% | 0% |
| | | Evening | 22% | 22% | 28% | 49% | 49% | 36% | 0% | 0% | 0% |
| | | Night | 33% | 33% | 31% | 31% | 31% | 34% | 0% | 0% | 0% |
| **Anchorage** | Autumn | Day | 34% | 34% | 34% | 86% | 96% | 84% | 94% | 100% | 88% |
| | | Evening | 40% | 37% | 41% | 62% | 72% | 60% | 91% | 100% | 84% |
| | | Night | 56% | 53% | 56% | 51% | 53% | 49% | 80% | 100% | 60% |
| | | School | 34% | 34% | 34% | 86% | 96% | 84% | 94% | 100% | 88% |
| | Winter | Day | 41% | 41% | 41% | 90% | 98% | 90% | 100% | 100% | 100% |
| | | Evening | 43% | 41% | 43% | 67% | 79% | 67% | 100% | 100% | 100% |
| | | Night | 60% | 56% | 60% | 52% | 56% | 52% | 100% | 100% | 100% |
| | | School | 41% | 42% | 41% | 91% | 98% | 91% | 100% | 100% | 100% |
| | Spring | Day | 12% | 11% | 16% | 85% | 89% | 77% | 25% | 44% | 3% |
| | | Evening | 22% | 21% | 26% | 61% | 65% | 53% | 16% | 32% | 0% |
| | | Night | 38% | 39% | 37% | 42% | 45% | 47% | 0% | 10% | 0% |
| | | School | 14% | 12% | 17% | 85% | 91% | 78% | 33% | 58% | 4% |
| | Summer | Day | 0% | 0% | 0% | 67% | 67% | 55% | 0% | 0% | 0% |
| | | Evening | 0% | 0% | 0% | 43% | 43% | 31% | 0% | 0% | 0% |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Night | 0% | 0% | 0% | 26% | 26% | 29% | 0% | 0% | 0% |

**Supplementary Data Table 2. Average Effectiveness During Work Day and Commutes by City, Season, and Shift by Time Change Condition**

