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THE COUNTER-TERRORISM RESOURCE ALLOCATION QUEUING FAIRNESS APPRAISAL OF LEADERSHIP DECAPITATION APPROACH

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Abstract

Leadership decapitation, the preferential policy of targeting/interdiction of terrorist leadership class in CT environment derived its policy justification from the psychological beliefs that such tactical approach is key to disrupting and destabilizing of the operational/strategic functioning of the organization. Hence accelerate the weakening of the organization's cohesiveness and capacity to conduct operations, which are prerequisites for the collapse of the organization. Given the high resilience characteristics, unperturbed dynamics and the proliferation of terrorist groups as well as other institutions of organized crime in recent years, most scholars have appraised the failure of the kingpin strategy from the perspective of insufficient credible intelligence gathering and analysis endemics to the system. We x-rayed the popular mono-tactical CT approach on the lens of conformity to the fundamental principle of social justice, equity and fairness – the performance measure of any socio-economic and political agenda in human society. We showed that, though the prioritization of leadership decapitation may have greater utility in depopulating key echelon of the organization in the short term, but in general such approach in a crime fighting environment does not conform to either the fundamental principles of preferential service in a queuing system, or the basic principle of social justice, equity and fairness in human society. The security implication of this tactical approach is the high system discrimination and unfairness coefficients; high interdiction of foot-soldiers' class in expense of key terrorist leaders; the overall high waiting and sojourn times of the operatives as well as high delay probability and response time of the CT forces. To address these conflict, the study recommended the deployment of multi-tactical (e.g. sticks and carrots) alternative approach as well as the deployment of specialized non-conventional covert intelligence agents to infiltrate CT environment, and boost credible intelligence for proper identification, categorization, and smart targeting of terrorist locations. These results which might sound simpler and intuitive to many researchers can be used to build confidence in CTRAQF unfairness and class discrimination metrics; both of which are very new to the terror-queue theorists and hence require examination and trust building. Once the deserved confidence and trust has been built, CTRAQF model can be used to evaluate and study CT systems where the results may not be explicit.

Key Words: Leadership decapitation, CTRAQF, Prioritization, class discrimination, system unfairness, covert intelligence agents

1.0 INTRODUCTION

In the conventional security and defense philosophy of counter-terrorism (CT), a high premium is place on the interdiction of terrorist leaders, operational planners, weapon experts, commanders and individuals deploying their expertise in areas such as IED (explosives), recruitments, cyber operations and propagandas; hence, the dominant leadership decapitation strategy of most world governments CT policies[22,23];[24]. The policy justification for prioritizing the decapitation of terrorists' leadership in CT environment may not be unconnected with the psychological beliefs that targeting the leadership of an organization would disrupt the operational and strategic functioning of the group. With enough destabilization of these core elements of the group, the organizations' capacity to conduct operations would diminish, and the organization's cohesiveness would decline. With enough disruption too, it should even be possible to induce distrust, infighting and atomization of the group, which in turn may lead to the collapse of the organization[8];[43].

Price[8] observed that terrorist organizations' clandestine and cataclysmic dynamics often create a mythical image of their leaders. This makes the replacement of such leaders after their demise very difficult, and thus causes the group to splinter. Predicated on this theory, the author argued that decapitation strategies are meant to interrupt the group's operational routine and deter other members from aspiring to leadership position based on the assumption that they will also fear being killed. The fall of the organization, like the shining path in Peru, hitting at the leadership of an organization should reduce its operational capabilities and compels it to divert resources and attention to self-protection rather than focusing on attacking[8];[22,23].

Decapitation is also attractive because leaders of terrorist organizations are often directly in charge of monitoring, auditing, and compensating middlemen; punishing members for shirking their duties; and overseeing intra and inter-group communications. And so in their absence, proponents of decapitation are further convinced that the organizations will be significantly weakened irrespective of size and ideology, the groups have a higher probability of withering. Corroborating these convictions, Byman[16] observed that decapitation can substantially deplete a group's skilled personnel in areas such as bomb making, recruitment, indoctrination, and training, thus rendering the group highly vulnerable. Predicated on this philosophy, leadership decapitation or the kingpin strategy as it is commonly called, or the killing or capturing as well as coercive actions against terrorist leadership has been a core feature of most democratic governments' CT policy since the Al-Qaida attack on the World Trade Centre, USA in September 11, 2001.

Significantly, according to the US Department of Justice, with unrelenting force and unprecedented cooperation the US and its allies have identified and disrupted over 150 terrorist threats and cells; captured or assassinated nearly two thirds of Al-Qaida's known senior leadership around the world, including Osama Bin Laden - the mastermind of the 9/11 attacks; incapacitated over 3,000 operatives around the world; investigated and frozen over $136 million assets of senior terrorist leaders around the world; tried and convicted over 195 individuals; investigated and removed over 515 individuals linked to the September 11th attacks from the US[7];[55,56] to mention just but few success story of the US CT exploits.

In the sub-Saharan African CT environment also, journalistic accounts and documentary evidences also abound of the many Boko Haram and Islamic State of West Africa Province (ISWAP) key leaders, commanders, weapon experts, and senior operatives that have been decapitated since the Nigerian war on terror started in 2008. For example on July 31 2009 the news of the captured and subsequent assassination of Mohammed Yusuf – the erstwhile founder and leader of the dreaded Boko Haram terrorist group and his deputy by the Nigerian Police Force was announced and received with a sense of victory by the federal government of Nigeria[1];[6];[45].

Notwithstanding this unprecedented effort of the Nigerian government, the killing of Yusuf and his deputy has marked a turning point in Boko Haram's tenor, dynamic style, and targets escalation. Since then, Boko Haram has gained global attention for attacks on both hard and soft targets of local, national, and international significance. The increase in the number of deadly attacks carried out by the group since the demise of its founding leaders is another example that calls into questioning the efficacy of the decapitation approach. Suffice it to say also that under the reign of Yusuf's successor - Abubakar Shekau, documentary evidences and journalistic accounts also abound of the inevitable exploit of decapitation strategy in the areas of capturing, assassination and surrendering of the group commanders, leaders and other senior operatives.

Tentatively, in 2013, the Nigeria's military had announced the killing of one of the group top commander - Momodu Bama in a gun battle[67]. Then followed the assassination of another feared Boko Haram commander popularly known as Amir along with 200 other militants on September 13, 2014 in an unprecedented airstrikes by the Nigerian military[48]. The 2016 CT exploit capped the records with the Nigerian military confirming the assassination of at least two-third of top commanders of the organizations, while the group's elusive leader Abubakar Shekau was injured in an unprecedented and spectacular airstrikes, which signalled a rare victory for Nigeria's armed forces[10];[49,50]. Suffice it to say also that from

September 2018 to February 2021, not less than eighteen additional key leaders including Abubakar Shekau and other top commanders of both Boko Haram and ISWAP have been reportedly killed by either their rivalry group or in some unprecedented airstrikes by the Nigerian military[51-53].

Notwithstanding these unrelenting efforts and unprecedented exploits of decapitation as a strategy for states to fight the scourge of terrorism (and other institutions of organized crime), there is little conclusive evidence that prioritizing terrorist leadership class as a CT strategy is successful in disrupting terrorist campaign, or even mitigating its destructive effects in the world, especially in Nigeria and other sub-Saharan African region. Instead, nations the world over are plague with an increasingly more fluid and complex terrorist landscape, populated with diverse array of actors employing new technologies and tactics to advance their nefarious agendas. Terrorist organizations are growing more dynamically diffused and resilience in strength, with increasing number of groups, networks, and individuals exploiting global trends; including innovative and sophisticated intelligence, the emergence of more secure modes of communications, the expansion of social and mass media and persistent instability across several regions[8];[22,23].

In assessing the level of accomplishment or otherwise of the on-going global-war-on-terror (GWOT) championed by the US, stakeholders' success emphases have always been placed on the above theoretical "body count" approach, which is characterized by discrepancies in figures, and hence attracted much criticisms[2]. Johnson and Tierney[17], observed that, *"the war on terror is … one of the most inherently ambiguous conflicts in American history, with no precedent, and with much of the conduct of the war on both sides kept secret. This ambiguity has allowed people to choose their own criteria for success, thus encouraging the selection of arbitrary or self-serving metrics"*.

Notwithstanding the discrepancies in the figures and the claims of the theoretical "body count" approach, Ballen and Bergen[29] observed that looking at the gains of CT measures through the "body count" approach without comparing or reconciling them with results from analytical metrics, paints a partial and therefore potentially inaccurate picture of the efforts expended. Another key problem with the various indicators of success obtained through the "body count" approach is that they are not directly related to the aims of the States in GWOT. In other words the theoretical "body count" approach does not given a formative evaluation of the employed strategies as well as showing how much closer the State are to the desired end-point through the specific CT approach.

Thus, in perplex reaction to the expected discrepancies, ambiguity and selective self-serving metrics of CT stakeholder as well as the US theoretical "body count" approach, the US Defence Secretary - Donald Rumsfeld once opined: "*Today, we lack relevant metrics to know if we are winning or losing GWOT"*. In practical terms, *"are we capturing, killing or deterring and dissuading more terrorists every day than the madrassas and the radical clerics are recruiting, training and deploying against us?"*,[66]. Corroborating Rumsfeld's statement, Raphael[38] also observing that the *"uncertainty with respect to both strategies and measurements methods makes it difficult to describe progress accurately and to demonstrate progress to the public or U.S. allies"*. These keen observations made almost 18 years ago, not only remains valid today but it also seems that democratic governments are no closer to a conclusive answer at present than they were in 2003.

Therefore, to address these cogent observations, and thus contribute to the lean but demanding literature on CT performance appraisal, this study suggests a holistic empirical appraisal of the employed CT strategies over the years, especially the "leadership decapitation" approach champion by the US. In particular, *"how fair or equitable or result oriented does the prioritization of leadership decapitation in CT environment conforms to the basic philosophy and principle of social justices*"?, which demand that at any point in time *"equally needy members of a group should share equally the resources (the pie) available to the group*"[58];[59]. In a terror queue concept, *"how does the prioritization of CT targets as well as granting preferential interdiction to some class of terrorist operatives impact on the performance of the system as well as on the dynamical evolution of the organization?* This is the main focus of the present work – ***A Counter-Terrorism Resource Allocation Queuing Fairness (CTRAQF) Appraisal of Leadership Decapitation Approach.*** The goal of CTRAQF is to serve not only as one of the formative/summative evaluation standards for the on-going GWOT, but also to help address the inherent ambiguity in the theoretical "body count" results, and other self-servicing metrics of CT performance.

