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A State-Dependent Terror Queueing Model of Counterterrorism Strategies: The Perspective of Nigerian Counterterrorism Environment

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ABSTRACT

The study is an adaptation of the conventional state-dependent queuing theory to evaluate the performance of key counterterrorism (CT) strategies in the Nigeria CT environment. It analysed the use of coercive measures (Sticks), non-coercive/conciliatory strategies (Carrots), covert intelligence agents driven syndromnized intelligence optimizing pseudo-terrorists (SIOP) agents), as well as their combined variants. The model incorporates state transitions to capture the dynamic nature of terrorist recruitment processes in Nigeria CT environment. The performance measures are adapted from conventional queue frameworks to assess the effectiveness of these CT strategies in mitigating terrorist threats. The results show the importance of maximizing interdiction rate, discrimination rate, system efficiency, and intelligence integration while minimizing system unfairness factors, response time, and queue length for optimal CT operations. The study also highlights the exploitation of the positive correlation that exist between the Stick and Carrot strategies, as well as their intelligence-driven variants, to execute an enhanced, balanced and coordinated intelligence-driven terrorists interdiction strategies. Therefore, study suggests leveraging viable Carrots instruments with credible Sticks option and SIOP agents in a CT environment, for enhanced credibility and sufficiency of intelligence gatherings as well as covert supervision of terrorists' compliance to Carrots instruments in CT environment, and hence optimizing CT efforts.

KEYWORDS: *Counter-terrorism strategies, SIOP agents, Sticks and Carrots CT strategies, Terrorists' recruitment processes, performance measure*

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1. BACKGROUND OF THE STUDY

Terrorism has become a significant threat to global peace and security, with various countries facing the menace of terrorist attacks. Nigeria, in particular, has experienced a significant increase in terrorist activities over the past decade, particularly from the Boko Haram and ISWAP (Islamic State of West African Provines) insurgency in the north-eastern part of the country. These insurgent organizations have resulted in the loss of tens of thousands of lives, displacement of people, destruction of property and substantial instability in the country. Boko Haram, which emerged in 2009 with a radical ideology that calls for establishing an Islamic state based on strict Sharia law in Nigeria, has gained notoriety through acts of suicide bombings, kidnappings, mass killings targeting schools, churches and government buildings. Boko Haram was responsible for over 6,000 deaths in Nigeria and Cameroon in 2014 alone. Over the years, Boko Haram has evolved and undergone factionalization, with ISWAP emerging as a splinter group that pledged allegiance to the Islamic State (IS) in 2015. This development further complicated the Nigerian CT efforts, as both organizations has continued to carry out unrented attacks on the Nigerian populations, as well as demonstrating undaunted resilience and adaptability in its operations, with the consequential proliferation various armed banditry groups in recent years[22],[38],[55].

It is estimated that about 10,000 civilians have lost their lives to terrorism-related violence in Nigeria since Boko Haram inception in 2009, with significant impacted most on the northeastern Nigerian states. In the area of education, over 910 schools have been destroyed and 1,500 forced to close due to terrorist attacks between 2009-2015. About 611 teachers have been killed while 19,000 fled since 2009. Additionally, more than 300 students lost their lives from 2012-2014. Significantly, in April 2014 Boko Haram abducted over 276 girls from a school in Chibok, with 57 escaping but leaving 219 still held captive[22],[38],[55]. Recently, 21 more girls were released through negotiation while over 190 still remain with their captors. Terrorism has also had devastating human and economic costs. It is estimated that more than 30,000 Nigerian and neighbouring country lives have been lost since 2009. Around 800,000 children, mostly in northeast Nigeria, have been displaced from their homes and schools. By 2016, the number of children forced out of education reached 952,029 due to safety fears. An estimated 1.5 million people have been internally displaced across Nigeria due to the unrelenting terrorists violence, of which over 10.5 million children have dropped out of school nationwide[22],[38],[55].

The rising government expenditure on CT operations have also impacted negatively on the nation economic development, with Nigeria even being removed from certain bond market indexes in 2015, as a consequence of heavy indebtedness. For instance, in July 2014, the government obtained a $1 billion loan specifically to combat the Boko Haram insurgency. Consequence upon these, foreign investment has reduced substantially, while stock exchange markets weakened as more foreign investors exited the country due to increasing terrorism. The insurgency has also led to higher food prices as key agricultural regions like the northeast experience scarcity due to mass displacement of farmers and lost cultivation seasons. It is estimated that $9 billion will be required to rehabilitate the devastated communities in the northeast, in addition to ongoing costs of maintaining IDP camps, as well as medical aids, education and upkeep of refugees[13],[37],[42],[50].

In response to this growing terrorist threats, the Nigerian government has adopted various CT strategies, including both military and non-military strategies. Militarily, the Nigerian armed forces, in collaboration with support from regional and international partners, have conducted several CT operations against insurgent organizations. These include offensive campaigns, intelligence gathering and cross-border collaboration. Beyond military efforts, the government has also deployed non-military strategies like socio-economic development programs, community engagement, deradicalization and reintegration initiatives, as well as interfaith dialogue to address the roots of terrorism and extremism. The legal framework for CT has also been strengthened through new legislation and specialized agencies[22],[38].

Notwithstanding these government efforts, Boko Haram and ISWAP has continued to evolve and present increasingly complex terrorist landscape, with persistent attacks, recruitment of new fighters and spillover effects in neighbouring countries. This persistent struggle of Nigeria against terrorist organizations, and its related institutions of organized crime has made the Nigerian CT environment an important area of study and research. The present work, therefore, seek to apply a state-dependent queuing modeling (SD-TQM) approach toward providing valuable insight into the evaluation of Nigeria's CT performance, based on the arithmetical progression of terrorist recruitment rates, intelligence practices, interdiction success and systemic efficiency.

The concept of terror queueing models (TQM), though relatively in terrorism research, involves the use of mathematical models to analyze the dynamics of terrorist activities and the impact of CT strategies. The SD-TQM analogy is a specific type of TQM that takes into account the different states of terrorist activity, such as the planning stage, the recruitment stage, the execution stage, and the post-attack stage[30]. By SD-TQM, it is possible to assess the effectiveness of CT strategies at different stages of terrorist activity. The study uses a quantitative approach to analyze the data collected on Boko Haram and ISWAP recruitment processes, and the CT strategies implemented by the Nigerian CT agencies. The data was collected from various sources, including academic journals, government reports, and personal interviews with repented terrorists' operatives. Relevant statistical analysis tools are deployed to evaluate the data and draw conclusions on the effectiveness of the sampled CT strategies.

The significance of this study lies in its ability to provide policy-makers and CT agencies with valuable insights into the effectiveness of their CT strategies.

By identifying the strengths and weaknesses of these strategies, the study can help inform the development of more effective CT policies that can help combat terrorist organizations and its related institutions of organized crimes such armed banditry in Nigeria. Additionally, the study can contribute to the broader academic literature on terrorism and CT efforts, providing a unique perspective on the use of SD-TQM to assess CT strategies. Overall, this study aims to provide a rigorous and quantitative analysis of the efficacy of the sampled CT strategies in combating combat terrorist organizations, and its related institutions of organized crimes in Nigeria. By using an SD-TQM, the study help identify areas of improvement in the CT strategies and provide valuable insights for policy-makers and CT agencies.

1.1. Concept of Terror Queueing System (TQS)

The notion of queues, which refers to waiting lines that frequently occur when there are limited resources or services available, is commonly seen in everyday human activities such as transport networks or commercial outlets. By analogy, the concept of terror queuing proposes that terrorists and criminals engaged in illicit activities can metaphorically be viewed as joining an imaginary queue awaiting CT agencies' disruptive efforts.

A terror queueing system (TQS), therefore, connote a mathematical model deployed to analyze and understand the infiltration and interdiction of ongoing terror plots by CT agents. It applies concepts from queueing theory and Markov population processes to assess the performance measures of a given CT environment. TQM therefore, seeks to represent the flow of terrorist operations within a defined CT environment and the potential responses from governmental CT strategies[30] .

The CT environment encompasses elements like the presence and nature of terrorist threats, the legal framework, capacity of security agencies, socio-political dynamics, technological aspects, community relations, available resources and international cooperation. Understanding this milieu is pivotal for crafting viable strategies to battle terrorism while upholding human rights and social stability. CT efforts refers to the diverse strategies, policies and actions adopted by government authorities to prevent, deter and respond to terrorist activities. These include steps to dismantle terrorist networks, shield potential targets, and minimize the impact of attacks. The principal CT strategies in Nigerian CT environment can be categorized into three major strategies. These are the conventional Sticks CT strategies – emphasising coercive law enforcement strategies, the Carrots CT strategies - emphasising non-coercive or conciliatory programs aimed at addressing the root causes of terrorism, and combined variants. Considering the asymmetric nature of CT operations across heterogeneous terrains, the infiltrating "syndromized intelligence optimizing pseudo-terrorists" (SIOP) agents which may sometime function as guerrilla reconnaissance units to strengthen intelligence credibility warrants examination as a potential CT approach to complement the three basic paradigms[44],[49],[58].

