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An AHP-MIP Approach for Duty Assignment with Officer-Centered Workload Fairness

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ABSTRACT

This study develops a fairness-oriented police duty scheduling framework minimizing perceived workload imbalances among officers. A Mixed Integer Programming (MIP) model is used for fairness-aware scheduling, incorporating officer-perceived workload into optimization. The model follows Taiwan's regulations mandating balanced rest/duty times—specifically the '12-hour duty, 8-hour break' rule, requiring at least eight consecutive daily rest hours and limiting late-night duty to at most 4 hours. Workload intensities, derived via Analytic Hierarchy Process (AHP) from Taiwanese police survey data, capture officers' subjective duty intensity perceptions. Personalized weights are embedded in the model, which minimizes deviations in assigned duty workloads from the average across all officers for equitable distribution. Computational testing using CPLEX on Taiwanese police scenarios (35 & 40 officers, varying duty/rest hours) finds optimal solutions within hours, confirming its practical applicability. A repeated-measures ANOVA shows that reducing daily working hours from 12 to 10 lowers officers' weekly perceived workload because they work fewer shifts, while workload per shift does not change significantly. The length of the daily rest period (6 or 8 hours) has no significant effect.

Keywords: *police duty scheduling, workload distribution, mixed integer programming, AHP*

1. INTRODUCTION

As societal security demands intensify, police officers face escalating workloads and psychological stress amid rising domestic crime rates. This burden underscores an urgent need to reform workforce management strategies. Traditional duty scheduling—often manual and subjective—does not account for officer-perceived workload differences across duties such as spot checks, station duty, patrol, on-call duty, and traffic enforcement. Fatigue is linked to burnout among police officers (Basinska *et al.*, 2014), and shift schedules are associated with burnout, poor sleep, and poor health (Peterson *et al.*, 2019; Garbarino *et al.*, 2019; Nevels *et al.*, 2021); officers also report adverse effects from skipping on-the-job breaks (Toh & Cho, 2023).

For instance, 12-hour shifts were associated with more sleepiness and lower alertness than 8-hour shifts (Amendola *et al.*, 2011), and 13-hour 20-minute shifts showed no clear advantages but considerable liabilities (Bell *et al.*, 2015). Night shift work has been associated with long-term injury (Violanti *et al.*, 2013), and male officers on afternoon shifts reported more tiredness than those on day shifts (Violanti *et al.*, 2018). Drowsy driving is a further safety risk (James & Vila, 2015; Howarth & Taylor, 2021). Globally, shift work exacerbates stress and sleep deficits (Vila *et al.*, 2002), emphasizing the need for schedules that balance wellness and operational efficacy, although Hassmén and Burgess (2024) found no direct effect of night shifts on sleep quality or burnout among Australian officers.

These challenges are acute in jurisdictions like Taiwan, where Article 16 of the Police Duty Regulations mandates ≥ 8 consecutive daily rest hours and caps late-night duty at ≤ 4 hours. Yet beyond rest compliance, equitable distribution of perceived workload intensity across duties—patrol, station duty, traffic enforcement, and others—also may influence officer morale, engagement, and job performance. Traditional manual scheduling overlooks these subjective disparities, creating workloads that officers view as unfairly assigned—a potential factor in burnout and reduced service quality. To bridge this gap, we propose a hybrid framework integrating the Analytic Hierarchy Process (AHP) and Mixed Integer Programming (MIP). Our framework quantifies officers' perceived workload weights of different duty assignments via AHP and embeds them into MIP optimization to minimize duty workload deviations from the average among officers—actively promoting fairness in duty assignments while enforcing legal rest constraints.

Using a Taiwanese police case study, we validate the MIP model with IBM CPLEX across staffing scenarios (35–40 officers) and shift variations (varying daily duty and rest hours). This work delivers four contributions:

- An MIP scheduling model that defines fairness by each officer's perceived workload of his own assignment, measured with that officer's AHP weights;
- A linear objective that penalizes deviations from the average workload per assignment, which we show is an upper bound on the deviation of each officer's total workload from the average (Section 4);
- Empirical validation under real-world regulatory constraints (e.g., rest rules, coverage needs), confirming practical viability;
- A comparison of daily working hours (12 or 10) and rest periods (6 or 8 hours), showing that weekly perceived workload falls with fewer working hours through fewer shifts, while the rest period length has no significant effect.

In summary, our framework intelligently balances core duty types—spot checks, station duty, patrol, on-call duty, and traffic enforcement—across weekly schedules. By defining objectives (e.g., fairness in officer-perceived workload, rest compliance) and constraints (e.g., limits on working days and hours, staffing minima), the model minimizes deviations of duty workloads from the average to achieve distributional equity. This balances perceived workload across officers, based on each officer's own assessment of duty burden. Furthermore, we analyze policy impacts (e.g., adjusted rest periods) on workloads, advancing toward a resource-efficient, personalized scheduling system that harmonizes legal standards with human factors.

The rest of this paper is organized as follows. Section 2 reviews optimization and multi-criteria decision-making studies on police scheduling and workload. Section 3 describes the problem and the scheduling rules, explains how officer-perceived duty workloads are measured with AHP, and presents the MIP model. Section 4 presents the optimal schedule, compares four scenarios of daily working hours and rest periods, reports computation times, and shows that the model's objective is an upper bound on an alternative objective based on each officer's total workload. Section 5 concludes with a summary of the main findings, followed by a possible model extension, limitations, and directions for future research.

2. LITERATURE REVIEW

The Police duty scheduling is crucial to law enforcement, as it strikes a balance between public safety, resource optimization, and officer well-being. To our knowledge, while prior literature in rostering and manpower planning has incorporated constraints on hours, shift rotations, and legal compliance (Todovic *et al.*, 2015), few models operationalize fairness from the perspective of workload perception. Furthermore, fairness is often defined in terms of hours worked, rather than the psychological and physical toll of duty types.

2.1 Fairness and workload-centered optimization approaches

While optimization models—from deterministic mathematical programming and machine learning–based dynamic approaches to multi-objective hybrids—are vital in solving police scheduling problems under complex constraints, the literature increasingly emphasizes workload balancing for fairness. Namoco *et al.* (2017) used integer programming to determine how many patrol police to assign, and where to position them, within the central business district of Cagayan de Oro City. Camacho-Collados *et al.* (2015) defined workload as a metric combining operational and spatial attributes like area, crime risk, compactness, and support. Instead of incident counts, they used a weighted sum of normalized indicators reflecting demand and logistical burden. Chen *et al.* (2019) defined workload as a combination of several attributes and designed patrol districts on the street network using a tabu search heuristic, tested on data from London. Zhu *et al.* (2021) estimated beat workload from 911 calls and their processing time, formulated beat design as an MIP with contiguity and compactness constraints, solved it with simulated annealing, and reduced workload variance across beats in South Fulton, Georgia. Yan *et al.* (2022) developed manpower planning models that minimize total manpower supply-hours, tested with data from Taiwan police stations. He *et al.* (2026) provided mixed-integer linear/conic reformulations solvable with standard optimization software for police resource allocation for crime prevention.

Workload and staffing also appear in recent operations studies of other settings. Kwakye and Sohn (2026) developed a MILP that jointly optimizes patient scheduling, routing, and resource allocation in a dental prosthesis supply chain, minimizing lead time while enforcing fairness through worst-case constraints. Ananpalasak and Kritchanchai (2025) used simulation to evaluate third-party logistics models for a tertiary public hospital in Thailand, motivated in part by freeing medical staff from logistics tasks. Gnanendran *et al.* (2026) developed an integrated aggregate planning model that determines optimal production, workforce, and inventory levels while accounting for pricing and cash flow. Our model adds to this work by building each officer's perceived workload directly into the scheduling decision.

To accommodate real-time adjustments of policing, researchers have turned to reinforcement learning (RL) and related techniques. Joe *et al.* (2022) developed an RL approach that dispatches officers to incidents and reschedules patrols, balancing two objectives: patrol presence and timely incident response. Joe and Lau (2023) extended it to multiple agents (Multi-Agent Dynamic Police Patrol Dispatching and Rescheduling Problem, MADPRP), combining multi-agent value function approximation with a rescheduling heuristic. Wong *et al.* (2023) addressed the same two-objective problem with multi-agent RL, using an asynchronous proximal policy optimization method that learns dispatch rules. Guedes *et al.* (2019) used a multi-objective evolutionary algorithm with an emergency call simulator to balance conflicting dispatch goals such as response time and unattended calls.

2.2 Multi-criteria and hybrid decision-making approaches

Multi-criteria decision-making (MCDM) methods complement optimization and learning models for public safety strategies. For example, Basilio and Pereira (2020) used ELECTRE IV to rank policing strategies, and Basilio *et al.* (2021) applied PROMETHEE II to prioritize interventions based on Brazilian criminal data. Their hybrid

Table 1 Comparison of this Study with Related Optimization Studies on Police Workload and Scheduling

Study	Workload Measure	Fairness Definition	Main Constraints	Solution Method	Data
Camacho-Collados *et al.* (2015)	Weighted sum of area, crime risk, compactness, and support	Balanced workload across patrol sectors	Districting (contiguity, compactness)	Multi-criteria model, heuristic algorithm	Central District of Madrid
Chen *et al.* (2019)	Combination of attributes	Balanced workload across districts	Districting on street network	Heuristic (tabu search)	London
Zhu *et al.* (2021)	911 calls × processing time	Low variance of workload across beats	Beat design	MIP solved by simulated annealing	South Fulton, Georgia
Todovic *et al.* (2015)	Hours and shifts	Meeting goals for hours and shift rotation	Hours, shift rotation, legal rules	Goal programming	Police station in Bosnia and Herzegovina
Yan *et al.* (2022)	Manpower demand per shift	None (minimizes total supply-hours)	Shift demand, mutual support between stations	Mathematical programming	Taiwan police stations
Namoco *et al.* (2023)	None; AHP weights rank patrol beat locations (crime rate, population, traffic, establishments, lighting)	Not addressed (maximizes weighted police visibility)	Minimum and maximum personnel per location, total personnel available	AHP + integer programming	Illustrative example: 4 beat locations, 11 personnel
This Study	**Each officer's AHP weights across duty types**	**Each officer's perceived workload of his own assignment close to the average**	**Daily hours, consecutive shifts, 8-hour continuous rest, late-night limit, staffing per duty**	**MIP (CPLEX)**	**County C, Taiwan (35 officers; 40 simulated)**

EC-PROMETHEE approach enhances robustness with randomized weight iterations (Basilio *et al.*, 2024).