1.1 Fairness of a Queuing System

Fairness or justice or equity in the allocation or distribution of resources among contending customers/jobs in a queuing system is both a fundamental and consequential issue in human society, especially in crime fighting environment. This has always been and still is a cardinal issue in all cultures, traditions and socio-economic system; as fairness is the fabric that holds the human societies together as well as the major driver of most human behavioural patterns. Unlike every customers in a conventional queuing situation, terrorist are smart guys that are prone to exploiting any error or inconsistency of lapse in CT environment to their advantage, hence the prioritization of leadership decapitation cannot be an exception. According to the *"law of loopholes in action"*, *"Every loophole will eventually be exploited; every exploited loophole will eventually be closed"*[19].

The net implication of this law according to Freeman[57] is an ever-expanding set of security measures and requirements to be put in place, generally in response to any security breaches. Such rules and requirements are necessary to prevent a re-occurrence of a particular or unforeseen incident resulting from strategies inconsistences or lapses in the system. Nonetheless, to the extent a determined adversary's focus is on causing destruction and mayhem, these types of rules and requirements simply mean that as the CT forces are maximizing their effort and resources toward the decapitation of a particular class of terrorist operatives, the organization also adjust or shifted their attention and energies toward re-strategizing toward optimizing their nefarious agenda through other classes of operatives. This perhaps informed the unprecedented resilience characteristics, unperturbed dynamics and proliferation of terrorist groups and other institutions of organized crime in recent years, the world over.

Therefore, the analysis of the fairness characteristics of the priority terror queuing system, as well as its correlation with CT performance is inevitable not only for the assessment of the level of accomplishment or otherwise of a given CT measure, but also to help optimize the allocation of CT resources toward a fair and sustainable CT operation. Unfortunately, since the advent of the contemporary wave of insurgency in September 11 2001, growing academic literature on terrorism that have sought to appraise the performance of GWOT has hardly considered this important psychological concept but dwelled extensively on the political motivation, strategic choices of CT measures, and material support of terrorist organizations[9];[21];[34];[60-64],[65].

Tentatively, the issue of whether the implementable primary tactical CT approach of governments conform to the fundamental principle of social justice, equity and fairness in human society; which determine the successes or otherwise of every governments' socio-economic and political agenda has hardly been studied. The issue of how the prioritization of leadership decapitation and or granting preferential interdiction services to some class of terrorist operatives in CT environment affect the performance of GWOT, as well as drive the dynamical evolution of the organization has not been evaluated empirically and thus not fully understood. Our focus in the present study is to quantitatively examine the effect of *preemptive priority* interdiction polices on the fairness factors of a two-class terror queuing system using RAQF model proposed in the literature by Raz et al[40,41,42]. In order to focus on the pure fairness and pure queuing properties, we've limited our analysis to CT environment where class prioritization is based only on job seniority (arrival time) and service requirement (job size) differences. Systems where class prioritization may have other attributes such as different technical attributes, can be treated by weighting mechanisms, which are out of the scope of this study and may be dealt with in future work.

1.2 Class Prioritization in Terror Queuing System

One common CT policy used to implement preferential interdiction of terrorist operatives in the on-going GWOT is class *prioritization* - in which some classes of terrorist operatives, mostly the leadership cadre are categorized as high priority targets, while the rank-and-files or foot-soldiers are accorded low priority class target in CT environment. And a non-preemptive priority interdiction policy is assigned on operatives belonging to the higher priority class over those belonging to lower priority class. As observed in our introduction, the policy justification for adopting this tactical CT policy may not be unconnected with the psychological beliefs that targeting terrorist leadership class would disrupt and destabilized the operational and strategic functioning of the organization. Hence, dismissing the organization's cohesiveness and capacity to conduct operations, and thus, inducing distrust, infighting and atomization of the group which in turn may lead to the collapse of the organization[8];[43]. In this hypothetical non-preemptive priority CT queuing variant,

- If the high priority operative are detected while a low priority operative has earlier been detected, the low priority operative must be targeted and interdicted fully before the high priority operative is targeted (i.e., the low priority operative is not preempted by the high priority operatives, but on the other hand, no other low priority operative will be targeted until all detected higher priority operatives in the system are targeted and interdicted).
- The targeting of a low priority operative affect (slightly) the interdiction of high priority operatives, since the targeting and interdiction of a detected high priority operative in the CT environment has to be delayed for a full interdiction of the low priority operatives earlier detected.

This hypothetical terror queuing model is invariably the tactical CT approach employed in most conventional military-offensive CT measures tagged leadership decapitation, and of course the one analyse in this work. Ironically, by queue preferential service policy, the prioritisation of terrorist leadership in CT environment may not be unconnected with the ideal of service requirement preference principle, as the more experience and skilful leaders are comparatively fewer in number than the less experience rank-and-file foot-soldiers. Therefore, prioritizing such targets in CT environment may be fair, economically advantageous and technically rewarding than otherwise if properly implemented.

However, considering that the high resilience characteristics of today's ethno-religious and politically driven terrorist organizations, as well as the proliferation of other related institutions of organized crimes in the last decades has debunk the potency of leadership decapitation to provide sustainable and consistent degradation of terrorist organizations. This study therefore presents a quantitative appraisal and evaluate of the relative unfairness/fairness characteristics as well as the class discrimination coefficient of the non-preemptive terror queuing system tagged leadership decapitation. Thus, determining the effect of the priority interdiction policy of CT stakeholder on the overall queue fairness index of a two-class terrorist organization – leaders and foot-soldier, as classified by Gutfraind[21]. Such analysis will provide a measure of fairness for the CT systems that can be used to quantitatively account for fairness when considering alternative CT measure. The quantitative model would enhance the existing CT measures in which efficiency and fairness are only accounted for in a qualitative way.

To carry out the study, the Section 2.0 briefly reviewed some related literature on the subject matter of terror queue; the concept of terror queue fairness, as well as a brief conceptual framework on fairness measurement in terror queuing system. The Section 3.0 briefly reviewed and adapts the RAQF analytical framework to terror queue - Counter-terrorism Resources Allocation Queue Fairness (CTRAQF); the System Model of CTRAQF; the performance measure of leadership decapitation terror queuing (LDTQ) system as well as the analysis of fairness characteristics of LDTQ system. Finally, in Section 4.0, we present and discuss the result of the analysis, conclusion and some recommendations.

2.0 REVIEW OF RELATED LITERATURE

Though applying methods that rely on pure empirical inputs to yield an empirically supported conclusion that is devoid of context and predictive values was challenging and slow in coming, however, a number of mathematicians have developed methodologies from queue and games theories that attempt to characterize and study the performance of CT intelligence gathering systems[3];[25];[26];[27,28];[46]. For example, Kaplan[25] interpreting terror plots as customers and intelligence agents as servers in a queuing model to determine the optimal detection of terror plots as well as their interdiction by covert intelligence agents. Kaplan[25] terror queue model also introduced a new paradigm to determining the size of terrorists' state variable by estimating the numbers of terror threats in a given area that have not yet been detected, and then adding the number that have already been detected which of course is known to the state authorities. Originally, the author's terror queue analogy was purely descriptive, aimed at analysing the infiltration and interdiction of on-going terror plots by intelligence agents.

However, in a follow-up papers Kaplan[27,28] included staffing level optimization; to determine the number of agents that could maximizes the benefits minus-costs of preventing terror attacks. Moreover, by presuming that terrorists are smart guys that may deduce the staffing level of CT agencies by observing the fraction of attacks interdicted, the author also extended his investigation to a simple terror queue staffing game. In another complementary effort to Kaplan's contributions, aimed at addressing the dynamic aspects of inter-temporal staffing problem, with respect to the number of covert intelligence agent require to optimally detect and interdict terror plots, Seidl et al[3] extended Kaplan's work by applied Pontryagin's maximum principle of optimal control theory. The work which provides a useful method for understanding the qualitative behaviour of CT staffing system, predicted that the optimal strategy for the government depends on both the number of known and unknown terror plots; and as these state variables change dynamically over time, so too should the government strategy evolve.

Similar terror queue model by Wrzaczek et al[46], also seek to determine terrorist optimal attack rates over time as government simultaneously develop optimal CT staffing levels. Here, the authors determine the numbers of successful and interdicted terror attacks via an underlying fluid terror queue model. Considering three different possibilities of information structures between the terrorist and government, the authors characterize the optimal controls for both the terrorists and the government in terms of the associated state and co-state variables. And thus, deducing and solving the co-state equations numerically for the different information structures, the authors observed that if government is not able to observe terrorists by any means and therefore detect any terror plots, it is optimal for the terrorists to initiate terror plots at a constant rate, -

a motivation for the assumption of a constant attack rate made in Seidl et al[3]. Hence, it is optimal for terrorist to initiate more terror plots if the number of existing terror plots is high than if it is low.

One common characteristic of these terror queue models is the authors' unflinching interest in government's strategic choice of optimizing the detection and interdiction of terror plots through covert intelligence agents. However, the question of whether all the detected terror plots or operatives in the CT environment have been judiciously, equitably or fairly targeted and interdicted promptly, as well as the possible implications of any discriminative or unfairness in the CT policy has hardly been studied nor accorded due empirical analysis till date. In our terror queue variant, prospective terrorist operatives are treated as customers while the conventional military-offensive tactical CT approach connotes a server in a queuing model. This is aimed at studying the performance measures as well as the unfairness characteristics of the CT system that prioritized the decapitation of terrorist leadership class.

Susceptible individuals joining terrorist organization are assumed to arriving CT environment randomly in a Poisson distribution, and if detected by intelligence agents, he/she enters the "queue". If the detected operative is targeted for possible interdiction, he/she enters "service" and is finally remove from the system if interdicted. Sometimes detected operatives may evade targeting and interdiction as a result of the preferential service policy or intelligence lapse or system failure, and thus complete a terror attack. In terms of a conventional queuing model this is synonymous to customers who renege from the queue before being served. However, our queuing model analogy may be not exact. Unlike customers in conventional queues, terrorist operatives are not visible upon arrival at the system, but must be detected before targeting and possible interdiction, i.e. before CT measures can begin, thus, waiting customers (i.e. detected but un-interdicted operatives) and available CT actors may coexist in the system.

2.1 The Concept of Terror Queue Fairness

What is fairness in reality? And how can it be measured in a queuing situation? Though by mere mental ascent almost every child, if asked, can tell what is fair and what isn't fair. However, in scientific context, it is quite a demanding undertaking to have a commonly agreed definition of fairness, especially in a complex socio-economic system like terrorism, much more so when it comes to defining a quantitative measure of the level of fairness in a given CT environment. The issue of fairness generally has been a subject of contention and debate by philosophers, prophets and spiritual leaders since the beginning of recorded history. However, in modern time, many economists and social scientists have joined the debate, and as is to be expected, a large volume of researches and publications on the reviews and interpretation of social justice and fairness doctrine abound in literature, mostly by philosophers, economists, social and behavioural scientists[12];[13];[15];[18].

