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# Manning level and shift schedule analysis for the Combined Aerospace Operations Centre

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## IMPORTANT INFORMATIVE STATEMENTS

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# Abstract

The Combined Aerospace Operations Centre (CAOC) at 1 Canadian Air Division (1 CAD) operates primarily on two shifts of twelve hours each to provide 24 hour manning. This is atypical amongst NORAD Aerospace Operations Centres, most of which operate on three shifts of eight hours each. The Operational Research and Analysis Directorate (ORAD) at 1 CAD was tasked to determine how the efficacy of the CAOC might be affected/improved by changes in shift scheduling. Meetings with CAOC personnel and an analysis of three years' worth of shift schedules revealed that, in the present state, a move to 8 hour shifts is unadvisable since the CAOC is undermanned. A move to 8 hour shifts is only recommended if the CAOC achieves proper manning levels by being able to realizes no-fail mechanisms which prevent crews from working when not scheduled. Some recommendations are independent of shift scheduling and include having the outgoing shift deliver the morning brief to the General Officer, implementing late shift starts and tracking and increasing the Senior Operations Duty Officers' (SODOs) rates of participation in exercises.


# Significance to defence and security

This document outlines a transparent, realistic and impartial methodology to estimate annual rates of work for non-shift workers, shift workers on 8 hour shifts and shift workers on 12 hour shifts as well as minimum manning levels. Using this methodology senior staff can evaluate whether their sections are in compliance with the Canadian Forces Leave Policy Manual (A-PP-005-LVE/AG-001) Section 2.8.01 where shift workers are to be given "equivalent time off…at regular intervals" (as compared to regular, non-shift workers) so as to "provide members with rest time associated with weekends and statutory holidays." Scientifically-based shift schedule recommendations are provided for the current CAOC composition (*i.e.*, undermanning) as well as recommendations for the regime of proper manning levels.

# Résumé

Le Centre multinational d'opérations aérospatiales (CMOA) de la 1re Division aérienne du Canada (1 DAC) fonctionne principalement au moyen de deux quarts de travail de 12 heures, pour avoir du personnel en poste 24 heures par jour. Cette organisation de l'horaire est atypique parmi les centres d'opérations aérospatiales du NORAD, qui fonctionnement pour la plupart selon trois quarts de travail de huit heures. La Direction d'analyse et de recherche opérationnelle (DARO) de la 1 DAC a été mandatée de déterminer dans quelle mesure l'efficacité du CMOA serait améliorée ou affectée par un changement dans l'horaire de quart. Des rencontres avec le personnel du CMOA et une analyse des horaires de quart de travail sur trois ans ont révélé que dans l'état actuel, un changement vers des quarts de huit heures n'est pas avisé étant donné que le CMOA n'a pas l'effectif nécessaire. Un changement vers des quarts de huit heures n'est recommandé que si le CMOA atteint un niveau d'effectif suffisant, et peut employer des mécanismes qui empêchent les équipages de travailler quand ils ne sont pas de quart. Certaines recommandations ne relèvent pas de l'horaire des quarts, mais plutôt du fonctionnement : avoir le quart sortant donner l'exposé du matin à l'officier général; mettre en place des arrivées tardives dans le quart de nuit et faire le suivi du taux de participation des officiers supérieurs de service des opérations dans les exercices.

# Importance pour la défense et la sécurité

Le rapport présente une méthode transparente, réaliste et impartiale d'estimer les taux de travail annuels pour les travailleurs selon un horaire régulier, selon un quart de travail de huit heures, et selon un quart de travail de douze heures, de même que le niveau d'effectif minimal. À l'aide de cette méthode, les cadres supérieurs peuvent évaluer si leurs sections sont conformes au Manuel sur les politiques régissant les congés des Forces canadiennes (A-PP-005-LVE/AG-001) Section 2.8.01, selon lequel, les travailleurs par quart doivent recevoir « une période équivalente de repos ... à intervalles réguliers » (comparativement à un travailleur ordinaire), de manière à « offrir aux militaires la période de repos associée aux fins de semaine et aux jours fériés. » Des recommandations fondées sur des données scientifiques relativement aux horaires de travail par quart sont fournies pour la composition actuelle du CMOA (en sous-effectif), de même que pour un effectif complet.

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# 1 Introduction

## 1.1 Tasking to look at shift schedules for the Combined Aerospace Operations Centre

The A3/Combined Aerospace Operations Centre (CAOC) Combat Operations Division tasked the Operational Research and Analysis Directorate (ORAD) at 1 Canadian Air Division (1 CAD) to determine whether the efficacy of the CAOC could be improved by changing the shift schedule. The CAOC supports the Canadian NORAD Region (CANR), 1 CAD and the Combined Joint Forces Air Component Command (CJFACC). Typical NORAD Aerospace Operations Centres operate on three shifts of eight hours each in order to provide 24 hour manning whereas the CANR/1 CAD/ CJFACC CAOC (hereafter referred to as the CAOC) operates primarily on two shifts of twelve hours each. We were asked specifically to look at the impact of moving the CAOC to 8 hour shifts as compared to the *status quo* in light of a recent scientific study (see [1]) which indicated that health and performance benefits for individuals can be realized by implementing shift length reductions. The authors were specifically asked to investigate and recommend shift schedules that allow for leave and days-off that are better aligned with those of (non-shift working) day staff and to ensure that the shifts are equitable amongst the various CAOC (shift working) crews. During the course of our analysis we realized that there was a need to broaden the range of considerations in order to optimize CAOC operations by treating it as a system of systems. Further, the authors realized that some changes in shift schedule would have zero impact on performance.

## 1.2 Methods of analysis in this study

For the current tasking the authors employed a variety of investigative approaches and analyses to identify potential improvements in CAOC function broadly and at the system level, *i.e.*, our goal was to optimize the overall (net) function of the CAOC and not to aim to simultaneously improve all sub-systems. In addition to the typical review of peer-reviewed scientific literature, we made an attempt to meet, individually or as a group, with each CAOC worker in order to identify how shift schedules impact on their physical or mental health (in compliance with [2]). These meetings occurred with all "those employed by the CAOC," *i.e.*, CAOC shift workers, (non-shift) CAOC day workers and Division staff workers who are qualified to fill in as CAOC workers (collectively referred to as "proficiency-shift workers" or "pro-shifters"), CAOC trainers, CAOC evaluators, the Chief of Combat Operations (CCO) and those qualified as acting CCOs. In these meetings several common themes emerged—these themes are referred to collectively as "Recurring Factors" or RFs. For each RF we investigated and reported on:

1. the perception of the RF;
2. research methods in investigating the RF;
3. the reality of the RF (based upon our research);
4. the impact (if any) of 12 hour shifts *vs*. 8 hour shifts on the RF; and
5. recommendations on which shift schedules would best mitigate the RF.

Finally, overall recommendations were made by favouring those RFs which were most likely to result in improvements in CAOC function at the system level for two different situations:

1. the assumption of the CAOC maintaining current manning levels; and

2. the assumption of the CAOC having increased manning.

In both cases, in addition to presenting the recommended shift schedule, attention was drawn to those RFs which may be negatively impacted by the recommended schedule.

In some cases the information analyzed by the authors was anecdotal (*e.g.*, commonly-held opinions offered by a large number of CAOC workers) and in other cases it was quantitative (*e.g.*, the analysis of scheduled work hours as compared to the schedule of actual hours worked). All CAOC-specific information analyzed by the authors was supplied by CAOC personnel.

While scheduled work hours were available from 1 January 2014 to 31 December 2016, the authors had access to actual hours worked only for the period of time 1 January 2014 to 31 July 2016 (we were engaged with this study in August 2016). The Exercise RIMPAC 2016 had a pronounced, anomalous effect (increase) on workload in July 2016 and was therefore excluded from our analysis. We found that the hours worked between 1 January 2014 and 30 June 2014 was approximately half the hours worked in all of 2014. Similarly, the hours worked between 1 January 2015 and 30 June 2015 was approximately half the hours worked in all of 2015. Given these similarities we were able to exclude extra hours worked because of RIMPAC 2016 and instead used the hours worked between 1 January 2016 and 30 June 2016 to extrapolated to the total hours to be worked in 2016.

In data gathering, data analysis and in formulating recommendations we constrained by: (1) we did not conduct a formal, systematic survey of members; and (2) when considering equity between shift workers and non-shift workers, CAOC leadership directed us to use [2] as a guiding document and basis for comparison. In [2] it stipulates that shift workers must be given "equivalent time off…at regular intervals" (as compared to non-shift workers) so as to "provide members with rest time associated with weekends and statutory holidays" (Section 2.8.01). As it is impractical to calculate "time off" and "rest time" we chose to use annual rates of work (which are easier to calculate) as a proxies for determining whether or not there is equity in the available "time off" and "rest time" for shift workers and non-shift workers.

## 1.3 CAOC composition

According to current CAOC leadership, when it was originally stood up, on any shift the CAOC was to normally comprise a Senior Operations Duty Officer (SODO), a Deputy Duty Officer (DDO), a Senior Operations Duty Technicians (SODT) and two Deputy Duty Technicians (DDTs) with the CCO either present and on duty or on call. Anecdotally it was reported that since approximately 2014 the CAOC has never operated with more than two technicians (one SODT and one DDT) per shift. A cursory examination of CAOC shift logs corroborates this assertion.

# 2 Results and discussion

## 2.1 The emergence of Recurring Factors (RFs)

Four Recurring Factors (RFs) emerged during meetings with those employed by the CAOC:

1. equity/human resources deficit;
2. Situational Awareness (SA);
3. human factors/preferences; and
4. proficiency.

The first RF refers to the perception that the hours worked by shift workers was different from that worked by typical (non-shift) workers and therefore contrary to [2]. The second RF refers to the perception that, on occasion, the SODO demonstrates a lack of SA (see Section 2.4) in his/her daily brief to the Commander of CJFACC/CANR/1CAD (hereafter this is referred to as the "brief to the General Officer (GO)"). The third RF refers to, among other things, the perception of a conflict between the shift-lengths preferred by CAOC shift workers and the preference of their superiors. The final RF refers to the perception that, on occasion, the Senior Operations Duty Officer (SODO) demonstrates a lack of proficiency at his/her duties.

