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Modelling Fatigue and Performance Capabilities in Nigerian Security Agencies Workforce

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Abstract

Fatigue is a physiological state of reduced mental or physical performance capabilities resulting from sleep loss or extended wakefulness, circadian phase or workload emanating from mental or physical activities. It has contributed to poor productivity level and performance, accidents, high risk as well as significant problems in security agencies and modern society. With the high demand in workplaces, long task periods, disrupted circadian rhythms, social and societal demands and insufficient sleep caused by fatigue, it effects had over time affected worker's ability to think and make decisions, reduced the ability to do complex planning and communication skills. Many scholars have assessed the causes of fatigue in aircrew workforces but for security agencies not to my knowledge. A structured questionnaire was administered to security agencies and the data got was analyzed using MATLAB software and the findings were used to formulate a Model of Fatigue and Performance Capabilities for Nigerian Security Agencies Workforce. This model was used to solve a numerical example indicating that the model aids improvement in the agility, performance and productivity of workers mentally, physically and psychologically.

Keywords: Agencies • Fatigue • Model • Performance • Security

Introduction

Fatigue according to the International Civil Aviation Organization (ICAO) 2012 manual for regulators, is a physiological state of reduced mental or physical performance capabilities resulting from sleep loss or extended wakefulness, circadian phase or workload (emanating from mental or physical activities) that can impair a crew members' alertness and ability to safely operate an aircraft or perform safety related duties [International Civil Aviation Organization (ICAO), 2012, xii] [1]. From the definition above, circadian also called chronotype is an attribute that showcases the period or time of the day that a person's physical, mental or behaviour functions (level of his/her hormones, temperature of the body, cognitive developments and faculties, eating and sleeping patterns) are active, change or reach a certain level. Etymologically, circadian process consists of categories of people known as Early Wakers and Late Enders. The Early Wakers (Morning Persons) are those who prefer to get up early in the morning to do their duties at the early hours of the day while the Late Enders (Evening persons) prefer to working at late hours and goes to bed very late.

The research work conducted by Tucker and Folkard (2013) reveals that Fatigue Risk Index (FRI) is used to estimate the increased risk of occupational accidents and injuries on a range of commonly used rotating shift systems [2]. However, Tucker, Marquie, Gentil, Folkard and Ansiau (2011) believe that there are no evidences that cognitive impairments depend on duration of exposure to shift work [3]. That, there exist cognitive abilities recovered during retirements from shift work either fully or intermittently. This is buttressed by the work carried out by Ozdemir, Selvis, Ozkol, Aydin, Tuluce, Boyson and Besiroglu (2013) which states that shift workers score higher than their day worker counterparts on a wide range of cognitive performance measures [4]. In another development, Cabon, Deharvengt, Grau, Maille, Berechet and Mollard (2012) has it that crew operating under reduced rest provisions (a minimum of 7 hours 30 minutes not 13 hours between shifts) had a decrease in frequency of flight data monitoring events severity levels with high risk of fatigue [5]. This implies that if the rest time is small then the fatigue risk becomes higher. Sleeplessness causes a high risk of fatigue and safe fewer situations. Meanwhile, safety and safety measures in a workplace, during a duty or task are key. Amalberti (2001) believes that in aviation, Fatigue and safety are linked, intertwined or interwoven as a difficult task because of the very low accident rate and complexity of accidents aetiology [6]. The research of Williamson, Lombardi, Folkard, Stutts, Courtney and Connor (2011) identified the links between sleep homeostatic factors (sleep deprivation and time since walking), impaired performance and increased accidents involvement [7]. They also considered the effects of various fatigue related outputs (Circadian, sleep homeostasis and task related influences) on fatigue and safety outcomes, evidences for each and performance capabilities [7]. From the backdrop, there is a dire need to model the Fatigue and Performance Capabilities of Nigerian Security Agencies Workforce.