Perhaps one of the foremost relevant formulations of fairness issue is Aristotle's idea in "Nicomachean Ethics" which states that *"justice consists, at least in part, in treating equal cases equally and unequal cases in proportional manner. Also, there will be the same equality between the persons and the shares: the ratio between the shares will be the same as that between the persons"* [4]. Another prominent and comprehensive publication on fairness issue is Rawl's "Theory of social Justice", whose general conception demands that: *"All social primary goods/services such as liberty and opportunity, income and wealth, and the bases for self-respect, should be distributed equally unless an unequal distribution of any or all of these goods is to the advantage of the least favoured"*[39].

We therefore see that throughout the social justice debate, key emphasis is place on fair resource allocation, or the idea that fairness is achieved when the resource "pie" is appropriately (equally) divided between contending consumers. But what is the pie in the case of a terror queuing system, and how should it be divided fairly? And what is the implication of unfair division? A very similar concept in queuing theory is that of Processor Sharing (PS), as embodied by the ideal PS policy, analysed as early as Kleinrock[30,31] and Coffman et al[11]. The root idea of this policy is that *"at every moment of time, the servers' service rate (in this case terrorist interdiction rates) should be divided equally amongst the jobs (terrorist class) present in the system… and a violation of this policy connotes unfairness to the job"*. Tentatively, this is idea behind RAQF model principle which opined that *"at every epoch of time all jobs present in the system deserve an equal share of the system's service rate and a deviation from it create discriminations (positive or negative) …and accounting for such discriminations with summary statistics give yields a measure of unfairness"* [40,41].

As observed in Rafaeli et al[36], a system serving a queue of people is a microcosm social construct; therefore, its fairness concept must conform to the general cultural perception of social justice and equity in the human society. In the conventional queues, emotions and resentment may flare if unfairness is practiced or is perceived as being practiced, while courtesy and even comradeship due to same experience -sharing may result when fairness in treatment is perceived. However, in a terror queuing situation, terrorist are smart guys that seek to exploit any unfair situation or inconsistency or lapse in CT environment to achieve their nefarious organizational goal, hence fairness in allocation of resources in CT environment is a panacea to optimal CT performance.

2.2 Fairness Measurement of Terror Queuing System

According to the proponents of queue fairness measures[5];[36,37];[40,41,42];[44];[68], two fundamental determinants of queuing process and job scheduling policies in a queuing system (i.) job seniority (arrival time) requirement and (ii.) the service time (job size) requirement, are also the fundamental variables for determining queue fairness. Therefore, by the preferential service principles of the conventional queuing system, consider a CT environment where detected terrorist operatives (customers) are targeted and interdicted through a tactical military-offensive approach (server). Susceptible individuals who became a terrorist T_i join the organization at arbitrary epochs $a_1, a_2, \ldots$ respectively; where $a_i \leq a_{i+1}$, and T_i belonging to one of u-classes ($index\ 1,2,\ldots,u$) of operatives. As a terrorist operative, a detected T_i deserves prompt targeting and interdiction at time s_i by the CT forces through some CT policy. We assumed that once T_i is detected he/she must be targeted and interdicted (killed or arrested) immediately to prevent further terror attacks. The time requires to target and interdict T_i denoted by s_i is called his/her interdiction time and, T_i is out of the system at an epoch d_i. The period T_i is detected to the period he/she is interdicted, $t_i = d_i - a_i$ is called the system time. The duration T_i is detected but not targeted and interdicted, $w_i = t_i - s_i = (d_i - a_i) - s_i$ is call the waiting time of T_i. The notations $(a_i, s_i, d_i, t_i, w_i)$ denote the actual values attributed to T_i in a specific sample path of the system.

Similar to the conventional queue preferential service policy, the seniority requirement of T_i at epoch t is $t_i - a_i$ and the service time requirement of T_i is denoted s_i. It is natural to expect that a "fair" terror queue policy will give preferential targeting/interdiction to highly senior class of operatives (class of operatives that were detected earlier) and to operatives' class with smaller service-requirement (class of operatives with fewer members). Thus, the fundamental principles of job seniority preference (JSP) and service requirements preference (SRP) as applied to terror queue can be stated as:

2.1.1 The SRP Principle: Let a_k denote the arrival epoch of a class-k operative T_k, and a_j denote the arrival epoch of a class-j operative T_j. If $a_k = a_j$ and $s_k < s_j$, then for operatives T_k and T_j residing concurrently in the system, it will be more fair (profitable) to complete targeting/interdiction of T_k ahead of T_j than vice versa.

2.1.2 The JSP Principle: Let s_k denote the interdiction time of a class-k operative T_k, and a_j, denote the interdiction time of class-j operative T_j. If $s_k = s_j$ and $a_k < a_j$, then for operative T_k and T_j residing concurrently in the system, it will be more fair (profitable) to complete targeting/interdiction of T_k ahead of T_j than vice versa

It is worthy of note that the JSP principle is rooted in the common belief that operatives detected in the CT environment earlier "deserve" to be interdicted first, while the SRP principle is rooted in the belief that it is dangerous (counterproductive) to ignore the targeting/interdiction of the fewer but more experienced/skilful class of operatives in CT environment but target the more numerous but less experience/unskilful class of operatives. It should be noted that when $a_k < a_j$ but $s_k > s_j$ or $a_k = a_j$ and $s_k = s_j$ the two principles may conflict each other; and thus, the relative fairness of the possible scheduling of operative T_k and T_j is likely to depends on the relative values of the parameters. These two preference principles can be considered as two axioms expressing one's basic belief in terror queue fairness. Hence a fair Terror queue is said to follow either of the two preference principles if it associates higher fairness (profitability) values with targeting and interdiction policy that is fairer.

Axiom 2.0 - The JSP Principle*:* Consider a detected class-k operative T_k and a detected class-j operative T_j having equal interdiction times $s_k = s_j$ but $a_k < a_j$. Let π be an interdiction policy where the interdiction of T_k is completed before that of T_j such that π' is identical to π, except for exchanging the interdiction policy of T_k and T_j. A fairness (result oriented) measure is said to adhere to the JSP principle if the fairness value it associates with π is higher than that it associates with π'.

Axiom 2.1 - The SRP Principle: Consider a detected class-k operative T_k and a detected class-j operative T_j, arriving the CT environment at the same time $a_k = a_j$ but $s_k < s_j$. Let π be an interdiction policy where the interdiction of T_k is completed before that of T_j such that π' be identical to π, except for exchanging the interdiction policy of T_k and T_j. A fairness (result oriented) measure is said to adhere to the SRP principle if the fairness value it associates with π is higher than that it associates with π'.

3.0 COUNTER-TERRORISM RESOURCE ALLOCATION QUEUE FAIRNESS (CTRAQF)

Divergence of opinions, thoughts and theories abound on the studies, measurements, and quantifications as well as the analysis of queue fairness and the influence of jobs' classification/service prioritization in the queuing systems. However, a host of these studies and measurements are predicated on the delay distribution perspective[14];[20];[32,33] (i.e., average time spent by a tagged job in the queuing system). Only a few are poised to consider queue fairness in terms of whether the actual services rendered to the customers commensurate with their delay probabilities. Tentatively, this is the platform under which Raz et al[40,41,42] proposed the RAQF model and its associated class discrimination analysis that accounts for the expected discrimination experienced by a tagged customer in the queuing system.

Adapting RAQF model, CTRAQF principle also requires that: *"at every epoch t at which there are N classes of terrorist operatives in CT environment, they all are entitled to equal targeting/interdiction policy (system resources), and any deviation from this principle represent discrimination (positive or negative)"*. By this adaptation, CTRAQF model also possessed not only the unique properties of sensitivity to JSP and SRP principles, but also track the operatives' inter-class discrimination, as well as the resulting unfairness throughout the terror queuing progress processes. These allow understanding and evaluation of terror queue fairness at the individual operatives' class and the general system unfairness levels as well as the class discrimination and the unfairness of specific scenario at the one hand, and the overall system unfairness or policy on the other hand. Thus, CTRAQF is composed of two distinctive parts:

(i) *Class Discrimination:* Each operative's class is assigned a single measure representing how well or worst they are treated. A positive number means the detected class of operatives was well targeted and interdicted maximally, while a negative number means the operative's class was minimally targeted and interdicted or treated with kids' globes, hence under interdicted.

(ii) *Fairness:* A summary measure taken over the class discriminations. The non-negative result of this summary measure gives the system's unfairness, such that a low value means an unfair (minimized) system, and vice versa.

3.1 The System Model of CTRAQF

Consider a non-idling CT environment with m tactical CT approaches, indexed $1,2, \dots m,$ (that is a CT system whereby if there are u-classes of operatives, with m tactical CT approaches; then $min\{m, u\}$ of these tactical approaches are employable). Suppose all m-tactical approaches have equal interdiction rates, and for simplicity, a rate of one (1) - unit of interdiction per unit time. The system is subject to the arrival of stream of operatives $T_j; j = 1,2, \dots$ who arrived randomly at the system. Each operative belongs to one of u-priority classes, indexed $1,2, \dots u$, and an order of priority interdiction is assigned to the classes; where lower class index mean higher priority. Let a_j and d_j denote the respective detection and interdiction epochs of T_j, and let s_j denote the time require to target and interdict T_j. By RAQF adaptation all class of operatives detected in CT environment at any epoch deserve equal share of the total interdiction rate granted by the employed tactical CT approaches at that epoch. Let $0 \leq \omega(t) \leq m$ denote the total interdiction rate of the employed tactical CT approaches at epoch t, which usually is an integer equal to the total number of class-j operatives interdicted at that epoch, and let $N(t)$ denotes the number of operatives' class in the system at epoch t. Then by CTRAQF model the fair interdiction called the momentary warranted interdiction rate of class-j operatives is given mathematically:

$$R_j(t) = \frac{\omega(t)}{N(t)} \tag{3.0.0}$$

Let $\sigma_j(t)$ be the momentary rate at which a class-j operative is interdicted at epoch t, called the momentary granted interdiction rate. The momentary discrimination rate of a class-j operative at epoch t denoted by $\delta_j(\text{t})$ is therefore, the difference between the granted interdiction rate and the warranted interdiction rates. Mathematically given by:

$$\delta_j(\text{t}) = \sigma_j(t) - R_j(t) = \sigma_j(t) - \frac{\omega(t)}{N(t)} = \frac{N(t)\sigma_j(t) - \omega(t)}{N(t)} \tag{3.0.1}$$