A TQM applies conventional queuing theory principles to analyze and optimize resource allocation and manpower within CT environments. It mirrors regular queuing models by managing the flow of terrorists or "terror-related threats, or events or incidents" through sequenced processes. The objective is to ensure efficient resource utilization and reduced delays or bottlenecks in the CT environment. Relevant factors include each stage's carrying capacity, task arrival rate (terrorist recruitment), processing time, priority and inter-stage dependencies. A TQM provides performance insights, pinpoints opportunities for progress and facilitates decision-making regarding resource distribution and workflow streamlining in CT operations[30].

Specifically, this study conceptualizes a State-Dependent Terror Queuing Model (SD-TQM) framework incorporating the prevailing state of terrorist recruitment dynamics. An SD-TQM allows for evaluation of the sampled CT strategies relative to this dimension. It depicts CT agencies' intelligence, surveillance, investigation and engagement as "Servers" handling the "arrival population" of recruited terrorists, and a "departure population" as interdiction rate relying on intelligence quality, coordination, assets and response abilities. The queuing process represents terror-related threats, or events or incidents traversing the CT landscape amid state transitions as recruitment ebbs and flows, altering arrival rates and necessary strategies. Specialized SIOP units, outreach initiatives and military offensives exemplify parallel servers within the contemplated TQM. performance metrics then help streamline the CT landscape.

1.2. Objectives of the Study

Predicated on the above background, this study seeks to achieve the following objectives:

1. To apply state-dependent queuing theory in assessing the performance of CT strategies and evaluate their effectiveness in mitigating terrorist threats.
2. To analyze the correlation between the Stick (use of force) and the Carrot (non-coercive strategies) CT strategies, as well as their intelligence-driven

variants, and emphasize the need for a balanced and coordinated intelligence-driven CT approach.

3. To highlight the importance of maximizing interdiction rate, discrimination rate, system efficiency, and intelligence integration while minimizing system unfairness factors, response time, and queue length for optimal CT operations.
4. To propose the integration of syndromnized intelligence optimizing pseudo-terrorists (SIOP) agents for enhanced credibility of intelligence gathering, and covert supervision of terrorists' compliance to Carrot instruments in the CT environment.
5. To contribute to the existing literature on CT research and provide insights for informed decision-making in optimizing CT strategies, supporting the development of more efficient and adaptive strategies to combat terrorism.

2. REVIEW OF RELATED LITERATURE

The earliest acknowledged study on queuing theory and its applications can be traced back to the pioneering work of A.K. Erlang in the early 20th century. Erlang developed the classical "B-formula" or Erlang Loss Formula to model telephone call waiting times for the Danish Telephone Company[16]. However, until the event of 9/11 bombing of the World Trade Centre USA, queuing theory was predominantly applied to conventional business service systems[14],[17],[20],[28],[41],[51]. The state dependent queueing model (SDQM) allows the characteristics of a queuing system to change depending on its internal state. These models have found diverse real-world applications for analyzing complex systems and optimizing performance. For instance, Kelly and Williams[16], applied a state-dependent queuing model to optimize traffic signal control strategies based on dynamic traffic flow variations. Gans et al[40] also reviewed state-dependent models in call centre operations to improve performance metrics like wait times and customer satisfaction through factors like staffing levels and routing.

Hossein et a[19], presented a state-dependent M/G/1 queue with finite and infinite buffers, deriving the steady-state solution and analyzing state probabilities at arrival epochs. Singh and Bose[50], provided a comprehensive survey of state-dependent models operating under admission control policies with applications in communications, healthcare, manufacturing and more. Van der Wal et al[27] highlighted the need for data-driven queueing science perspectives to develop models explaining patient flow dynamics in healthcare. Wang et al[13] further reviewed and discusses the applications of SDQM in various service industries like hospitality, retail and entertainment for queue management, staffing and service time guarantees. This study demonstrates how SDQM can enhance customer satisfaction, improve operational efficiency, and optimize resource allocation in service-oriented industries.

Notwithstanding extensive applications of conventional queueing model and its SDQM variants, both TQM and its SD-TQM applications to combat systems and terrorism has remains relatively scarce, except the recent quest for optimal interdiction of terror plots in CT environment[5],[30],[32,33,34],[53] and terrorist leadership decapitation appraisal[23]. Udoh, et al[23] had adapted the novel RAQFM[47] principle to assess unfairness characteristics of the popular leadership decapitation CT approach of most world government. Thus, determining if the prioritization of terrorist leaders in CT environment conforms to the principles of equitable allocation of CT resource. The study which observed that prioritizing terrorist leaders in CT operation engendered high marginalization of low-level operatives, and hence violate the concepts of queue fairness, proffered a dual-targeting tactics, and the simultaneous deployment different CT strategies as a better alternative.

Prior to Udoh, et al[23] adaptation of RAQFM[47] on leadership decapitation strategy in CT operations, Agnieszka[2] had developed a multi-class Markovian queueing model to analyze key CT strategies, considering different types of plots that causes various level of damages. Finding the optimal assignment of detection resources to maximize terror plots prevention using optimization algorithms and approximating the model via Ornstein-Uhlenbeck processes, the author concluded that prioritizing terrorist leaders in CT environment violates queue fairness principles

Another significant works on SD-TQM was Kaplan's[30] efforts to optimize terror plot interdiction using queueing frameworks. The author represented terror plots as tasks and covert intelligence agents as servers, descriptively studying the effect of infiltration and interdiction on plots. Analysis introduced determining terrorist state variables as sums of detected and undetected threats. In follow-up works, Kaplan[32,33] optimized staffing levels of CT personnel to maximize attack prevention benefits. Considering terrorists deduction of CT personnel staffing level from observed interdiction rates, the model was extended to a simple staffing game. Seidl et al[4] applied optimal control theory to Kaplan's model[32,33], addressing dynamic inter-temporal staffing issues and predicting optimal strategies depend on detected and undetected plots over time. Wrzaczek et al[52], also sought optimal terrorist attack rates as government develops staffing levels optimally. By estimating successful and interdicted attacks via an underlying fluid queue, the authors characterized optimal controls for both sides under different information structures, observing constant attack rates may be optimal for unobserved terrorists.

Queuing models have also been commonly deployed to optimized law enforcement operations[6],[44],[47]. For instance, Baskett et al[6] had presented one of the earliest, incorporating a threshold policy to dynamically manage emergency call centre staffing levels based on call volumes. Kolesar et al[44] develops a multiple dispatch queueing model to analyze police patrol operations in a more realistic way. In particular, allowing for calls requiring multiple patrol cars to respond, in contrast to previous models. Terror plots was modelled as arriving in different classes with varying attributes, thus, agents can be divided between classes to handle plot classes preferentially. The interactions between plots and agents were represented as a Markov population process. Optimization determines the agent assignment maximizing either detection success or damage prevention. Using Ornstein-Uhlenbeck analysis and simulation techniques offer insights for resource deployment strategy. Extending Kolesar et al[44] work, Green[35] also develops a multiple dispatch queueing model of police patrol operations to better understand real-world scenarios where multiple cars respond to calls. Terror plot was also modelled as arriving in classes with different characteristics, with agents divided between classes to handle plot classes preferentially. Finds the agent allocation that maximizes either detection probability or prevent damage, the Ornstein-Uhlenbeck analysis and simulation approximations provided insights into the deployment strategy.

These examples demonstrate queuing applications in resource allocation, response time optimization and overall efficiency enhancement across policing functions by incorporating context-specific factors. However, state-dependent modeling of Nigerian CT strategies remains limited. Therefore, this paper aims to complement existing literature by studying a state-dependent terror queue framework for the Nigerian CT environment. Incorporating factors like terrorist recruitment dynamics and interdiction rates, the model evaluates CT approach performance to assist informed decision making and strategy development, given growing calls for proper assessment of domestic measures against the persistent asymmetric threat. It is hoped this research will contribute valuable insights to the lean but urgent discourse on security performance evaluation.