The four RFs, above, are an admixture of qualitative perceptions and quantifiable values. For example, scheduled and actual hours worked by shift workers can be quantified and compared to hours worked by non-shift workers. On the other hand instances of the SODO demonstrating a lack of proficiency are difficult to quantify without first establishing rigorous metrics for quantifying proficiency, then applying them in a controlled environment. Owing to time constraints the authors analyzed the equity RF quantitatively and the remaining three RF qualitatively. The analysis of the equity RF is presented below. Of the qualitative RFs, SA emerged as being pivotal to the function of the CAOC and that RF is included in the main body of this document. The authors captured the remaining two qualitative RFs in annexes so as to document the findings of their meetings with those employed by the CAOC.

## 2.2 Equity

### 2.2.1 Method of analysis

As noted above, the equity/human resources deficit RF was analyzed/reported on in five parts:

1. perception;
2. research;
3. reality;
4. impact of 12 hour shifts *vs*. 8 hour shifts; and
5. recommendations.

The perception of this RF is that the current manning makes it difficult to allow time for professional development, career courses, *etc.*, for the shift workers and that the current shift schedule of four 12 hour shifts followed by a recovery day and four days off is overly generous (with respect to time off work). We investigated this RF by analyzing three years' worth of CAOC shift work schedules (both planned shift schedules and schedules of actual shifts worked) as supplied by CAOC personnel as well as having discussions with those employed by the CAOC so as to ensure a clear understanding of CAOC schedules and shift composition.

### 2.2.2 Determination of annual hours worked by shift workers and non-shift workers

The Canadian Forces Leave Policy Manual [2] requires that shift workers must be given "equivalent time off…at regular intervals" (as compared to non-shift workers) so as to "provide members with rest time associated with weekends and statutory holidays" (Section 2.8.01). The authors took the number of annual hours worked as a metric for determining "time off."

Current CAOC 12 hour shifts schedules comprise four types of "day": a 12 hour day (D) shift, a 12 hour night (N) shift; a recovery (R) day[1] [3–6]; and days off (O). The current CAOC schedule is DDNNROOOO. The adoption of an 8 hour shift requires the introduction of a fifth type of shift—the evening (E) shift. From the point of view of health and well-being it is a generally-accepted best practice to have 8 hour shifts [4–5, 8] that rotate rapidly [4–6, 8] through the types of shift and that such shifts should be forward-rotating [4–6, 8, 9] (also referred to as clockwise rotation, *e.g.*, DEN) rather than backward-rotating [3, 10] (also referred to as counter-clockwise rotation, *e.g.*, night-evening-day or NED). An example an 8 hour schedule that adheres to these best practices is DDEENNROOO. Solely from the point of view of health and well-being the authors recommend adoption of rapid forward-rotating 8 hour shifts. Unfortunately there are many more factors to account for than simply health and well-being when optimizing the function of the CAOC. For a recent sleep study on CAOC personnel on a 12 hour DDNNROOOO schedule consult [7].

Calculating the *scheduled* annual hours worked is straightforward. Conversely, calculating the *actual* or *real* annual hours worked by a typical member can be contentious. Institutionally there are traditional days of leave (*e.g.*, short days, sport days) for some CAF members that are customary and expected yet have no official annual allotment. In order to meaningfully compare actual rates of work for shift workers and non-shift workers it is important to realistically and transparently document customary and expected periods of leave. Such a method for calculating the annual hours worked was agreed upon by the authors and CAOC senior staff—it was presented initially in [11] and expanded upon herein for shift workers on 12 hour shifts, shift workers on 8 hour shifts and non-shift workers. Table 1, below, indicates the position-based daily hours worked while the annual days worked is presented in Table 2. Both Tables 1 and 2 were presented initially in [11] and are reproduced below with the introduction of associated uncertainties. Positive numbers indicate time that a member gives to an establishment while negative numbers indicate "time off" that an establishment gives to a member. Some of the tabulated values have no associated uncertainty (*e.g.*, a notional 8 hour work day comprises exactly 8 hours) while some values carry inherent uncertainty (*e.g.*, a given 30 minute lunch break may in reality be longer or shorter than

[1] Within the CAF a recovery day is recognized as a day spent off-duty with the purpose of allowing the member to recover from having worked shifts. A recovery day (R) is distinct from a day off (O) in that it is recognized that it is not spent recreating. In this document recovery days are not counted towards days off nor are they counted towards days worked.

30 minutes). Zero-values for hours worked (*e.g.*, lunch break for shift workers) indicate that in the work schedule zero hours have been allocated to the break or task (*i.e.*, lunch is eaten while on duty with no associated break). The uncertainties in time for PT, lunch and handover (where applicable) were estimated and are presented below. The effects of these uncertainties on the total daily hours worked (*i.e.*, the propagation of errors) were be calculated as a Taylor series expansion (see Annex A):

$$\sigma_T = \sqrt{\sigma_a^2 + \sigma_b^2 + \sigma_c^2 + \sigma_d^2} \tag{1}$$

where $\sigma_T$ denotes the uncertainty in the total daily hours worked, $\sigma a$ represents the uncertainty in baseline hours (zero), $\sigma_b$ represents the uncertainty in time for PT, *etc.* The uncertainty in the total hours worked annually was calculated in a similar fashion.

***Table 1:*** *Scheduled daily hours worked by position for RCAF members (modified from [11]).*

| **Leave Type** | **Scheduled Daily Hours Worked by Position (Hours/Day)** | | |
|---|---|---|---|
| | **Non-Shift Worker** | **CAOC Shift Worker** | |
| | | **12 Hour Shifts** | **8 Hour Shifts** |
| Baseline hours | 8 ± 0 | 12 ± 0 | 8 ± 0 |
| Gym time / PT | -0.5 ± 0.2 | 0 ± 0 | 0 ± 0 |
| Lunch | -0.5 ± 0.1 | 0 ± 0 | 0 ± 0 |
| Handover | 0 ± 0 | 0.5 ± 0.2 | 0.5 ± 0.2 |
| Total | 7.0 ± 0.2 | 12.5 ± 0.2 | 8.5 ± 0.2 |

In accounting for the scheduled daily hours worked (Table 1) the authors attributed a handover duration of (0.5 ± 0.2) hours for shift workers based on self-reported durations by CAOC staff. Handovers occur when workers going off shift have to brief relevant, non-closed out tasks to new workers coming onto shift. In the case of non-shift workers any non-closed out tasks are resumed the next work day by the same member, therefore there is no handover.

***Table 2:*** *Scheduled annual days worked by position for RCAF members (modified from [11]).*

| Leave Type | Scheduled Annual Days Worked by Position (Days/Year) | | |
|---|---|---|---|
| | Non-Shift Worker | CAOC Shift Worker | |
| | | 12 Hour Shifts | 8 Hour Shifts |
| Baseline days | 260 ± 0.6 | 146 ± 0.6 | 219 ± 0.6 |
| Annual leave | -25 ± 2 | -25 ± 2 | -25 ± 2 |
| Special Christmas | -2 ± 0 | 0 ± 0 | 0 ± 0 |
| Short days | -6 ± 2 | 0 ± 0 | 0 ± 0 |
| Sport days | -2 ± 1 | 0 ± 0 | 0 ± 0 |
| Statutory holidays | -10 ± 0 | 0 ± 0 | 0 ± 0 |
| Total | 215 ± 3 | 121 ± 2 | 194 ± 2 |

The non-zero value of the uncertainty in the baseline days was determined as follows: a calendar repeats itself once every 28 years. Over a 28 year period there are (260.9 ± 0.6) work days per calendar year (four years are 262 work days long, seven years are 260 work days long and seventeen years are 261 work days long). One commonly-used simplification is that each year comprises 52 weeks of 7 days each with five work days per week. For a non-shift worker the result is $52 \times 5 = 260$ work days per year. The result is a random error of ± 0.6 annual work days and a systematic error of -1 annual work days per year. If the approximation of 260 annual work days in a year is applied to both shift-workers and non-shift workers and we are interested in the difference between shift workers and non-shift workers, the systematic error of -1 day per year cancels out, resulting in (260 ± 0.6) baseline work days per year for non-shift workers.

For non-shift workers, associated uncertainties in the number of annual days off work were commuted to annual leave (±2 days is an estimate to account for a small number of members having accrued 30 days annual leave), short days and sport days (±2 days and ±1 day, respectively, as estimates to allow for annual and location-based variances). The typical number of days off in a year for a non-shift worker is tabulated in Table 2, or (45 ± 3) days off work, which is equivalent to (320 ± 10) hours off work, resulting in a net number of hours worked of $215 \times 7.0 = 1505$ hours per year. The net number of hours worked by a typical (non-shift) worker is properly expressed, after rounding off to the appropriate number of significant figures, as (1500 ± 50) hours per year. For a non-shift worker, time for professional development, career courses, Annual Personal Readiness Verification (APRV) requirements, *etc.*, would be deducted from this value of (1500 ± 50) hours per year worked.

For shift workers on 12 hour shifts one cycle comprises four work days at 12.5 hours each (this includes a 30 minutes overlap at the handover) followed by one recovery day and five days off. There are 36.5 ten-day cycles in one year, with a year of shift work corresponding to (146 ± 0.6) shifts worked. The associated uncertainty in the number of annual days off work if the uncertainty in the annual leave, or ±2 days to account for a small number of members having accrued 30 days annual leave). The typical number of days off in a year for a 12 hour shift worker is tabulated in Table 2, or (25 ± 2) days off work, which is equivalent to (310 ± 5) hours off work. Deducting 25 days of annual leave, the result is 121 shifts per year. The shift workers therefore work a net 121 × 12.5 =1512.5 hours per year. In addition to the ±2 days uncertainty in the amount of annual leave, another sources of uncertainty was estimated to be ±0.2 hours associated with each 30 minute handover. After rounding off the net number of annual hours worked by a shift worker on a 12 hour shift is (1510 ± 30) hours. Conversations with those who originally stood up the CAOC revealed that it was the intent to have pro-shifters fill-in for CAOC shift workers so that the latter could attend to professional development, career courses, APRV requirements, *etc.*, during their regularly scheduled shifts. Anecdotally it was widely reported that these requirements are usually completed by CAOC shift workers on their normal days off whereas such tasks are normally completed by non-shift workers during regular work hours. This effectively extends a CAOC worker's time worked beyond (1510 ± 30) hours per year. Insufficient manning is reported as the reason for these duties being completed during non-work hours.