This can be viewed as the rate at which discrimination accumulates for class-j operatives at epoch t. Let $\delta_j(\text{t}) \stackrel{\text{def}}{=} 0$, if a class-j operative is not in the system at epoch t. However, as we are only interested in $\delta_j(\text{t})$ when class-j operative is in the system, and for the omitted, the total discrimination of class-j operative, denoted by D_j is given mathematically by

$$D_j = \int_{a_j}^{d_j} \delta_j(\text{t})dt = \int_{a_j}^{d_j} \frac{N(t)\sigma_j(t) - \omega(t)}{N(t)}dt \tag{3.0.2}$$

3.1.1 Alternative Definition of CTRAQF Model: The definition of the momentary warranted interdiction $R_j(t)$ of class-j operative and thus discrimination $\delta_j(\mathrm{t})$ given above is based on the concept that a class-j operative deserves an equal attention of the CT forces present in the system at that epoch t and any deviation from it creates discrimination among the operatives classes residing in the system. If some of the CT forces are not operational at epoch t, e.g., due to system idling, or due to the use of only part of the CT forces, it may be considered as being inefficient but not as a discrimination and unfairness. In this case, one could consider an alternative concept by which at epoch t a class-j operative deserves an equal attention of all the available CT forces in the system. Under this notation the warranted interdiction rate is defined as:

$$R_j(t) = \frac{m}{N(t)} \neq \frac{\omega(t)}{N(t)} \tag{3.0.3}$$

And that the momentary discrimination given by,

$$\delta_j(\mathrm{t}) = \sigma_j(t) - R_j(t) = \sigma_j(t) - \frac{m}{N(t)} = \frac{N(t)\sigma_j(t) - m}{N(t)} \tag{3.0.4}$$

The difference between equation (3.0.0) and (3.0.3) is conceptual and relates only to situations where some tactical CT measures are suspended. One such case is a multi-tactical approach environment at epoch t, where the operatives' class is not adaptable to more than m-tactical employable approaches ($N(t) < m$). Another case is a CT environment which allows for a cease-fire (idling) when there are detected operatives in the system. This issue and the tradeoff between the alternative is more pronounced in multi-tactical CT environment. For this work we choose to focus on the concept of fair division of the granted interdiction rate (equation 3.0.0) as this might be appealing since the leadership decapitation approach is limited to only the military-offensive approach. For example, if each class of operative is located in an independent cell, the military-offensive approach can target each class of operatives in isolation of others at epoch t; and this may possibly be interpreted as non-discriminatory.

For work conserving CT environment, where the total interdiction rate of a class-j operatives over time equals its interdiction requirement: $s_j = \int_{a_j}^{\infty} \sigma_j(\mathrm{t})$, we have from equations 3.0.1 and 3.0.2 that the accumulative discrimination of class-j operatives:

$$D_j = s_j(t) - \int_{a_j}^{d_j} \frac{\omega(t)}{N(t)} dt = \int_{a_j}^{\infty} \sigma_j(\mathrm{t}) - \int_{a_j}^{d_j} \frac{\omega(t)}{N(t)} dt \tag{3.0.5}$$

A positive or negative value of D_j means that a detected class-j operative is maximally targeted and interdicted, while a negative value denote a gross marginalization or under-interdiction; therefore a class-j operative is positively or negatively discriminated. An important property of this measure is that it obeys for every non-idling work conserving system and for every t, $\sum_j D_j = 0$; that is, every positive discriminations is balanced with negative discrimination. Corroborating Raz et al[40,41,42], for a single tactical CT approach in a work conserving and non-idling CT environment, the expected value of discrimination also obeys $E[D_j] = 0$. Thus, the unfairness of the system is defined as the second moment of the discrimination $E[D^2]$. The same property also holds in multi-tactical CT approaches.

3.1.2 CTRAQF Measures of System Unfairness: Let $E[D^2|k]$ for $k = 0,1,2, \ldots$ denote the expected value of the square of class-j discrimination, given that a class-j operative $T_j; j = 1,2, \ldots u$ encounters k class-j operatives on arrival in the system (including the ones being targeted for interdiction). Let P_k be the steady state probability that there are k class-j operatives in the system. Then, the second moment of D (the unfairness) follows:

$$E[D^2] = \sum_{k=0}^{\infty} E[D^2|k]P_k; \quad P_k = (1-\rho)\rho^k \tag{3.0.6}$$

Where P_k denotes the steady state probability of a single-queue M/M/1 system, k the number of class-j operatives in the system, and $(1-\rho)$ denote the probability of an empty system.

3.1.3 CTRAQF Conformity to the Fundamental Principles of Queue Fairness: To demonstrate the conformity of CTRAQF model on the two fundamental principles of queue fairness – job seniority and service time requirement principles, consider the following scenario: a class-i operative T_0 serving as a "by-stander" for this analysis arrives at an empty system at epoch a_0 and is immediately targeted and interdicted at epoch d_0. At an epoch say $a_0 < a_L < d_0$ arrive a class-j operative T_L (larger service requirement) with an interdiction time requirement of s_L. At another epoch say $a_L < a_S < d_0$ arrive a class-k operative T_S (smaller service requirement) with interdiction time requirement $s_S < s_L$. The question now is, whether it is fairer under CTRAQF to target/interdict the class-k operative T_S ahead of class-j operative T_L, given that all of them have been detected in the system? The line diagram below illustrates the two possible orders of interdictions.

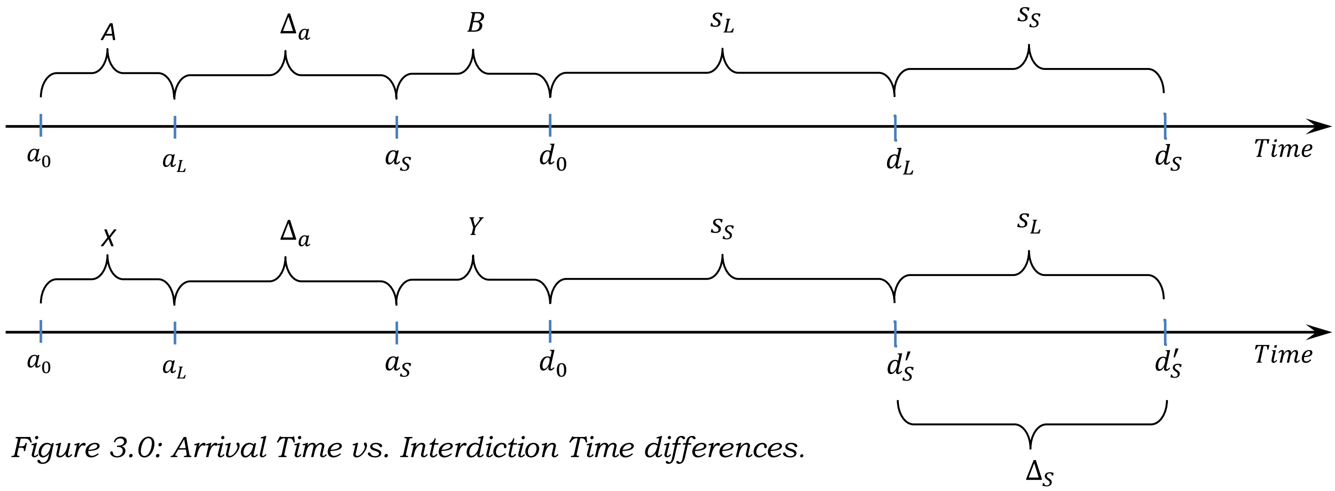


Figure 3.0: Arrival Time vs. Interdiction Time differences.

Let $A = a_L - a_0$ denote the length of the interval (a_0, a_L), and $B = d_0 - a_S$ denote the remainder of the interdiction time requirement left for operative T_0 after a_S. Let $\Delta_a = a_S - a_L$ denote the difference in job seniority between operatives T_S and T_L, and let $\Delta_S = a_L - a_S$ denote the difference in interdiction time requirement between operatives T_S and T_L. In the top half of the figure-1, above, operative T_L is served before T_S, and in the bottom half, the opposite is the case. If the operative T_L is interdicted before T_S, then T_L is out of the system at epoch $d_L = d_0 + s_L$, and T_S will be out of the system at epoch $d_S = d_0 + s_S + s_L$. Applying the CTRAQF discrimination model

$$D_i(t) = s_i - R_i(t) = s_i - \frac{\omega(t)}{N(t)} \tag{3.0.7}$$

Therefore, the discriminations of the three classes of operatives are:

$$D_0 = [A + \Delta_a + B] - \left[A + \frac{\Delta_a}{2} + \frac{B}{3}\right];\ D_L = s_L - \left[\frac{\Delta_a}{2} + \frac{B}{3} + \frac{s_L}{2}\right];\ D_S = s_S - \left[\frac{B}{3} + \frac{s_L}{2} + s_S\right] \quad (3.0.8a)$$

And the total unfairness of the system at the epoch T_L is interdicted before T_S is:

$$\sum D_i^2 = \frac{1}{3}[D_0^2 + D_L^2 + D_S^2] \quad (3.0.8b)$$

If operative T_S is targeted and interdicted before T_L, then operative T_L is out of the system at epoch $d_L' = d_0 + s_S + s_L$, and T_S will be out of the system at epoch $d_S^{'} = d_0 + s_S$. Similarly, the discriminations of the three operative classes are:

$$D_0^{'} = [A + \Delta_a + B] - \left[A + \frac{\Delta_a}{2} + \frac{B}{3}\right];\ D_L^{'} = s_L - \left[\frac{\Delta_a}{2} + \frac{B}{3} + \frac{s_S}{2} + s_L\right];\ D_S = s_S - \left[\frac{B}{3} + \frac{s_S}{2}\right] \quad (3.0.9a)$$

And the total unfairness at the epoch T_S is interdicted before T_L is:

$$\sum [D_i^{'}]^2 = \frac{1}{3}\left[\left(D_0^{'}\right)^2 + \left(D_L^{'}\right)^2 + \left(D_S^{'}\right)^2\right] \quad (3.0.9b)$$

Taking the difference of the two unfairness values (3.0.9b) and (3.0.8b), we have

$$\begin{aligned}\sum [D_i']^2 - \sum D_i^2 &= \frac{1}{3}[(D_0')^2 + (D_L')^2 + (D_S')^2] - \frac{1}{3}[D_0^2 + D_L^2 + D_S^2] \\ &= \frac{1}{6}(s_S + s_L)(\Delta_a - \Delta_S)\end{aligned} \quad (3.0.9c)$$

The equation 3.0.9c above shows that the unfairness differences in this case is monotonic in the difference between arrival time differences and the interdiction time differences $(i.e., \Delta_a - \Delta_S)$. Thus, the higher this difference $(\Delta_a - \Delta_S)$ is, the more unfair it is to interdict T_S before T_L, and the lower this difference is, the more unfair it is to interdict T_L before T_S. The point of indifference is exactly when these differences equal each other $(i.e., \Delta_a = \Delta_S)$. Therefore, CTRAQF also account for both job seniority difference and interdiction time requirement differences in the proper perspective.