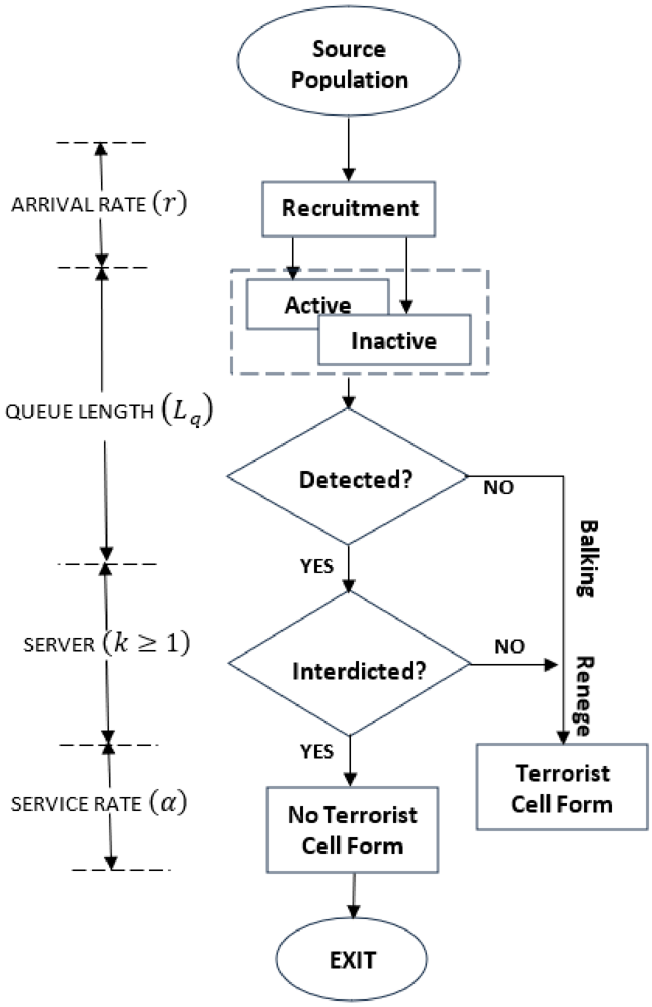


Figure 3.0: The Terror Queuing System Flow Chart

3. Terror Queuing Framework

In this terror queue analogy, diagrammatically illustrated by Figure 3.0, susceptible individuals (recruits) joining terrorist organizations (active and inactive) are assumed to arrive (detected) the CT environment at random, following a Poisson process, and targeted for interdiction (service) through a given CT approach, at normally, First-Come-First-Serve (FCFS) service policy, except otherwise instructed by CT authority. If a terrorist is detected by covert intelligence agents, he/she is assumed to have entered the "queue", and hence, subject to targeting and interdicted (remove from the system) immediately. Therefore, the number of detected terrorists per cycle of CT operation forms the queue length (L_q), while the sum of detected and interdicted terrorists forms the system size (L).

In a CT environment, sometimes a terrorist or groups of terrorists may evade detection by covert intelligence agents (Balk), and hence complete his/her intention. For instance, intelligence gaps regarding an individual or group's intentions and methods can make it challenging to identify potential terrorists. Terrorist organizations may also infiltrate insiders into CT agencies who can compromise operations by providing information to terrorists or misleading investigations. Terrorists often adapt sophisticated communication tactics like advanced encryption to coordinate clandestinely and thus, avoid detection. Also, having insider knowledge of CT strategies, techniques or technologies employed can help terrorists exploit weaknesses, and hence, evade detection. Instances also abound where some radicalized individuals may operate as lone wolves without suspicious behaviors or criminal histories, making it difficult for covert agent to identify them. Limited resources mean CT efforts must prioritize tactics based on intelligence, allowing some threats to potentially evade detection due to receiving less attention.

Furthermore, if a detected terrorist is targeted for interdiction, he/she is assumed to have entered “Service” and is finally removed from the system by either arrest or assassination or surrender, via any of the CT strategies (Servers). However, in a CT environment, there may be preferential interdiction policies or factors that can allow a detected terrorist to escape interdiction, and hence, complete terror attack. For Instances leadership decapitation strategies that solely target top terrorist leaders could divert CT resources away from interdicting lower-level operatives that are actively planning attacks. Also, the "sacred cow syndrome" phenomenon prevalence in most may CT environment may shield certain influential individuals from proper investigation or action due to political pressures, thus, allowing them to evade interdiction. CT agencies could also face operational constraints like insufficient resources or legal restrictions that hinder swift response to terror threats, or delays in communication or information sharing may impede timely response, thus, giving terrorists an opportunity to flee. Or terrorists may exploit vulnerabilities in transportation and border security to escape across jurisdictions.

Also, insider threats or assistance from sympathetic individuals within CT agencies could compromise interdiction by leaking intelligence or obstructing investigations or facilitating escape routes. Instances also abound, where forged identities or false documentation may complicate CT forces tracking efforts. Terrorist can also exploit jurisdictional complexities when operating internationally, if CT agencies do not coordinate effectively. In either of these scenarios, a detected terrorist escaping interdiction, is synonymous to a customer who “renege” from the conventional queue prior to being served. Though, this assumption may not hold exact in our TQM analogy, because unlike customers in the conventional queues, terrorists are not always visible upon arrival at the queue, but must be detected by covert intelligence agents before being targeted for interdiction. Thus, detected terrorist and the standby CT forces may coexist in a CT environment.

Finally, the CT strategies serving as service channel or server(s) in this TQM analogy, hypothetically underscores the adoption of the Pavlovian motivational learning philosophies - the Sticks (S), Carrots (C), and specialized SIOP agents (S_0) strategies, as well as their combined variant, to the management of CT environment. Specialised SIOP agents, who may also assume guerrilla reconnaissance roles to optimize intelligence gathering, can also detect and covertly interdict potential terror plots as well as supervised terrorists’ compliance to Carrots instrument in the CT environment. The combined variants – Sticks & Carrots (SC), or Sticks & SIOP (SS_0) or Carrots & SIOP (CS_0), or Sticks, Carrots & SIOP, (SCS_0), underscores their simultaneous or parallel deployment in a given CT environment for both enhanced accuracy and optimal interdiction of terrorist plots.

3.1. Terrorist Interdiction Capacity of CT Strategy

Terrorist interdiction capacity (TIC) as a crucial component of CT measures, refers to a CT strategy’s capability to detect, prevent, disrupt and responds to terrorist activities before they can be carried out. TIC involves various strategic and tactical strategies, as well as capabilities aimed at identifying and neutralizing potential terror-related threats. Key among these mutually reinforcing characteristics of TIC include: Intelligence gathering from sources like human intelligence, signals intelligence and open sources is crucial to identify threats and understand terrorist tactics. Surveillance techniques like physical and electronic monitoring are also used to track suspects. Border security plays an important role through measures such as biometric screening and information sharing to control cross-border movement of terrorists and illicit materials. While, law enforcement conducts investigations and gathers evidence to apprehend terrorist suspects.

International cooperation is key, involving intelligence and information exchange with partners to disrupt networks and jointly investigate and prosecute cases. While technology and innovation enhance capabilities through tools like advanced surveillance systems, data analytics and cybersecurity. Building community and organizational resilience is also part of interdiction capacity, focusing on public awareness, training first responders, and strengthening emergency response abilities to withstand and recover from attacks. In summary, these mutually reinforcing characteristics work together to enable detection, prevention and response to thwart terrorist activities before their execution[6],[8],[9],[11],[27],[39],[52].

3.2. Steady State Terror Queuing Model

When CT operations commences, we assume a progressive interdiction process via the respective of CT strategies, but attains stability after some time. Before the commencement of interdiction, the CT environment is very much influenced by the initial number of terrorists, and the elapsed time. This period of transition may be termed, the transient state of the CT environment. Therefore, a CT environment endowed with more than one CT approach, $(M/M/k;\ k > 1)$ is said to be in transient-state when its operating characteristics is time-dependent. However, after sufficient time has elapsed, the CT environment may become independent of the initial conditions and the elapsed time (except under very special circumstance), and thus, enters a steady state condition. Therefore, a TQS is said to be in steady state condition when the behaviour of the CT environment becomes independent of time.

By considering terrorists' recruitment rate as the arrival epoch, CT strategies as Server(s), and the CT approach interdiction rate as the departure or service rate, this model, assume that the TQS attend a steady state when the number of terrorists recruited and the CT interdicted rate remains relatively constant over time. Let $P_n\ (t)$ denote the probability that the CT environment is in state (n) - there are n recruited terrorists at time t. We know that the change of $P_n\ (t)$ with respect to time (t) can be denoted by its derivative $\left(\frac{d}{dt}P_n\ (t)\right)$. Therefore, TQS assumed stability, eventually, if $P_n(t)$ is independent of time (t), i.e., remains the same as time passes $(t\ \rightarrow\ \infty)$.