| | | | Average Effectiveness Commute to Work | | | Average Effectiveness at Work | | | Average Effectiveness Commute Home | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **City** | Season | Shift | CTA | DST | ST | CTA | DST | ST | CTA | DST | ST |
| **New York City** | Autumn | Day | 99.26 | 99.04 | 99.11 | 97.63 | 97.52 | 97.55 | 98.57 | 98.39 | 98.42 |
| | | Evening | 96.71 | 96.66 | 96.57 | 97.53 | 97.60 | 97.55 | 87.37 | 87.73 | 87.81 |
| | | Night | 90.39 | 91.42 | 91.37 | 73.61 | 73.97 | 73.94 | 70.01 | 69.41 | 69.45 |
| | | School | 97.64 | 97.37 | 97.41 | 98.18 | 98.09 | 98.10 | 96.22 | 96.05 | 96.09 |
| | Winter | Day | 99.03 | 99.01 | 99.03 | 97.51 | 97.50 | 97.51 | 98.35 | 98.34 | 98.35 |
| | | Evening | 96.60 | 96.55 | 96.60 | 97.58 | 97.53 | 97.58 | 87.87 | 88.21 | 87.87 |
| | | Night | 91.19 | 91.19 | 91.19 | 73.85 | 73.85 | 73.85 | 69.54 | 69.54 | 69.54 |
| | | School | 97.43 | 97.41 | 97.43 | 98.11 | 98.11 | 98.11 | 96.09 | 96.07 | 96.09 |
| | Spring | Day | 98.86 | 99.06 | 99.07 | 97.41 | 97.53 | 97.53 | 98.17 | 98.38 | 98.34 |
| | | Evening | 96.38 | 96.56 | 96.62 | 97.48 | 97.60 | 97.67 | 88.49 | 88.30 | 88.00 |
| | | Night | 90.78 | 91.12 | 91.09 | 72.64 | 73.80 | 73.80 | 67.22 | 69.53 | 69.55 |
| | | School | 96.96 | 97.31 | 97.31 | 97.89 | 98.06 | 98.06 | 95.86 | 96.02 | 96.04 |
| | Summer | Day | 99.08 | 99.08 | 99.12 | 97.53 | 97.53 | 97.56 | 98.40 | 98.40 | 98.40 |
| | | Evening | 96.79 | 96.79 | 96.64 | 97.60 | 97.60 | 97.56 | 87.11 | 87.11 | 87.46 |
| | | Night | 91.19 | 91.19 | 91.13 | 73.85 | 73.85 | 73.84 | 69.54 | 69.54 | 69.57 |
| **Chicago** | Autumn | Day | 99.26 | 99.04 | 99.11 | 97.63 | 97.52 | 97.55 | 98.57 | 98.39 | 98.42 |
| | | Evening | 96.73 | 96.66 | 96.60 | 97.55 | 97.60 | 97.55 | 87.33 | 87.73 | 87.77 |
| | | Night | 90.39 | 91.42 | 91.37 | 73.61 | 73.97 | 73.94 | 70.01 | 69.41 | 69.45 |
| | | School | 98.48 | 98.25 | 98.27 | 98.14 | 98.06 | 98.07 | 96.33 | 96.18 | 96.21 |
| | Winter | Day | 99.03 | 99.01 | 99.03 | 97.51 | 97.50 | 97.51 | 98.35 | 98.34 | 98.35 |
| | | Evening | 96.60 | 96.55 | 96.60 | 97.58 | 97.53 | 97.58 | 87.87 | 88.21 | 87.87 |
| | | Night | 91.19 | 91.19 | 91.19 | 73.85 | 73.85 | 73.85 | 69.54 | 69.54 | 69.54 |
| | | School | 98.29 | 98.28 | 98.29 | 98.08 | 98.08 | 98.08 | 96.21 | 96.19 | 96.21 |
| | Spring | Day | 98.85 | 99.06 | 99.06 | 97.40 | 97.53 | 97.51 | 98.15 | 98.38 | 98.32 |
| | | Evening | 96.35 | 96.55 | 96.62 | 97.45 | 97.60 | 97.67 | 88.57 | 88.31 | 88.00 |
| | | Night | 90.78 | 91.12 | 91.09 | 72.64 | 73.80 | 73.79 | 67.22 | 69.53 | 69.55 |
| | | School | 97.83 | 98.19 | 98.17 | 97.86 | 98.04 | 98.01 | 95.94 | 96.15 | 96.12 |
| | Summer | Day | 99.09 | 99.09 | 99.12 | 97.54 | 97.54 | 97.56 | 98.42 | 98.42 | 98.40 |
| | | Evening | 96.77 | 96.77 | 96.64 | 97.61 | 97.61 | 97.56 | 87.27 | 87.27 | 87.46 |
| | | Night | 91.19 | 91.19 | 91.13 | 73.85 | 73.85 | 73.84 | 69.54 | 69.54 | 69.57 |
| **El Paso** | Autumn | Day | 99.26 | 99.04 | 99.11 | 97.63 | 97.52 | 97.55 | 98.57 | 98.39 | 98.42 |
| | | Evening | 96.73 | 96.66 | 96.60 | 97.55 | 97.60 | 97.56 | 87.32 | 87.73 | 87.76 |
| | | Night | 90.39 | 91.42 | 91.37 | 73.61 | 73.97 | 73.94 | 70.01 | 69.41 | 69.45 |
| | | School | 99.31 | 99.08 | 99.15 | 97.65 | 97.54 | 97.57 | 98.63 | 98.43 | 98.46 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Winter | Day | 99.09 | 99.01 | 99.09 | 97.55 | 97.50 | 97.55 | 98.38 | 98.34 | 98.38 |
| | | Evening | 96.45 | 96.55 | 96.45 | 97.53 | 97.53 | 97.53 | 88.20 | 88.21 | 88.20 |