Mourtgos *et al.* (2024) used Bayesian Holt-Winters state-space models with Salt Lake City data and found that staffing levels affect police response times more than call volume, overtime, or proactive work. Such estimates can inform MCDM approaches to staffing and rostering. While MCDM methods like ELECTRE and PROMETHEE specialize in ranking alternatives under constraints, AHP primarily structures subjective judgments into hierarchical weights—transforming qualitative preferences into quantifiable criteria for optimization or prioritization. Namoco *et al.* (2023) combined the two: AHP weights for patrol beat locations, based on crime rate, population, traffic, number of establishments, and lighting, enter an integer program that allocates patrol personnel across locations to maximize weighted police visibility. In their model, AHP ranks locations; in ours, AHP measures each officer's perceived workload of each duty.

Table 1 compares this study with related optimization studies on police workload and scheduling. Our framework differs from these studies in three ways:

- Uses each officer's own AHP weights as his perceived workload of each duty, rather than average weights for all officers;
- Uses these weights in the MIP objective to bring each officer's perceived workload close to the average, rather than balancing hours worked or duty counts;
- Includes Taiwan's Police Duty Regulations as constraints: daily work hours, a continuous daily rest period, and a limit on late-night shifts.

Fairness is thus defined by each officer's perceived burden of his own assignment, while the regulatory limits on work and rest are enforced.

3. METHODOLOGICAL FRAMEWORK

This section addresses the police officer scheduling problem, providing a problem description and constructing a mathematical model. Duties are categorized into static and dynamic types based on their characteristics, and the shortcomings of current scheduling methods are discussed. An MIP-based scheduling model is designed to minimize deviations of duty workloads from the average and incorporates duty classifications, workload metrics, and scheduling constraints into an optimization framework.

3.1 Problem Description

We examine a police department in a county in Taiwan (alias County C), where officer duties comprise five types: station duty, on-call duty, spot checks, patrol (including special operations), and traffic enforcement. We categorize these duties into static and dynamic types to analyze their differing demands and impacts on schedule design. Static duties (station duty, on-call duty) are performed at fixed locations with stable time requirements. Dynamic duties (patrol, spot checks, traffic enforcement) require high mobility and responsiveness, demanding route/task adjustments based on real-time incidents.

County C's current scheduling practice begins by confirming daily duty requirements and officer availability, followed by manual roster creation. While this approach offers flexibility for ad-hoc needs, it suffers from critical

Table 2 Description of Primary- and Sub-Criteria Evaluation Focus (Fan, 2023)

Main Criteria	Sub-Criteria	Evaluation Focus Description
Task Aspect	Mental demands	Refers to the requirement for sustained concentration and focus (e.g., mental effort, visual/auditory attention) during duty.
	Physical demands	Refers to physical actions required during duty (e.g., sitting, standing, running, climbing, prolonged walking, kicking, prone positioning, crouching, upward gazing, bending).
	Time demands	Refers to perceived time pressure during duty execution.
Personal Aspect	Task performance	Importance of perceived satisfaction with performance when completing tasks.
	Effort level	Importance of mental/physical exertion required to achieve performance standards.
	Frustration level	Importance of negative states (insecurity, discouragement, irritation, stress, annoyance) versus positive states (safety, satisfaction, relaxation, complacency) experienced during tasks.
Enviromental Aspect	Regulatory constraints	Evaluated based on compliance requirements with regulations during duty execution.
	Staffing level	Evaluated based on the adequacy of police personnel numbers.
	Modern equipment & tools	Importance of utilizing modern equipment/tools during task execution.

limitations: susceptibility to subjective bias and cognitive constraints, especially under complex policing demands and limited resources. Manual methods struggle to balance workloads equitably, often overburdening some officers while underutilizing others—leading to low morale, operational inefficiencies, and long-term public safety risks.

To address these gaps, we establish an objective mathematical model incorporating scheduling constraints and officer-perceived workload intensities. By formulating these elements into an optimization framework with a fairness-driven objective (e.g., equitable workload distribution) and regulatory requirements (e.g., rest periods, limits on working days and hours), the model generates duty assignments that mitigate human biases. Although computational demands may scale with problem size, this approach ensures compliance while strategically aligning resources with operational needs—transcending the limitations of manual methods.

The following sections reference data from Fan (2023), who studied this department. While the department has 40 officers, our analysis uses 35 validated questionnaires to measure perceived duty workloads.

3.2 Scheduling Constraints

The According to Taiwan's regulations, about one-third of the total police force should be on rest each day, and in practice this number may be slightly above or below one-third, safeguarding their fundamental right to rest. There are 12 shifts during the 24-hour time period (00:00-24:00), each having 2 hours. Shift 1 covers 00:00-02:00, shift 2 02:00-04:00, and so on with shift 12 (the last shift) covering 22:00-24:00. Regarding the arrangement of police officers' duty hours, shift scheduling and staffing must adhere to the following institutional regulations as fundamental principles:

- Daily duty requirement: Each officer on duty must complete 12 duty hours (6 shifts) on their working day with no more than 2 shifts in a row. The officer will not be assigned to the same duty more than twice.
- Weekly rest days: Every officer must be scheduled for two full rest days per week. Short breaks during other periods cannot substitute for this requirement.
- Continuous rest period: Shift arrangements must guarantee at least one continuous 8-hour rest period daily. This mitigates the impact of prolonged work on health and efficiency while maintaining officers' alertness and service quality.
- Shift restrictions: The police department categorizes daily operations into day shift (06:00-18:00), night shift (18:00-24:00), and late-night shift (00:00-06:00). Late-night duties are subject to special constraints: they must not exceed 4 hours in principle. In addition, such duties must be performed continuously to minimize disruption to circadian rhythms and sleep quality caused by nighttime work.

As previously mentioned, officer duties comprise five types. The labor force required by each duty type is addressed below based on nature and execution:

- Station duty: Administrative tasks like communication and documentation. Performed solo at fixed locations for clear responsibility and immediate response.
- Patrol duty: Crime prevention and public safety through active surveillance. Requires ≥ 2 officers for safety and emergency response.
- Traffic enforcement: Maintains orderly road traffic and enforces traffic laws. Conducted by ≥ 2 officers for efficiency and on-site handling.
- Spot check: High-mobility inspections of suspicious targets. Requires ≥ 2 officers due to higher risks and evidence collection needs.
- On-call duty: Readiness for emergency deployment. Staffed with ≥ 2 officers for rapid response and flexible support capacity.

3.3 Measuring Officer-Perceived Duty Workloads

Based on Hart and Staveland's (1988) NASA-TLX dimensions of subjective workload and Tengpongsthorn's (2017) finding that manpower imbalance and a lack of modern equipment hinder police performance, Fan (2023) identified nine key characteristics: mental demands, physical demands, time demands, task performance, effort level,

Table 3 Weights for the Criteria of Workload Evaluation and Duty Workloads (Fan, 2023)

Workload Evaluation Criteria and Duty Assignments			Original Weight	Geometric Mean Weight	Relative Weight	Percentage (%)	Ranking
Main Criteria		Task Aspect	0.336	0.254	0.341	34.10	2
		Personal Aspect	0.369	0.289	0.386	38.60	1
		Environmental Aspect	0.314	0.204	0.273	27.30	3
Sub-Criteria	Task Aspect (0.341)	Mental demands	0.401	0.320	0.148	14.80	2
		Physical demands	0.291	0.196	0.091	9.10	6
		Time demands	0.307	0.216	0.080	8.00	8
	Personal Aspect (0.386)	Task performance	0.346	0.258	0.136	13.60	3
		Effort level	0.249	0.188	0.099	9.90	5
		Frustration level	0.405	0.334	0.175	17.50	1
	Environmental Aspect (0.273)	Regulatory constraints	0.242	0.175	0.065	6.50	9
		Staffing level	0.435	0.321	0.119	11.90	4
		Modern equipment & tools	0.323	0.235	0.087	8.70	7
Duty Assignments		Station duty	0.226	0.206	0.238	23.80	2
		Patrol duty	0.166	0.142	0.164	16.40	4
		Traffic enforcement	0.189	0.158	0.183	18.30	3
		Spot check	0.261	0.232	0.268	26.80	1
		On-call duty	0.157	0.128	0.148	14.80	5

Table 4 Weights Representing Duty Workloads Perceived by Each Officer (Fan, 2023)