The number of annual hours worked increases if shift lengths are reduced to 8 hours. On an 8 hour shift schedule (DDEENNROOO) there are six work days of 8.5 hours each (with a 30 minute overlap at handover) for a total of 8.5 × 6 = 51 hours per cycle. The work cycle has a periodicity of 10 days per shift resulting in 36.5 such cycles in a year. In one work year there are 36.5 × 6 = 219 shifts worked. The typical number of days off in a year for an 8 hour shift worker is tabulated in Table 2, or (25 ± 2) days off work, which is equivalent to (210 ± 5) hours off work. Deducting the annual leave of 25 days, the result is 194 shifts per year. The net number of annual hours worked by a shift worker on 8 hour shifts is 194 × 8.5 =1649 hours. The uncertainty in the hours worked was determined to be influenced by uncertainty in time for handover (±0.2 hours) and uncertainty in the number of days leave (taken to be ±2 days so as to approximate that portion of members which have accrued 30 days annual leave). After rounding off the net number of hours worked by a 8 hour shift worker is (1650 ± 40) hours per year. It is assumed that professional development, career courses, APRV requirements, *etc.*, are done on normal days of rest as is the convention for 12 hour shift workers, again due to low manning levels.

The authors found a disparity between the *scheduled* shift hours per year and the shift hours per year that were *actually worked*, with those hours actually worked being greater than the scheduled work hours in the majority of the cases. This disparity is caused by the fact that some CAOC positions are unmanned, resulting in an undermanning situation where, in order to maintain 24/7 operations, shift workers are required to work more than the (1510 ± 30) hours per year that were deemed equitable when the CAOC was being stood up. A detailed analysis of the disparity between scheduled and actual hours worked is presented in Section 2.2.3, below.

### 2.2.3 Pro-shifters—roles and responsibilities

Pro-shifters are non-shift workers that belong to Directorates other than the CAOC and who report to Directors other than the CAOC CCO. When a pro-shifter is filling in a CAOC shift they are not available to perform their regular duties. When the CAOC was stood up it was assumed that (non-shift working) pro-shifters would be able to provide sufficient flexibility that shift workers would be able to take career courses, accomplish professional development, attend to APRV requirements, *etc.*, on a normal day of

work. In practice, however, it is a widely-held belief that the pro-shifters are not delivering the flexibility that they were intended to provide. Widely-held (anecdotal) observations regarding pro-shifters are:

1. some pro-shifters don't want to take shifts, especially not night shifts or weekend shifts;

2. some superiors make their pro-shifters available less than the requisite twice per month citing that their staff are required for the performance of their regular duties;

3. shift workers who would normally work two day shifts followed by two night shifts (*i.e.*, DDNN) regularly work an extra night shift (*i.e.*, DNNN or NDNN) in order to make day shifts available as it is perceived that pro-shifters are generally unwilling/less willing to take night shifts; and

4. shift workers often spend off-days on-duty covering a colleague's shift because pro-shifters were unable to fill in.

We analyzed CAOC work schedules for 2014–2016 to assess the average number of shifts per month worked by a pro-shifter. These results are presented in Table 3. On average, pro-shifter CCOs and SODOs were found to meet or exceed the requirement of two shifts per month. The high values of the standard deviations presented in Table 3 reflect the fluctuations in availability and utilization. Pro-shifting DDOs on average met or exceeded the requirement of two shifts per month from 1 January 2014 to approximately 30 July 2015, then (as seen in Figure 1) their rates of participation began to steadily decline (see Figure 1). Pro-shifter day shift workers (DSs) have consistently been below the target of averaging two shifts per month (see Figure 2). The authors lack the data to ascertain the validity of first two anecdotal observations regarding pro-shifters (see above). A shiftwork analysis was not carried out to ascertain the validity of the third anecdotal pro-shifter observation. However, in light of the data presented in Table 3, it seems that, in the case of SODTs/DDTs as well as in the case of DDOs after approximately 30 July 2015 the fourth anecdotal pro-shifter observation may be valid as, in these cases, participation in pro-shifting falls below the target rate. However, in the case of CCOs and SODOs, pro-shifters are participating at the requisite rate of twice per month. Instances of shift worker CCOs and SODOs spending off-days on-duty to cover a colleague's shift could not be attributed to pro-shifters, rather, it is indicative of a structural manning problem in the CAOC, most likely undermanning.

***Table 3:*** *Average number of pro-shifter shifts worked per month by year (modified from [11]).*

| Position | Year | Shifts Per Month |
|---|---|---|
| CCO | 2014 | 2.2 ± 1.1 |
| | 2015 | 2.0 ± 1.4 |
| | 2016 | 2.4 ± 0.6 |
| SODO | 2014 | 2.1 ± 0.7 |
| | 2015 | 2.0 ± 0.8 |

| Position | Year | Shifts Per Month |
|---|---|---|
| | 2016 | 2.1 ± 0.5 |
| DDO | 2014 | 2.7 ± 1.0 |
| | 2015 | 2.7 ± 0.8 |
| | 2016 | 1.5 ± 0.7 |
| SODT/DDT | 2014 | 0.7 ± 0.6 |
| | 2015 | 0.4 ± 0.6 |
| | 2016 | 0.4 ± 0.5 |

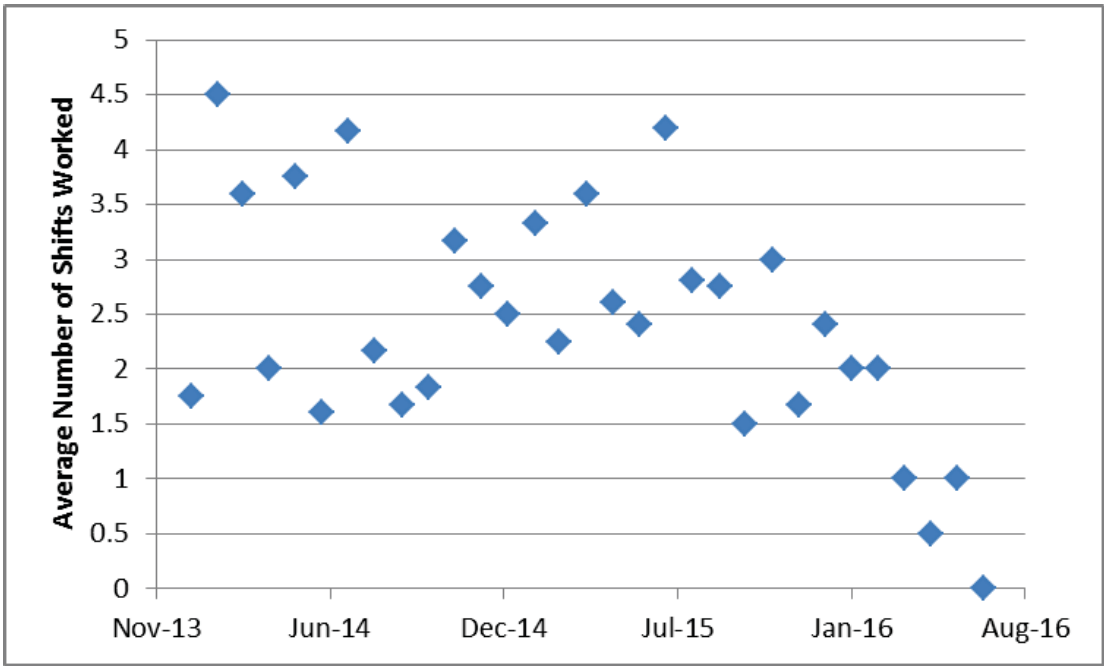


***Figure 1:*** *Average number of shifts worked per month by pro-shift DDOs.*

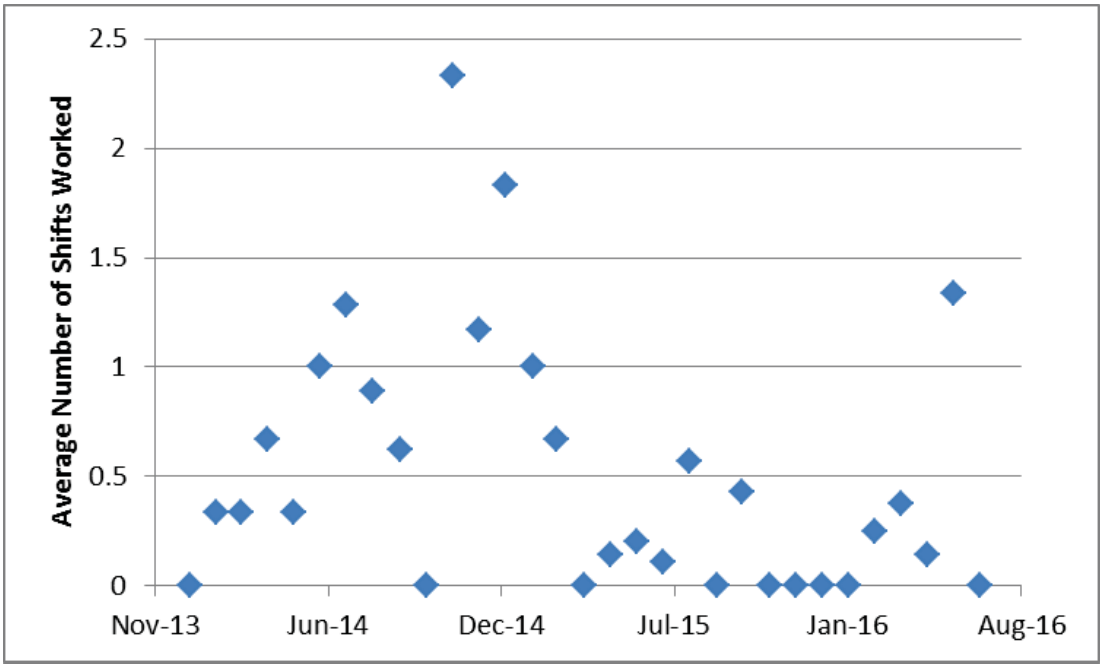


***Figure 2:*** *Average number of shifts worked per month by pro-shift SODTs/DDTs.*

### 2.2.4 Work schedule *vs*. actual hours worked

The annual hours scheduled and worked by shift workers by position in 2014 and 2015 are shown in Figures 3 and 4, respectively, as are the scheduled hours for non-shift workers. The annual hours worked for shift workers in 2016 is estimated from hours worked between 1 January 2016 and 30 June 2016 and is shown in Figure 5. As noted above, the net number of hours worked by a typical (non-shift) worker is (1500 ± 50) hours per year and generally includes time taken during regular work hours for professional development, career courses, APRV requirements, *etc.*, while (according to CAOC personnel) the annual hours worked for a CAOC shift worker generally do not.