| | | Night | 91.13 | 91.19 | 91.13 | 73.84 | 73.85 | 73.84 | 69.57 | 69.54 | 69.57 |
| | | School | 97.94 | 97.89 | 97.94 | 97.98 | 97.92 | 97.98 | 96.54 | 96.51 | 96.54 |
| | Spring | Day | 98.83 | 99.02 | 99.09 | 97.39 | 97.51 | 97.54 | 98.15 | 98.36 | 98.36 |
| | | Evening | 96.46 | 96.64 | 96.62 | 97.51 | 97.64 | 97.67 | 88.32 | 88.13 | 88.00 |
| | | Night | 90.76 | 91.14 | 91.09 | 72.63 | 73.80 | 73.80 | 67.24 | 69.52 | 69.55 |
| | | School | 97.42 | 97.76 | 97.81 | 97.73 | 97.86 | 97.92 | 96.21 | 96.43 | 96.45 |
| | Summer | Day | 99.12 | 99.12 | 99.12 | 97.56 | 97.56 | 97.56 | 98.40 | 98.40 | 98.40 |
| | | Evening | 96.64 | 96.64 | 96.65 | 97.56 | 97.56 | 97.55 | 87.46 | 87.46 | 87.39 |
| | | Night | 91.13 | 91.13 | 91.13 | 73.84 | 73.84 | 73.84 | 69.57 | 69.57 | 69.57 |
| **Los Angeles** | Autumn | Day | 99.26 | 99.04 | 99.11 | 97.63 | 97.52 | 97.55 | 98.57 | 98.39 | 98.42 |
| | | Evening | 96.75 | 96.66 | 96.65 | 97.57 | 97.60 | 97.57 | 87.25 | 87.73 | 87.59 |
| | | Night | 90.39 | 91.42 | 91.37 | 73.61 | 73.97 | 73.94 | 70.01 | 69.41 | 69.45 |
| | | School | 98.22 | 97.98 | 98.00 | 98.26 | 98.17 | 98.19 | 96.20 | 96.06 | 96.09 |
| | Winter | Day | 99.09 | 99.01 | 99.09 | 97.55 | 97.50 | 97.55 | 98.38 | 98.34 | 98.38 |
| | | Evening | 96.45 | 96.59 | 96.45 | 97.53 | 97.56 | 97.53 | 88.20 | 88.04 | 88.20 |
| | | Night | 91.13 | 91.19 | 91.13 | 73.84 | 73.85 | 73.84 | 69.57 | 69.54 | 69.57 |
| | | School | 98.04 | 98.03 | 98.04 | 98.21 | 98.19 | 98.21 | 96.11 | 96.09 | 96.11 |
| | Spring | Day | 98.85 | 99.06 | 99.07 | 97.41 | 97.53 | 97.53 | 98.17 | 98.38 | 98.34 |
| | | Evening | 96.38 | 96.56 | 96.63 | 97.47 | 97.60 | 97.66 | 88.45 | 88.30 | 87.97 |
| | | Night | 90.78 | 91.12 | 91.09 | 72.64 | 73.80 | 73.80 | 67.22 | 69.53 | 69.55 |
| | | School | 97.57 | 97.92 | 97.89 | 97.99 | 98.16 | 98.16 | 95.86 | 96.03 | 96.04 |
| | Summer | Day | 99.12 | 99.12 | 99.09 | 97.56 | 97.56 | 97.53 | 98.40 | 98.40 | 98.37 |
| | | Evening | 96.64 | 96.64 | 96.65 | 97.56 | 97.56 | 97.55 | 87.46 | 87.46 | 87.39 |
| | | Night | 91.13 | 91.13 | 91.13 | 73.84 | 73.84 | 73.84 | 69.57 | 69.57 | 69.57 |
| **Anchorage** | Autumn | Day | 99.20 | 99.04 | 99.04 | 97.60 | 97.52 | 97.52 | 98.55 | 98.39 | 98.39 |
| | | Evening | 96.71 | 96.56 | 96.62 | 97.54 | 97.55 | 97.56 | 87.80 | 88.37 | 88.05 |
| | | Night | 90.46 | 91.42 | 91.42 | 73.65 | 73.97 | 73.97 | 69.97 | 69.41 | 69.41 |
| | | School | 98.90 | 98.71 | 98.71 | 97.99 | 97.91 | 97.91 | 96.46 | 96.32 | 96.32 |
| | Winter | Day | 99.01 | 99.01 | 99.01 | 97.50 | 97.50 | 97.50 | 98.34 | 98.34 | 98.34 |
| | | Evening | 96.52 | 96.49 | 96.52 | 97.51 | 97.50 | 97.51 | 88.41 | 88.57 | 88.41 |
| | | Night | 91.19 | 91.19 | 91.19 | 73.85 | 73.85 | 73.85 | 69.54 | 69.54 | 69.54 |
| | | School | 98.76 | 98.76 | 98.76 | 97.94 | 97.94 | 97.94 | 96.34 | 96.34 | 96.34 |
| | Spring | Day | 98.80 | 99.02 | 99.07 | 97.38 | 97.51 | 97.53 | 98.14 | 98.36 | 98.37 |
| | | Evening | 96.42 | 96.62 | 96.56 | 97.48 | 97.63 | 97.62 | 88.46 | 88.22 | 88.24 |
| | | Night | 90.77 | 91.15 | 91.09 | 72.64 | 73.81 | 73.80 | 67.23 | 69.52 | 69.55 |
| | | School | 98.33 | 98.65 | 98.68 | 97.73 | 97.88 | 97.91 | 96.05 | 96.26 | 96.29 |
| | Summer | Day | 99.09 | 99.09 | 99.09 | 97.54 | 97.54 | 97.54 | 98.43 | 98.43 | 98.43 |
| | | Evening | 96.51 | 96.51 | 96.51 | 97.49 | 97.49 | 97.49 | 88.50 | 88.50 | 88.50 |
| | | Night | 91.19 | 91.19 | 91.19 | 73.85 | 73.85 | 73.85 | 69.54 | 69.54 | 69.54 |