Statement of the Problem

Fatigue has contributed to poor productivity level and performance, accidents, high risk as well as significant problems in security agencies and modern society. Meanwhile, there is a high demand in workplaces, long task periods, disrupted circadian rhythms, social and societal demands and insufficient sleep caused by fatigue. Fatigue has an effect on person's ability to think and make decisions, reduces the ability to do complex planning and communication skills. The state and feelings of a worker either being tired, wearied, sleepy from insufficient sleep, prolonged mental and physical work, anxiety all affects the agility and performance as well as productivity of a worker. In the light of the above, the research work seeks to formulate a Model of Fatigue and Performance Capabilities for Nigerian Security Agencies Workforce.

Aim and Objective of the Study

The Aim of the study is to Model a Fatigue and Performance Capabilities for Nigerian Security Agencies Workforce. The objective of the study is to assess the different types of fatigue models; identify the variables that contribute to fatigue in a workforce; model a fatigue and performance capabilities for Nigerian Security Agencies.

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Review of Related Literatures

The research conducted by Willamson (2011) reveals that fatigue is a biological drive for recuperative rest [7]. That the sources of fatigue are in three fold, namely: (a) Homeostatic factors (time since sleep). This has an effect on the person such that, the longer one is awake, the higher the risk of accidents and the greater the performance decrement. (b) Circadian influences (time of days) leads to complex issues. That the subjective ratings of fatigue and objective sleep measures or sleep latency shows marked circadian rhythms effect with a maximum effect occurring between three O'clock to five O' clock in the morning and (c) Nature of the task that includes the duration either short or long time, workload and monotony. Other researches related to fatigue include: Smolensky, Milia, Ohayon and Phillip (2011) identified five types of sleep disorder that impacts on the fatigue and safety namely: Insomnia, Narcolepsy, Obstructive sleep apnoea syndrome (Sleep apenoea), Periodic limb movement disorder, Restless legs syndrome [8]. While the ICAO (2014) guidelines document stated seven Biomathematical Fatigue Models as follows [9] (Table 1) CASA Guidance Document for Bio-mathematical Fatigue Models (2014).

Scientific Modelling of Fatigue

The original model of sleep regulation formulated by Boebely (1982) revealed both the timing and duration of sleep with their interactions [10]. That sleep regulations involve two main scientific processes called SLEEP and CIRCADIAN (CLOCK).

SLEEP PROCESS is the first process also called the HOMEOSTATIC PROCESS gets to an onset called the peak or kurtosis (P) and wake up occurs when sleep gets to a flat or low level (L). As sleep goes on, the homeostatic process decreases in a geometrical doubling way. The result to sleep loss with increased shift or schedule time increases sleep process thereby causing "homeostatic pressure". Similarly,

CIRCADIAN PROCESS is an undulating clockwise process that aids sleep to take place at night and come to an end during the day. From day to night yields a circular or clockwise pattern called CIRCADIAN PATTERN. Varying parameters like light or darkness of the enabling environment, time horizon changes, night shifts and irregular hours of schedules affect this Circadian Pattern.

Methodology

The research design adopted for this work was the survey design and analytical approach. A structured questionnaire was administered to one thousand five hundred personnel across the six geopolitical zones aimed at collating data in order to elicit the objectives of the Corps. The data collected from the respondents was analyzed using mathematical software called MATLAB. The findings of the results were used to formulate and propose a Model for Fatigue and Performance capabilities in Nigerian Security Agencies Workforce

$$\min F = w_1 \times S_1^+ + w_2 \times S_2^- + w_3 \times S_3^+ + w_4 \times S_4^+ + w_5 \times S_5^+ + w_6 \times S_6^- \quad (1)$$

Objective function with same set of constraints is given as:

$$Obj = W_1 \times \frac{S_1^+}{45,599,500} + W_2 \times \frac{S_2^+}{114,230} + W_3 \times \frac{S_3^+}{409,820} + W_4 \times \frac{S_4^+}{2710} + W_5 \times \frac{S_5^+}{5,000,000} + W_6 \times \frac{S_6^+}{204,810} \quad (2)$$

Where W_i are the weights and S_i are the positive (surplus) and negative (slacks) deviations.