Officer	Spot Check	Station Duty	Patrol Duty	On-call Duty	Traffic Enforcement
1	0.4056	0.1148	0.0605	0.1468	0.2723
2	0.4121	0.2094	0.0504	0.1596	0.1686
3	0.2960	0.1252	0.0578	0.1663	0.3547
4	0.3159	0.1296	0.0523	0.1640	0.3382
5	0.3146	0.1929	0.1041	0.0986	0.2899
6	0.2598	0.1326	0.1779	0.0816	0.3482
7	0.2190	0.2172	0.1513	0.1763	0.2362
8	0.2812	0.2110	0.1591	0.1636	0.1852
9	0.1266	0.3014	0.0670	0.1073	0.3977
10	0.2134	0.1801	0.1459	0.2991	0.1615
11	0.3310	0.1346	0.1050	0.1087	0.3207
12	0.3106	0.1575	0.0954	0.1014	0.3351
13	0.2644	0.1532	0.0537	0.2719	0.2569
14	0.0986	0.2660	0.2867	0.2722	0.0764
15	0.3249	0.1334	0.1558	0.1683	0.2176
16	0.3373	0.2465	0.1226	0.1029	0.1907
17	0.4417	0.1031	0.0827	0.1982	0.1743
18	0.3171	0.0534	0.2734	0.0502	0.3060
19	0.2008	0.2884	0.3733	0.0404	0.0971
20	0.1894	0.2759	0.2281	0.0317	0.2748
21	0.1757	0.4627	0.2202	0.0593	0.0821
22	0.2755	0.1991	0.3702	0.0389	0.1163
23	0.2402	0.3996	0.1993	0.0380	0.1229
24	0.1343	0.2300	0.3045	0.0954	0.2358
25	0.2771	0.2583	0.1545	0.2580	0.0522
26	0.3229	0.3709	0.1285	0.0918	0.0859
27	0.0489	0.3129	0.3637	0.2254	0.0491
28	0.3191	0.2781	0.1936	0.1381	0.0712
29	0.3919	0.1689	0.1410	0.1154	0.1828
30	0.4030	0.2113	0.1189	0.0694	0.1974
31	0.0855	0.3583	0.1231	0.3516	0.0815
32	0.1606	0.2748	0.1883	0.3128	0.0635
33	0.4459	0.1498	0.0984	0.1597	0.1462
34	0.0829	0.3542	0.2560	0.2283	0.0786
35	0.1174	0.2725	0.1550	0.3950	0.0602
Max.	0.4459	0.4627	0.3733	0.3950	0.3977
Min.	0.0489	0.0534	0.0504	0.0317	0.0491
Mean	0.2612	0.2265	0.1662	0.1567	0.1894
Std dev	0.1073	0.0922	0.0912	0.0932	0.1028
CV	0.4107	0.4069	0.5486	0.5945	0.5428

Table 5 Parameters, Sets and Indices

Category	Symbol	Definition
Parameters	n	Workforce size (number of available officers) at the police department
	d	Number of days the officer is required to work during the week
	s	Number of shifts the officer is required to work during the day
	m	Number of officers that should be resting during the day
	p	Minimum number of assignments per week for the duty required for the officer
	q	Maximum number of daily assignments for the duty for the officer
	h	Minimum number of consecutive shifts during which the officer should be at rest
	r	Maximum number of consecutive shifts during which the officer should be on duty
	m_o	Number of officers required for station duty during the shift
	m_e	Minimum number of officers required for patrol duty during the shift
	m_t	Minimum number of officers required for traffic enforcement during the shift
	m_c	Minimum number of officers required for spot check during the shift
	m_s	Minimum number of officers required for on-call duty during the shift
	w_{il}	Weight representing the perceived workload of duty type l by officer i
Sets	$I = \{1, \dots, n\}$	Officers, indexed by i
	$J = \{1, \dots, j_{max}\}$	Days of the week, indexed by j ($j_{max} = 7$)
	$K = \{1, \dots, k_{max}\}$	Two-hour shifts in a day, indexed by k ($k_{max} = 12$; shift 1 = 00:00–02:00)
	$L = \{1, \dots, l_{max}\}$	Duty types, indexed by l ($l_{max} = 5$): 1 = station duty, 2 = patrol duty, 3 = traffic enforcement, 4 = spot check, 5 = on-call duty

frustration level, regulatory constraints, staffing level, and modern equipment and tools. Using Super Decisions software, these characteristics were structured into a multi-level AHP hierarchy (Table 2), categorizing criteria into primary and secondary dimensions linked to duty types. During analysis, pairwise comparison matrices were validated through maximum eigenvalue calculations and Consistency Ratios (CR), ensuring judgmental coherence. The resulting weights—for both workload criteria and the perceived burden of each duty—are quantified in Table 3.

Table 3 indicates that, for most respondents, the "personal aspect" was considered the main factor influencing their workload, with "frustration level" bearing the greatest weight within this category. This demonstrates how police officers encounter significant stress and misunderstandings when engaging with the public, which heightens their psychological burden. In comparison, the "task aspect" was the second leading source of workload, where "mental demands" had the most substantial effect, underscoring mental fatigue caused by sustained high concentration, frequent communication, command execution, and intensive public interaction during shifts. Within the "environmental aspect," the importance assigned to "staffing level" was considerably higher than that of "regulations" and "modern equipment/tools," suggesting that widespread police understaffing in Taiwan greatly elevates workload pressures. Among the five types of duty, "spot checks" was identified as the duty with the highest workload, generating the most stress. "Station duty" (e.g., answering calls, public communication) ranked second, requiring ongoing focus and responsiveness. The other duties—"traffic enforcement" (18.3%), "patrol" (16.4%), and "on-call duty" (14.8%)—showed minor differences but were generally perceived as having comparable moderate to low workloads.

The AHP hierarchy, questionnaire, and weights in Tables 2–4 are from Fan (2023); this study collected no new survey data. Our study on officer-perceived duty workload diverges from Fan's (2023) study by using individual officers' subjective workload assessments (Table 4) to establish personalized duty workload coefficients rather than relying on overall average weights. This approach captures variations in officers' perceived task intensity, enhancing schedule fairness and practical applicability. Technically, original weights in Table 4 were multiplied by 100 in Python to generate workload coefficients. Within the scheduling model, these coefficients reflect each officer's perceived workload of each duty. They further serve as parameters in our MIP model, where the workload-adjusted objective function ensures balanced distribution of high/low-intensity duties across personnel, aiming to prevent fatigue and efficiency loss while making schedule outcomes more responsive to actual operational needs.

Each officer's weights in Table 4 sum to one across the five duties. A higher weight means the officer perceives the duty as more burdensome relative to the other duties. An officer's total weight over his weekly assignments therefore measures how burdensome he perceives his own assignment to be. Because every officer's weights sum to one, these totals are on the same relative scale for all officers. For example, an officer assigned each of the five duties six times during the 30-shift week has a total weight of 6 (six times the sum of his weights, which is 1), or 600 after scaling by 100, regardless of his weights. The model brings each officer's total close to the average, so that each officer's assignment is about equally burdensome by his own ranking. It does not compare the absolute burden of one officer with that of another.

3.4 Model

To model the scheduling problem, the parameters for the problem to be used in the model are summarized in Table 5. Most of them pertain to regulatory requirements. Four binary variables (x_{ijkl} , v_{ij} , y_{ijk} , u_{ijk} with x_{ijkl} being the scheduling decision variable) are defined in Table 6. Subscripts i, j, k, and l index officers, days, shifts, and duty types. $l = 1, 2, 3, 4,$ and 5 represent station duty, patrol duty, traffic enforcement, spot check, and on-call duty, respectively.

Table 6 Decision Variables

Variables	Definition
x_{ijkl}	Equals 1 if officer i is assigned to duty type l during shift k on day j, and 0 otherwise.
v_{ij}	Equals 1 if officer i works on day j, and 0 otherwise.
y_{ijk}	Equals 1 if officer i works during shift k on day j, and 0 otherwise.
u_{ijk}	Equals 1 if officer i works during at least one of the h consecutive shifts including shift k, shift $k+1$, ⋯, and shift $k+(h-1)$ on day j; can be 0 or 1 otherwise.
Z^+_{ijkl}, Z^-_{ijkl}	The positive and negative parts of $w_{il}x_{ijkl} - e$
e	The average workload weight per duty assignment (this is an expression in x_{ijkl}, not a separate variable)

First, we outline the scheduling constraints in the problem, covering regulatory requirements (Section 3.2) and supervisor recommendations. These suggestions may only apply to County C's police department. Then, we convert each constraint into MIP formulation. Since each officer must have two full rest days per week—though not necessarily consecutive—and work for 5 days, meaning $d = 5$, the schedule should reflect this for County C's police department. Also, day index j ranges from 1 to 7. Letting $j_{max} = 7$, the equation for this constraint is:

$$\sum_{j=1}^{j_{max}} v_{ij} = d \quad \forall i \tag{1}$$

There is a requirement for the minimum number of officers off duty (i.e., m) during the day (about one-third of the total police force is granted rest days). This number can be different at different police departments. The equation for this requirement constraint is:

$$\sum_{i=1}^{n} v_{ij} \le n - m \quad \forall j \tag{2}$$

Each officer on duty must complete s shifts (12 duty hours required for County C's police department, i.e., 6 shifts, $s = 6$) on their working day. Clearly, the officer does not work during any shift on their day off. For County C's police department, shift index k ranges from 1 to 12 with $k_{max} = 12$. The equation for this constraint is:

$$\sum_{k=1}^{k_{max}} y_{ijk} = s \cdot v_{ij} \quad \forall i, j \tag{3}$$

An officer can only perform one type of duty during one shift, or if not scheduled to work that day, this officer cannot be assigned any duties for any shift. For County C's police department, duty index l ranges from 1 to 5 with $l_{max} = 5$. The equation for this constraint is:

$$\sum_{l=1}^{l_{max}} x_{ijkl} = y_{ijk} \quad \forall i, j, k \tag{4}$$

The constraints on consecutive work shifts, late-night shifts, and continuous rest apply within each day (00:00–24:00). Each officer should not be on duty for more than r consecutive shifts ($r = 2$ for County C's police department). It means that for consecutive $r+1$ shifts, covering from shift k to shift $k+r$, there should be at least one variable equal to 0 among the $r+1$ binary variables of y_{ijk}, $y_{ij(k+1)}$,⋯, and $y_{ij(k+r)}$. This translates into the equation below:

$$y_{ijk} + y_{ij(k+1)} + \cdots + y_{ij(k+r)} \le r \quad \forall i, j, k \in \{1, 2, \dots, k_{max} - r\} \tag{5}$$