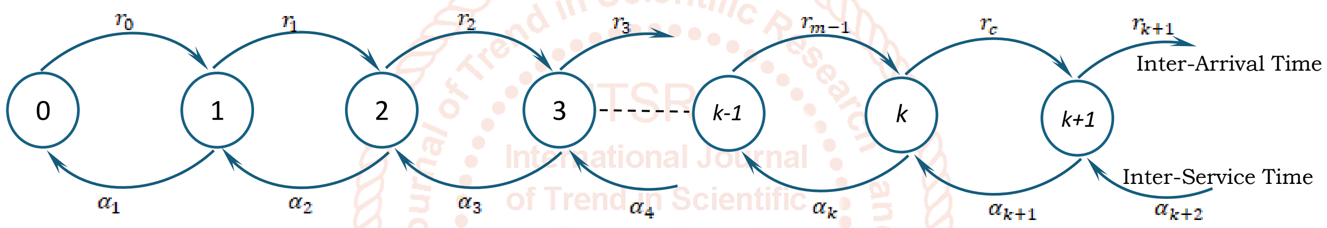


Figure 3.1: Flow diagram of M/M/k, $k \geq 1$ queuing Model

Mathematically, $\lim_{t\to\infty} P_n(t) = P_n(\text{independent of } t) \Rightarrow \lim_{t\to\infty} \frac{d}{dt} P_n(t) = \frac{d}{dt} \lim_{t\to\infty} P_n = \frac{dy}{dx} P_n = 0$. And from Lee's[4] point of view, a TQS under steady state condition can be represents diagrammatically by Figure 3.1 above. Consider the various states of CT environment, from the rate-diagram above, let

- r denote the average number of terrorists recruited per year.
- α denote the average number of terrorists interdicted per year.
- ρ denote the system traffic intensity per year
- L denote the number of detected and interdicted terrorists per year,
- L_q denote the queue length (number of detected terrorists) per yearω denote the average time spent by an arbitrary terrorist from detection to interdiction,
- ω_q denote the average time spent by an arbitrary detected terrorist before interdicted,
- P_0 denote the probability that there is no terrorist in the CT environment (idle server).

Considering the transition that take place in CT environment, state by state, we assumed that at steady state: *The rate of detection of terrorists = The rate of interdiction of terrorists*, therefore, when the system is in:

$$\text{State } (0)\text{: } P_0 \text{ at steady state: } \alpha_1 P_1 = r_0 P_0 \Rightarrow P_1 = \left[\frac{r_0}{\alpha_1}\right] P_0$$

$$\text{State } (1)\text{: } P_1 \text{ at steady state: } \alpha_2 P_2 + r_0 P_0 = (\alpha_1 + r_1) P_1 \Rightarrow P_2 = \left[\frac{r_0}{\alpha_1}\right]\left[\frac{r_1}{\alpha_2}\right] P_0$$

$$\text{State } (2)\text{: } P_2 \text{ aAt steady state: } \alpha_3 P_3 + r_1 P_1 = (\alpha_2 + r_2) P_2 \Rightarrow P_3 = \left[\frac{r_0}{\alpha_1}\right]\left[\frac{r_1}{\alpha_2}\right]\left[\frac{r_2}{\alpha_3}\right] P_0 \qquad (3.0.1)$$

$$\vdots$$

$$\text{State } (n)\text{: } P_n \text{ at steady state: } \alpha_{n+1} P_{n+1} + r_{n-1} P_{n-1} = (\alpha_n + r_n) P_n \Rightarrow P_{n+1} = \left[\frac{r_0}{\alpha_1}\right]\left[\frac{r_1}{\alpha_2}\right] \cdots \left[\frac{r_n}{\alpha_{n+1}}\right] P_0$$

By mathematical induction, therefore, when the system is in state (n) - there are n-terrorists in CT environment[4],[54]:

$$P_n = \prod_{i=1}^{n} \frac{r_{i-1}}{\alpha_i} P_0;\ k \geq 1 \ (3.0.2)$$

But, we also have

$$\sum_{n=0}^{\infty} P_n = P_0 + P_1 + P_2 + \cdots + P_n + P_{n+1} = P_0 + \sum_{n=1}^{\infty} P_n = 1 \ (3.0.3)$$

Substituting equation (3.0.2) into (3.0.3), we have

$$P_0 + \sum_{n=1}^{\infty} \prod_{i=1}^{n} \frac{r_{i-1}}{\alpha_i} P_0 = 1 (3.0.4)$$

Therefore, the probability that there are no terrorists in the CT environment - no CT option is deployed, (P_0) is given by:

$$P_0 = \left[1 + \sum_{n=1}^{\infty} \prod_{i=1}^{n} \frac{r_{i-1}}{\alpha_i}\right]^{-1} \ (3.0.5)$$

3.2.1. System Size/Queue Length Distribution: By queuing theory[4],[16],[54] the system size – number terrorists detected, and interdicted (L) is given by:

$$L = E[N] = \sum_{n=1}^{\infty} nP_n = P_0 \sum_{n=1}^{\infty} n \prod_{i=1}^{n} \frac{r_{i-1}}{\alpha_i} (3.0.6)$$

And the queue length - mean number of terrorists detected per cycle of CT operation, given that there are k-CT strategies is given by:

$$L_q = E[N-k] = P_0 \left[\sum_{n=1}^{\infty} \prod_{i=1}^{n} \frac{r_{i-1}}{k\alpha_i}\right] \left[n - \sum_{k=1}^{m} k\right] (3.0.7)$$

The average rate at which a terrorist is detected in CT environment is given by: $\bar{r} = (L - L_q)\alpha$

3.2.2. System Waiting/Response Time Distribution: The average time an arbitrary terrorist spent in CT environment after detection is be given by: $\omega = L(\bar{r})^{-1}$. And the average time a detected terrorist spent in CT environment before he/her interdicted, can be given by: $\omega_q = L_q(\bar{r})^{-1}$.

3.2.3. System Behaviour: Suppose the terror queue is not empty (the system has at least $n \leq k$ cells), then we assumed that a detected cell must be targeted and interdicted immediately, otherwise a new cell will be established. Now, let P_n be the steady state probability that there are n-cells in the CT environment. Then by PASTA property, this is also the probability that n-terrorists are seen by an arbitrary arrival at a given CT cycle. Then P_n can be given by:

$$P_n = \begin{cases} \frac{(k\rho)^n}{n!} P_0;\ n \leq k \\ \\ \frac{\rho^n k^k}{k!} P_0; n \geq k \end{cases} ;\ \rho = \frac{r}{a} \ (3.0.8)$$

A. ***Probability of forming a new terrorist Cell:*** The probability that a new cell will be established, given that there are $n \leq k$ cells in CT environment is given by:

$$\text{Prob(Terrorist entering CT environment)} = \text{Prob(At least one detected cell in CT environment)}$$

$$= \text{Prob}(\text{at most k cells interdicted in CT environment})$$

$$P_{n \le k} = \sum_{n=1}^{k} \frac{(k\rho)^n}{n!} P_0 \qquad (3.0.9)$$

B. ***Probability of that a new Cell cannot be formed:*** The probability that a new cell cannot be established, given that there are $n \geq k$ cells in CT environment is given by:

$$\text{Prob}(\text{Terrorist balking}) = \text{Prob}(\text{At least } k \text{ detected cell in CT environment})$$

$$= \text{Prob}(\text{at most } k + 1 \text{ cells interdicted in CT environment})$$

$$P_{n \ge k} = \sum_{n=1}^{k+1} \frac{\rho^n k^k}{k!} P_0; n \ge k \qquad (3.1.0)$$

C. ***Probability of a Terrorist Reneging***: The probability that a detected terrorist will renege upon seeing that upon seeing $n \geq k$ terrorist in the system is given by:

$$\text{Prob (Renege)} = \sum_{n=1}^{k+1} \frac{(1 - \rho)(1 - \rho^{(k-n)})}{1 - \rho^k} \quad (3.1.1)$$

D. ***Probability of interdiction of terrorist cell:*** Suppose the queue is not empty, then by Erlang loss formula[16],[54] the probability that the interdiction of a detected terrorist cell will be delayed given that there are $n \geq k$ detected cells in the CT environment can be given by:

$$\text{Prob (Delayed Interdiction)} = \text{Prob (At least k detected cells in the system)}$$

$$= \text{Prob (At most } k + 1 \text{ targeted cells in system)}$$

$$C(n, \rho) = \frac{(\rho(n - 1 - \rho) \cdot C(n - 1, \rho))}{(n - 1)(n - \rho) - \rho C(n - 1, \rho)}$$

$$= \sum_{n=1}^{k+1} \frac{\left[\rho(n - 1 - \rho)\left(\frac{(n-1)!}{\rho!\,(n - 1 - \rho)!}\right)\right]}{\left[(n - 1)(n - \rho) - \rho\left(\frac{(n-1)!}{\rho!\,(n - 1 - \rho)!}\right)\right]} \qquad (3.1.2)$$

3.3. State Dependent Terror Queuing Model

A state dependent terror queuing system (SD-TQS) is one in which either the terrorist recruitment or CT interdiction rates or both parameters depends on the state of the CT environment. Research and field findings indicate that, terrorist organization's primary objective is to strategically establish a network of resilient combat units (cells) within its area of conquest first, before launching any attack. Consider a CT environment predisposed to some predetermined CT strategies, k, aimed at combating the terrorists' combat cells, and hence, terrorists' activities. We assumed that the respective CT strategies often interdict susceptible terrorists' cells according to some exponential laws, with mean, say α-cells per CT cycle. Susceptible terrorists' cells are also assumed to recruit members randomly according to the state of CT environment, but at a constant rate, say r-terrorist per CT cycle, as long as there is at least one (1) combat cell established in the CT environment. However, if at least 2-terrorists' cells are successfully established in the CT environment, the recruitment rate increases arithmetically with the number of interdicted terrorists. But, if at least 10 cells are successfully established in a CT environment, then terrorists' recruitment rate declines considerably. Let k denote the number of CT strategies (servers) available for deployment on n number of terrorist cells in the CT environment. Let P_n denote the probability that there are n cells in the system per year. Then by adapting the Steady State queue measure of Section 3.1, the transition of SD-TQM, $(M/M/k, k \geq 1)$, can be tabulated as below in Table 3.0, for analysis of the relevant performance measures.