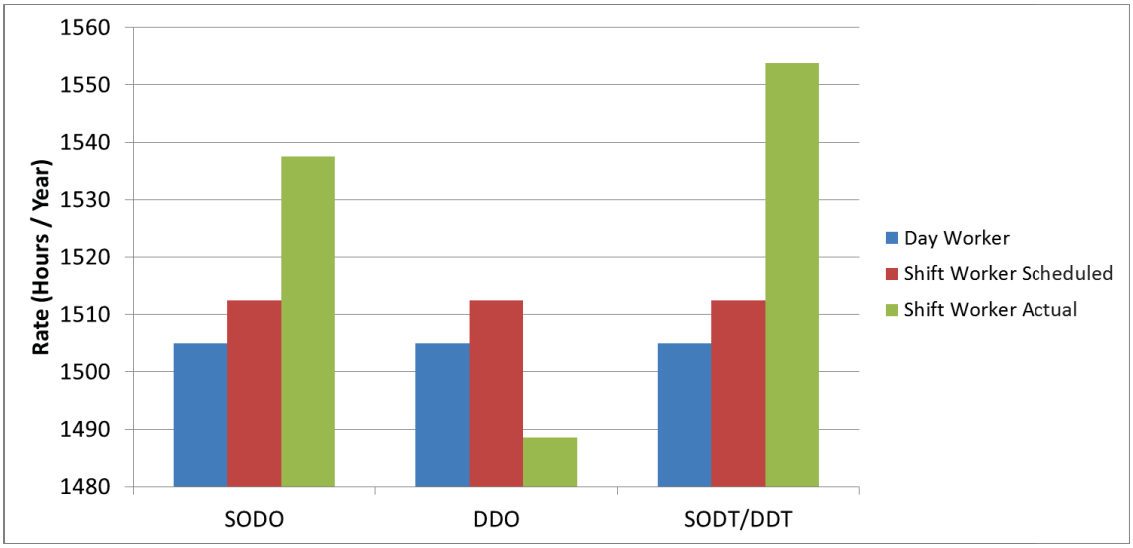


***Figure 3:*** *Annual hours worked in the CAOC by position in 2014 compared to non-shift workers.*

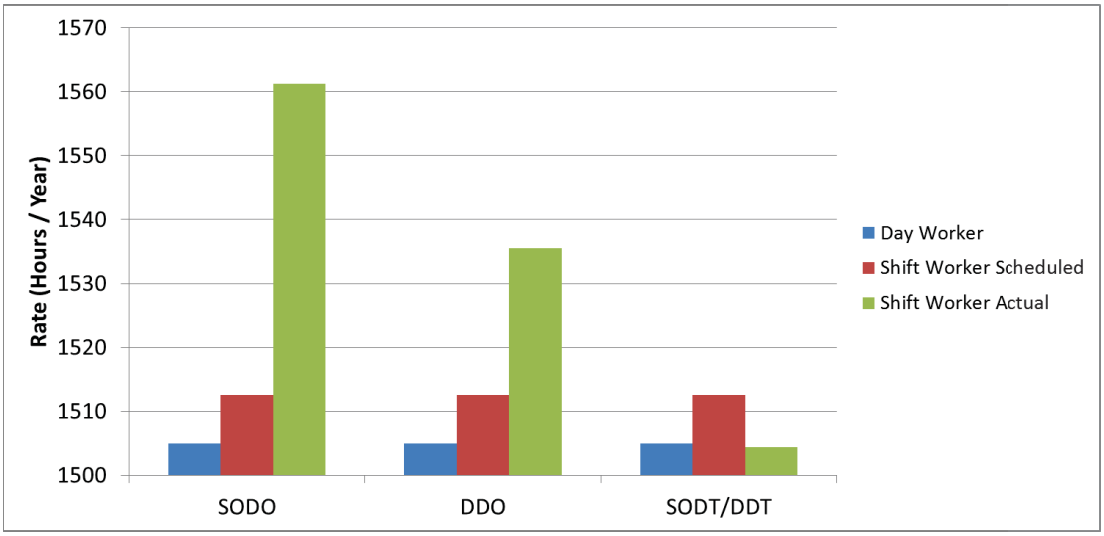


***Figure 4:*** *Annual hours worked in the CAOC by position in 2015 compared to non-shift workers.*

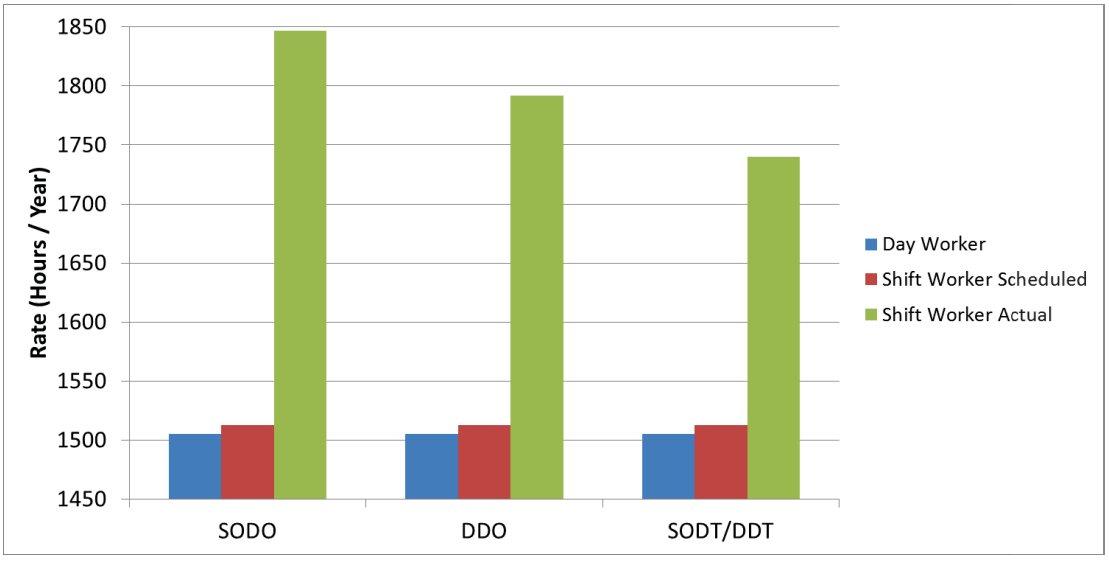


***Figure 5:*** *Annual hours worked (extrapolated) in the CAOC by position in 2016 compared to non-shift workers.*

In Figures 3–5 scheduled hours of work for non-shift workers are represented by blue bars, scheduled hours of work for shift workers on 12 hour shifts are represented by brown bars and actual hours worked by shift workers on 12 hour shifts are represented by green bars. As noted previously, the inherent uncertainties in annual rates of scheduled work were estimated to be ±50 hours for non-shift workers and ±30 hours for shift workers on 12 hour shifts. Based on data from 1 January 2014 through 30 June 2016 the standard deviation in the annual rates of work was calculated to be approximately ±50 hours for SODOs, ±10 hours for DDOs and ±40 hours for SODTs/DDTs. The standard deviation in actual rates of work and the estimated uncertainties in the schedules rates of work are in good agreement indicating that there is unlikely to be an unaccounted for systematic error in our assumptions. While graphically CAOC shift workers appear in general to work more hours annually than do non-shift workers and to work more hours than scheduled, in 2014 and 2015 the disparity is small and within calculational uncertainty. In the first half of 2016 all CAOC workers worked significantly more hours than non-shift workers and significantly more hours than they were scheduled to work. The (extrapolated) total annual rate of work for 2016 (see Figure 5) exceeds the benchmark (1500 ± 50) hours per year by more than three standard deviations. In 2016 the (extrapolated) annual hours of work exceed that of a non-shift worker by (340 ± 70) hours for SODOs, by (290 ± 50) hours for DDOs and by (240 ± 70) hours for SODTs/DDTs.

In an ideal situation the scheduled hours worked per year should be identical to the actual hours worked in a year. Small deviations from scheduled hours worked are to be expected. The authors conclude that instances where actual hour worked exceed scheduled hours are largely attributable to undermanning. From 1 January 2014 through 30 June 2016 there is a general upward trend in annual hours worked exceeding scheduled hours with the exception of SODTs/DDTs in 2015 (where a Reserve worker was able to alleviate undermanning). The manning problem is worst for the most senior position (SODO). A widely-reported consequence of undermanning was that personnel were required to work shifts in addition to their regularly-scheduled shifts and as a result the actual schedule worked had poor predictability.

### 2.2.5 Required manning levels by shift type

As reported in [11], when CAOC was first stood up, the desired end-state was:

1. Five teams of five shift workers each;

2. One team of five day workers who can double as pro-shifters; and

3. Two additional pro-shifters elsewhere in the HQ with each pro-shifter doing two shifts per month to maintain proficiency.

The initial CAOC manning was to consist of 12 hour shifts. Once fully manning was achieved, the goal was to implement 8 hour shifts.

