PHMSA White Paper

Staffing of Regular, Cyclic 24/7 Operations

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The most prevalent cause of shiftwork schedule problems may be management's failure to assure the availability of enough qualified shiftworkers[1] to meet the 24/7 work demand. This white paper addresses that issue.[2]

Number of Crews. In regular, cyclic 24/7 operations, the number of crews[3] used should be greater than the number of shifts per day so that at least one crew is off each day. The number of crews that the operator decides to use sets the work demand on the controller: the number defines the average yearly, weekly, and daily amounts of time worked by an individual. Each year provides (364 days[4] per year x 24 hours per day =) 8,736 hours to be worked in continuous operations. Each crew must work their proportional share of the year (Table 1). If the operator uses four crews, then each person in the crew must work 2,184 hours per year, an average of 42 hours per week and an average of 6 hours per day (across all days of the year; this is not shift length). Note that among all numbers of crews shown in the left-hand column of Table 1, the 4-crew solution most closely approximates the usual work demand placed on weekday-only workers, i.e., 40 hours per week.

Table 1. Average annual work demands in regular schedules for different numbers of crews and weekday-only workers, in hours (this is not shift length).

Number of Crews	*Average Hours Worked per Day*	*Average Hours Worked per Week*
2	12	84
3	8	56
4	6	42
Weekday only	5.7	40
5	4.8	33.6
6	4	28

It is natural to think that work demand changes in a simple, straight-line manner when the number of crews changes. However, this is not the case in regular, cyclic shiftwork plans. When you plot the numbers in the "per week" column of Table 1, you can see that the relationship between the average amount of time an individual works and the number of crews used is not a straight line (Figure 1).

Because the line is curved, changing the number of crews may change factors such as staffing and payroll in unexpected ways. The 4-crew solution provides optimal balance between (1) the work, health, social, and safety demands placed upon the shiftworker in terms of hours worked per unit time (the y axis in Figure 1) and (2) the personnel cost to the employer for safe and productive system operation in terms of the number of crews employed (the x axis in Figure 1).

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1 Shift leads, controllers, analysts.

2 Portions of this white paper were adapted from Miller, J. C. (2006). *Fundamentals of Shiftwork Scheduling*, Report no. 2006-0011, Brooks City-Base TX: Air Force Research Laboratory. (NTIS accession no. ADA446688)

3 A crew may be as small as one person.

4 364 workdays are used for a year (instead of 365) because schedules are typically established in increments of 7 days or 13 weeks, which are factors of 364.

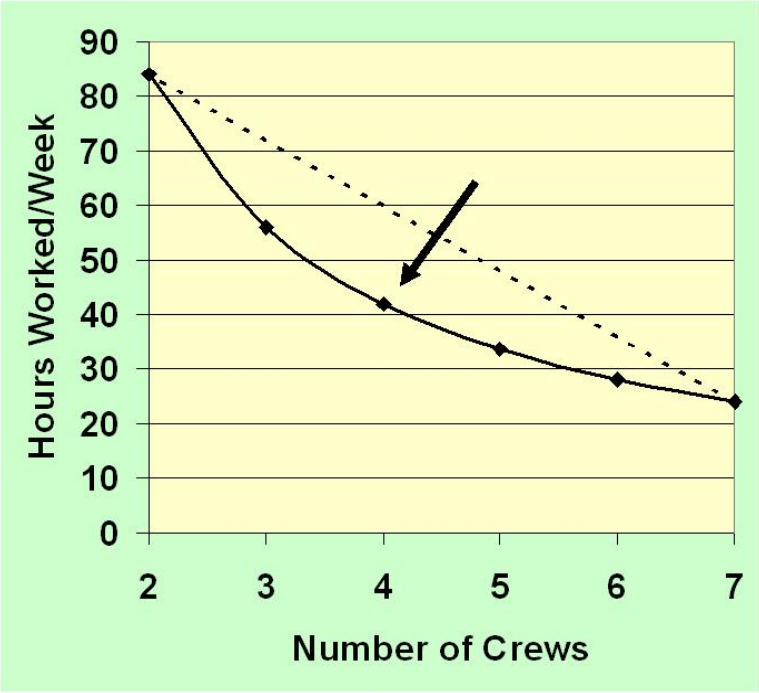

Figure 1. The actual relationship from Table 1 between the average amount of time a crew works and the number of crews employed (solid line), and the intuitive straight-line relationship between the two (dotted line). The arrow indicates the optimal balance between the work demand placed on the crews (hours worked) and personnel costs for crews (number of crews).

The 4-crew solution, with an average 42-hour work week makes good sense for regular, cyclic shiftwork scheduling. The DuPont plan is an example of a 4-crew solution.

Employment Ratio. The employment ratio makes allowances for holidays, sick leave, annual leave and other administrative and training time. This allows the operator to expand a plan, such as the DuPont plan into a shiftwork schedule. Staff strength must be at a level greater than the minimum staff needed for all crews on any given day. An employment ratio is a number greater than 1 that may be calculated as, for example:

ratio = (364 work + 10 hol + 14 ann + 14 sick + 14 tng) ÷ 364 days per year
= 416 days ÷ 364 days
= 1.14

where there are 364 days to be worked (work), 10 holidays per year (hol), 14 days of annual leave (ann), 14 days of sick leave (sick), and 14 days of training (tng). Staffing may then be calculated as the product of the minimum number of people for a single crew, the number of crews required, and the employment ratio. If the minimum crew is ten people and four crews are needed, then staffing is:

10 workers per crew x 4 crews x 1.14 = 46 workers

where the product, 45.6 workers, is rounded up to 46 workers to avoid the bother of hiring six tenths of a worker.