Table 3.0: Transition of the SD-TQM

n	r_n	α_n	$P_n = \frac{r_{n-1}}{\alpha_n} P_{n-1}$
0	r	0	$P_0 = P_0$
1	$r + a$	ka	$P_1 = \frac{r_0}{\alpha_1} P_0 = \frac{r}{ka} P_0$
2	$r + a$	ka	$P_2 = \frac{r_1}{\alpha_2} P_1 = \frac{r(r+a)}{(ka)^2} P_0$
…	…	…	…
m	r	ka	$P_n = \frac{r_{m-1}}{\alpha_m} P_{m-1} = \frac{r(r+a)^{m-1}}{(ka)^m} P_0$

Considering the transition on Table3.0 above,

$$\sum_{n=0}^{m} P_n = P_0 + P_1 + P_2 + \cdots + P_{10} = P_0 + \sum_{n=1}^{m} P_n = 1 \ (3.1.3)$$

A. By equation (3.0.5), the probability that there is no terrorist cell in the CT environment after a given CT cycle is given by:

$$P_0 = \left[1 + \frac{r}{ka} \sum_{n=0}^{m} \left(\frac{r+a}{ka}\right)^n\right]^{-1} \ (3.1.4)$$

B. The probability of having at least one terrorist cell in the CT environment after a given CT cycle $(Prob(n \geq 1))$ cells) is given by:

$$Prob(1 \leq n \leq m) = \sum_{n=1}^{m} P_n = \left(r \sum_{n=1}^{m} \frac{(r+a)^{n-1}}{(ka)^n}\right) P_0 \ (3.1.5)$$

C. The traffic intensity of the CT environment is given by: $\rho = r[ka]^{-1}$. We assumed that if a terrorist enters the CT environment, he/she should be detected, targeted and interdicted immediately. However, if his/her interdiction is forestalled due to some preferential interdiction policy (e.g., prioritized leadership decapitation or Sacred Cow syndrome) or intelligence lapse or system failure, then, the additional time required to complete the interdiction of such a terrorist follows an exponential distribution with mean: $\rho^{-1} = kar^{-1}$.

D. By equation (3.0.6), the total number of terrorist cells established (detected and interdicted) in the CT environment after a given CT cycle is given by:

$$L = \sum_{n=1}^{m} nP_n = \left[r \sum_{n=1}^{m} \frac{n(r+a)^{n-1}}{(ka)^n}\right] P_0 \ (3.1.6)$$

E. And by equation (3.0.7) the total number of detected but yet to be interdicted cells (queue length) in CT environment after a given CT cycle is given by:

$$L_q = \sum_{n=1}^{10} (n-k)P_n = \left[\left(r \sum_{n=1}^{10} \frac{n(r+a)^{n-1}}{(ka)^n}\right) - \left(k \sum_{n=1}^{10} \frac{(r+a)^{n-1}}{(ka)^n}\right)\right] P_0 \ (3.1.7)$$

F. The total number of terrorist cells interdicted in per a given CT cycle can be given by: $\varphi = L - L_q$. Then the effective terrorist flow rate $(\bar{r})$ – the average rate at which terrorist cells are established in the system is given by: $\bar{r} = (L - L_q)\alpha = \varphi\alpha$.

G. Let ω and ω_q denote the respective durations a terrorist cell exists in the CT environment, from detection and after interdiction. Therefore, the expected duration a detected terrorist cell can exist in the CT environment before interdiction is given by: $\omega = L(\bar{r})^{-1} = r(\theta a k)^{-1}$.

H. And the duration a terrorist cell can exist in CT environment after detection is given by: $\omega_q = L_q(\bar{r})^{-1}$. Therefore, the time taken to target and interdict a detected terrorist cell in the CT environment (response time) is given by: $T = \omega - \omega_q$.

3.4. Discrimination/Unfairness Characteristics of the SD-TQM

The concept of discrimination and unfairness in TQS underscored the potential biases or inequities that may characterise the treatment or priority given to terrorist or terrorist-related events, with respect to their waiting times and interdiction rate within the CT environment. Discrimination may be inferred when certain individuals or groups are unfairly or differently targeted for interdiction based on specific characteristics such as race, religion, political, nationality, or other factors. In the context of TQS, discrimination may manifest in various ways, such as interdiction below or above the internationally established IT biased profiling, or targeting specific groups disproportionately, or subjecting individuals to different levels of scrutiny based on their characteristics. Such action can undermine the fairness and effectiveness of the CT strategy and may lead to negative consequences, including the potential for overlooking genuine threats or unfairly targeting innocent individuals, and hence gross decrease in interdiction rate.

Unfairness, on the other hand refers to situations where individuals or groups are treated unjustly or inequitably within the CT environment. This can occur due to various factors, including biased decision-making, unequal allocation of resources, or inconsistent application of security measures. Unfairness in a TQS can lead to disparities in the treatment of individuals, resulting in unequal levels of security or increased vulnerability for certain groups. It is important to address and mitigate unfairness in CT operations to ensure that the system operates with integrity and respects the rights and dignity of all individuals, as well as enhancing interdiction accuracy. To account for the discrimination and unfairness characteristics in a TQS, certain criteria or thresholds values are often established to guide CT operations in a given CT environment. These are the interdiction threshold (IT), the discrimination threshold (DT), and the fairness threshold[11],[26],[46],[57].

3.4.1. Interdiction Thresholds (IT):

The concept of interdiction thresholds (IT) in the context of TQS, refers to the point at which CT measures are implemented to disrupt or prevent terrorist activities. Setting an IT involves determining the optimal time for intervention and acceptable level of interdiction based on intelligence, risk assessment, and operational capabilities. Establishing an IT allows for timely intervention to minimize attacks' impacts legally and ethically while accounting for operational effectiveness. It also enables risk mitigation through comprehensive intelligence gathering and analysis to understand terrorist intentions, capabilities, and vulnerabilities. This supports effective operational planning and efficient resource allocation to reduce collateral damage and maintain public trust.

Determining an IT sends a strong deterrent message that CT forces actively monitor threats. It can discourage individuals from engaging in terrorism and hinder terrorist networks, planning, and resource access making operations more difficult. Robust intelligence underpinning an IT improves information sharing between agencies and coordination for broader CT efforts. Additionally, IT's flexibility permits adaptation to terrorists' changing tactics and strategies for effective threat countering. In summary, setting an appropriate interdiction threshold is important for legally disrupting terrorism, mitigating risks, and deterring involvement through intelligence support for timely and adaptive operational responses[11],[26],[46],[57].

3.4.2. Discrimination Thresholds (DT):

The concept of discrimination thresholds (DT) within the context of TQS refers to the level at which CT measures differentiate between individuals or groups based on certain criteria for additional scrutiny or targeting. Setting a DT allows security forces to prioritize targeting individuals who meet criteria associated with higher terrorist risks. This allows for more efficient allocation of limited resources to those who cross the threshold. DT also enables risk assessment through evaluation of factors like behavior, travel patterns, associations and other indicators of terrorist involvement to help identify individuals requiring closer attention. However, DT must strike a balance between security needs and civil liberties protections. If set too low or use discriminatory criteria, it could violate rights and erode public trust. Lack of DT may also lead to unhealthy profiling of certain groups based on attributes like race, religion or ethnicity. While DT could inadvertently create intelligence gaps if missing certain individuals, regular evaluation and adjustment of the threshold based on evolving threats and lessons learned can help address this. Overall, establishing an intelligence-based and non-discriminatory DT is crucial to ensure CT operations are both effective in targeting risks, while respecting individual rights and civil liberties[11],[26],[46],[57].

3.4.3. Fairness Thresholds (FT):

The concept of fairness thresholds (FT) within the context of TQS, underscored the level at which CT operations aim to achieve fairness and equity in applying various strategies. Setting an FT helps ensure individuals and groups are treated equally without bias or discrimination. This can help build trust with communities and reduce the risk of alienation or radicalization. Ensuring fairness also fosters cooperation from communities as individuals will be more likely to support law enforcement if they perceive measures are applied fairly. An FT additionally shapes positive public perception and maintains trust in CT efforts. When the public views operations as impartial and just, it enhances confidence in their effectiveness and legitimacy. Complying with an FT prevents discriminatory practices, protecting rights and liberties from legal challenges or human rights violations.

Applying CT measures in a fair manner without prejudice can also minimize potential backlash from affected groups. Unfair policies can lead to resentment and mistrust, undermining overall success. A fairness threshold further encourages inclusive intelligence gathering from diverse sources for a comprehensive understanding of threats. Regular re-evaluation allows operations to remain impartial while adapting to social change. In summary, establishing an FT that upholds principles of equity, non-discrimination and individual rights is important for building trust, cooperation and maintaining effective CT operations[11],[26],[46],[57].