There is a requirement similar to the above for late-night duties (shifts 1, 2, and 3) for County C's police department. The officer's late-night duties must not exceed 4 hours (i.e., 2 shifts) in principle. In addition, such duties must be performed continuously, implying that shift 1 and shift 3 cannot be used together if the officer works for 2 late-night shifts. We have the following equations:

$$\sum_{k=1}^{3} y_{ijk} \le 2, \quad y_{ij1} + y_{ij3} \le 1 \quad \forall i, j \tag{6}$$

The officer should have at least one continuous h-shift rest period daily. County C's police department requires continuous 8 hours, equivalently, $h = 4$. We relate binary u_{ijk} to officer i's schedule of h consecutive shifts on day j covering from shift k to shift $k+h-1$, where y_{ijk}, $y_{ij(k+1)}$,⋯, and $y_{ij(k+h-1)}$ indicate how these shifts are scheduled. Clearly, we will need u_{ij1}, u_{ij2}, ⋯, and $u_{ij(k_{max}-h+1)}$ for day j. u_{ijk} is 1 if officer i is scheduled to work during any of the h consecutive shifts, meaning:

$$y_{ijk} \le u_{ijk}, y_{ij(k+1)} \le u_{ijk}, \cdots, y_{ij(k+h-1)} \le u_{ijk} \quad \forall i, j, k \in \{1, 2, \dots, k_{max} - h + 1\} \tag{7}$$

Since there should be at least one continuous h-shift rest period daily, u_{ij1}, u_{ij2},⋯, and $u_{ij(k_{max}-h+1)}$ ($k_{max} - h + 1$ variables) cannot be all 1 and should have at least one equal to 0. This leads to the following equation:

$$\sum_{k=1}^{k_{max}-h+1} u_{ijk} \le k_{max} - h \quad \forall i, j \tag{8}$$

The officer should not be assigned to the same duty more than q times per day (currently $q = 2$ at County C's police department). Also, each officer must be assigned to every duty type at least p times per week (supervisors specified $p = 1$). Thus, we have:

$$\sum_{k=1}^{k_{max}} x_{ijkl} \le q \quad \forall i, j, l \tag{9}$$

$$\sum_{j=1}^{j_{max}} \sum_{k=1}^{k_{max}} x_{ijkl} \ge p \quad \forall i, l \tag{10}$$

At County C's police department, the officer will not have more than 2 static duties (station duty and/or on-call duty, i.e., duty types 1 and/or 5) per day. This further leads to the equations below:

$$\sum_{k=1}^{k_{max}}(x_{ijk1}+x_{ijk5})\le 2,\quad \sum_{k=1}^{k_{max}}x_{ijk1}\le 2,\quad \sum_{k=1}^{k_{max}}x_{ijk5}\le 2\quad \forall i,j \tag{11}$$

There is a requirement of certain numbers of officers on duty for each duty type during the shift, as indicated by the parameters of m_o, m_e, m_t, m_c, and m_s. For County C's police department, there are 5 duty types, where $m_o = 1$, $m_e = 2$, $m_t = 2$, $m_c = 2$, and $m_s = 2$ for duty types 1, 2, 3, 4, and 5, respectively. The following equations address this requirement:

$$\sum_{i=1}^{n}x_{ijk1}=m_o,\quad \sum_{i=1}^{n}x_{ijk2}\ge m_e,\quad \sum_{i=1}^{n}x_{ijk3}\ge m_t,\quad \sum_{i=1}^{n}x_{ijk4}\ge m_c,\quad \sum_{i=1}^{n}x_{ijk5}\ge m_s\quad \forall j,k \tag{12}$$

All the above equations in this section address the scheduling constraints for our problem. Next, our study focuses on achieving overall fairness in officers' duty workloads. Since the AHP provides weights representing each officer's perceived workloads for the duties (Table 4), we can measure the differences between an individual officer's workload weight for a duty assignment and the average workload for all officers' duties, where a smaller difference means the distribution of workloads over different duty types for this officer is closer to the overall duty workload of all officers. Thus, one reasonable objective is to minimize these differences to achieve more evenly distributed workloads over officers' duty assignments, thereby enhancing fairness.

Technically, the average workload weight of all officers' duty assignments for the week, denoted by e, is calculated below:

$$e=\frac{\sum_{i=1}^{n}\sum_{j=1}^{j_{max}}\sum_{k=1}^{k_{max}}\sum_{l=1}^{l_{max}}w_{il}x_{ijkl}}{n\cdot s\cdot d} \tag{13}$$

The objective value to minimize, Z, is the sum of all officers' duty workload deviations from their average duty workload. It can be written in the following form:

$$Z=\sum_{i=1}^{n}\sum_{j=1}^{j_{max}}\sum_{k=1}^{k_{max}}\sum_{l=1}^{l_{max}}\left|w_{il}x_{ijkl}-e\right| \tag{14}$$

To present it in a linear form, two new variables of Z^{+}_{ijkl} and Z^{-}_{ijkl} are defined:

$$Z^{+}_{ijkl}\ge w_{il}x_{ijkl}-e,\quad Z^{+}_{ijkl}\ge 0\quad \forall i,j,k,l$$
$$Z^{-}_{ijkl}\ge e-w_{il}x_{ijkl},\quad Z^{-}_{ijkl}\ge 0\quad \forall i,j,k,l \tag{15}$$

With the above new variables added to the constraint equations, the objective is rewritten as follows:

$$Min\quad Z=\sum_{i=1}^{n}\sum_{j=1}^{j_{max}}\sum_{k=1}^{k_{max}}\sum_{l=1}^{l_{max}}\left(Z^{+}_{ijkl}+Z^{-}_{ijkl}\right) \tag{16}$$

Because each officer works s shifts on each of d working days, exactly $n\cdot s\cdot d$ of the variables x_{ijkl} equal 1, and the remaining $N_0 = n\cdot j_{max}\cdot k_{max}\cdot l_{max} - n\cdot s\cdot d$ equal 0. For each $x_{ijkl}=0$, the term $\left|w_{il}x_{ijkl}-e\right|$ equals e. The objective can therefore be written as

$$Z=\sum_{\{(i,j,k,l):x_{ijkl}=1\}}\left|w_{il}x_{ijkl}-e\right|+N_0\cdot e \tag{17}$$

The first term of Eq. (17) penalizes assignments whose weight differs from the average weight e. The second term is e multiplied by a constant, so minimizing it lowers e, that is, it assigns officers more often to the duties they perceive as lighter.

The complete model minimizes Eq. (16) subject to constraints Eqs. (1) – (12) and (15), with x_{ijkl}, v_{ij}, y_{ijk}, and u_{ijk} binary. These constraints rule out schedules that meet the rules in total but not in time order. First, by Eq. (3), an officer works no shift on a rest day, and by Eq. (4), an officer holds exactly one duty in each shift he works and none in any other shift, so no two duties overlap. Second, the daily rest requirement applies to specific consecutive shifts, not to a count of rest shifts. By Eq. (7), $u_{ijk}=0$ forces $y_{ijk}=y_{ij(k+1)}=\cdots=y_{ij(k+h-1)}=0$, that is, h consecutive rest shifts starting at shift k, and Eq. (8) requires at least one such k each day. If a day has no h consecutive rest shifts, every u_{ijk} must equal 1 by Eq. (7), which violates Eq. (8). Third, Eq. (5) applies to every set of $r+1$ consecutive shifts in the day, so no officer works more than r shifts in a row within the day. Fourth, Eq. (6) prevents late-night work in shifts 1 and 3 without shift 2. We checked the optimal schedule in Table A1 against constraints Eq. (1) – (12), and it satisfies each of them.

4. ANALYSIS RESULTS AND DISCUSSIONS

The optimal weekly schedule of 35 officers (with $n=35$ and $m=10$, that is, 10 officers resting each day, close to one-third of the force) is shown in Table A1 (see Appendix). With this schedule for the week, Table 7 shows the frequencies of duty assignments for each officer and their workloads, including total workloads ($\sum_{j=1}^{j_{max}}\sum_{k=1}^{k_{max}}\sum_{l=1}^{l_{max}}w_{il}x_{ijkl}=$ officer i's total workload) and workloads for each duty type (officer i's workload of duty type $l=\sum_{j=1}^{j_{max}}\sum_{k=1}^{k_{max}}w_{il}x_{ijkl}$). Based on the coefficients of variation (CV) in Table 7, officers' total workloads are close to one another (CV = 0.097), meaning each officer's assignment is about equally burdensome by his own ranking of the duties. The same does not hold for their workloads within each duty type.