5-Crew Solution. There are many cases in which training or other activities are so demanding of shiftworkers' time that a 4-crew solution seems impractical. A solution to this problem is to use five crews. The question remains, "At what point do I decide that the employment ratio is too big, and that I should just use a 5-crew solution?" The answer depends upon the decision criterion that you select. If the criterion is worker pay, then the differences between the direct-plus-overhead costs for the 4-crew and 5-crew solutions may be calculated for hours worked per year. If the criterion is worker, system or public safety, then the 5-crew solution is probably the way to go. In the 5-crew solution, a week of day-only work is added to the plan as four 10-hour days and three days off, or five 8-hour days with the weekend off.

When this kind of a 5-crew system is used, the calculations, above, are retained. For example, if two controllers are needed on each shift, the operator needs a minimum of (2 desks x four crews =) eight controllers to cover all shifts. Having just eight controllers on the payroll would produce an employment ratio of (8 ÷ 8 =) 1.0. The fifth crew, i.e., two more controllers, produces an employment ratio of (10 ÷ 8 =) 1.25. Any other qualified, current controllers on staff drive the ratio higher. However, policy and procedures must assure that all qualified controllers remain current on the desks for which they are qualified.

Size of the Operation. Generally, the smaller the operation, the larger the employment ratio should be. Assuming the use of four crews:

- With one desk, one would want to employ at least five controllers (ratio = 5 ÷ 4 =1.25).
- With two desks, and assuming that the controller on one desk can cover safety-related issues on the other desk, one would want to employ at least nine controllers (ratio = 9 ÷ 8 = 1.125).
- Building on the preceding logic with three desks, one would want to employ at least 13 controllers (ratio = 13 ÷ 12 =1.08).

The following table shows a larger number of examples.

No. of Desks	*Controllers needed for 4 crews (ratio = 1.0)*	*Ratios for 4 crews + 1 controller*	*Ratios for 4 crews + 2 controllers*
1	4	1.250	1.500
2	8	1.125	1.250
3	12	1.083	1.167
4	16	1.063	1.125
5	20	1.050	1.100
6	24	1.044	1.083

Generally, there is a limited capacity for a controller on one desk to cover safety-related issues on another desk. Thus, it is best to favor the ratios for the fewest number of desks; for example, an employment ratio of at least 1.25.

Replacing Shiftworkers. Often it is necessary to fill open slots in crews because of shiftworkers' holidays, vacation, sick leave, and training. There are two replacement options: use a shiftworker or use a day worker. With each method, the shiftwork schedule of the individual moving into the open slot must be considered with care. Replacement by a shiftworker means that a shift or night worker on another crew switches crews, and switches schedules, to fill the empty slot. The main concern when using a shiftworker is that the worker has had at least 24 hours off since the last night shift, or at least 16 hours off since the last day or swing shift. Also, the additional shift(s) should not cause the worker to work more than a total of about six consecutive days.

Replacement by a day worker means that an individual not on this (or any other) shiftwork or night work schedule fills the empty slot. If the individual has been off duty for at least 24 hours prior to the replacement, he or she has most likely operated on a day-awake, night-asleep schedule. The main concern for the day worker is that the additional shift(s) should not cause the worker to work more than a total of about six consecutive days.

For both kinds of replacements, as they continue to work with one crew and then another, the scheduler should assure that sleep hygiene and chronohygiene recommendations are met. Part time workers may need more days off for recovery than the full-time shiftworkers due to poor sleep habits forced upon the part-timers by schedule unpredictability.

Differences between Desks. The employment ratio, above, assumes that all desks are the same. For operators with multiple desks and controllers not qualified at all desks, operators should calculate the employment ratio on a per desk basis, considering only the controllers qualified for that desk.

Single-Desk Operations. Operators are encouraged to avoid single-desk operations during the 2:00 a.m. To 6:00 a.m. period. The ability to mitigate the potential effects of controller fatigue on pipeline operations is sharply limited when only one controller is on duty at night. First, it may be difficult or impossible to replace a controller who becomes excessively fatigued or ill in the middle of a night shift without interrupting the sleep of an on-call controller. Second, it is difficult to take a break at night, and on-duty napping is not possible unless the operator has a means to insure that the controller can still take a nap while being able to react to an alarm if one occurs. Third, there is no controller with whom to discuss potential solutions to system problems that arise at night.

Overall, single-controller operations should be used only when the nighttime workload is demonstrably low. If operators find that single-desk operations at night are unavoidable, they should be prepared to demonstrate that workload is low and that appropriate fatigue mitigation measures (countermeasures) are in place to reduce the risks associated with fatigue. Overall, if managed and mitigated properly and sufficient justification is provided, one controller/single-desk shift operations at night may be adequate.

Caveat. The employment ratio is a guideline only. Achieving these employment ratio guidelines does not alleviate the operator's responsibility to establish and implement adequate hours of service limits and assure shiftworkers have an opportunity to obtain 8 hours of continuous sleep between consecutive work shifts.