Numerical Example Computation [11] (Table 2).

Notations and Model Variables

The proposed mathematical model assumes the following: That,

1. Costs of hiring, firing and training Corps are known and deterministic.

2. Availability of Corps to be equal to 87.5% with daily breaks.

$$\frac{11\,hours \times 5\,days \times 4\,weeks}{12\,hours \times 5\,days \times 4\,weeks} = \frac{210}{240} = 87.5\% \equiv 0.875 \approx 0.88$$

3. Number of Corps' skilled level=number of schedules and machines

Table 1. Guidance document for biomathematical fatigue models (2014).

S/No.:	Models	Parameters representing the models
	The Boeing Alertness Model (BAM)	3 Process models + task related
2.	The Circadian Alertness Simulator (CAS)	2 Process models + task related
3.	The Fatigue Assessment Tool by Inter Dynamics (FAID)	2 Process models + task related
4.	The Fatigue Risk Index (FRI)	Cumulative, duty time and job time breaks data from aircrews, train drivers and laboratory studies
5.	The System for Aircrew Fatigue Evaluation (SAFE)	3 Process models + task related
6.	The Sleep, Activity and Task Effectiveness Model and associated Fatigue Avoidance Scheduling Tool (SAFTE-FAST)	2 Process models + task related
7.	The Sleep Wake Predictor (SWP)	3 Process models + task related

Table 2. The worst possible of deviational variables

Unwanted deviations	Maximum value
S_1^+ (Cost)	45,599,500
S_2^+ (Profit)	114,230
S_3^+ (Break)	409,820
S_4^+ (Fatigue)	2710
S_5^+ (Motivation and Staff overturn)	5,000,000
S_6^+ (Error rate)	204,810

levels.

4. Productivity of Corps is increased exponentially overtime.

5. Capabilities and willingness of Corps are increased as skills and personality levels/ranks increases.

6. Parameter values are certain over scheduled period of time.

The Indices are:

1. T=Time or planning periods per week. t=1, 2, 3,…,T
2. S=human skill level. j, k=1, 2, 3, …., S.
3. M=Machine or arms level. x, y=1, 2, 3, ,,,, M.
4. P=Personality attributes or ranks. p=1, 2, 3, …, P.
5. q=Motivational gifts, awards, conversion, promotions etcetera. q=1, 2, 3, …, Q

The Parameters are:

1. h_{jt}=Cost of hiring a Corp with j-skill within period t.
2. f_{jt}=Cost of firing a Corp with j-skill within period t.
3. tr_{jkt}=Cost of training a Corp from skill k to skill j within period t.
4. sl_{jpt}=weekly/monthly salary of a p-level staff with j skill within period t.
5. r_{jt}=hourly rate of a Corp with j skill at overtime within period t.
6. A_{jt}=Available regular working hours of a Corp with j skill within period t.
7. AOT_{jt}=Available overtime working hours of a Corp with j skill within period t.
8. C_{jp}=Capacity of a p-level Corp with j skill.
9. O_{x}=Opportunity to work on or use machine level x in each period t.
10. R_{jpx}=Readiness/willingness of p-level worker with j-skill working in x-machine.
11. D_{jt}=Demand for skill j within period t.
12. Q_{jktx}=Motivational cost or cost of motivating a Corp with j-skill tok-skill working with x-machine with period t.