The high CV observed in weekly station duty assignments across officers (Table 7) reflects significant variability in assignment frequency. This outcome can likely be attributed to two factors: consistency in perceived workloads and tight scheduling constraints. For the first factor, officer perceptions of station duty workload exhibit less variability (CV = 0.4069, see Table 4), implying high substitutability among officers for this duty type. Swapping one officer for another during duty scheduling is likely to have a minimal impact on overall workload distribution. This flexibility enables schedulers to create station duty assignments with increased disparity in individual assignment frequencies without compromising perceived workload equity. Regarding the second factor, station duty

Table 7 Frequencies of Weekly Duty Assignments and Workloads for Each Officer in the Optimal Schedule

Officer	Frequency of Weekly Duty Assignments					Workload (Weight × 100)					
	S.C.	S.D.	P.D.	O.D.	T.E.	S.C.	S.D.	P.D.	O.D.	T.E.	Total
1	8	3	7	5	7	324.4896	34.4313	42.3577	73.4120	190.5974	665.2880
2	8	2	6	7	7	329.6480	41.8862	30.2430	111.6850	117.9878	631.4500
3	5	6	8	4	7	147.9985	75.1206	46.2392	66.5244	248.2844	584.1671
4	9	2	7	8	4	284.3325	25.9138	36.6233	131.1952	135.2772	613.3420
5	9	2	8	6	5	283.1562	38.5724	83.2512	59.1372	144.9470	609.0640
6	7	2	7	8	6	181.8453	26.5150	124.5048	65.2928	208.8996	607.0575
7	8	2	7	6	7	175.2176	43.4410	105.8841	105.8034	165.3197	595.6658
8	8	6	5	4	7	224.9352	126.5742	79.5585	65.4356	129.6176	626.1211
9	8	1	7	6	8	101.2560	30.1430	46.8846	64.3908	318.1632	560.8376
10	9	3	5	4	9	192.0159	54.0363	72.9715	119.6272	145.3653	584.0162
11	7	2	8	6	7	231.7245	26.9124	84.0024	65.2152	224.4956	632.3501
12	7	1	9	6	7	217.4396	15.7493	85.8600	60.8322	234.5644	614.4455
13	6	3	6	7	8	158.6196	45.9726	32.1972	190.3020	205.4952	632.5866
14	9	2	6	7	6	88.7670	53.2074	172.0188	190.5701	45.8352	550.3985
15	7	1	7	7	8	227.4391	13.3416	109.0306	117.7862	174.1176	641.7151
16	8	3	7	5	7	269.8472	73.9410	85.7857	51.4720	133.5082	614.5541
17	9	1	6	6	8	397.4976	10.3066	49.6428	118.9188	139.4696	715.8354
18	5	2	8	7	8	158.5385	10.6802	218.7024	35.1316	244.7648	667.8175
19	9	5	5	1	10	180.7407	144.1980	186.6525	4.0365	97.1110	612.7387
20	9	3	6	4	8	170.5032	82.7829	136.8324	12.6964	219.8512	622.6661
21	5	2	8	7	8	87.8335	92.5484	176.1256	41.5401	65.6728	463.7204
22	5	2	9	7	7	137.7735	39.8218	333.1530	27.2223	81.3995	619.3701
23	4	3	9	7	7	96.0856	119.8737	179.3439	26.5979	86.0573	507.9584
24	9	3	7	6	5	120.8304	68.9949	213.1577	57.2604	117.9080	578.1514
25	8	3	6	5	8	221.6872	77.4789	92.6706	128.9750	41.7816	562.5933
26	6	2	8	7	7	193.7670	74.1844	102.8016	64.2460	60.0950	495.0940
27	8	2	9	6	5	39.1272	62.5814	327.3282	135.2376	24.5450	588.8194
28	6	2	5	8	9	191.4444	55.6262	96.7775	110.4648	64.0431	518.3560
29	9	2	7	7	5	352.6821	33.7810	98.7238	80.7835	91.3935	657.3639
30	7	1	7	7	8	282.1217	21.1253	83.2293	48.6003	157.9104	592.9870
31	7	1	9	6	7	59.8556	35.8304	110.8089	210.9594	57.0276	474.4819
32	9	2	7	6	6	144.5490	54.9512	131.8261	187.6812	38.1054	557.1129
33	7	4	8	3	8	312.1615	59.9184	78.6808	47.9031	116.9840	615.6478
34	8	1	7	7	7	66.3400	35.4224	179.2021	159.7750	55.0186	495.7581
35	9	2	5	7	7	105.6159	54.4900	77.4750	276.5196	42.1547	556.2552
Max.	9	6	9	8	10	397.4976	144.1980	333.1530	276.5196	318.1632	715.8354
Min.	4	1	5	1	4	39.1272	10.3066	30.2430	4.0365	24.5450	463.7204
Mean	7.4857	2.4000	7.0286	6.0000	7.0857	193.0825	53.1530	117.4442	94.6637	132.1077	590.4510
Std dev	1.4627	1.2649	1.2482	1.5146	1.2689	89.7449	32.1898	73.7640	62.0060	73.6253	57.2877
CV	0.1954	0.5270	0.1776	0.2524	0.1791	0.4648	0.6056	0.6281	0.6550	0.5573	0.0970

Notes: S.D. = Station Duty, P.D. = Patrol Duty, T.E. = Traffic Enforcement, S.C. = Spot Check, O.D. = On-Call Duty

entails only one officer per shift, unlike other duty types which mandate at least two officers each. This constraint limits the total number of station duty assignments available per schedule cycle. Consequently, it becomes inherently more difficult to distribute these scarce assignments evenly, thereby increasing the potential for variability across officers compared to duties that allow for multiple concurrent assignments.

As shown in Table 7, although the total workloads for each duty type exhibit a certain level of variability among officers, the total workloads for all duties across all officers appear to be relatively consistent. This observation highlights the model's capability in managing the frequencies of duty assignments (i.e., distribution of duty assignments) to balance officers' high and low workloads of different duties for the leveled total workloads of all duties

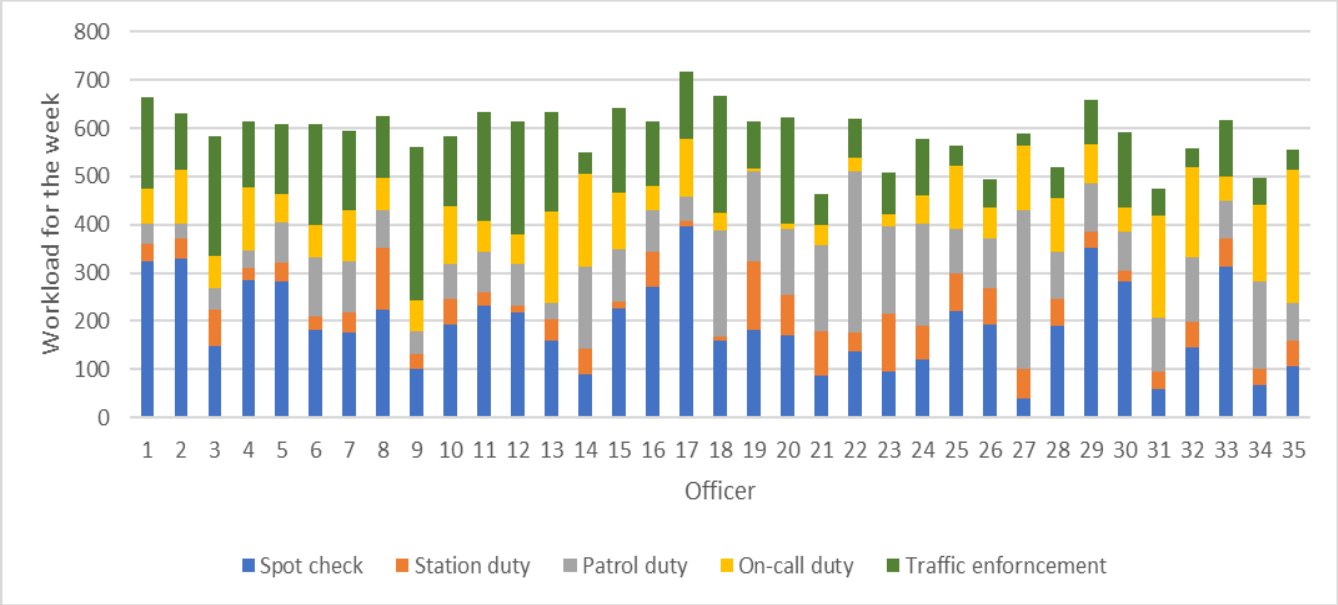


Figure 1 Workloads Across Duties and Total Workloads for Each Officer

Table 8 Statistics of Officers' Weekly Workloads for Different Continuous Rest Time Periods and Daily Working Hours

	Work 12 Hours Rest 6 Hours	Work 12 Hours Rest 8 Hours	Work 10 Hours Rest 6 Hours	Work 10 Hours Rest 8 Hours
Max.	717.468	715.835	618.557	603.268
Min.	394.517	463.720	384.078	392.988
Mean	579.812	590.451	498.003	497.330
Std dev	61.18	57.29	57.26	51.18
CV	0.106	0.097	0.115	0.103
Assignments per week	30	30	25	25
Mean per assignment	19.33	19.68	19.92	19.89
Std dev per assignment	2.04	1.91	2.29	2.05

for all officers (see Figure 1). Thus, we state that variability in perceived workloads by individuals and scheduling constraints define the characteristics of the scheduling outcome. The model manages the intricate relationship between these two factors effectively to produce the recommended solution.

As indicated in Section 3.3, there are multiple factors that influence an officer's perception of duty workload, which in turn affects this individual's total workload after scheduling. From the perspective of County C's police department, learning about how the factors relevant to their management impact an officer's overall workload is of interest to them. Here we investigate the factors of the on-duty officer's continuous rest time period (8 hours and 6 hours, i.e., $h = 4$ and $h = 3$) and daily working hours (12 hours and 10 hours, i.e., $s = 6$ and $s = 5$), leading to 4 scenarios. For each scenario, the model produces a different optimal schedule of 35 officers. Descriptive statistics of 35 officers' weekly workloads from each optimal schedule are summarized in Table 8.

Table 8 shows that officers' average weekly workload is lower with 10-hour days (about 498) than with 12-hour days (about 580 to 590). This follows mainly from the number of assignments. Each officer has 25 assignments per week with 10-hour days and 30 with 12-hour days. The average workload per assignment is similar across the four scenarios (19.33 to 19.92). Among the four scenarios, the 10-hour duty/8-hour rest schedule has the smallest standard deviation (51.18). Relative to the mean, however, the 12-hour duty/8-hour rest schedule has the smallest variation (CV = 0.097).

Next, we examine how daily working hours and the continuous rest period affect officers' perceived workload. The unit of observation is an officer in a scenario, giving 35 × 4 = 140 observations. We use two dependent variables: the officer's weekly workload, and the officer's workload per assignment (weekly workload divided by the number of assignments, 30 or 25). Because the same 35 officers appear in all four scenarios, we use a two-way repeated-measures ANOVA, with working hours and rest period as within-officer factors. This treats each officer's AHP weights as a random draw from the population of officers. Each factor has two levels, so the sphericity assumption holds automatically. Shapiro–Wilk tests on each officer's contrast scores do not reject normality ($p \geq 0.38$ for all effects).