Similarly, consider two arbitrary operatives T_1 and T_2 from two different classes, residing together in the CT environment, with arrival time $a_1 < a_2$ but with equal interdiction time requirement $s_1 = s_2$, and are scheduled for interdiction adjacently. Suppose there exist the following two possible cases: (i) they are to be interdicted sequentially by the same tactical approach (sticks), or (ii) they are to be interdicted simultaneously by two different tactical approaches (Sticks and Carrots) in a partially parallel manner. Considering also the following two possible interdiction policies: (a) the order of job seniority (FCFS) is preserved such that operative T_1 is targeted/interdicted before operative T_2, or (ii) the order of interdiction of operative T_1 and T_2 is interchanged, such that the order of job seniority is violated. Then by CTRAQF model, the unfairness of the seniority preserving policy in (a) will be smaller than the unfairness of seniority violating policy in (b) for every arrival pattern.

3.2 PERFORMANCE MEASURE OF LEADERSHIP DECAPITATION TERROR QUEUING (LDTQ) SYSTEM

Consider a work conserving non-idling CT environment (the military-offensive confrontation is never constraint to be idle when a class-j operatives have been detected), with a single tactical CT approach, targeted at u priority classes of operatives. Where class-j ($j = 1,2, \dots, u$) operatives arrival at the CT environment follow a Poisson process with mean λ_j, and their required interdiction rates are identical independent random variable exponentially distributed with mean μ_j^{-1}. Then, the total operatives' arrival and interdiction rates of the M/M/1 terror queuing system can be given by

$$\lambda \stackrel{\text{def}}{=} \sum_{j=1}^{u} \lambda_j \text{ ; and } \mu \stackrel{\text{def}}{=} \sum_{j=1}^{u} \mu_j \text{ ;} \tag{4.0.0}$$

For stability, we assumed that the system traffic intensity: $\rho \stackrel{\text{def}}{=} \lambda\mu^{-1} < 1$. And for a hierarchically structured two class terrorist organization, let the mean arrival rate of a class-j operative be denoted by its internal dynamics *(promotion, recruitment and commission processes)* and its interdiction rates be represented by the organization's external dynamics - CT measures targeted specifically at arresting, assassinations, kidnapping as well as coercive efforts to force the operatives into long-term inactivity. Under the conventional military-offensive tactical CT approach, research findings and journalistic accounts of how Al-Qaida, ISIS, Hezbollah and their affiliates have developed over the last decades indicates that a notional terrorist organization under the influence of an orchestrated military-offensive CT operation can at-most be depopulated by 20% annually. While the organization's dynamics often appreciated by an annual rate of 3% per leadership class, and 12% per foot-soldiers' class,[21];[34]. Let $m = 1$ denote the single tactical approach (military-offensive) targeted at a class-j operatives under a non-preemptive priority interdiction policy; which hampered the organization's dynamical evolution annually.

3.2.1 LDTQ System Birth/Dearth Rate Distribution:

For the hypothetical two class terrorist organization, the mean arrival and interdiction rates of the class-j terrorist operatives can be given by tables-4.0 below:

Table 4.0: Mean Arrival/Interdiction Rates of the Organization

Class of Operative	Mean Arrival Rates			Mean Interdiction Rate		
	Opt./Day	Opt./year	Hrs/Opt.	Opt./Day	Opt./year	Hrs/Opt.
Leaders	0.03	10.95	800	0.20	73	120
Foot-soldiers	0.12	43.80	200	0.20	73	120
System	0.15	54.75	400	0.40	146	120

The table 4.0 above shows that an average of 10.95 ≈ 11 highly experienced/skilful foot-soldier are promoted to leadership cadre annually, while an average of 43.8 ≈ 44 new foot-soldiers are recruited annually. This gives the organization's annual arrival rate of 54.75 ≈ 55 operatives. Similarly, averages of 73 operatives are interdicted annually, giving a total of 146 interdictions annually. These gives an averages arrival (birth) rate of 400 hours per class-j operative and an average interdiction rates of 120 hours per class-j operative.

3.2.2 Traffic Intensity/Tactics Utilization of LDTQ System:

Given a work conserving non-idling and stable CT environment, the class-j traffic intensity and tactics utilization is given by table 2 below:

Table 4.1: Traffic Intensity/System Utilization

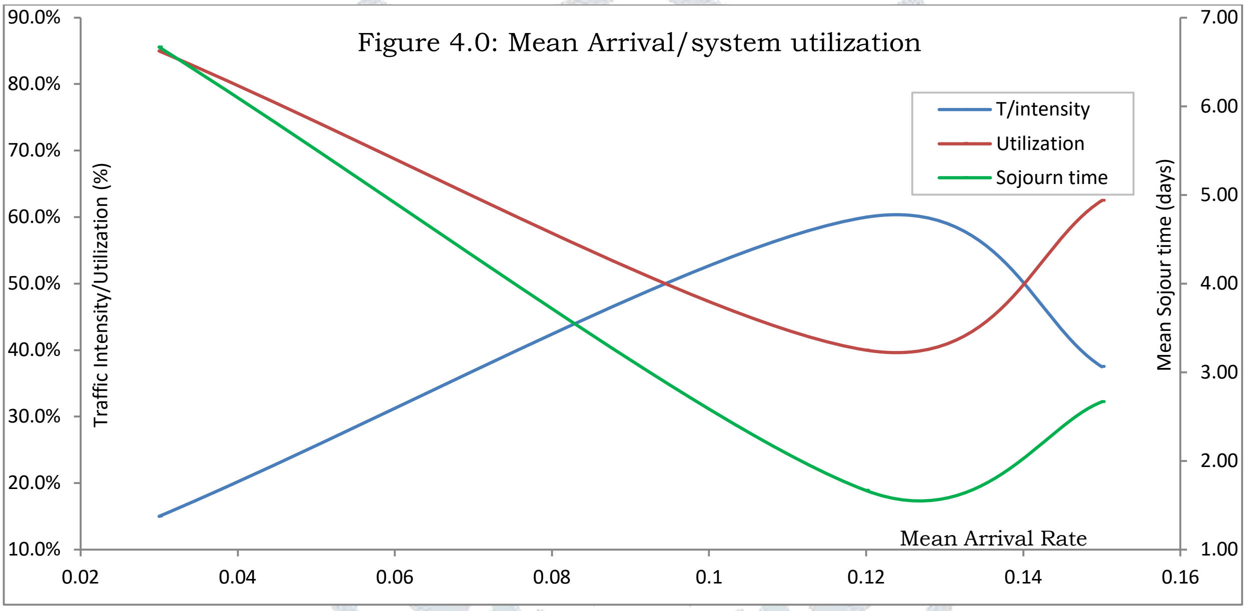
Operatives' Class	Traffic Intensity (ρ)	Utilization ($1-\rho$)	Sojourn Time (ρ^{-1})
Leaders	0.15	0.85	6.6667
Foot-soldiers	0.60	0.40	1.6667
System	0.375	0.625	2.6667

The table 4.1 above implies that the CT forces are always busy targeting/interdicting the leadership class only at 15% of the times, while at 85% of the time the CT forces are lethargic (idle) targeting the leadership class.

If a leadership class has been detected, we assume that he/she must be targeted/interdicted fully (killed or arrested), since he/she is the high priority class. However, if his/her targeting/interdiction is obstructed due to incredible intelligence or system failure, or the presence of already targeted foot-soldier in the system, then the detected leadership class may sojourn for an average of 6.6667 days (160 hrs.) in the system before being targeted/interdicted.

Similarly, the table 4.1 above shows that, the CT forces are always busy targeting/interdicting a detected foot-soldiers class at 60% of the time, while at 40% of the time the CT forces are lethargic (idle) targeting the foot-soldiers class. Also, if a foot-soldier has been detected, we assume that he/she must be targeted and interdicted in time to prevent further attack. However, if his/her targeting/interdiction is obstructed due to incredible intelligence or system failure or the presence of already detected leader in the system, then the detected foot-soldier class may sojourn for an average of 1.6667 days (40 hrs.) in the system before targeted and interdicted.

Thus, in general the CT forces are always busy targeting interdicting a detected class-j operative at only 37.5% of the times, while at 62.5% of the time the CT forces are lethargic (idle) targeting the operatives. Also, if an operative has been detected, we assume that he/she must be targeted and interdicted in time to prevent further attack, however, if his/her interdiction is obstructed due to incredible intelligence or system failure, then the detected class-j operative may sojourn for an average 2.6667 days (64 hrs.) in the system before targeted and interdicted. The figure 4.0 below illustrates the above distribution.



The figure 4.0 above shows that the system traffic intensity increases with increase arrival rate of the operatives, while the system utilization as well as the operatives' sojourn time after detection decreases with increase in the operatives' arrival times.

3.2.3 LDTQ System Waiting/Response Time Distribution: Given that the M/M/1 priority terror queuing system, by Sztrik[47] the expected steady state waiting time of a detected class-j operative on the queue before being targeted can be given by:

$$\overline{W}_{q_j} = \left[\frac{1}{\rho!\,(1-\rho)!}\right]\frac{1}{\mu}\left[\left(1-\frac{1}{\mu}\sum_{i=1}^{j-1}\lambda_i\right)\left(1-\frac{1}{\mu}\sum_{i=1}^{j}\lambda_i\right)\right]^{-1}\ ;\ j = 1,2,3 \tag{4.0.1}$$

$$W_{q_1} = 3.0633\ days;\ W_{q_2} = 5.4546\ days$$

This implies that due to either incredible intelligence or system failure, or the presence of already detected foot-soldier in the system, a detected leadership class may spent an average of 3.0633 days (73.5192 hour) on the queue before being targeted. Also due to either incredible intelligence or system failure, or the presence of already detected leader in the system, a detected foot-soldier class may spent an average of 5.4546 days (130.9104 hours) on the queue before being targeted. Thus, due to either incredible intelligence or system failure, a detected class-j operative may spend an average of 4.259 days (102.216 hours) on the queue before being targeted. Also the expected steady state waiting time of a detected class-j operative in the system before being targeted and interdicted can be given by:

$$W_j = \frac{1}{\mu} + \overline{W}_{q_j};\ W_1 = 5.5633\ days\ (133.5192\ hrs);\ W_2 = 7.9546\ days\ (190.9104\ hrs) \tag{4.0.2a}$$

This implies that due to either incredible intelligence or system failure, or the presence of already detected foot-soldier in the system, a detected leader may spent an average of 5.5633 days (133.192 hrs) in the CT environment before being targeted and interdicted. And due to either incredible intelligence or system failure or the presence of already detected leader in the system and a detected foot-soldier spent an average of 7.9546 days (190.9104 hrs) in the CT environment before being targeted and interdicted. Thus, due to either incredible intelligence or system failure, or the presence of already detected operative in the system, a detected class-j operative may spend an average of 6.759 days (162.216 hrs) in the CT environment before being targeted and interdicted. Therefore, the mean response time for the CT force to target and interdict a detected class-j operative in the system can be given by:

$$\bar{T} = W_j + \frac{1}{\mu};\ \bar{T}_1 = 8.0633\ days\ (193.5192\ hrs);\ \bar{T}_2 = 10.4546\ days\ (250.9104\ hrs) \qquad (4.0.2b)$$

This implies that due to either incredible intelligence or system failure, or the presence of already detected foot-soldier in the system, the CT forces may spend an average of 8.0633 days (193.5192 hrs) before interdicting a detected terrorist leadership class in CT environment. While the CT forces may spend an average of 10.4546 days (250.9104 hrs) before interdicting a detected foot-soldier class in the CT environment due to either incredible intelligence or system failure, or the presence of already detected leadership class in the system. Thus, the CT forces may spend an average of 9.259 days (222.216 hrs) before interdicting a detected class-j operative in the CT environment due to either incredible intelligence or system failure, or the presence of already detected operative in the system.