The Decision Variables are:

1. W_{jtx}=Number of Corps with j-skill assigned to x-machine within period t.
2. H_{jtx}=Number of hired Corps with j-skill assigned to x-machine at period t.
3. E_{jtx}=Number of existing Corps with j-skill assigned to x-machine at period t.
4. Y_{jkyt}=Number of Corps assigned to y-machine, trained from k-skill to j-skill further assigned to a higher machine x within period t.
5. OT_{jtx}=Overtime hours of a Corp with j-skill working on x-machine at time t.
6. Pr_{jptx}=Productivity if p-level Corps with j-skill working with x-machine within period t.
7. Per_{jptx}=the output performance from a p-level Corps with j-skill working on x-machine within period t.
8. IT=Ideal time and
9. B_{jptsx}=Break time

To achieve these, we carried out normalization or linear scalarization of the multi-objective optimization problem through aggregation or reformulation of the objective functions and the constrained single-objective problems. That is:

$$\min \sum_{i=1}^{m} w_i f_i(x);\ x \in \chi$$

Where W_i=the weighted sums and $\chi$is the space.

Proposed Fatigue and Performance Capabilities Model

The objective function of the model is stated as follows:

Goal 1: z_1=Ideal time minimization and interruption periods.

$$z_1 = \sum_{s=1}^{TS} (B_{jptsx} + IT_{jptsx}) \tag{4}$$

Goal 2: z_2=Fatigue minimization and the rate of interruptions in a scheduled task.

$$z_2 = \sum_{S=1}^{TS} (fra_{ps} \times IT_{jptsx}) - m \sum_{S=1}^{8.75} (fra_{ps} \times B_{jptsx}) - (m-1) fra_{ps} \times B_{jptsx} \le F_{MAX\ ps} \tag{5}$$

Goal 3: z_3=Error rate minimization.

$$z_3 = \sum_{t=1}^{T} \sum_{p=1}^{P} \sum_{j=1}^{s} \sum_{x=1}^{M} (W_{jptx} + Y_{jptx} + tr_{jptx}) - m \sum_{S=1}^{TS} (fra_{ps} \times IT_{jptsx}) \tag{6}$$

The constraints are respectively explained as:

1. Total available Corps working hours=number of hours for each skill in each period.

$$0.875 \times A_{jt} \sum_{p=1}^{P} \sum_{x=1}^{M} (A_{jptx} \times W_{jptx}) + \sum_{p=1}^{P} \sum_{x=1}^{ML} (OT_{jptx}) = D_{jt} \tag{7}$$

2. Available workforce in any period=previous workforce + current changes in workforce.

$$W_{jptx} = W_{jp(t-1)x} + H_{jptx} - E_{jptx} + \sum_{\substack{k=j-1 \\ j\ge 2}}^{j} \sum_{\substack{y=x-1 \\ x\ge 2}}^{x} (Y_{kjptxy}) - \sum_{\substack{k=j+1 \\ k\ge 2}}^{k} \sum_{\substack{y=x+1 \\ y\ge 2}}^{y} (Y_{kjptxy}) \tag{8}$$

3. Overtime workforce is less than maximum available overtime workforce.

$$OT_{jptx} \le AOT_{jt} \times W_{jptx} \tag{9}$$

Weight space analysis

In weighted Goal Programming Models, we use a set of preference weights assigned to the penalization of unwanted deviations to provide solutions that are of practical use. The weights of all unwanted deviational variables must be greater than zero to avoid the possibility of generating Pareto inefficient solutions. From the above definitions, a small weight of 0.001 is assumed to replace a zero weight. The works of Jones & Tamiz (2010) developed a Heuristic method and sensitivity analysis to finding the weight values in the weighting space [12]. The essence of the sensitivity analysis is to find out solutions that will fit into any Security Agencies' requirements and which piece(s) of information should be estimated most carefully (Table 3).