Table 9 reports the results. Weekly workload is 87.47 higher with 12-hour days than with 10-hour days ($F(1,34) = 154.33, p < 0.001$). Workload per assignment does not differ significantly between 12-hour and 10-hour days ($F(1,34) = 2.45, p = 0.127$). The difference in weekly workload therefore comes from the number of assignments, not from lighter assignments. The rest period has no significant effect on either measure, and there is no significant interaction between working hours and the rest

Table 9 Repeated-Measures ANOVA of Officer Workload on Daily Working Hours and Continuous Rest Period ($n = 35$ Officers, 4 Scenarios)

Effect	Weekly Total: Estimate (SE)	$F(1, 34)$	p	Per Assignment: Estimate (SE)	$F(1, 34)$	p
Working hours (12 h – 10 h)	87.47 (7.04)	154.33	< 0.001	−0.40 (0.26)	2.45	0.127
Rest period (8 h – 6 h)	4.98 (6.11)	0.67	0.420	0.16 (0.22)	0.54	0.469
Interaction	11.31 (15.02)	0.57	0.457	0.38 (0.55)	0.48	0.492

Notes: Estimates are differences in means: 12 h − 10 h for working hours, 8 h − 6 h for rest period, and (12 h: 8 h − 6 h) − (10 h: 8 h − 6 h) for the interaction. SE = standard error across officers.

Table 10 Computation Times (In Seconds) Under Different Scenarios

Scenario	35 Officers	40 Officers
12 daily working hours, 6 consecutive rest hours	4,676	5,469
12 daily working hours, 8 consecutive rest hours	12,199	25,813
10 daily working hours, 6 consecutive rest hours	4,229	5,461
10 daily working hours, 8 consecutive rest hours	4,393	5,644

period. One limitation applies to these tests. Within a scenario, the 35 officers' workloads come from a single optimal schedule, and the staffing constraints link them, so they are not fully independent. The results should be read with this in mind.

For County C, these results indicate that, under our model, officers' weekly perceived workload depends on how many shifts they work per week, not on the length of the daily rest period. Extending the rest period from 6 to 8 hours did not significantly raise perceived workload, so the department can keep the 8-hour rest requirement for officers' health and for regulatory compliance without increasing perceived workload in our results. Other factors that may affect perceived workload, such as task intensity and emotional demands, are outside the scope of this analysis.

To evaluate practical implementation, we measured the model's computational efficiency through solution times. We tested 8 scenarios: combinations of 35 and 40 officers across the 4 aforementioned operational conditions (different continuous rest time period and daily working hours) with the other parameters unchanged (e.g., $m = 10, p = 1, q = 2$). When testing scenarios for 40 officers, the weights of the 5 additional officers for each duty type, representing their perceptions of duty workload, were simulated from the weight distributions for each duty type (Table 4) using the Monte Carlo method. The simulated weights for each duty type were divided by their sum such that the sum of the scaled weights across duty types equals 1. The model was implemented in Python 3.8.20 and solved with IBM CPLEX 22.1.1 on a computer with an Intel Core i7-9700F processor (3.00 GHz), 64 GB of RAM, and Windows 11 Pro (64-bit). Computation times (Table 10) ranged from 4,229 seconds (~1.1 hours) to 25,813 seconds (~7.2 hours). As the number of officers increased, the number of decision variables grew, raising computation time and complexity. Times of 1 to 7 hours are acceptable for a schedule prepared once a week.

In the end, we would like to point out that the management may consider the officer's overall workload of all duty assignments instead of workload of a duty assignment for fairness. In this case, the objective function Z and E (which replaces previously defined e in the model) should be defined as follows:

$$E = \frac{\sum_{i=1}^{n}\sum_{j=1}^{j_{max}}\sum_{k=1}^{k_{max}}\sum_{l=1}^{l_{max}} w_{il}x_{ijkl}}{n} \tag{18}$$

$$Z = \sum_{i=1}^{n}\left|\sum_{j=1}^{j_{max}}\sum_{k=1}^{k_{max}}\sum_{l=1}^{l_{max}} w_{il}x_{ijkl} - E\right| \tag{19}$$

To present it in a linear form, two new variables of Z_i^+ and Z_i^- are introduced and the objective is rewritten below:

$$\begin{aligned} &Z_i^+ \geq \sum_{j=1}^{j_{max}}\sum_{k=1}^{k_{max}}\sum_{l=1}^{l_{max}} w_{il}x_{ijkl} - E, \;\; Z_i^+ \geq 0 \quad \forall i \\ &Z_i^- \geq E - \sum_{j=1}^{j_{max}}\sum_{k=1}^{k_{max}}\sum_{l=1}^{l_{max}} w_{il}x_{ijkl}, \;\; Z_i^- \geq 0 \quad \forall i \\ &Min \quad Z = \sum_{i=1}^{n}(Z_i^+ + Z_i^-) \end{aligned} \tag{20}$$

We chose the previously defined Z (Eq. (14)) over this Z (Eq. (19)) as our model's objective function for minimization because the previous Z is actually the upper bound of this alternative Z, meaning lowering the previous Z helps lower this alternative Z. This can be understood as follows.

With Eq. (3) and Eq. (4), we have:

$$\sum_{k=1}^{k_{max}}\sum_{l=1}^{l_{max}} x_{ijkl} = s \cdot v_{ij} \tag{21}$$

Then, with Eq. (1) and Eq. (21) we have:

$$\sum_{j=1}^{j_{max}}\sum_{k=1}^{k_{max}}\sum_{l=1}^{l_{max}} x_{ijkl} = s\sum_{j=1}^{j_{max}} v_{ij} = s \cdot d \tag{22}$$

Therefore, Eq. (13), Eq. (18), and Eq. (22) lead to:

$$\left|\sum_{j=1}^{j_{max}}\sum_{k=1}^{k_{max}}\sum_{l=1}^{l_{max}} w_{il}x_{ijkl} - E\right| = \left|\sum_{j=1}^{j_{max}}\sum_{k=1}^{k_{max}}\sum_{l=1}^{l_{max}} w_{il}x_{ijkl} - s \cdot d \cdot e\right|$$

$$= \left| \sum_{j=1}^{j_{max}} \sum_{k=1}^{k_{max}} \sum_{l=1}^{l_{max}} w_{il} x_{ijkl} - e \sum_{j=1}^{j_{max}} \sum_{k=1}^{k_{max}} \sum_{l=1}^{l_{max}} x_{ijkl} \right|$$
$$= \left| \sum_{j=1}^{j_{max}} \sum_{k=1}^{k_{max}} \sum_{l=1}^{l_{max}} (w_{il} - e) x_{ijkl} \right|$$
$$\leq \sum_{j=1}^{j_{max}} \sum_{k=1}^{k_{max}} \sum_{l=1}^{l_{max}} \left| (w_{il} - e) x_{ijkl} \right|$$

That is,

$$\left| \sum_{j=1}^{j_{max}} \sum_{k=1}^{k_{max}} \sum_{l=1}^{l_{max}} w_{il} x_{ijkl} - E \right| \leq \sum_{j=1}^{j_{max}} \sum_{k=1}^{k_{max}} \sum_{l=1}^{l_{max}} \left| (w_{il} - e) x_{ijkl} \right| \quad (23)$$

If $x_{ijkl} = 1$, $\left|(w_{il} - e)x_{ijkl}\right| = \left|w_{il}x_{ijkl} - e\right|$; if $x_{ijkl} = 0$, $\left|(w_{il} - e)x_{ijkl}\right| = 0 \leq e = \left|w_{il}x_{ijkl} - e\right|$. Hence, $\left|(w_{il} - e)x_{ijkl}\right| \leq \left|w_{il}x_{ijkl} - e\right|$, and Eq. (23) implies:

$$\left| \sum_{j=1}^{j_{max}} \sum_{k=1}^{k_{max}} \sum_{l=1}^{l_{max}} w_{il} x_{ijkl} - E \right| \leq \sum_{j=1}^{j_{max}} \sum_{k=1}^{k_{max}} \sum_{l=1}^{l_{max}} \left| w_{il} x_{ijkl} - e \right| \quad (24)$$

With Eq. (24), Eq. (14), and Eq. (19), it shows that the previous Z serves as the upper bound of the alternative Z.

5. CONCLUSION

This study developed a police duty scheduling framework that combines AHP and MIP to balance officers' perceived workloads. AHP gives each officer a workload weight for each duty type, so fairness is measured by each officer's own view of how demanding each duty is. The MIP model uses these weights to minimize the deviations of assignment workloads from the average while meeting rest, duty-hour, and staffing requirements. We showed that this objective is an upper bound on the total deviation of officers' total workloads from their average, so a schedule with a low objective value also has a low imbalance in officers' total workloads. In the County C case study, the model produced schedules in which officers' total weekly workloads were close to one another, although their workloads within individual duty types varied more. The scenario comparison showed that shorter daily working hours lowered officers' weekly perceived workload through fewer assignments per week, not lighter assignments, and that the length of the continuous rest period had no significant effect. These scenario results depend on County C's officers and rules; other departments can run the same comparison with their own data. Solution times of one to seven hours for 35 and 40 officers show that, at this size, the model can be used for a schedule prepared once a week.