The number of requisite fully-manned teams is influenced by the length of the shift, with longer shifts requiring fewer teams than shorter shifts. CAOC workers on 12 hour shifts work 121 shifts per year (see Table 2). There are 365 × 2 = 730 shifts of 12 hours each in one year. The minimum number of teams required that will be calculated will be a true minimum—it will not account for any absence from work due to sickness or other reason, nor will it allow for PD, career courses, APRV, *etc.*, to be carried out during work hours. In order to man the CAOC one needs 730 ÷ 121 = 6.03 teams—this minimum value should be rounded upwards. If two pro-shifters each take two shifts of 12 hours each per month, this reduces the shift burden by 12 × 2 × 2 = 48 shifts per year, leaving 730 - 48 = 682 shifts per year to be manned by CAOC personnel. There is therefore a need for 682 ÷ 121 = 5.64 CAOC teams. Ideally there would be six CAOC teams as this would ensure the flexibility to deal with sick leave or other absences, PD, *etc*. Currently there are five CAOC teams plus two pro-shifters per position, leaving the shortfall of 5.64 – 5 = 0.64 teams to be made up by five CAOC day workers who can double as pro-shifters. If the number of teams required is $N$, then the uncertainty in this value, denoted $\sigma_N$, is given by the expression (see Eq. A.8):

$$\sigma_N = N\sqrt{\left(\frac{\sigma_T}{T}\right)^2} \tag{2}$$

where $T$ is the total annual work days and $\sigma_T$ is the associated uncertainty (see Table 2 and Eq. 1). The number of teams required is properly expressed (with the associated uncertainty) as (5.64 ± 0.09) teams with CAOC day worker doubling as pro-shifters making up the remaining (0.64 ± 0.09) teams. As noted in Section 2.2.1 in the case of 8 hour CAOC shifts, members would work (1650 ± 40) scheduled hours per year, or (140 ± 70) hours more than non-shift workers. It is possible to either grant a combined 17 days leave to bring the annual hours worked into compliance with [2] or to require that shift workers work (140 ± 70) hours more per year more than do non-shift workers.

If additional leave is not granted, annually shift workers would work 194 shifts. There are 365 × 3 = 1095 such shifts in one year, requiring 1095 ÷ 194 = 5.64 teams. If two pro-shifters each take three shifts of 8 hours each per month (two shifts of 12 hours each is identical to three shifts of 8 hours each), this reduces the shift burden by 12 × 2 × 3 = 72 shifts per year, leaving 1095 - 72 = 1023 shifts per year to be manned by CAOC personnel. There is therefore a need for 1023 ÷ 194 = 5.27 CAOC teams. Ideally there would be six CAOC teams as this would ensure the flexibility to deal with sick leave or other absences, PD, *etc*.

Currently there are five CAOC teams plus two pro-shifters per position, which (under this shift scenario) would leave a shortfall of 5.27 – 5 = 0.27 teams to be made up by five CAOC day workers who can double as pro-shifters. The number of teams required is properly expressed (with the associated uncertainty) as (5.27 ± 0.05) teams with CAOC day worker pro-shifters making up the remaining (0.27 ± 0.05) teams.

If CAOC shift workers were granted 17 days leave to bring their work hours into compliance with [2] this would result in 194 – 17 = 177 annual shifts. The minimum number of teams would be 1095 ÷ 177 = 6.19 teams. If two pro-shifters each take three shifts of 8 hours each per month this reduces the shift burden by 12 × 2 × 3 = 72 shifts per year, leaving 1095 - 72 = 1023 shifts per year to be manned by CAOC personnel. There is therefore a need for 1023 ÷ 177 = 5.78 CAOC teams. Ideally there would be six CAOC teams as this would ensure the flexibility to deal with sick leave or other absences, PD, *etc*. Currently there are five CAOC teams plus two pro-shifters per position, which (under this shift scenario) would leave a shortfall of 5.78 – 5 = 0.78 teams to be made up by five CAOC day workers who can double as pro-shifters. The number of teams required is properly expressed (with the associated uncertainty) as (5.78 ± 0.05) teams with CAOC day worker pro-shifters making up the remaining (0.78 ± 0.05) teams. The need for (5.64 ± 0.09) teams in the case of 12 hour shifts *vs.* (5.78 ± 0.05) teams in the case of 8 hour shifts shows the increasing inefficiency realized in moving to shorter shifts where a 30 minute handover accompanies the shift changes.

### 2.2.6 Other factors influencing workload

As part of an analysis into work equity, the authors analyzed the instances of SODT/DDT positions being manned by only one technician on the night shift with a second technician on standby to respond if needed. While these occurrences are not tracked explicitly by the CAOC, the authors analyzed almost three years of work schedules for instances where only one SODT/DDT technician was on-duty during the night shift and assumed that a second SODT/DDT technician was therefore on standby. In 2014 there were 10 occurrences of SODT/DDT positions being on standby. This practice was expanded to 81 instances in 2015, and again to 100 instances between 1 January 2016 and 20 June 2016 (see Figure 6). There is no department-wide policy on awarding compensatory time-off (CTO) or other form of credit for being on standby other than the [2] requirement for "equivalent time off" (as compared to regular, non-shift workers). It is broadly acknowledged that being on standby imposes limits on one's ability to recreate (as they must be able to report fit-for-duty within 30 minutes) and is not truly equivalent to time-off, yet for the purpose of calculating the annual shift rates actually worked by SODTs/DDTs, Figures 3 through 5 have a zero rate of CTO.

The authors were directed to commute a 50% CTO rate to shifts spent on standby (*i.e.*, 6 hours of work are credited to every 12 hour shift spent on standby) by the CAOC CCO. The authors were informed by CAOC personnel that only SODTs/DDTs are put on standby and that the vast preponderance of the time the standby SODT/DDT is a shift worker (as opposed to a pro-shifter). The effect of a 50% CTO rate on SODT/DDT shift workers for the years 2014, 2015 and 2016 (the latter rate is extrapolated from the first 6 months of 2016 data) is shown in Figure 7. With the 50% CTO rate, in the years 2014 and 2015 the SODT/DDT shift workers worked the same number of hours as (non-shift) day workers. However, based on the first 6 months of 2016 data the SODT/DDT shift workers are projected to work (240 ± 70) hours more than a (non-shift) day workers with a zero CTO rate and (430 ± 70) hours more than a (non-shift) day workers with a 50% CTO rate.

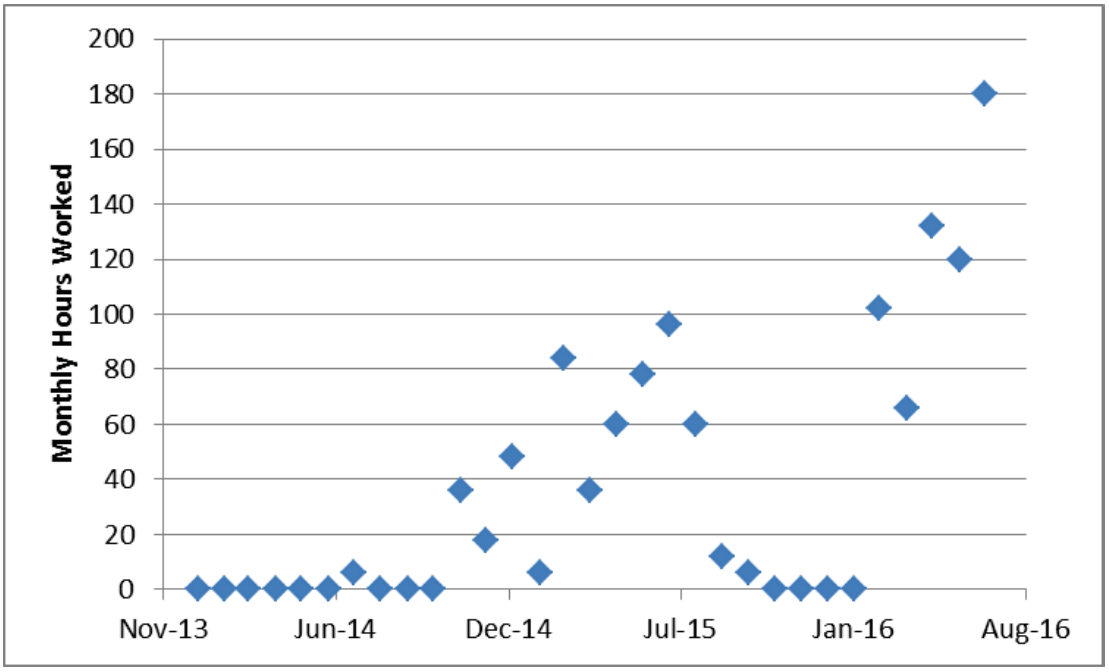


***Figure 6:*** *Monthly hours worked on standby (at 6 hours per 12 hour standby shift) by shift worker SODTs/DDTs.*

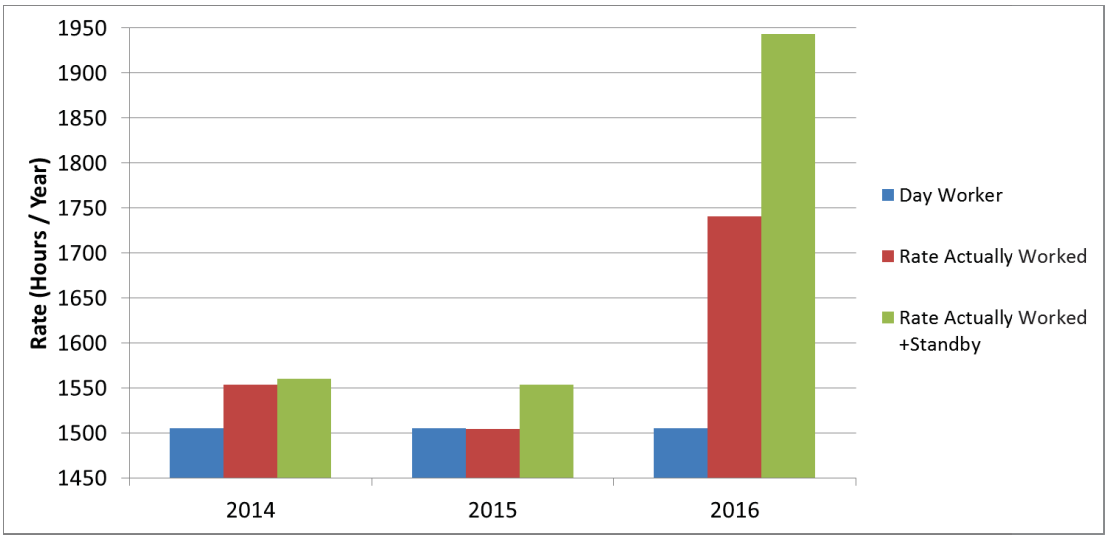


***Figure 7:*** *Annual hours worked by SODTs/DDTs in the CAOC by year (2016 data is extrapolated) compared to non-shift workers illustrating the effect of taking into consideration a CTO rate of 50% for time spent on standby.*

The current composition of the CAOC is significantly smaller than the end-state envisioned during its formulation, resulting in inequity. Some positions unmanned, resulting in a general undermanning of the CAOC. As a result, in Figures 3–5 we observe that shift workers are required to work more hours than they are scheduled to work in order to maintain 24/7 manning. The average annual differences between

the actual hours worked by a CAOC shift worker and the scheduled hours worked by a CAOC shift worker taking into consideration a CTO rate of 50% for time spent on standby is seen in Figure 8 where negative hours indicate underwork and positive values indicate overwork. In meetings with CAOC personnel it was widely-reported that undermanning resulted in overwork and that consequently schedules had poor predictability—this situation seemed to particularly cause distress amongst those members who volunteered that they were single parents.