Script Written In Matlab for Level of Fatigue and Recovery Rates of Corps

```
Rank=[1;2;3];

FATIGUE=[0.88;0.60;0.13];

DUTY1=[0.8;0.5;0.10];

DUTY2=[0;0.5;0.1];

DUTY3=[0;0.5;0.1];
```

DUTY4=[0;0;0.1];

DUTY5=[0;0;0.1];

subplot(3,1,1)

plot(Rank,FATIGUE,'-o',Rank,DUTY1,'-o',Rank,DUTY2,'-or',Rank, DUTY3, '-om', Rank, DUTY4, '-ob', Rank, DUTY5, '-ok'), legend('FATIGUE1', 'DUTY 1','DUTY 2','DUTY 3', 'DUTY 4','DUTY 5', 'DUTY 6'), xlabel('Fatigue and Duty'), ylabel('Fatigue Fraction'), title('Goal types againts fatigue and duty')

FATIGUE=[0.88;0.60;0.13];

DUTY1=[0.5;0.5;0.4];

DUTY2=[0;0.5;0.4];

DUTY3=[0;0.5;0.4];

DUTY4=[0;0;0.4];

DUTY5=[0;0;0.4];

subplot(3,1,2)

plot(Rank,FATIGUE,'-o',Rank,DUTY1,'-o',Rank,DUTY2,'-or',Rank,DUTY3,'-om',Rank,DUTY4,'-ob',Rank,DUTY5,'-ok'),legend('FATIGUE1','DUTY 1','DUTY 2','DUTY 3','DUTY 4','DUTY 5','DUTY 6'), xlabel('Fatigue and Duty'), ylabel('Recovery Rates')

FATIGUE=[0.88;0.60;0.13];

DUTY1=[1.1;1.15;0.35];

DUTY2=[0;1.15;1.35];

DUTY3=[0;1.15;1.35];

Table 3. Level of fatigues and recovery rates (0.875 approximated to 0.88)

Types of Goals	Levels of Rank	Fatigue Max	Task/ Duty				
			1	2	3	4	5
Fatigue Fraction	R_1	0.88	0.8				
	R_2	0.60	0.5	0.5	0.5		
	R_3	0.13	0.10	0.1	0.1	0.1	0.1
Recovery Rates	R_1	0.88	0.5				
	R_2	0.60	0.5	0.5	0.5		
	R_3	0.13	0.4	0.4	0.4	0.4	0.4
Endurance Rate	R_1	0.88	1.1				
	R_2	0.60	1.15	1.15	1.15		
	R_3	0.13	1.35	1.35	1.35	1.35	1.35

DUTY4=[0;0;1.35];

DUTY5=[0;0;1.35];

subplot(3,1,3)

plot(Rank,FATIGUE,'-o',Rank,DUTY1,'-o',Rank,DUTY2,'-or',Rank,DUTY3,'-om',Rank,DUTY4,'-ob',Rank,DUTY5,'-ok'),legend('FATIGUE1','DUTY 1','DUTY 2','DUTY 3','DUTY 4','DUTY 5','DUTY 6'), xlabel('Arms Usage R1 R2 R3Fatigue and Duty'), ylabel('Endurance Rate')

Matlab Script for Comparing Different Weights With Goal Cases 1 To 9 And Considering Fatigue For Each Case

FATIGUE2=[0;45.2;65.3;0;53.2;8.4;38.3;0;0];

W1=[0.35;0.85;0.002;0.002;0.56;0.003;0.58;0.003;0.50;];

W2=[0.35;0.002;0.002;0.002;0.005;0.56;0.56;0.003;0.003];

W3=[0.35;0.002;0.852;0.002;0.56;0.001;0.56;0.003;0.003];

W4=[0.35;0.002;0.002;0.85;0.005;0.001;0.001;0.85;0.003];

W5=[0.35;0.002;0.005;0.004;0.038;0.0045;0.002;0.003;0.001];

W6=[0.35;0.002;0.85;0.003;0.025;0.65;0.001;0.85;0.001];

plot(FATIGUE2,W1,'-o',FATIGUE2,W2,'-o',FATIGUE2,W3,'-or',FATIGUE2,W4,'-om',FATIGUE2,W5,'-ob',FATIGUE2,W6,'-ok'),legend('WEIGHT 1','WEIGHT 2','WEIGHT 3','WEIGHT 4','WEIGHT 5','WEIGHT 6'), xlabel('FATIGUE'), ylabel('WEIGHTS'),title('Comparing Weight with FATIGUE') (Figure 1).