5.1 Model Extension: Rest Periods Spanning Two Days

In our problem, there is a requirement that each officer should have at least one continuous h-shift rest period during the day. In general, the administration may allow this continuous h-shift rest period to come across two adjacent days rather than being confined within one day. In this case, for day j we will need u_{ij1}, u_{ij2},⋯, and $u_{ijk_{max}}$ (k_{max} variables), where u_{ijk} is 1 if officer i is scheduled to work during any of the h consecutive shifts starting with day j's shift k. Then, the following constraint should be added in the model:

$$y_{ijk} \leq u_{ijk}\ , y_{ij(k+1)} \leq u_{ijk}\ , \cdots , y_{ij(k+h-1)} \leq u_{ijk} \quad \forall i, j, k \in \{k_{max} - h + 2, \dots, k_{max}\}$$

Here when shift index k exceeds k_{max}, y_{ijk} becomes $y_{i(j+1)(k-k_{max})}$. By the same token, when day index j exceeds j_{max}, y_{ijk} becomes $y_{i(j-j_{max})k}$ because the schedule repeats after j_{max} days (e.g., the schedule repeats every week with $j_{max} = 7$). The above revision of the constraint equations regarding the requirement of the officer's continuous rest hours makes our model more general in practice, while it somewhat increases the complexity of the model. The same treatment can be applied to $y_{ijk} + y_{ij(k+1)} + \cdots + y_{ij(k+r)} \leq r, \forall k \in \{1, \dots, k_{max}\}$, regarding consecutive work shifts, using the same convention for k and j indices that exceed k_{max} or j_{max}.

5.2 Limitations and Future Research

The model has several limitations. First, its practical implementation requires consideration of economic costs inherently tied to scheduling outcomes, such as overtime pay, night shift allowances, and personnel expenses. Furthermore, the current model treats each officer's perceived workloads as fixed, although they may change over time or with physiological state, and does not fully integrate the impact of personal circumstances on duty suitability. In addition, the AHP judgments in this study are crisp numbers; fuzzy AHP, as in Rajabpour *et al.* (2022), could represent uncertainty in officers' pairwise judgments.

Beyond economic factors, incorporating social support considerations—such as avoiding late-night shifts for officers with school-age children needing evening family care, or preventing prolonged consecutive night duties for single parents or primary caregivers—would enhance work-life stability, job engagement, schedule flexibility, and humanization. Implementing 'Holiday Duty Assignment Restrictions' is also recommended to prevent recurring holiday coverage by the same individuals or small groups, ensuring more equitable vacation distribution. Future work should involve testing the model in experimental cycles (e.g., one week or month) and gathering detailed officer feedback through focus groups and surveys on fairness, workload burden, rotation logic, and rest arrangements. This real-world input is crucial for refining the model, boosting its adaptability and operational feasibility, and facilitating the transition of these optimization techniques from theory to practice.

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The authors have no competing interests to declare.

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APPENDIX

In this appendix, abbreviations are used for each duty type: S.D. = station duty, P.D. = patrol duty, T.E. = traffic enforcement, S.C. = spot check, O.D. = on-call duty.

Table A1 The Optimal Schedule of Officers' Duty Assignments for the Week

Day 1	Officers																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
00:00~02:00	P.D.	O.D.			P.D.	T.E.		S.C.	T.E.			S.C.	O.D.	S.C.	P.D.		O.D.	
02:00~04:00	P.D.	S.C.	T.E.	P.D.	O.D.	O.D.	T.E.	T.E.	S.C.	T.E.	P.D.	O.D.	P.D.	T.E.	T.E.		S.C.	P.D.
04:00~06:00			P.D.	S.C.			T.E.			S.D.	O.D.							P.D.
06:00~08:00	T.E.				S.D.	O.D.		O.D.						P.D.	S.C.		T.E.	
08:00~10:00	S.D.				T.E.					S.C.	S.C.			O.D.	P.D.	P.D.		T.E.
10:00~12:00						P.D.		T.E.		S.C.	P.D.					S.D.		O.D.
12:00~14:00	T.E.	T.E.							P.D.			P.D.	S.D.		O.D.			
14:00~16:00	S.C.	S.C.	P.D.	P.D.			O.D.		P.D.			O.D.	T.E.		T.E.	P.D.		
16:00~18:00			S.D.	O.D.			S.C.									S.C.	T.E.	
18:00~20:00		P.D.			S.C.				T.E.			S.C.	T.E.	O.D.			O.D.	
20:00~22:00		O.D.	S.C.	S.D.	S.C.	S.C.	O.D.	O.D.	S.C.	O.D.	T.E.	P.D.	S.C.	T.E.		O.D.		T.E.
22:00~24:00			O.D.	S.C.		P.D.	S.C.	S.C.		T.E.	S.C.					S.C.	P.D.	S.D.
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	--
00:00~02:00		T.E.	T.E.		S.D.	S.C.												
02:00~04:00	S.C.	T.E.	S.D.	P.D.	T.E.	T.E.	T.E.											
04:00~06:00	T.E.			O.D.			S.C.											
06:00~08:00		S.C.			P.D.													
08:00~10:00				P.D.			O.D.											
10:00~12:00				S.C.	O.D.		T.E.											
12:00~14:00			O.D.		S.C.	S.C.												
14:00~16:00	S.D.																	
16:00~18:00	P.D.	P.D.	T.E.			O.D.												
18:00~20:00		S.D.				P.D.												
20:00~22:00	S.C.		P.D.	T.E.			S.C.											
22:00~24:00	T.E.	S.C.	P.D.	S.C.	P.D.	P.D.	O.D.											

Day 2	Officers																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
00:00~02:00	S.D.	P.D.			S.C.							P.D.	O.D.	S.C.	O.D.			
02:00~04:00	P.D.	S.C.	P.D.	O.D.	S.C.	S.C.	S.D.	S.C.	T.E.	S.C.	P.D.	S.C.	T.E.	P.D.	S.C.	S.C.		
04:00~06:00			T.E.	P.D.		T.E.	P.D.	O.D.	O.D.	S.C.	S.C.					S.D.		
06:00~08:00	T.E.	S.C.			T.E.							S.D.	S.C.	O.D.				
08:00~10:00	O.D.	T.E.				S.C.	P.D.	S.C.	T.E.		S.D.		T.E.					
10:00~12:00					O.D.	S.D.	S.C.	O.D.	P.D.		T.E.	P.D.						
12:00~14:00	S.C.				P.D.							T.E.	P.D.		T.E.			
14:00~16:00	T.E.		S.D.	S.C.						T.E.			O.D.		O.D.	O.D.		
16:00~18:00			S.D.	O.D.						T.E.				S.C.		T.E.		
18:00~20:00		O.D.												P.D.	S.C.			
20:00~22:00		T.E.	T.E.	P.D.		S.D.	T.E.	P.D.	P.D.	P.D.	T.E.				P.D.	S.C.		
22:00~24:00			S.C.	T.E.	O.D.	T.E.	O.D.	P.D.	S.C.	P.D.	S.C.	S.C.		S.D.		T.E.		
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	--
00:00~02:00								P.D.		O.D.	S.C.	T.E.		P.D.	T.E.		P.D.	
02:00~04:00								P.D.		T.E.	P.D.	P.D.		S.C.	O.D.		T.E.	
04:00~06:00																		
06:00~08:00												P.D.		P.D.			O.D.	
08:00~10:00			T.E.		P.D.							O.D.		O.D.			O.D.	
10:00~12:00			T.E.		S.C.													
12:00~14:00								S.C.		O.D.	S.D.				O.D.			
14:00~16:00			O.D.		P.D.			S.C.			P.D.							
16:00~18:00			P.D.		O.D.					P.D.					S.C.			
18:00~20:00								T.E.		T.E.	S.D.	O.D.		O.D.	P.D.		S.C.	
20:00~22:00			O.D.		O.D.			O.D.			S.C.	T.E.		S.C.			T.E.	
22:00~24:00			S.C.		S.C.					S.C.					S.C.			

Day 3	Officers																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
00:00~02:00		T.E.											P.D.		T.E.			T.E.
02:00~04:00	S.C.	S.C.	P.D.	T.E.	P.D.					S.C.			S.D.	S.C.	P.D.			T.E.
04:00~06:00	P.D.		S.D.	S.C.	T.E.					S.C.				P.D.				
06:00~08:00		S.C.											S.C.					P.D.
08:00~10:00	S.C.	O.D.	O.D.	S.C.								P.D.	T.E.	T.E.		P.D.		S.D.
10:00~12:00	O.D.		S.C.	S.D.								T.E.		O.D.		P.D.		
12:00~14:00													O.D.		O.D.			S.C.

Table A1 The Optimal Schedule of Officers' Duty Assignments for the Week (Cont'd)