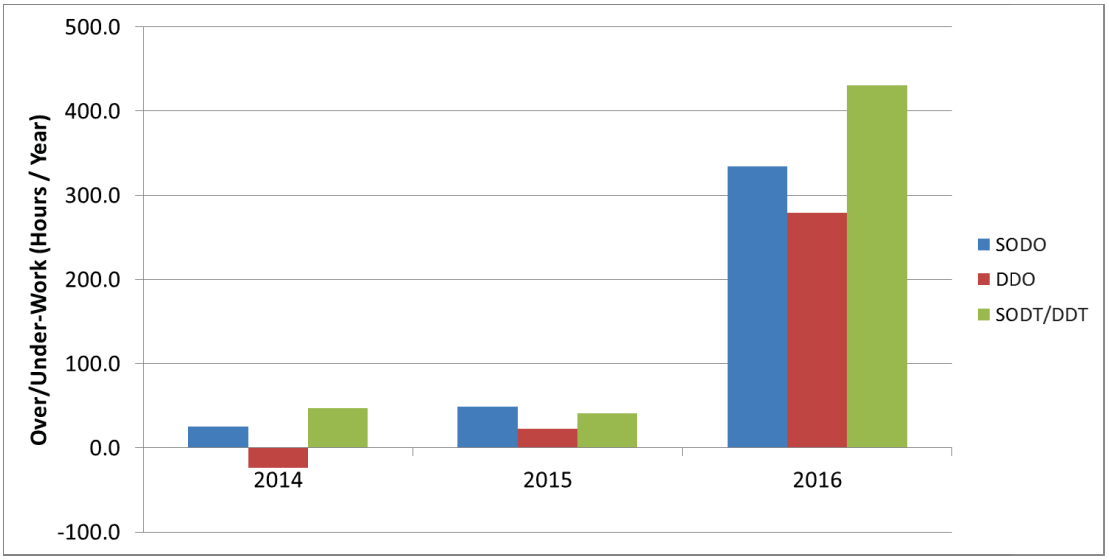


***Figure 8:*** *Average annual differences between the actual hours worked by a CAOC shift worker and the scheduled hours worked by a CAOC shift worker taking into consideration a CTO rate of 50% for time spent on standby (taken from [11]).*

In 2014 there were 37 individuals that worked in the CAOC—these individuals are represented as vertical lines in Figure 9 whose ordering is randomized so as to protect their individual identities. Figure 9 shows the percent of regular workload that individual workers spent on-shift in the CAOC in 2014 (with a 0% CTO rate), with each vertical bar representing the over/underwork by an individual. The scheduled annual hours of work in the CAOC is (1510 ± 40) hours—an individual working this number of hours per year would be indicated by a 0% over/underworked. The majority of workers work more than the scheduled amount of hours. Six workers worked less than 95% of scheduled time, while four were in the CAOC for approximately half a year. Most instances of personnel working significantly less than expected are workers who did not work a full year and were permitted to use a disproportionate amount of leave during that time, contrary to [2] which stipulates that shift workers must be given "equivalent time off…at regular intervals." In undermanned environments, one consequence of disproportionate leave use is over-work for the remaining workforce.

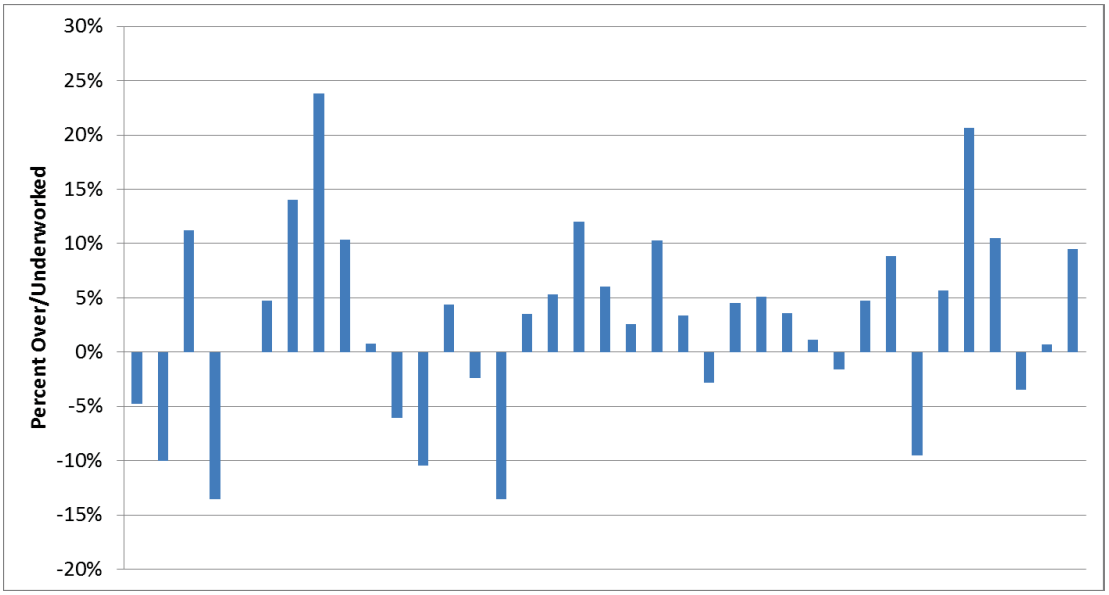


***Figure 9:*** *Percent deviation of individual shift worker regular workload spent on-shift in 2014. Individual lines represent individual workers, displayed in a randomized order.*

### 2.2.7 Recommendations based solely upon equity RF

Under the RF of CAOC shift worker equity with non-shift workers, the authors identified (above) four sub-categories:

1. a disparity between hours worked and hours scheduled for work resulting in a tendency towards (comparative) the over-work of shift workers that is becoming more pronounced with time and results in poor schedule predictability;

2. an increasing use of standby night shifts for SODT/DDT positions which impacts on how and where those individuals can spend their days off;

3. the approval of leave at irregular intervals whereby some individuals were permitted to use a disproportionate amount of leave during that time, shifting the burden onto the remaining shift workers (contrary to [2] which requires the granting of "equivalent time off [compared to non-shift workers]…at regular intervals and not accumulated over long periods of time"); and

4. the employment of pro-shift DSs for less than two shifts per month and/or the trend towards the employment of pro-shift DDOs for less than two shifts per month, resulting in an increased workload for shift workers.

From the point-of-view of equity as described by the above sub-categories, there will be no positive impact in moving to 8 hour shifts *vs*. the current 12 hour shifts as the problem of inequity (with shift workers working too many hours, *etc.*) is one of undermanning, not of work schedule. It is possible that moving to 8 hour shifts will increase the participation rates of pro-shift DDOs and DSs. However, given the undermanning of the CAOC it is likely that 8 hour shifts may (on occasion) lead to some last-minute shifts which have a counter-clockwise shift rotation (which is detrimental to the health and performance

of the individual, see [4, 12]). On the preponderance of the evidence, a move to 8 hour shifts *vs*. the current 12 hour shifts (at current manning levels) is not recommended on the consideration of the equity RF. If CAOC manning levels were to be increased, it is our recommendation that both 8 hour and 12 hour shifts would be equally equitable.

## 2.3 Situational Awareness (SA)

### 2.3.1 Terminology and context

CAOC personnel colloquially refer to the occurrence of an outgoing shift worker not briefing the oncoming shift of a critical non-closed out item at handover as someone (typically the outgoing member) "dropping the ball." The presence of non-closed out items in the CAOC is not a problem as it is normal for some tasks to span multiple shifts (*e.g.*, co-ordinating an airlift across the globe). A problem occurs when a non-closed out item is not briefed to the oncoming staff as then the task is (at least temporarily) lost track of. When such on occurrence gives rise to the responsible shift worker not being able to properly brief the GO, CAOC personnel describe that member's a lack of knowledge as a "lack of SA." The reason for calling the lack of knowledge a lack of SA became evident when we investigated where in a shift schedule the lack of SA occurred (see below). It is important to noted that a lack of SA in the CAOC does not equate with a lack of vigilance, rather, it reflects the reality that human endeavours always involve the possibility of encountering errors.

### 2.3.2 Manifestation of a lack of SA

Prior to the commencement of our study we were informed by some CAOC senior staff that a lack of SA sometimes manifests itself within the CAOC—the RF that we were asked to investigate is the effect of shift schedules on incidents where a lack of SA is observed. We investigated this RF by Meeting with all those employed by the CAOC. Anecdotal observations of a lack of SA were reported to occur by some on a weekly basis and by others to occur on a monthly basis. The perceived lack of SA appears to only be manifested by the SODO, it is manifested only at the daily brief to the GO and that lack of SA only occurs on the first day shift after some days off. After the first (day) shift there are no reported instances of a lack of SA. Rather than calling the error in the SODO brief to the GO a lack of knowledge, it was inferred by CAOC staff that exposure to CAOC activity confers sufficient SA to the SODO to deliver good briefs to the GO, and any lack of knowledge (after a stretch of days off) is indicative of a lack of SA.

We investigated the sequence of events which occur in a handover so as to ascertain how to minimize bad handovers. The sequence of events in a bad handover were previously reported in [11] and are:

1. SODO 1 completes two day shifts and a first night shift during which SODO 1 prepares a brief for SODO 2 to deliver to the GO in the morning;

2. SODO 2 is briefed by SODO 1 at the morning handover when SODO 2 begins the day shift. Despite the existence of checklists, some critical information is not passed to SODO 2 resulting in a bad handover; and

3. after approximately 90 minutes on-duty (including the handover), SODO 2 delivers the morning brief to the GO (which had been developed by SODO 1). A lack of SA is demonstrated by SODO 2.