Discussion and Conclusion of Results

The results obtained in Table 3 and Figure 2 reveals that, an increase in the rank of the Corps results into a decrease in the fatigue value level, error rates and idle time minimization of Corps. This implies that, learning on the job, getting much experience through refresher courses and on-the-job training contributes to reducing fatigue level, error rates and idle time minimization of Corps among personnel (from 0.88 to 0.1). Similarly, the recovery rates of Corps got reducing as the Corps ranks or skill level increased. This implies that the older the personnel, the lesser it takes for the Corps to recover from fatigue. In another development, Endurance rates of Corps reduced over time but at a certain level for the older/bigger ranks (peak of the carrier), the endurance rates dwindle. It could be as a result of aging, not being at the forefront of the security tasking duty or shift, too busy with administrative work in the office and relaxation from the work since they

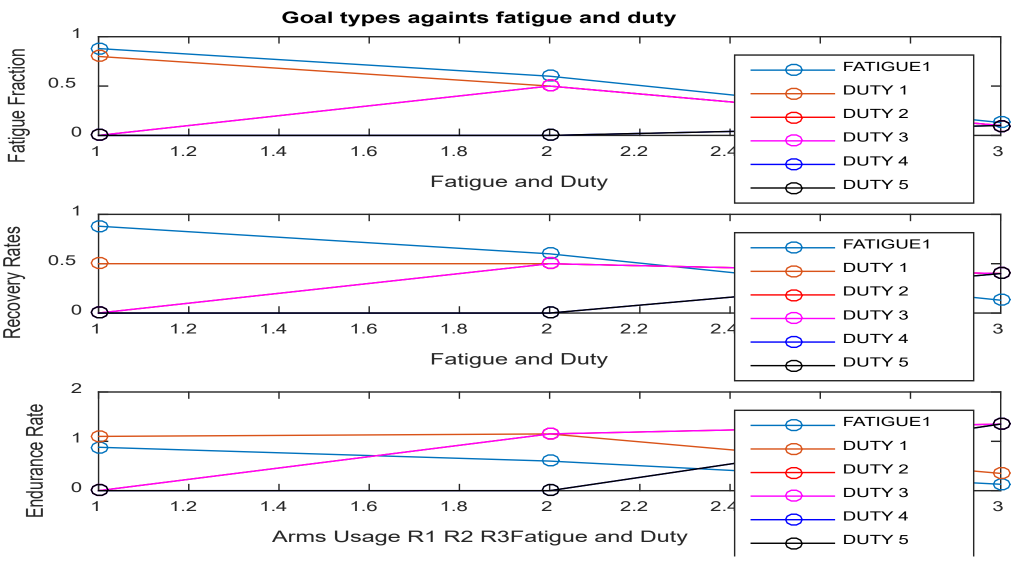

Figure 1. Level of fatigue and recovery rates of corps.