**Supplementary Data Table 3. Average Effectiveness and Percent Darkness During Morning Rush Hour by City, Season, and Time Change Condition**

| | | Average Effectiveness | | | Percent Darkness | | |
|---|---|---|---|---|---|---|---|
| **City** | Season | CTA | DST | ST | CTA | DST | ST |
| **New York City** | Autumn | 88.97 | 88.61 | 88.66 | 0% | 3% | 0% |
| | Winter | 88.67 | 88.65 | 88.67 | 0% | 33% | 0% |
| | Spring | 87.68 | 88.63 | 88.64 | 0% | 0% | 0% |
| | Summer | 84.31 | 84.31 | 84.35 | 0% | 0% | 0% |
| **Chicago** | Autumn | 89.25 | 88.90 | 88.94 | 0% | 1% | 0% |
| | Winter | 88.95 | 88.94 | 88.95 | 0% | 25% | 0% |
| | Spring | 87.97 | 88.93 | 88.93 | 0% | 0% | 0% |
| | Summer | 84.31 | 84.31 | 84.35 | 0% | 0% | 0% |
| **El Paso** | Autumn | 87.83 | 88.76 | 88.82 | 0% | 1% | 0% |
| | Winter | 84.35 | 84.35 | 84.35 | 0% | 19% | 0% |
| | Spring | 89.53 | 89.18 | 89.24 | 0% | 0% | 0% |
| | Summer | 88.87 | 88.81 | 88.87 | 0% | 0% | 0% |
| **Los Angeles** | Autumn | 87.88 | 88.84 | 88.84 | 0% | 0% | 0% |
| | Winter | 84.35 | 84.35 | 84.33 | 0% | 14% | 0% |
| | Spring | 89.16 | 88.81 | 88.85 | 0% | 0% | 0% |
| | Summer | 88.90 | 88.86 | 88.90 | 0% | 0% | 0% |
| **Anchorage** | Autumn | 89.36 | 89.05 | 89.05 | 40% | 88% | 34% |
| | Winter | 89.10 | 89.10 | 89.10 | 87% | 100% | 87% |
| | Spring | 88.12 | 89.06 | 89.10 | 1% | 7% | 0% |
| | Summer | 84.31 | 84.31 | 84.31 | 0% | 0% | 0% |

| **Included Schedules by Shift** | Day | Evening | Night | School | Total |
|---|---|---|---|---|---|
| Commute to Work | 20 | 0 | 0 | 15 | 55 |
| Commute Home | 0 | 0 | 20 | 0 | |

**Supplementary Data Table 4. Average Effectiveness and Percent Darkness During Evening Rush Hour by City, Season, and Time Change Condition**

| | | | Average Effectiveness | | | Percent Darkness | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| Evening | New York City | Autumn | 97.64 | 97.53 | 97.50 | 19% | 0% | 21% |
| | | Winter | 97.48 | 97.45 | 97.48 | 20% | 0% | 20% |
| | | Spring | 97.27 | 97.47 | 97.48 | 0% | 0% | 0% |
| | | Summer | 97.60 | 97.60 | 97.52 | 0% | 0% | 0% |
| | Chicago | Autumn | 97.65 | 97.53 | 97.51 | 24% | 0% | 27% |
| | | Winter | 97.48 | 97.45 | 97.48 | 25% | 0% | 25% |
| | | Spring | 97.25 | 97.46 | 97.47 | 0% | 0% | 0% |
| | | Summer | 97.59 | 97.59 | 97.52 | 0% | 0% | 0% |
| | El Paso | Autumn | 97.65 | 97.53 | 97.51 | 3% | 0% | 3% |
| | | Winter | 97.42 | 97.45 | 97.42 | 0% | 0% | 0% |
| | | Spring | 97.31 | 97.50 | 97.49 | 0% | 0% | 0% |
| | | Summer | 97.52 | 97.52 | 97.53 | 0% | 0% | 0% |
| | Los Angeles | Autumn | 97.66 | 97.53 | 97.54 | 13% | 0% | 14% |
| | | Winter | 97.42 | 97.46 | 97.42 | 9% | 0% | 9% |
| | | Spring | 97.27 | 97.47 | 97.49 | 0% | 0% | 0% |
| | | Summer | 97.52 | 97.52 | 97.51 | 0% | 0% | 0% |
| | Anchorage | Autumn | 97.63 | 97.48 | 97.50 | 7% | 0% | 7% |
| | | Winter | 97.43 | 97.41 | 97.43 | 17% | 0% | 17% |
| | | Spring | 97.28 | 97.49 | 97.46 | 0% | 0% | 0% |
| | | Summer | 97.47 | 97.47 | 97.47 | 0% | 0% | 0% |

| **Included Schedules by Shift** | Day | Evening | Night | School | Total |
|---|---|---|---|---|---|
| Commute to Work | 0 | 20 | 0 | 0 | 40 |
| Commute Home | 20 | 0 | 0 | 0 | |