3.5. SD-TQS Discrimination/Unfairness Metrics

It is crucial to note that the specific characteristics and implications of discrimination and unfairness in a TQS can vary depending on the context, policies, and implementation of the system. It is essential to have robust oversight, accountability mechanisms, and safeguards in place to minimize the potential security implications of discrimination and unfairness, and thus, ensure a just and equitable CT environment. By invoking the fundamental principle of social justice: *"equally needy members of a group should share equally the resources available to the group*"[40],[43]. Therefore, by adopting the Resource Allocation Queue Fairness (RAQF) metrics[47]: *"at every cycle of CT operation, that there are n-terrorist cells in the CT environment, all cells (or operatives) deserved optimal targeting, investigation, processing, and interdiction…, any deviation from this standard creates discrimination (positive or negative)*". According to Raz et al[47], accounting for such discriminations and their summary statistics yield a measure of unfairness of the CT strategy deployed.

In the context of TQS, the metrics of discrimination and unfairness in the CT environment can only be inferred on two fundamental performance measures: the number of terrorists interdicted per CT cycle, and the system response time. Hence, the two fundamental TQS resources expected to be allocated fairly (equitable) are the system size (total number of terrorists in the system) and the system waiting time. Let $X(t)$ denote the total warranted system resources per CT cycle, and k, the number of CT strategies deployed per CT cycle. Then, by RAQF principle, the momentary warranted rate $R(t)$ of a terrorist cell per CT cycle can be given by:

$$R(t) = \frac{Total\ warranted\ System\ Resources}{Total\ no\ of\ CT\ Approaches\ deployed} = \frac{X(t)}{\alpha k} \quad (3.1.8)$$

Where α denote the interdiction capacity of the deployed CT strategy(es). Let $\sigma(t)$ denote the momentary granted rate per CT cycle, then the momentary discrimination rate $\delta(t)$ per CT cycle is given by:

$$\delta(t) = \sigma(t) - R(t) = \sigma(t) - \frac{X(t)}{\alpha k} \quad (3.1.9)$$

The momentary discrimination rate, $\delta(t)$ can be viewed as the rate at which a CT strategy discriminates against a terrorist cell per CT cycle. A positive or negative value of $\delta(t)$ indicates that the CT strategy was fair or unfair, and thus, utilizes more or less system resources than the expected threshold value per CT cycle. Therefore, the accumulative discrimination rate, D over the $T = 1,2,\ldots,15$, cycle of CT operations is be given by:

$$D(t) = \int_{t=1}^{T} \delta(t)dt \ ; \ T \leq 15\ years \quad (3.2.0)$$

Similarly, a positive or negative value of $D(t)$ indicates that the deployed CT strategy(es) was fair or unfair, and thus, utilizes more or less system resources than the expected threshold value at the T-cycle of CT operations.

3.5.1. System Discrimination/Unfairness Coefficient:

Let $E[D_j]; i = 1,2,3$ .... denote the expected value of discrimination experienced by a terrorist cell of per CT cycle, given that a new terrorist cell formed meets $n \geq k$ cells in the CT environment (including the ones targeted for interdiction). Let P_n be the steady state probability that there are n-celles in the CT environment. Analogous to RAQF "unfairness" metrics[47], the expected discrimination (unfairness) of the system, given the probability that a new terrorist cell form encountered $n \leq k$ cells in the CT environment is given by:

$$E[D_j] = r_j[D_j P_n] = \begin{cases} r_j D_j \dfrac{(k\rho)^n}{n!} P_0 = r_j D_j \dfrac{[kr]^n}{n!\, a^n} P_0;\ n \leq k \\ r_j D_j \dfrac{\rho^n k^k}{k!} P_0 = r_j D_j \dfrac{k^k r^n}{k!\, a^n} P_0;\ n \geq k \end{cases} ;\rho = \frac{r}{ka};\ k \geq 1\ (3.2.1)$$

Where P_n is defined in equation (3.0.8), and the expectation of the accumulative discrimination over the T^{th}-cycle of CT operations is given by:

$$E[D] = \sum_{j=1}^{T} E[D_j] = \sum_{j=1}^{T} r_j[D_j P_n]\ (3.2.2)$$

Let $E[D^2|k]$ denote the expected value of the square of discrimination of a given CT strategy over the T-cycles of CT operations, given that a new terrorist cell formed meets $n \geq k$ cells in the CT environment. Therefore, the TQS efficiency denoted by the second moment of D (total discrimination) is given by:

$$E[D^2] = \sum_{j=0}^{T} E[D_j^2] = \sum_{j=1}^{T} r_j[D_j^2 P_n]\ (3.2.3)$$

And by Sztrik[54] the overall efficiency or unfairness index of the TQS, denoted by $Var[D]$ can be given by:

$$Var[D] = E[D^2] - [E[D]]^2 = \sum_{j=1}^{T} E[D_j^2] - \left[\sum_{j=1}^{T} E[D_j]\right]^2\ (3.2.4)$$

The validity and reliability of equation (3.2.4) is determined in the confidence interval: $CI = D_n \pm t_{\alpha/2}\sqrt{Var[D]}$; where $\alpha = 0.05\ (5\%)$ level of significance.

3.6. Data Presentation

Considering the relatively scarce and classified nature of high-quality empirical data on terrorism and terrorist organizations, such as their recruitment, fundraising, decision making, and organizational structure, proximate secondary data sources that are also amenable to scientific analysis were sourced from field reports, academic journal and government reports[3],[9],[1],[12],[15]. These includes field reports and intelligence on Boko Haram and ISWAP recruitment/combat cells formation frameworks, as well as terrorism combating capacity (TIC) ratings of key CT strategies, from literature and government reports. The systematic analysis of these dataset helps to shed new light on the behavioural dynamics of contemporary terrorist organizations in a CT environment, as viewed under the analytical lens of an SD-TQS analogy.

Tentatively, field reports and interactions with repented terrorists indicate that a terrorists' cell consists of at least six (6) operatives, while the organization's recruitment target is to established at least ten (10) cells in a given CT environment before a viable terrorist activity began. In addition, an average of 8.9 cells must be recruited per recruitment cycle, if the organization must sustain it strength and resilience characteristics in a given CT environment (mean recruitment rate: $\bar{r_n} = r = 8.9$ cells per CT cycle). On the interdiction capacity or index of the sampled CT strategies, Table 3.0 below summarized the ratings of key mutually reinforcing characteristics of the sampled CT strategies, [3],[9],[10],[12],[15].

Table 3.0: Terrorist Interdiction Capacity of CT Strategies

Mutually Reinforcing CT Characteristics	S	C	S_0	SC	SS_0	CS_0	SCS_0
Intelligence Optimization Capacity (IOC)	0.4	0.5	0.8	0.7	0.9	0.8	1.0
Terrorist Interdiction Capacity (TIC)	0.7	0.6	0.8	0.9	0.8	0.8	1.0
Terrorism Prevention Capacity (TPC)	0.5	0.8	0.6	0.9	0.7	0.8	0.9
Terrorism Detection Capacity (TDC)	0.7	0.4	0.9	0.8	0.9	0.8	0.9
Terrorism Denial Capacity (TDC)	0.8	0.5	0.7	0.9	0.8	0.7	0.9
Terrorism Response Capacity ((TRC)	0.6	0.6	0.7	0.8	0.7	0.7	0.9
Mean Terrorist Interdiction Capacity	**0.62**	**0.57**	**0.75**	**0.83**	**0.8**	**0.77**	**0.93**

For brevity of analysis and representation, let the sampled CT strategies can be define by:

- S: Conventional Sticks or military offensive strategies.
- C: Conventional Carrots (Non-violence conciliatory) strategies.
- S_0: Syndromnized Intelligence optimizing pseudo-terrorist (SIOP) agents.
- SC: Simultaneous deployment of conventional Sticks and Carrots strategies
- SS_0: Simultaneous deployment of Sticks and SIOP agents (intelligence driven Sticks strategies).
- CS_0: Simultaneous deployment of Carrots and SIOP agents (intelligence driven Carrots strategies).
- SCS_0: Simultaneous deployment of Sticks, Carrots and SIOP agents

4. PERFORMANCE MEASURE OF THE SD-TQM:

Taking into consideration the TIC as a measure of CT strategies (servers) interdiction capacity, the performance measure of the SD-TQM, as tabulated on Table 4.0 are analysed under the following performance distributions: (i) the system traffics and utilization factor, (ii) the system size/queue length distribution (iii) the system waiting and response times distribution (iv) the system abandonment distribution (v) the system behaviour/delay distribution, and (vi) System discrimination/unfairness distribution. Below is a summary presentation of the SD-TQS performance under the seven (7) sampled CT strategies.