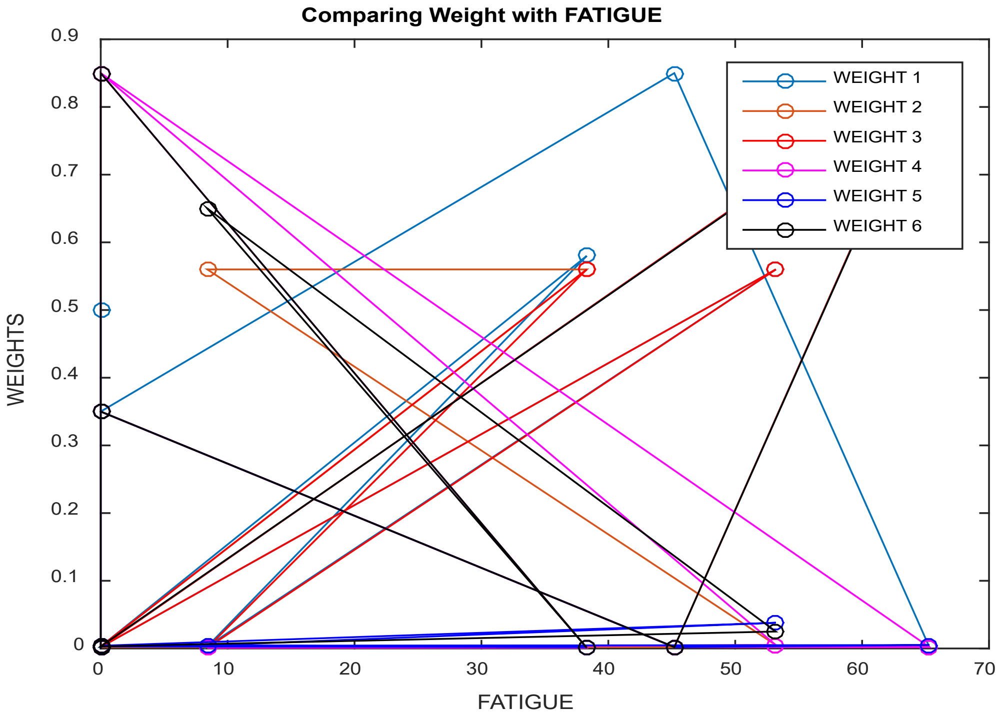

Figure 2. Comparing Different weights with goal cases 1 to 9 and considering fatigue for each case.

Table 4. Comparing different Weights with Goal Cases 1 to 9 and considering Fatigue for each case.

Goal Cases	W 1 (C)	W 2 (P)	W 3 (It)	W 4 (F)	W 5 (Er)	W 6 (SM)	Fatigue
1	0.35	0.35	0.35	0.35	0.35	0.35	0
2	0.85	0.002	0.002	0.002	0.002	0.002	45.2
3	0.002	0.002	0.852	0.002	0.005	0.85	65.3
4	0.002	0.002	0.002	0.85	0.004	0.003	0
5	0.56	0.005	0.56	0.005	0.038	0.025	53.2
6	0.003	0.56	0.001	0.001	0.0045	0.65	8.4
7	0.58	0.56	0.56	0.001	0.002	0.001	38.3
8	0.003	0.003	0.003	0.85	0.003	0.85	0
9	0.50	0.003	0.003	0.003	0.001	0.001	0

are not accounting to anybody or they are not under anybody's supervision. The simulation in Figure 2 reveals that, only experienced high ranking Corps is involved in duty/task 3 while the highest ranking Corps was involved in the duty/tasks 4 and 5 respectively since it is demanding of technocrat skills with the highest degree of expertise. From Table 4, same weights in Goal case 1 resulted to fatigue value level of "0". Increasing cost minimization in Goal case 2 and reducing other weights yields a fatigue value level of 45.2. Similarly, in Goal case 3, increasing the idle-time minimization and staff over turn weights gives rise to a peaked fatigue value of 65.3. On the contrary, in Goal cases 6, 8 and 9, decreasing idle-time weight, fatigue weight, error rates weight and staff overturn weight decreases the fatigue value level to "0". Meanwhile, in Goal case 5, decreasing performance weight to 0.005 and increasing other weights results to an increase in fatigue value level of 53.2. More fatigue yields less productivity and performance. This means that, to achieve maximum performance and productivity, the Corps fatigue, break time, idle-time and staff over turn weights ought to be reduced. In another development, Goal case 4 reveals that, even if the fatigue weight is increased to the maximum recovery level weights, while other weights are at minimal or least value level, the resultant effect will also be a fatigue value level of "0".

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