3.2.4 LDTQ System Size Distribution: Suppose the system is not empty, then the mean number of detected class-j operatives on the queue at any epoch can be given by:

$$\bar{L}_q = \lambda\bar{W};\ \Rightarrow\ \bar{L}_{q_1} = 0.1668\ Leaders;\ \bar{L}_{q_2} = 0.9546\ Footsoldiers \qquad (4.0.3a)$$

This implies that an average of 0.1668 leaders and 0.9546 foot-soldiers are on the queue at any epoch of time, thus, giving a total of 1.1214 class-j operatives on the queue at any epoch of time. And the mean number class-j operatives in the system at any epoch:

$$\bar{L} = \lambda\bar{T};\ \Rightarrow\ \bar{L}_1 = 0.2419;\ leaders;\ \ \bar{L}_2 = 1.2546\ Footsoldiers \qquad (4.0.3b)$$

This implies that an average of 0.2419 leaders and 1.2546 foot-soldiers are in the CT environment at any epoch of time, thus, giving a total of 1.4965 class-j operatives in the CT environment at any epoch of time. Therefore, the mean number of class-j operative interdicted at any epoch is given by:

$$\bar{L}_\alpha = \bar{L} - \bar{L}_q\ \Rightarrow\ \bar{L}_{\alpha_1} = 0.0751\ Leaders;\ \bar{L}_{\alpha_2} = 0.3\ Footsoldiers \qquad (4.0.3c)$$

This implies that an average of 0.0751 leaders and 0.3 foot-soldiers are interdicted at any epoch of time, thus, giving a total of 0.3751 class-j operatives interdicted at any epoch of time.

3.2.5 Delay Distribution in LDTQ System: Suppose the queue is not empty, then from Erlang loss formula the probability that the interdiction of a detected class-j operative will be delayed given that there are $k \geq n$ detected operatives on the queue:

$$\varphi = C(n,\rho) = \frac{\rho(n-1-\rho)\cdot C(n-1,\rho)}{(n-1)(n-\rho) - \rho C(n-1,\rho)} = \frac{\rho(n-1-\rho)\left(\frac{(n-1)!}{\rho!\,(n-1-\rho)!}\right)}{(n-1)(n-\rho) - \rho\left(\frac{(n-1)!}{\rho!\,(n-1-\rho)!}\right)} \qquad (4.0.4a)$$

Prob (Interdiction of operative will be delayed) = Prob (At least 1 detected/targeted operatives in the system)
= Prob (At most 2 detected but not targeted operatives in system)

$$\begin{aligned} \varphi &= \sum_{n=1}^{2}\left[\rho(n-1-\rho)\left(\frac{(n-1)!}{\rho!\,(n-1-\rho)!}\right)\right]\left[(n-1)(n-\rho) - \rho\left(\frac{(n-1)!}{\rho!\,(n-1-\rho)!}\right)\right]^{-1} \\ &= \rho + \left[\rho(1-\rho)\left(\frac{1}{\rho!\,(1-\rho)!}\right)\right]\left[(2-\rho) - \rho\left(\frac{1}{\rho!\,(1-\rho)!}\right)\right]^{-1} \end{aligned} \qquad (4.0.4b)$$

$\varphi_1 = 0.236\ (23.6\%);\ \varphi_1 = 0.9706\ (97.06\%)$

This implies that at 23.6% of the time, the interdiction of a detected leadership class in the system may be delayed if there are $k \geq n$ detected foot-soldiers in the system; while at 97.06% of the time the interdiction of a detected foot-soldier in the system will be delayed if there are $k \geq n$ detected leaders in the system. This gives an average of 65.33% of the time for the interdiction of a detected class-j in the system to be delayed if there are $k \geq n$ detected operatives in the system.

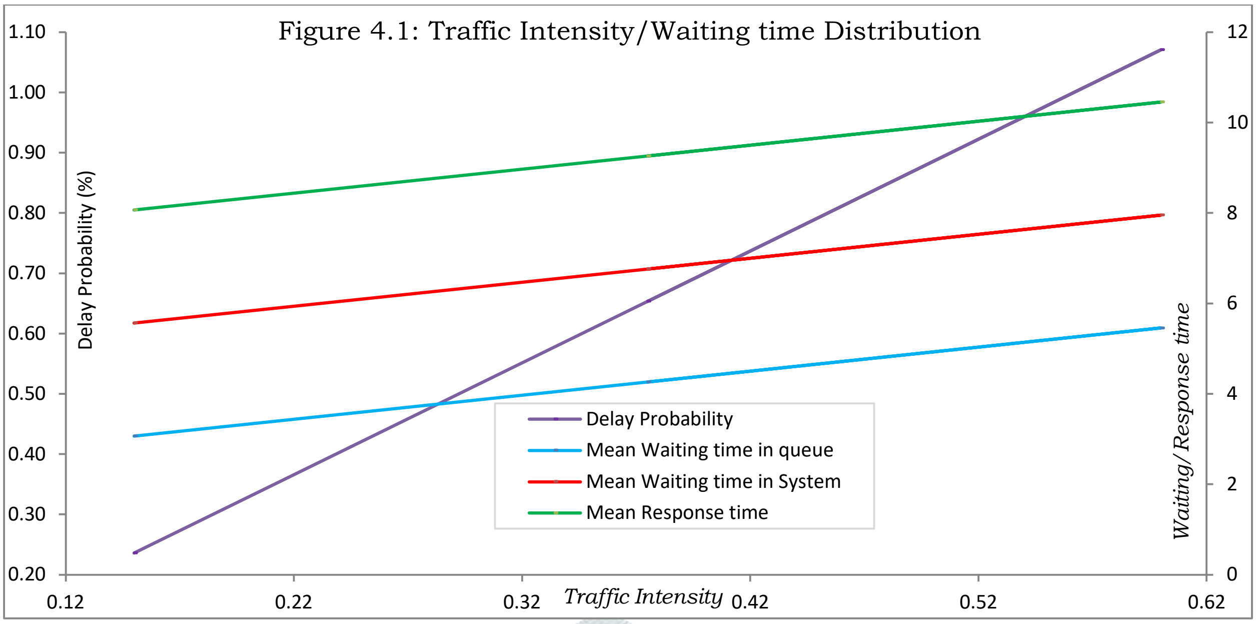


Figure 4.1: Traffic Intensity/Waiting time Distribution

The figure 4.1 above shows that the probability that the targeting/interdiction of a class-j operative will be delayed varies linearly with the system traffic intensity and vice versa (see purple cure). Similarly, both the waiting times in the system and on the queue as well as the system response time of a class-j operative also varies linearly with the system traffic intensity (see blue, red and green curves). The security implication of the linear increase in both waiting times and delay probabilities with respect to the system traffic intensity is the ever increasing terror attacks witness in recent years, especially in Nigeria CT environment.

3.2.6 Operatives' Behaviour in LDTQ System: Synonymous with terrorist behaviour, suppose the system is not empty then we assumed that a detected but not targeted operative will balk or renege from the queue if he encounters $k \geq n$ detected/targeted operatives in the system, otherwise he/she will join the system. By equation (3.0.6), the probability that a detected but untargeted operative will encounter $k \geq n$ detected and targeted operatives in CT environment:

$$P_k = (1-\rho)\rho^k; k \geq m \;\Rightarrow \therefore P_{k_1} = 0.85(0.15)^k;\; P_{k_2} = 0.4(0.6)^k;\; \text{ and } P_k = 0.625(0.375)^k \qquad (4.0.5a)$$

The probability that a detected but not targeted class-j operative will encounter $k \geq 1$ detected operatives in CT environment is given by:

Prob (An operative will balk/renege from queue) = Prob (At least 1 detected/targeted operatives in the system)
= Prob (At most 2 detected but not targeted operatives in system)

$$P_k = (1-\rho)\sum_{k=1}^{2}\rho^k; k \geq 1; \Rightarrow P_{k_1 \geq 1} = 0.85\sum_{k=1}^{2}(0.15)^k = 0.1466\ (14.66\%)$$

$$P_{k_2 \geq 1} = 0.4\sum_{k=1}^{2}(0.6)^k = 0.384\ (38.4\%);\; P_{k \geq 1} = 0.625\sum_{k=1}^{2}(0.375)^k = 0.3223(32.23\%) \qquad (4.0.5b$$

This implies that, on a busy CT environment, a detected but untargeted leader has at least 14.66% chance of balking/renege from the queue if he encountered $k \geq 1$ detected operatives in the system. While a detected but untargeted foot-soldier has at least 38.4% chance of balking/renege from the queue if he encountered $k \geq 1$ detected operatives in the system. And generally, a detected but untargeted operative has at least 32.23% chance of balking/renege from the queue if he encountered $k \geq 1$ detected operatives in the system.