Table 4.0: Performance Characteristics of SD-TQM

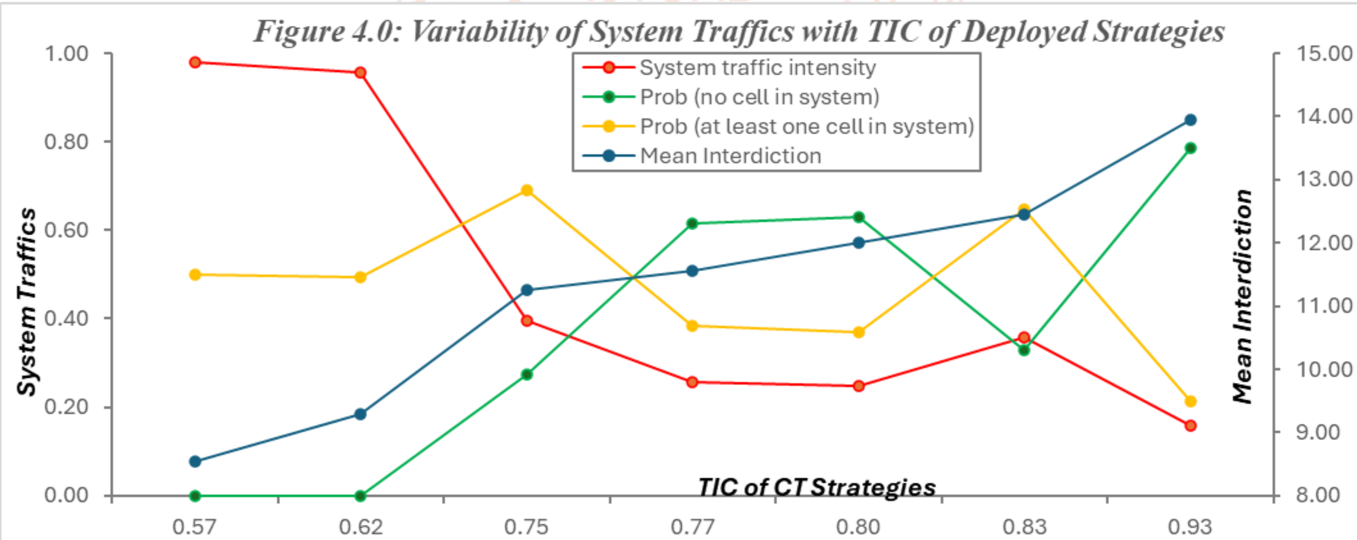
Terror Queueing Performance Measures		S	C	S_0	SC	SS_0	CS_0	SCS_0
A.	Mean Terrorist Recruitment Rate (r)	8.9	8.9	8.9	8.9	8.9	8.9	8.9
	Mean Terrorism Combating Capacity	0.62	0.57	0.75	0.83	0.8	0.77	0.93
	Mean CT Interdiction Rate (α)	9.3	8.55	11.25	12.45	12	11.55	13.95
B.	System traffic intensity, (ρ)	0.9570	0.9809	0.3956	0.3574	0.2472	0.2569	0.1595
	Prob (no terrorist in system) (P_0)	0.0006	0.0004	0.273	0.3284	0.6298	0.6154	0.7873
	Prob (at least one cell in system) (P_1)	0.4938	0.5012	0.6908	0.6465	0.3696	0.3837	0.2126
C.	Total Terrorists cell in system, (L)	4.4276	4.5345	3.1834	2.7662	0.865	0.9166	0.3598
	Total Terrorist cells on Queue (L_q)	4.3721	4.4782	2.9472	2.62092	0.7404	0.7873	0.2642
	Total cells interdicted, $(\varphi = L - L_q)$	0.0555	0.0563	0.2362	0.14528	0.1246	0.1293	0.0956
	Effective System flow rate $(\bar{r} = \varphi\alpha)$	0.5162	0.4814	2.6573	1.8087	1.4952	1.4934	1.3336
D.	Mean waiting time in the System, (ω)	8.5773	9.4194	1.1980	1.5294	0.5785	0.6138	0.2698
	Mean waiting time on queue, (ω_q)	8.4698	9.3025	1.1091	1.4491	0.4952	0.5272	0.1981
	Mean System (Resident) time, (ρ^{-1})	1.0449	1.0195	2.5278	2.7980	4.0453	3.8926	6.2696
E.	Prob (Terrorist Balking),	0.0011	0.0008	0.3352	0.3486	0.9272	0.9532	1.0075
	Prob (Terrorist Reneging),	0.9551	0.9893	0.0549	0.0917	0.0702	0.0528	0.0066
F.	System Response time, $(T = \omega - \omega_q)$	0.1075	0.117	0.0889	0.0803	0.0833	0.0866	0.0717
	Prob (Delayed Interdiction)	0.8908	0.9288	0.1554	0.102	0.1008	0.108	0.0757
	Prob (Forming a new cell) in System	0.1803	0.1766	0.1361	0.1411	0.1325	0.0012	0.0007

4.1. System Traffics/Utilization factor

By system traffics, the analyses underscore the measures of how busy a CT environment is (terrorist flow) under a given CT strategy - that is the rate of utilization of a given CT strategy during a given CT cycles. With an average recruitment rate of 8.9 cells per year, the Figure 4.0 below shows the variability of key parameters of the SD-TQS Traffics distribution with TIC of deployed strategies. The correlation coefficient $(r_i; i = 1,2,...,4)$ analyses of the variability indicate:

(i) A positive correlation between the CT interdiction rate and TIC of deployed Strategies $(r_1 = 0.9329, p < 0.001)$. The CT interdiction rate underscored the rate at which potential terrorist threats are intercepted or disrupted by the CT strategies deployed in a CT environment. It represents the effectiveness of the CT strategies in detecting and mitigating terrorist activities. In the context of SD-TQS, the positive correlation implies that the deployment of TIC enhanced strategies (S_0, SC, SS_0, CS_0, & SCS_0), can lead to an increase interdiction of terrorist cells, and hence, a robust CT environment. The coefficient values of 0.9329, indicates a very strong positive relationship between TIC of deployed Strategies and its interdiction rates.

*(ii)*A negative correlation between the traffic intensity and TIC of deployed Strategies $(r_2 = -0.9486, p < 0.001)$. Traffic intensity in a TQS is a measure of the rate at which new arrivals (events, incidents, or threats) enter the system, relative to the system's capacity to process or service those arrivals. In the context of SD-TQS, the negative correlation implies that the deployment of TIC enhanced strategies, (S_0, SC, SS_0, CS_0, & SCS_0), can lead to a decrease in the intensity or volume of traffic (incoming events, incidents, or threats) entering the CT environment - the rate at which new events or threats enter the CT environment tends to decrease. The coefficient values of -0.9486, indicates a very strong negative relationship between TIC of deployed Strategies and the system traffic intensity.



*(iii)*A positive correlation between the probability of having no terrorist cell in the system, with the TIC of deployed Strategies $(r_3 = 0.9589, p < 0.001)$This probability represents the system's ability to process and clear out all incoming threats or terror-related events effectively, leaving the system temporarily without any active cases or incidents to handle. In the context of SD-TQS, the positive correlation, implies that, with the deployment of TIC enhanced strategies, (S_0, SC, SS_0, CS_0, & SCS_0), the likelihood of the CT environment having no active terrorists or terror-related events would increases – the CT environment is free of active terrorists or terror-related events. The coefficient values of 0.9589, indicates a very strong positive relationship between TIC of deployed Strategies and the probability of having no terrorist cell in the CT environment.

*(iv)*A negative correlation between the probability of having at least one terrorist cell in the system, and the TIC of deployed Strategies $(r_4 = -0.51469, p < 0.001)$. This probability is a measure of the system's occupancy or the likelihood that there is at least one active case, incident, or threat present in the system at any given time. In the context of SD-TQS, the negative correlation implies that, with the deployment of TIC enhanced strategies, (S_0, SC, SS_0, CS_0, & SCS_0), the likelihood of the system containing active terrorists or terror-related events decreases - a reduced likelihood of the CT environment containing active terrorists or terror-related events. The

coefficient values of -0.51469, indicates a very strong negative relationship between TIC of deployed Strategies and the probability of having at least one terrorist cell in the CT environment.

4.1.1. Security Implications of the Variability of the System Traffics with TIC of Deployed Strategies: In an SD-TQS, if the system traffics exhibit the above variabilities with the introduction of CT strategies with enhanced TIC, (S_0, SC, SS_0, CS_0, & SCS_0), the following security implications can be applicable:

A. ***Interdiction Rate Increases with the TIC of Deployed Strategies*****:** This implies that with the deployment of TIC with enhanced strategies, the rate of successfully intercepting or disrupting terrorist activities increases. It suggests that the system becomes more effective in identifying and neutralizing potential threats.

B. ***System Traffic Intensity Decreases with TIC of Deployed Strategies:*** A decrease in traffic intensity with TIC of the deployed strategies, indicates that the system is able to detect and prevent potential terrorist activities, resulting in a reduced number of suspicious or malicious traffic. This can be seen as a positive security implication, as it suggests a more secure environment with fewer potential threats.