As noted above, those employed by the CAOC only noticed a lack of SA on the SODOs first day shift, presumably because immersion in the CAOC for a 12 hour shift was sufficient to provide the SODO with good SA. It would appear that, on occasion, the 90 minutes is insufficient for a SODO to establish SA after a period of absence from CAOC shift work. The authors were informed that the timing of the brief to the GO could not be changed.

The authors investigated how changes in start times might impact on SODO SA. Recent studies found that late starts [4–6, 8, 12] improve function if shift start time is delayed to between 0430 h and 0900 h. [12] reported that up to 70% of the extra time in the morning generated by a late start was used for sleep, resulting in positive effects for this range of shift start times. Late starts would also allow the GO to be briefed by the night shift SODO in the presence of the day shift SODO, thus eliminating the first day shift brief to the GO by a SODO with potentially poor SA. Further, the night shift SODO would be delivering a brief that he/she developed over the past 12 hours. Late starts are independent of the shift length.

### 2.3.3 Error rates and shift lengths

In the operational context the goal is to minimize the total rates of error in the CAOC (*e.g.*, the number of errors occurring in the CAOC in a 52 week period of 24/7 manning) rather than to minimize individual rates of error (*e.g.*, the number of errors made by a CAOC staff member in one period of 52 weeks). While the two are related, they are not the same.

The authors investigated the dependence of error rates (*e.g.*, bad handovers) on shift lengths. There is disagreement in the literature on whether or not increasing a shift lengths from 8 hours to 12 hours has an impact on rates of error [13]. However, there is broad support for the notion that increasing shift lengths beyond 12 hours will result in increasing rates of error [13]. After reviewing peer-reviewed scientific literature we concluded that, if there was a pronounced decrease in individual error rates associated with moving to shifts shorter than 12 hours, then there would be no contradiction in the scientific literature. The presence of disagreement in peer-reviewed scientific publications suggests that a decrease in individual error rates associated with shorter shifts (if it exists) must be relatively small.

If the errors that lead to a band handover occur only at the handover, then moving to 8 hour shifts adds one potential error in each 24 hour period. In order to offset the extra handover each day, individual error rates associated with 8 hour shifts must be 33% lower than the individual error rates associated with 12 hour shifts. A reduction in individual error rates by 33% (associated with moving from 12 hour shifts to 8 hour shifts) would be so significant that it would be evident in published literature. Since there is no such unanimity it is likely that moving from 12 hour shifts to 8 hour shifts will not sufficiently decrease in individual rates of error so as to offset the potential of an extra handover error in a 24 hour period associated with 8 hour shifts.

### 2.3.4 Recommendations based solely upon equity SA

A move from 12 hour shifts to 8 hour shifts is not recommended based on the consideration of SA since it is anticipated that this change will result in a net increase in the rates of error in the CAOC (*e.g.*, bad handovers) owing to the extra shift change in each 24 hour period. The authors do not believe that the shorter shift will result in individual error rates falling by 33% so as to offset the risk posed by the extra handover. Ideally the current error rates in the CAOC should be baselined in advance of any changes in shift schedule. Finally, the authors recommend the implementation of two shift-agnostic changes: the night shift SODO should brief the GO in the presence of the day shift SODO and the start of the day shift should be moved to later in the morning so as to facilitate better REM sleep which may result in decreased fatigue and increased performance [4].

# 3 Conclusion/final recommendations

As noted above, the authors' recommendations (*e.g.*, 12 hour *vs*. 8 hour shift *vs*. shift schedule has no effect) varied by RF. Optimizing on all RFs with equal weighting would be incorrect since some RFs are more critical to the operations of the CAOC than others. Our final (net) recommendations for CAOC scheduling are to optimize on mission effectiveness which is defined as the ability to:

1. deliver quality of brief to GO; and

2. deliver all CAOC effects, even with unanticipated shortages in manning.

We further recommend that the CAOC implement recommended changes that are shift-agnostic (so long as they are not contraindicated by other RFs).

As reported previously in [11], the following are our recommendations for optimizing on the SA RF in order of decreasing effectiveness:

1. 12 hour shifts with the night shift SODO briefing the GO in the presence of the day shift SODO and late starts;

2. 8 hour shifts with the night shift SODO briefing the GO in the presence of the day shift SODO and late starts;

3. the current 12 hour shifts with day shift SODO briefing the GO (the *status quo*); and

4. 8 hour shifts with regular start times and the GO being briefed by the day shift SODO.

As reported previously in [11], the following are our recommendations for optimizing the flexibility to respond to sudden shortages in manning in decreasing order of effectiveness:

1. increased CAOC manning and 8 hour shifts;

2. current CAOC manning and 8 hour shifts;

3. increased CAOC manning and 12 hour shifts; and

4. current CAOC manning and 12 hour shifts (the current state of affairs).

The optimal solution for maximizing both SA and flexibility is increased CAOC manning with 8 hour shifts and late starts such that the night shift SODO briefs the GO in the presence of the day shift SODO.

In the case of *increased manning* (as defined in the paragraph above) our recommendation is to move to 8 hour shifts while paying attention to the possibility of an increase in the number of errors in a 24 hour period (owing to an additional handover). In the case of *current manning* our recommendation is to stay with the current 12 hour shift schedule since, in the current state, it is anticipated that moving to 8 hour shifts will make the CAOC less effective.

The authors have noted that the tendency for CAOC shift workers to work more hours per year than they were scheduled to work can only be explained by undermanning. The authors further note that whereas non-shift workers tend to complete professional development, career courses, APRV requirements, *etc.*, during their regularly scheduled work hours, CAOC shift workers self-report that they normally carry out such tasks on scheduled days of rest. The minimum number of teams required for 24/7 manning of the CAOC was calculated assuming zero rates of illness and that all professional development, career courses, APRV requirements, *etc.*, will be carried out outside of regularly scheduled work hours and under the assumption that there are two pro-shifters for each position that will each take two shifts per month. Thus, it is a true minimum and an underestimation of the number of teams required for a functional CAOC. The minimum number of teams required for 12 hour shifts are (5.64 ± 0.09) teams. For 8 hour shifts where shift workers work (140 ± 70) scheduled hours per year more than non-shift workers (5.27 ± 0.05) teams are required. If instead shift workers on 8 hour shifts are given 17 days leave to bring their annual hours worked into compliance with [2] then (5.78 ± 0.05) teams are required. Since the CAOC has five teams the shortfall is covered by CAOC day workers.

# References


[1] DAOD 5062-0, Social Science Research, issue date 18 Jun 2014.

[2] Canadian Forces Leave Policy Manual, A-PP-005-LVE/AG-001, issue date 13 Jan 2009, amended date 1 Apr 2015.

[3] J. Aschoff, K. Hoffman, H. Pohl and R. Wever, "Reentrainment of circadian rhythms after phase-shifts of the Zeitgeber," *Chronobiol*, 23–78, Vol. 2, 1975.

[4] J. M. Harrington, "Health effects of shift work and extended hours," *Occup. Environ. Med*., 68–72, Vol. 58, 2001.

[5] P. Burgess, "Optimal Shift Duration and Sequence: Recommended Approach for Short-Term Emergency Response Activations for Public Health and Emergency Management," *Am. J. Public Health*, S88–S92, Vol. 97, No. S1, 2007.

[6] Canadian Centre for Occupational Health and Safety, "OSH Answers Fact Sheet," https://www.ccohs.ca/oshanswers/ergonomics/shiftwork.html, modified 16 Aug 2016, accessed 16 Aug 2016.

[7] L. Cheng, J. F. Rivest and J. Baranski, "Evaluation of two alternative work-shift schedules for the Combined Aerospace Operations Centre at CFB Winnipeg, January 2016," Defence Research and Development Canada, DRDC-RDDC-2016-L039, 16 Feb 2016.

[8] G. Costa, "Shift Work and Health: Current Problems and Preventive Actions," *Safety Health Work*, 112–123, Vol. 1, 2010.

[9] K. Viitasalo, E. Kuosma, J. Laitinen and M. Härmä, "Effects of shift rotation and the flexibility of a shift system on daytime alertness and cardiovascular risk factors." *Scand. J. Work Environ. Health*, 198–205. Vol. 34, No. 3, June 2008.

[10] L. G. van Amelsvoort, N. W. Jansen, G. M. Swaen, P. A. van den Brandt and I. Kant, "Direction of shift rotation among three-shift workers in relation to psychological health and work-family conflict," *Scand. J. Work Environ. Health*, 149–156, Vol. 30, No. 2, Apr 2004.

[11] M. W. P. Petryk and D. J. Ladouceur, "Shift Schedule Analysis and Recommendations for the Combined Aerospace Operations Centre," Defence Research and Development Canada, DRDC-RDDC-2017-L016, 16 Jan 2017.

[12] M. Ingre, G. Kecklund, T. Akerstedt, M. Söderström and L. Kecklund, "Sleep length as a function of morning shift-start time in irregular shift schedules for train drivers: self-rated health and individual differences," *Chronobiol. Int*., 349–358, No. 25, 2008.

[13] J. Clendon and V. Gibbons, "12 h shifts and rates of error among nurses: A systematic review." *Int. J. Nurs. Stud*., 1231–1242, Vol. 52, No. 7, Jul 2015.