3.3 Fairness Characteristics of LDTQ System

Given that the system interdiction rate of: $0 < \omega(t) \leq 0.4$ operatives per day, therefore, by equation (3.0.0) a class-j operative in the system deserved the momentary warranted interdiction rate: $R_1(t) = R_2(t) = 0.2$ operatives per class. But by equation $(3.1.0c)$, the momentary granted interdiction rate of a class-j operative $(\bar{L}_\alpha)$ at any epoch of time: $\bar{\sigma}_1(t) = 0.0751$ leaders/day, and $\bar{\sigma}_2(t) = 0.3$ foot-soldiers/day; giving the total momentary granted interdiction: $\bar{\sigma}(t) = 0.3751$ operatives/day. Therefore, by equation (3.0.1) the momentary discrimination of a class-j operative at any epoch of time is given by:

$$\bar{\delta}(t) = \bar{\sigma}(t) - R(t) \Rightarrow\; \bar{\delta}_1(t) = -0.1249 < 0;\; \bar{\delta}_2(t) = 0.1 > 0;$$

$$\bar{\delta} = \sum_{j=1}^{3}\bar{\delta}_j(t) = -0.0249 < 0 \qquad (4.0.6a)$$

This implies that the leadership class is under interdicted by 0.1249 operatives per day, while the foot-soldiers class is over-interdicted by 0.1 operatives per day. This gives instantaneous class discrimination (under-interdiction) of 0.0249 operatives per day. Therefore, by equation (3.0.2), the accumulative discrimination of class-j operative over a period of 12 calendar months (365 days) is:

$$D_1(t) = -45.5885 < 0\ ;\ D_2(t) = 36.5 > 0$$

$$D = \sum_{j=1}^{3} D_j(t) = -9.0885 < 0 \qquad (4.0.6b)$$

This implies that the leadership class was under-interdicted 45.5885≈ 46 operatives annually, while the foot-soldiers class is over-interdicted 36.5 ≈ 37 operatives annually. This gives a gross marginalization and under-interdiction of 9.0885 ≈ 9 operatives annually. The gross marginalization or under-interdiction of the leadership class is intuitive and consistence with the “sacred caw” syndrome inherent in most ethno-religious democratized nations as well as the endemic low credibility of intelligence in most conventional CT environment[34].

3.3.1 Class Discrimination Coefficient of LDTQ System: Let $E[\widetilde{D}_{(u)}]; u = 1,2$ denote the expectation of the value of the class discrimination, given that a detected but untargeted class-j operative encounters $k \geq 1$ detected/targeted operatives in the system. And let P_k denote the steady state probability that there are $k \geq 1$ detected/targeted operatives are in the system at any epoch. Therefore, from the “discrimination version” of Little’s Theorem[35], the class-j discrimination coefficient, given that a detected but untargeted class-j operative encountered P_k detected/targeted operatives in system is given: $E[\widetilde{D}_{(u)}] = \lambda[DP_k]$.

Table 4.2: Class Discrimination of M/M/1 Terror Queuing System

Class Discrimination $P_{k\geq1}$ Operative	**Leaders $P_{k\geq1} = 14.66\%$**	**Foot-soldiers $P_{k\geq1} = 38.4\%$**	**System $P_{k\geq1} = 32.23\%$**	$\mathbf{E[D_u]} = \sum_u E[\widetilde{D}_{(u)}]$
$E[\widetilde{D}_{(1)}] = \lambda_1[D_1P_k]$	-0.1426	-0.3734	-0.3134	-0.8294
$E[\widetilde{D}_{(2)}] = \lambda_2[D_2P_k]$	0.4566	1.1959	1.0038	2.6563
$E[\widetilde{D}_{(u)}] = \lambda_u[D_uP_k]$	-0.1421	-0.3722	-0.3124	-0.8267
$\mathbf{E[D_{(u)}]} = \sum_u E[\widetilde{D}_{(u)}]$	**0.1719**	**0.4503**	**0.378**	**1.0002**

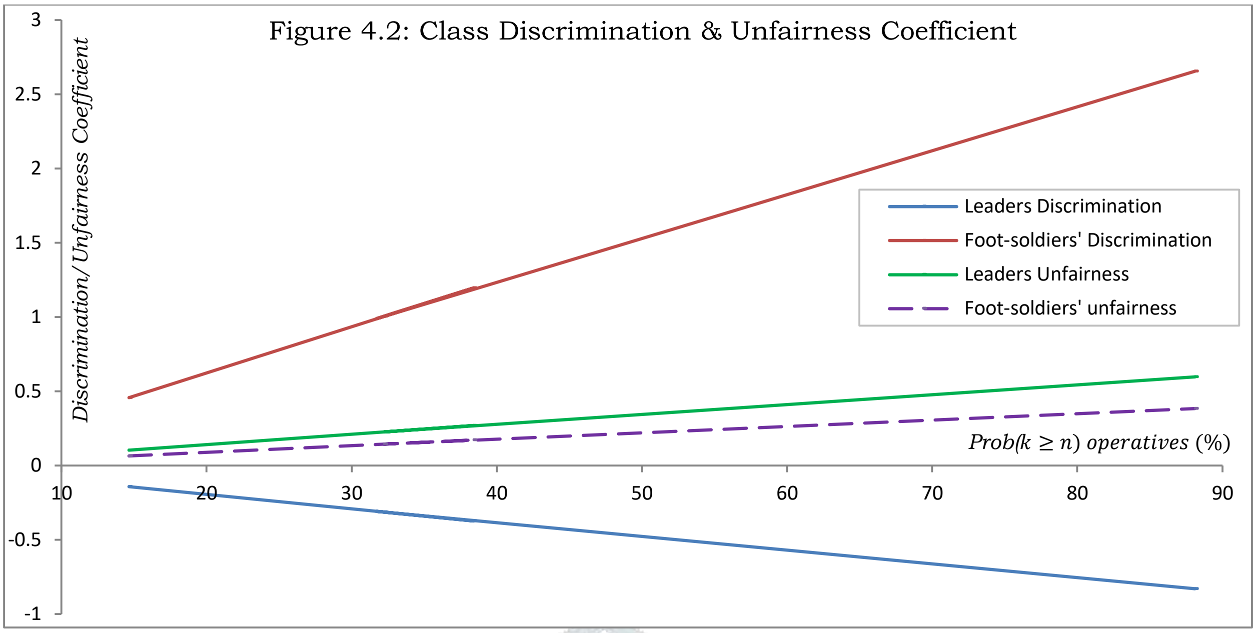
The table 4.2 above shows that in a busy CT environment, the system discrimination on the leadership class given that there are $k \geq 1$ detected leaders in the system: $E[D_{(1)}] = 0.1719$, (i.e. 82.81% discriminated), while the system discrimination on the foot-soldiers’ class given that there are $k \geq 1$ detected foot-soldiers in the system: $E[D_{(2)}] = 0.4503$, (i.e. 54.97% discriminated). And the general system discrimination on a class-j operative given that there are $k \geq 1$ detected class-j operatives in the system: $E[D_{(u)}] = 0.378$, (i.e. 62.2% discriminated).

3.3.2 System Unfairness Coefficient of LDTQ System: Let $E[D^2|k]$; $k = 1,2,\ldots$ denote the expected value of the square of the system discrimination, given that an undetected operative encounters $k \geq 1$ detected operatives in the CT environment. Let P_k denote the steady state probability that there are $k \geq 1$ detected operatives in the CT environment, then by equation (3.0.6) the system unfairness index, given that an undetected operative will encounter $k \geq 1$ detected operatives in the system is given by table 4 below:

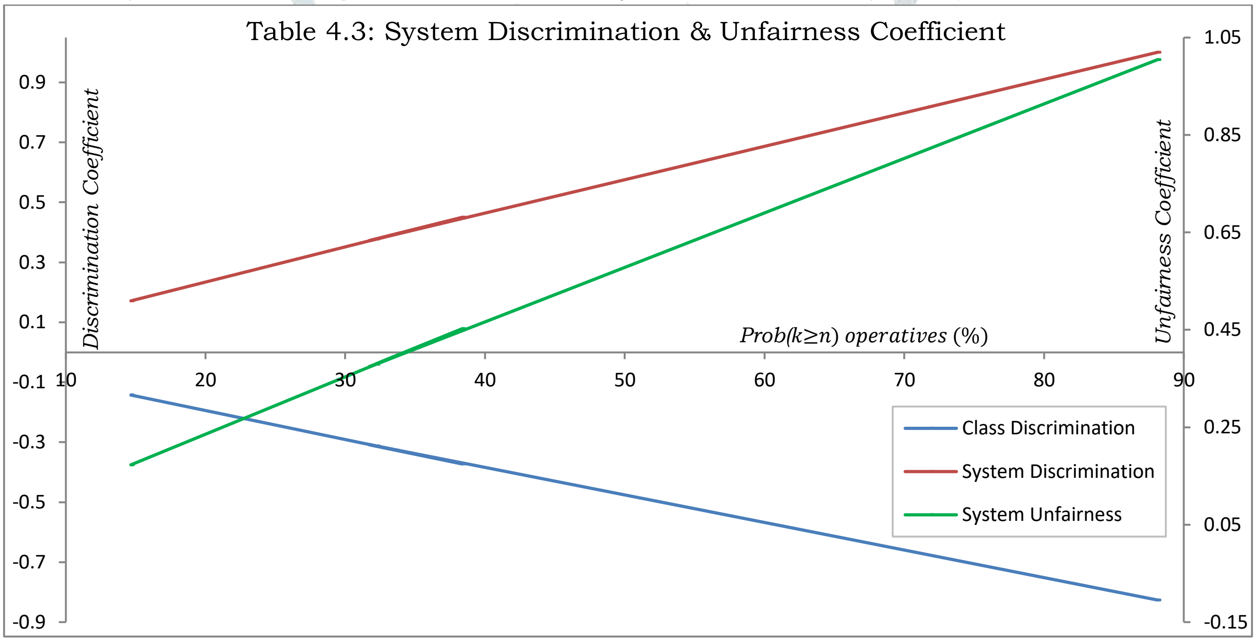
Table 4.3: Class Unfairness of M/M/1 Terror Queuing System

Class Unfairness $P_{k\geq1}$ Operative	**Leaders $P_{k\geq1} = 14.66\%$**	**Foot-soldiers $P_{k\geq1} = 38.4\%$**	**System $P_{k\geq1} = 32.23\%$**	$\mathbf{E[D^2]} = \sum_u E[D_u^2]$
$E[D_1^2] = D_1^2P_k$	0.1027	0.2690	0.2257	0.5974
$E[D_2^2] = D_2^2P_k$	0.0658	0.1724	0.1447	0.3829
$E[D_u^2] = D_u^2P_k$	0.0041	0.0107	0.0090	0.0238
$\mathbf{E[D^2]} = \sum_u E[D_u^2]$	**0.1726**	**0.4521**	**0.3794**	**1.0041**

The table 4.3 above shows that in a busy CT environment, the system unfairness to the leadership class given that there are $k \geq 1$ detected/targeted leaders in the system: $E[D_1^2] = 0.1726$, (i.e. 82.74% unfair), while the system unfairness to the foot-soldiers’ class given that there are $k \geq 1$ detected/targeted foot-soldiers in the system: : $E[D_2^2] = 0.4521$, (i.e. 54.79% unfair). And the general system unfairness to a class-j operative given that there are $k \geq 1$ detected/targeted class-j operatives in the system:$E[D^2] = 0.3794$, (i.e. 62.06% unfair).