Day 3	Officers																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
14:00~16:00					S.C.					O.D.		T.E.	T.E.		O.D.	O.D.		O.D.
16:00~18:00					P.D.					P.D.		O.D.				O.D.		
18:00~20:00		T.E.													S.C.			
20:00~22:00	P.D.	O.D.	S.C.	O.D.	S.D.					T.E.		S.C.		S.C.	S.C.	T.E.		
22:00~24:00	T.E.		P.D.	T.E.	S.C.					O.D.		S.C.		S.D.		T.E.		
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	--
00:00~02:00				S.C.		P.D.	S.D.		O.D.		O.D.	T.E.	S.C.	S.C.		P.D.	O.D.	
02:00~04:00			S.C.	T.E.		T.E.	P.D.	O.D.	S.C.		T.E.	O.D.	P.D.	S.C.	S.C.	S.C.	P.D.	
04:00~06:00			O.D.					O.D.							T.E.			
06:00~08:00							S.D.		T.E.		O.D.	P.D.	T.E.			O.D.		
08:00~10:00			P.D.					S.C.	P.D.		S.C.					T.E.		
10:00~12:00			T.E.				S.C.	P.D.										
12:00~14:00				O.D.		S.C.	P.D.		P.D.					T.E.		T.E.	S.D.	
14:00~16:00				P.D.					S.C.					P.D.	S.D.	S.C.		
16:00~18:00						S.D.						S.C.	S.C.		T.E.		T.E.	
18:00~20:00				O.D.		S.D.					P.D.	T.E.	O.D.	P.D.			S.C.	
20:00~22:00			T.E.	T.E.				P.D.						T.E.	P.D.			
22:00~24:00			P.D.			P.D.	T.E.	T.E.			P.D.	O.D.	T.E.		S.C.		S.C.	
Day 4	Officers																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
00:00~02:00						S.C.	O.D.	T.E.			O.D.		S.C.		P.D.		S.C.	O.D.
02:00~04:00		P.D.	T.E.			O.D.	P.D.	S.C.		P.D.	S.C.		S.C.		P.D.		P.D.	P.D.
04:00~06:00		O.D.	P.D.							S.C.								
06:00~08:00						P.D.					T.E.				S.D.		O.D.	S.C.
08:00~10:00		O.D.	P.D.												T.E.		T.E.	T.E.
10:00~12:00		S.C.	T.E.			P.D.					S.C.							
12:00~14:00						T.E.	T.E.	S.D.					O.D.				P.D.	P.D.
14:00~16:00								P.D.		S.C.			T.E.				S.C.	O.D.
16:00~18:00							T.E.			O.D.								
18:00~20:00							S.C.	S.D.					O.D.					
20:00~22:00		P.D.	O.D.					S.C.		T.E.	P.D.		P.D.		T.E.			
22:00~24:00		S.C.	O.D.			O.D.	O.D.			T.E.	O.D.				S.C.			
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	--
00:00~02:00	T.E.	S.C.		S.D.					P.D.	T.E.				O.D.		O.D.		
02:00~04:00	T.E.	P.D.	P.D.	P.D.	P.D.	P.D.		T.E.	P.D.	T.E.		O.D.	S.D.	P.D.		S.C.		
04:00~06:00			O.D.		S.D.	T.E.		T.E.				P.D.	S.C.					
06:00~08:00	S.C.			T.E.					O.D.							P.D.		
08:00~10:00			O.D.			S.D.	T.E.	P.D.	S.C.			S.C.						
10:00~12:00			P.D.			O.D.	T.E.	S.D.				O.D.						
12:00~14:00		O.D.								S.C.				S.C.				
14:00~16:00		O.D.			T.E.		S.D.			O.D.			P.D.					
16:00~18:00	P.D.			S.D.	T.E.		S.C.						O.D.	S.C.		P.D.		
18:00~20:00	P.D.	T.E.		P.D.					T.E.	S.C.				O.D.		O.D.		
20:00~22:00		P.D.	T.E.		S.D.	S.C.	S.C.	P.D.	O.D.			S.C.	P.D.					
22:00~24:00	S.C.		S.C.	S.C.	P.D.	S.C.	P.D.	S.D.		O.D.		T.E.	S.C.	P.D.		T.E.		
Day 5	Officers																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
00:00~02:00	P.D.				S.C.			S.D.	T.E.				P.D.	O.D.		S.C.	S.C.	T.E.
02:00~04:00	P.D.	T.E.			O.D.			S.C.	P.D.			P.D.	T.E.	T.E.	O.D.	P.D.	T.E.	P.D.
04:00~06:00		S.D.										P.D.			P.D.			
06:00~08:00					P.D.			T.E.						T.E.			P.D.	S.C.
08:00~10:00		P.D.			P.D.										T.E.		T.E.	
10:00~12:00		T.E.						S.D.							O.D.			
12:00~14:00	O.D.				S.C.			P.D.	O.D.				S.C.			T.E.	P.D.	
14:00~16:00	S.C.				T.E.				S.C.			T.E.					S.C.	
16:00~18:00												S.C.	P.D.	S.C.		T.E.		O.D.
18:00~20:00	O.D.								T.E.				S.D.	O.D.		P.D.		S.C.
20:00~22:00	S.C.	P.D.							O.D.			O.D.			S.C.			
22:00~24:00		S.D.						T.E.				T.E.	O.D.	S.C.	T.E.	S.C.		O.D.
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	--
00:00~02:00		S.C.							P.D.		P.D.				O.D.		S.C.	
02:00~04:00	T.E.	S.C.				P.D.	S.C.		P.D.		P.D.	S.C.	S.C.		P.D.	S.D.	T.E.	
04:00~06:00	T.E.					O.D.	O.D.					T.E.	S.C.			S.C.		
06:00~08:00		S.D.							O.D.						S.C.		O.D.	
08:00~10:00	S.D.	P.D.		O.D.		S.C.	T.E.		S.C.	S.C.			T.E.		T.E.		O.D.	

Table A1 The Optimal Schedule of Officers' Duty Assignments for the Week (Cont'd)

Day 5	Officers																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
10:00~12:00	S.C.			P.D.		O.D.	P.D.			S.C.			T.E.					
12:00~14:00		S.D.									T.E.				S.C.			
14:00~16:00				T.E.						S.D.	O.D.	P.D.			P.D.	O.D.		
16:00~18:00				O.D.						S.D.		T.E.				P.D.		
18:00~20:00									T.E.		S.C.						P.D.	
20:00~22:00	S.D.			P.D.		S.C.	S.C.		S.C.	T.E.	S.C.	S.C.	P.D.			T.E.	S.C.	
22:00~24:00	P.D.	T.E.		S.C.		P.D.	T.E.			T.E.		P.D.	P.D.			S.C.		

Day 6	Officers																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
00:00~02:00	T.E.			O.D.		S.C.	P.D.		S.C.	S.D.							O.D.	
02:00~04:00	T.E.			T.E.		P.D.	S.D.	P.D.	T.E.	T.E.	P.D.			T.E.			T.E.	
04:00~06:00								T.E.			P.D.			P.D.				
06:00~08:00	S.C.			P.D.		O.D.	P.D.			S.C.								
08:00~10:00				S.C.							T.E.	O.D.		O.D.				
10:00~12:00						S.C.	S.C.				S.D.	O.D.		P.D.				
12:00~14:00						P.D.	S.C.		O.D.								T.E.	
14:00~16:00								S.D.	S.C.			P.D.					S.C.	
16:00~18:00	O.D.							S.C.		S.D.		T.E.						
18:00~20:00	S.C.			O.D.					O.D.	P.D.							S.C.	
20:00~22:00				S.C.				S.D.	T.E.		T.E.	T.E.		S.C.			O.D.	
22:00~24:00	S.D.					O.D.	T.E.	T.E.		T.E.	O.D.	P.D.		S.C.				

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	--
00:00~02:00					T.E.			S.C.	P.D.		O.D.			T.E.	P.D.		T.E.	
02:00~04:00	S.C.				P.D.		T.E.	T.E.	O.D.	O.D.	S.C.	P.D.	S.C.	S.C.	T.E.	P.D.	S.C.	
04:00~06:00	S.C.						S.C.			T.E.		S.D.	O.D.			O.D.		
06:00~08:00					T.E.			O.D.			T.E.				S.D.			
08:00~10:00		O.D.			P.D.			O.D.		O.D.	T.E.	S.C.	P.D.		S.D.			
10:00~12:00		T.E.								P.D.		T.E.	O.D.					
12:00~14:00					O.D.				S.D.					T.E.	P.D.		S.C.	
14:00~16:00	T.E.	O.D.			O.D.		P.D.		P.D.						T.E.	T.E.	O.D.	
16:00~18:00	P.D.	T.E.					P.D.							O.D.		S.C.		
18:00~20:00								T.E.	T.E.					S.D.			P.D.	
20:00~22:00	T.E.	S.C.					O.D.	S.C.	S.C.	P.D.	O.D.	S.C.	T.E.			P.D.	O.D.	
22:00~24:00	O.D.	S.C.					O.D.			T.E.	S.C.	O.D.	P.D.	S.C.		T.E.		

Day 7	Officers																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
00:00~02:00			S.D.	O.D.	P.D.				O.D.							S.C.	T.E.	P.D.
02:00~04:00			T.E.	P.D.	T.E.	T.E.	T.E.		S.C.		O.D.					S.C.	S.C.	S.C.
04:00~06:00						S.C.	P.D.				S.C.							
06:00~08:00				S.C.	O.D.				S.D.							P.D.		
08:00~10:00					S.C.	T.E.			S.C.		P.D.							
10:00~12:00				P.D.		O.D.					O.D.					S.D.		
12:00~14:00			T.E.	S.C.					P.D.							O.D.	O.D.	P.D.
14:00~16:00							O.D.		P.D.								S.C.	
16:00~18:00			P.D.				P.D.											T.E.
18:00~20:00			S.C.		O.D.												S.D.	T.E.
20:00~22:00						O.D.	S.C.				T.E.							
22:00~24:00			S.D.	O.D.	P.D.	P.D.	S.C.				P.D.					T.E.	P.D.	O.D.

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	--
00:00~02:00			S.C.	P.D.	O.D.	S.C.		P.D.	P.D.						T.E.		T.E.	
02:00~04:00	S.D.	S.C.	O.D.	P.D.	S.C.	S.C.		S.C.	O.D.	P.D.	S.C.		T.E.	T.E.	T.E.		S.C.	
04:00~06:00	T.E.	P.D.								O.D.	T.E.		O.D.	S.D.				
06:00~08:00			T.E.		O.D.	T.E.		P.D.									S.C.	
08:00~10:00		T.E.	S.D.		P.D.	O.D.				O.D.	O.D.		O.D.			P.D.		
10:00~12:00		S.C.								T.E.	S.C.		P.D.			T.E.		
12:00~14:00					T.E.	O.D.			S.C.						S.D.			
14:00~16:00	S.C.			O.D.	T.E.	T.E.			S.D.					P.D.	S.C.	O.D.		
16:00~18:00	S.C.			O.D.				O.D.						T.E.		S.C.	S.D.	
18:00~20:00			P.D.					O.D.	S.C.						P.D.		T.E.	
20:00~22:00	S.D.	P.D.	S.C.	T.E.						S.C.	O.D.		P.D.	S.C.		O.D.		
22:00~24:00	T.E.	T.E.		T.E.				T.E.	T.E.	P.D.	P.D.		T.E.	O.D.	P.D.	S.C.	P.D.	