# Annex A Propagation of errors

## A.1 General derivation and specific forms for addition and multiplication

For a function *f* composed of *n* terms, the variance of *f* is denoted $\sigma^2$, which is the square of the standard deviation, $\sigma$. The variance of *f* can be expressed as:

$$\sigma^2 = \sum_i^n a_i^2 \, \sigma_i^2 + \sum_i^n \sum_{j(j \neq i)}^n a_i a_j \rho_{ij} \sigma_i \sigma_j \tag{A.1}$$

where $a_i$ and $a_j$ are expansion coefficients, $\sigma_i$ and $\sigma_j$ are the standard deviations of the $i^{\text{th}}$ and $j^{\text{th}}$ components of *f*, and $\rho_{ij}$ is the cross-correlation coefficient between the $i^{\text{th}}$ and $j^{\text{th}}$ components of *f*. If the $i^{\text{th}}$ and $j^{\text{th}}$ components of *f* are independent of one-another, Eq. A.1 simplifies to:

$$\sigma^2 = \sum_i^n a_i^2 \, \sigma_i^2 \tag{A.2}$$

Since the function *f* can be approximated by a first-order Taylor series expansion in the form:

$$f \approx f^0 + \sum_i^n \frac{\partial f}{\partial x_i} x_i \tag{A.3}$$

where $\partial f / \partial x_i$ is the partial derivative of *f* with respect to *x* of the $i^{\text{th}}$ component of *f*. If we ignore cross-terms (*i.e.*, the *n* components of *f* are independent of one another) as before, $\sigma$ can be expressed as the truncated Taylor series expansion:

$$\sigma = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial f}{\partial y}\right)^2 \sigma_y^2 + \left(\frac{\partial f}{\partial z}\right)^2 \sigma_z^2 + \cdots} \tag{A.4}$$

In the case of a function which is a sum:

$$f = A + B + \cdots \tag{A.5}$$

Eq. A.4 simplifies to:

$$\sigma_f = \sqrt{\sigma_A^2 + \sigma_B^2 + \cdots} \tag{A.6}$$

Note that Eq. A.5 applies to both sums and differences. Where the function is a product:

$$f = A \times B \times \ldots \tag{A.7}$$

Eq. A.4 simplifies to:

$$\sigma_f = |f| \sqrt{\left(\frac{\sigma_A}{A}\right)^2 + \left(\frac{\sigma_B}{B}\right)^2 + \cdots} \tag{A.8}$$

# Annex B Qualitative RFs

## B.1 Human factors/preferences

### B.1.1 Overview

Under the RF of human factors/preferences, the authors identified three sub-categories:

1. a conflict between the shift schedule preferred by shift workers *vs.* the scheduled preferred by most of their superiors;

2. flexibility and predictability of the schedule; and

3. the length of time shift workers can be without having contact with their superiors (referred to hereafter as a supervisory gap).

These sub-categories are examined separately below.

### B.1.2 Recommendations based solely upon preferences

We met with all those employed by the CAOC and determined that many shift workers have worked 8 hour shifts in other centres and that the majority of the shift workers have a preference for the current 12 hour shifts. In opposition to this, the shift workers' superiors (all of whom had a broad range of shift work experience) expressed an interest in adopting 8 hour shifts as such shifts are the norm in domestic and deployed operations. Under the sub-category of preference for shift type (12 hour *vs*. 8 hour) we have no scientifically-based advice.

### B.1.3 Recommendations based solely upon flexibility

As noted above, undermanning contributes to the overwork of shift workers and results in poor schedule predictability. As noted previously in the error rates and shift lengths section, error rates are known to increase if shift lengths are extended beyond 12 hours but there is no conclusive evidence that extending shift lengths from 8 hours to 12 hours has a significant effect on error rates [13]. Consequently, when considering schedule flexibility and error rates the authors would recommend 8 hour shifts over 12 hour as the former allows the flexibility of temporarily extending shifts from 8 hours to 12 hours in the case of, for example, injury, without the increase in error rates that would attend the extension of a 12 hour shift to beyond 12 hours for similar reasons.

### B.1.4 Recommendations based solely upon supervisory gap

Effective mentoring, guidance and supervision can only be practically achieved through contact between workers and their supervisors. In the case of the CAOC, shift workers are supervised by non-shift working superiors. A supervisory gap (where there is no contact between shift workers and their superiors) is impossible to avoid in such cases. In a clockwise rapid rotating shift the longest supervisory gap occurs when a crew begins their day shift on a Saturday. In the case of the current CAOC schedule (*i.e.*, 12 hour shifts DDNNROOOO) it is possible to encounter a maximum supervisory gap of 18 days with an average supervisory gap of 11 days. Under the assumption that effective supervision, guidance

and mentoring can be exercised during both D and E shifts in a 8 hour shift cycle the maximum supervisory gap is reduced to 9 days with an average gap of just under 8 days. While the average supervisory gap is similar in the cases of 12 hour and 8 hour shifts, the much higher maximum supervisory gap associated with the 12 hour shift should be avoided—under the sub-category of supervisory gap we recommend adoption of 8 hour shifts rather than the current 12 hour shifts.

## B.2 Proficiency

Another RF that the authors analyzed was proficiency. In the most general sense, proficiency is the ability to perform an acquired skill. In the context of the CAOC, proficiency refers to being able to execute all requisite functions without undue hesitation or misstep; colloquially this could be referred to as "being on the ball" or one "being on his/her game." It was widely-perceived by CAOC personnel that a lack of proficiency is routinely demonstrated by some SODOs. Further, at no time did any CAOC interested party object to the notion that a lack of proficiency was demonstrated (at least occasionally) by some SODOs. We investigated this RF by meeting with all those employed by the CAOC and observed that while a lack of proficiency among pro-shift SODOs was a common observation, the notion of a lack of proficiency among shift work SODOs never arose. Some of those employed by the CAOC expressed concerns about SODO selection, specifically that the selection of pro-shift SODOs who were not previously full-time (shift work) SODOs is problematic because those new SODOs cannot remain proficient while only taking a few shifts a month if they lack the foundation of having been a shift work SODO. The authors were informed that while participation is exercises is tracked from point of view of currency, it is not tracked from the point of view of proficiency, nor is there any established metric for tracking proficiency in the CAOC. The only method for a SODO to maintain proficiency (according to those employed by the CAOC) is through participation in Exercises. Our inference (based on meetings) is that shift work SODOs managed to participate in a sufficient number of exercises to maintain proficiency whereas some pro-shift SODOs do not. It is our recommendation that the CAOC should establish and track a metric for proficiency, *e.g.*, in how many exercises should a SODO participate in order to remain proficient. It was noted above (see Table 3) that pro-shift SODOs participate in an average of two shifts per month. It would be a benefit for pro-shift SODOs to have exercises align with their CAOC shifts.

A transition to 8 hour shifts will have no effect on proficiency. On the preponderance of the evidence, a move to 8 hour shifts *vs*. the current 12 hour shifts is neither recommended nor discouraged on the consideration of the proficiency RF.

## B.3 Summary of shift type recommendations for various RFs

The recommended shift types for given RFs are summarized below. For a justification of the summary please refer to the appropriate section, above.

Eight hour shifts are recommended for the following RFs:

1. Flexibility (caveat: improvements occur only in the case of increased manning);
2. Supervisory gap (caveat: improvements occur only in the case of increased manning); and
3. Health and well-being (caveat: improvements occur only in the case of increased manning).

Twelve hour shifts are recommended for the following RFs:

1. SA (caveat: improvements occur only in the case of late starts to the shift and the night shift SODO briefing the GO); and

2. Preference of current shift-workers.

The following RFs are shift-agnostic:

1. Equity (caveat: both eight and twelve hour shifts are deemed to be equally equitable in the case of increased manning—in the case of current undermanning twelve hour shifts are more equitable than eight hour shifts owing to the possibility of backward shift rotation for 8 hour shifts); and

2. Proficiency.

# List of symbols/abbreviations/acronyms/initialisms

| | |
|---|---|
| 1 CAD | 1 Canadian Air Division |
| APRV | Annual Personal Readiness Verification |
| CANR | Canadian NORAD Region |
| CAOC | Combined Aerospace Operations Centre |
| CCO | Chief of Combat Operations |
| CJFACC | Combined Joint Forces Air Component Command |
| CTO | Compensatory Time Off |
| DDO | Deputy Duty Officers |
| DDT | Deputy Duty Technicians |
| DGMPRA | Director General Military Personnel Research and Analysis |
| DND | Department of National Defence |
| DRDC | Defence Research and Development Canada |
| DSTKIM | Director Science and Technology Knowledge and Information Management |
| GO | General Officer |
| ORAD | Operational Research and Analysis Directorate |
| RF | Recurring Factor |
| SA | Situational Awareness |
| SODO | Senior Operations Duty Officer |
| SODT | Senior Operations Duty Technicians |

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The Combined Aerospace Operations Centre (CAOC) at 1 Canadian Air Division (1 CAD) operates primarily on two shifts of twelve hours each to provide 24 hour manning. This is atypical amongst NORAD Aerospace Operations Centres, most of which operate on three shifts of eight hours each. The Operational Research and Analysis Directorate (ORAD) at 1 CAD was tasked to determine how the efficacy of the CAOC might be affected/improved by changes in shift scheduling. Meetings with CAOC personnel and an analysis of three years' worth of shift schedules revealed that, in the present state, a move to 8 hour shifts is unadvisable since the CAOC is undermanned. A move to 8 hour shifts is only recommended if the CAOC achieves proper manning levels by being able to realizes no-fail mechanisms which prevent crews from working when not scheduled. Some recommendations are independent of shift scheduling and include having the outgoing shift deliver the morning brief to the General Officer, implementing late shift starts and tracking and increasing the Senior Operations Duty Officers' (SODOs) rates of participation in exercises.

Le Centre multinational d'opérations aérospatiales (CMOA) de la 1re Division aérienne du Canada (1 DAC) fonctionne principalement au moyen de deux quarts de travail de 12 heures, pour avoir du personnel en poste 24 heures par jour. Cette organisation de l'horaire est atypique parmi les centres d'opérations aérospatiales du NORAD, qui fonctionnement pour la plupart selon trois quarts de travail de huit heures. La Direction d'analyse et de recherche opérationnelle (DARO) de la 1 DAC a été mandatée de déterminer dans quelle mesure l'efficacité du CMOA serait améliorée ou affectée par un changement dans l'horaire de quart. Des rencontres avec le personnel du CMOA et une analyse des horaires de quart de travail sur trois ans ont révélé que dans l'état actuel, un changement vers des quarts de huit heures n'est pas avisé étant donné que le CMOA n'a pas l'effectif nécessaire. Un changement vers des quarts de huit heures n'est recommandé que si le CMOA atteint un niveau d'effectif suffisant, et peut employer des mécanismes qui empêchent les équipages de travailler quand ils ne sont pas de quart. Certaines recommandations ne relèvent pas de l'horaire des quarts, mais plutôt du fonctionnement : avoir le quart sortant donner l'exposé du matin à l'officier général; mettre en place des arrivées tardives dans le quart de nuit et faire le suivi du taux de participation des officiers supérieurs de service des opérations dans les exercices.