The figure 4.2 above which compare the discrimination and unfairness of a class-j operative shows that the system discrimination over the leadership class varies inversely with the probability of encountering $k \geq 1$ detected class-j operatives in the system (see blue curve); while the system unfairness on the leadership class varies directly with the probability of encountering $k \geq 1$ detected class-j operatives in the system (see green curve). However, both the system discrimination and unfairness on the foot-soldiers class all varies directly with the probability of encountering $k \geq 1$ detected class-j operatives in the system (see red and purple curves).



The figure 4.3 above, which compares the system discrimination and unfairness of a class-j operative shows that both the system discrimination and unfairness of class-j operative varies directly with the probability of encountering $k \geq 1$ detected operatives in the system (see red and green curves), while the individual class discrimination varies inversely with the probability of encountering $k \geq 1$ detected class-j operatives in the system (see blue curve).

3.3.3 Sensitivity Analysis of LDTQ System: Considering the implication of the high discrimination and unfairness coefficients of the system on the performance indicators of the CT measure, in this section we applied the sensitivity analysis of section 3.2 to determine the variability of the operatives' arrival and interdiction epochs with the discrimination and unfairness of the system. This is aimed at examining whether or not the leadership prioritization strategy conforms to the fundament principles of queue preferential services. Thus, by equation (3.0.9c):

$$\sum\left[D_i'\right]^2 - \sum D_i^2 = \frac{1}{6}(s_S + s_L)(\Delta_a - \Delta_S)$$
$$= \frac{1}{6}\left(\frac{1}{\mu_1} + \frac{1}{\mu_2}\right)\left(\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right) - \left(\frac{1}{\mu_1} - \frac{1}{\mu_2}\right)\right) \tag{4.0.7}$$
$$= \frac{1}{6}\,[10](25) = 41.6666 > 0$$

Given that the unfairness difference in the terror queuing system is monotonic in the difference between the arrival time and the service time differences $(i.e., \Delta_a - \Delta_S)$, then, by equation (4.0.7) above, $\Delta_a - \Delta_S = 25 \gg 0$ implies that it is more unfair to target and interdict the leadership before the foot-soldiers' class. Hence, leadership decapitation strategy does not conform to the fundamental principle of queue preferential service policies.

4.0 THE RESULTS OF THE ANALYSES AND DISCUSSION

In appraising the M/M/1 terror queue performance measures, as well as the queue fairness characteristics of the conventional military-offensive CT approach base on the non-preemptive priority interdiction queuing policy, key performance indicators and variables necessary for CT performance evaluation, as well as strategy optimization and re-orientation were reveals. As observed by the "law of loopholes in action", *"Every loophole will eventually be exploited; every exploited loophole will eventually be closed"* [19]. Thus, as CT stakeholders are optimizing the degradation and dysfunction of a given terrorist organization through prioritizing the targeting/interdiction of terrorist leaders, operational planners, weapon experts, battle commanders and individuals deploying their expertise in areas such as IED (explosives), recruitments facilities, cyber operations and propagandas, etc. The result of the analyses shows that terrorist organizations also shifted their attention, energies and resources toward re-strategizing and re-orientation of their bureaucratic and organizational structures so as to optimize their attacks and activities through other classes of operatives. Hence, the unparalleled resilience strength characteristics, unperturbed dynamical evolutions and thus, high proliferation of newer groups and other institutions of organized crime, even in the faces of the unprecedented exploit of leadership decapitation strategy in recent years.

4.1 Implication of LDTQ System Performance Measure

A brief summary of the system performance measures reveals that due to either incredible intelligence[34] or system failure, or the presence of already detected foot-soldier in the system, proper identification, categorization and definition as well as targeting of the clandestine roles of salient terrorist leaders classes were underestimated or treated with *"kids' globe"*. Hence at 85% of the time detected terrorist leaders such as the moral persuasive or venture leaders and the recruiters were not targeted and interdicted in the CT environment; while the CT forces mostly targeted and interdicted detected foot-soldiers' class at 60% of the time. On delay perspective, the result of the analyses also shows that even the targeting and interdiction of detected foot-soldiers class in the CT environment often experienced delay at 79.06% of the time, while the targeting and interdiction of the detected few combatant leaders in the system only experienced at least 23.6% delay. Hence the CT forces' response time for targeting and interdiction of a detected terrorist operative rises as high as 9.259 days in the average. The security implication of the linear increase in both waiting times and delay probabilities with respect to the system traffic intensity is the ever increasing terror attacks witness in recent years, especially in Nigeria CT environment.

4.2 Implication of LDTQ System Unfairness Characteristics

On the system discrimination perspective, the result of the analyses also shows that the leadership class has always been grossly marginalized, under-targeted and under-interdicted by an average of 46 operatives annually, while the interdiction of the foot-soldiers' class only experienced a marginally fair interdiction of 37 operatives in excess annually. This gives the net deficit (under-interdiction) of about 9 operatives annually by the non-preemptive priority leadership decapitation approach of most world government. Thus, by CTRAQF discrimination criterion, the prioritization of the interdiction of terrorist leadership class in CT operations does not conform to either the arrival time requirement (job seniority) or service time requirement preference principles. Hence, the result of high negative discrimination (under-interdiction) of the leadership class and marginally fair interdiction of the foot-soldiers' class annually.

In general, the general system unfairness coefficient also uphold that the prioritization of leadership decapitation in CT operation does not only violate the two fundamental queue preferential service principles – the job seniority and the service time requirement differences, but yield as much as 82.74% unfairness in the targeting and interdiction of the leadership class operatives, and 54.79% unfairness in the targeting and interdiction of the foot-soldiers annually. Thus, giving a general system unfairness rate of 62.06% operatives annually – an indication of inefficient CT approach as well as unfair allocation of CT resources toward the prevention and control of terrorism. The security implication of the high marginalization of terrorist leadership class is the ever proliferation of terrorist groups & other institutions of organized crime as well as increase terror attacks witness in recent years, especially in Nigeria CT environment.

5.0 CONCLUSION

The study presents an appraisal of the performance measure as well as the resource allocation queue fairness characteristics of an M/M/1 terror queuing system; where terrorist interdiction is prioritize to two classes of terrorist – leaders and foot-soldiers based on interdiction requirement principle. Analysing the performance measure of the two-class M/M/1 terror queue architecture under the non-preemptive priority interdiction policy, shows that both the response and the waiting times as well as the delay probability of the operatives' class increases linearly with the system traffic intensity. That is the targeting and interdictions of detected operatives' class with larger mean arrival rate (foot-soldiers) are always delayed, thus resulting in larger waiting and sojourn times before they are interdicted from the system. The security implication of the high waiting times and delay probability of the foot-soldiers' class is the ever increasing terrorist attacks and proliferation of terrorist groups in the face of the perceived unprecedented decapitation of terrorist leadership class in the CT environment.

Furthermore, analyses of the queue fairness characteristics of the system using the CTRAQF model shows that the expected system discrimination and unfairness coefficients of the highest priority classes (leaders) increases linearly with increase probability of encountering more operatives in the system and vice versa. That is operatives' class with lager mean interdiction rates or lower priority class (foot-soldiers) are always positively discriminated while those with smaller means interdiction rates or higher priority class (leaders) are always negatively discriminated. Thus, though prioritizing the interdiction of operatives' class with fewer members over those with larger members may be justified if both classes reside concurrently in the system. However, the non-preemptive prioritization of class of fewer operatives (leaders) that may be detected later, over class of larger operatives (foot-soldiers) that was detected earlier in the CT environment may not be fair and economically viable. As many operatives of the foot-soldiers class that were detected early in the system may have to wait for eternity for the completion of interdiction of many leadership class that may have been detected late. This is possibly discrimination and an unfair treatment or marginalization by the CT forces, and hence a violation of operatives' arrival time (seniority) preference principle.

Also the high waiting time of the foot-soldiers in the system may drive a proportional high reneging probability of the operatives to carry on terror attacks notwithstanding the busy CT environment. The security implication of this discriminatory and unfair treatment of the foot-soldiers class is intuitive. That is any delay in targeting and interdicting any detected terrorist operative in the CT environment poses great disservices to the system even before the targeting and interdiction of the detected leadership class are completed. Therefore, since all classes of terrorist operatives detected in the CT environment deserved equal or proportional interdiction time and CT forces' attention, then by arrival time difference (seniority) principle, the prioritization of operatives' interdiction based on arrival time difference (seniority) may be fair and justified. Otherwise, deploying dual tactical approach (combining sticks and carrots instruments) or dedicating separate tactical approach to separate class of terrorist operatives and interdicting each class under the first-come-first-out (FIFO) interdiction policy will be a fairer, justifiable and more efficient alternative.

Finally, in addressing the issue of class discrimination that may arise in the management of single-tactics CT measure, the results of the analyses shows that for multi-class terrorist operatives: (i.) the (weighted) value of class discrimination is always bounded by the system unfairness, that is, an operative class cannot be highly discriminated if the overall system unfairness is low, (ii.) in the non-preemptive priority variant, the highest priority class may not always enjoy positive discrimination if class prioritization is bases on interdiction time differences only. However, if consideration is also given to operatives' arrival time differences (seniority), then the highest priority class may always enjoy positive discrimination.

In general the prioritization of leadership decapitation in a crime fighting environment does not conform to either the fundamental principles of preferential service in a queuing system, or the basic principle of social justice, equity and fairness in human society. Since terrorist are smart guys, the security implication of such tactical approach is that potential leaders may disguise as ordinary operatives to evade interdiction, hence the gross interdiction of the foot-soldiers' class in expense of key leaders. Therefore, to mitigate the overall high waiting and sojourn times of the operatives as well as high delay probability and response time of the CT forces which drives the high negative class discrimination of the leadership class and the system unfairness coefficient, the study recommend the deployment of multi-tactical approaches (e.g. sticks and carrots) as an alternative measure to the single tactics non-preemptive priority interdiction policy.

Also, to address the gross marginalization and under-interdiction of the leadership class, the study recommends the syndromnization of intelligence measure (SIM) in CT environment. That is the deployment of specialized non-conventional covert intelligence agents to infiltrate terrorist organization, and boost credible intelligence gatherings for proper identification, categorization, definitions and smart targeting of terrorist locations. The results derived in this work can serve for two purposes. First, the simpler results, which might sound intuitive to many researchers, can be used to build confidence both in the CTRAQF unfairness and class discrimination metrics; both of which are very new to the terror-queue theorists and hence require examination and trust building. Second, once CTRAQF model has acquired the deserved confidence and trust, the model can be used to evaluate and study CT systems where the results may not be explicit.

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