C. ***The Probability of having no Terrorist Cell in the System Increases with TIC of Deployed Strategies***: An increase in the probability of having no terrorist cell in the system suggests that the deployment of TIC enhanced strategies has the potential to effectively detect and eliminate terrorist cells. This implies a higher level of security and a reduced risk of terrorist activities within the system.

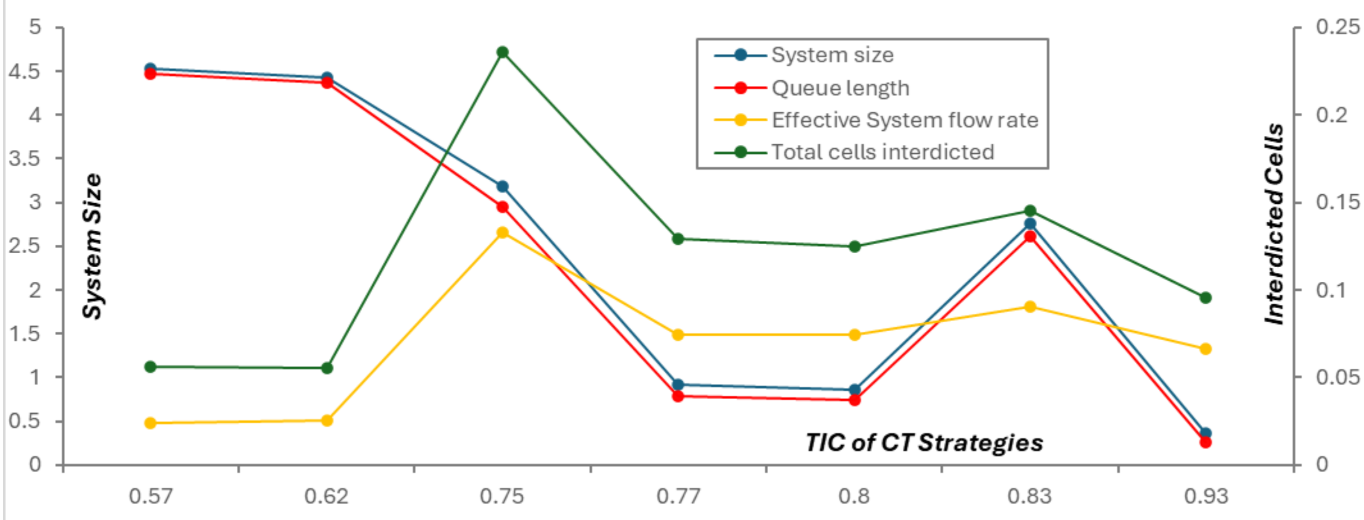
D. ***Probability of having at least one Terrorist Cell in the System Decreases with TIC of Deployed Strategies***: A decrease in the probability of having at least one terrorist cell indicates that the deployment of TIC enhanced strategies has the potential to successfully prevent the formation or operation of terrorist cells within the system. This implies a stronger security posture and a reduced likelihood of terrorist activities taking place.

In summary, the above performance characteristics suggest that the deployment of TIC enhanced strategies has the potential to guarantee positive CT environment, such as increased interdiction rate, decreased traffic intensity, higher probability of having no terrorist cell, and lower probability of having at least one terrorist cell. These characteristics indicate an enhanced ability to detect, prevent, and neutralize potential threats, leading to a more CT environment.

4.2. System Size and Queue Length Distribution

In an SD-TQS, the system size, queue length, and system effective flow rate play crucial roles in understanding its behavior and implications. The difference between the total number of terrorist cells in the system and those on the queue (detected) is often a measure of the actual number of terrorist cells interdicted in a given CT environment over a given CT cycle, and hence, the success rate of type of CT strategy(es) deployed. With an average recruitment rate of 8.9 operatives per CT cycle, Figure 4.1 below shows the variability of key parameters of the system size distribution with TIC of the deployed strategies. The correlation coefficient $(r_i; i = 1,2,...,4)$ analyses of the variability indicate:

Figure 4.1: Variability of System Size with TIC of Deployed Strategies



(i)The system size and the queue length are respectively, negatively correlated with the TIC of deployed Strategies
$(r_1 = -0.9335;\ r_2 = -0.939, p < 0.001)$.

The system size refers to the total number of entities (incoming events, incidents, or threats) that the queueing system can accommodate at any given time. The System size can impact on the CT strategy capacity and its ability to handle incoming entities. While, the queue length represents the number of entities waiting in the queue (detected) before they can be processed or serviced by the system. It indicates the level of congestion or backlog in the system, which can impact on the CT strategy delays probability and terrorist discrimination index. In the context of SD-TQS, the negative correlation implies that, the deployment of TIC enhanced strategies (S_0, SC, SS_0, CS_0, & SCS_0), can lead to the decrease in both the number incoming and waiting entities in the CT environment. The coefficient values of -0.9335, and -0.939, both indicates a very strong negative relationship between TIC of deployed Strategies and the system size and queue length respectively.

(ii)The number of interdicted cells and the system effective flow rate are respectively, positively correlated with TIC of deployed Strategies$(r_3 = 0.3706;\ r_4 = 0.5165, p < 0.001)$. The system effective flow rate measures the rate at which entities are successfully processed or serviced by the system. It represents the overall efficiency or throughput of the system or how quickly entities can be processed by the system. In the context of SD-TQS, the positive correlation, implies that the deployment of TIC enhanced strategies (S_0, SC, SS_0, CS_0, & SCS_0), can increase the rate at which entities are successfully processed or serviced by the CT environment. The coefficient values of 0.3706, indicates a weak positive relationship between TIC of deployed Strategies and the number of interdicted cells, while the coefficient values of 0.5165, indicates a strong positive relationship between TIC of deployed Strategies and the system effective flow rate.

4.2.1. Security Implications of the Variability of System Size/Queue Length with TIC of Deployed Strategies:

In an SD-TQS, if the system size, the queue length, the number of interdicted cells and system effective flow rate exhibit the above variabilities with the deployment of enhanced TIC strategies (S_0, SC, SS_0, CS_0, & SCS_0), the following security implications can be applicable:

(i)Both System Size and Queue Length decrease with the TIC of Deployed Strategies: A decrease in system size and queue length with the deployment of TIC enhanced strategies, suggests that the efficiency of the system in processing and handling potential threats, is becoming enhanced with the deployment of TIC enhanced strategies. This implies that the TIC enhanced strategies have the potential to successfully identify and interdicts terrorist cells, resulting in a smaller system size and shorter queue length. It indicates a more streamlined and responsive security system.

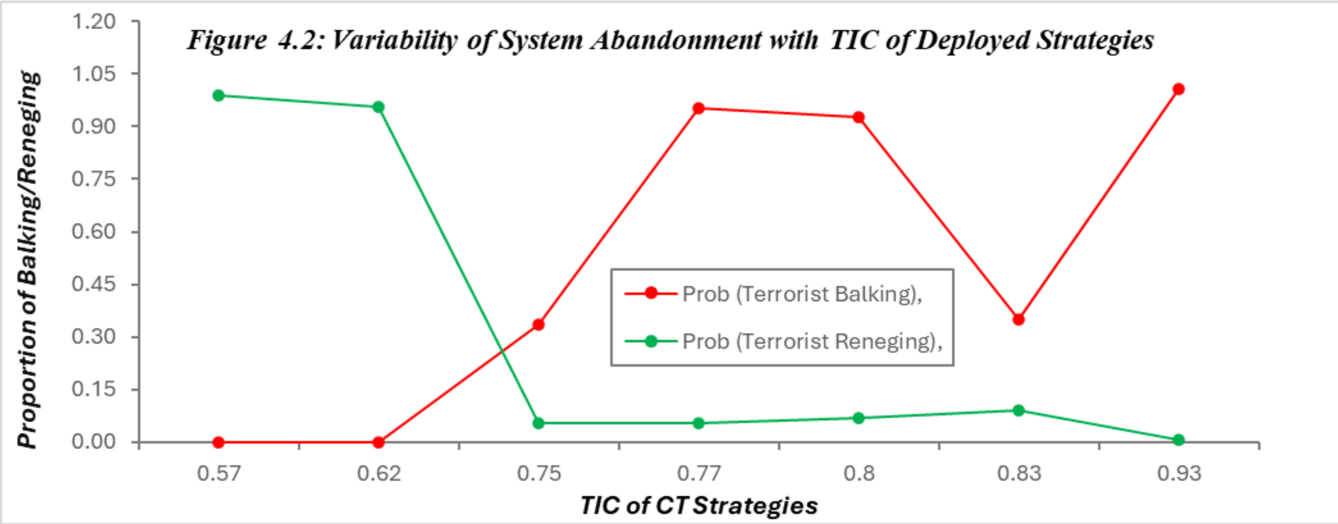
(ii)Both the Number of Terrorist Cells Interdicted and the System Effective Flow Rate Increase with TIC of Deployed Strategies: An increase in the number of interdicted terrorist cells and the system effective flow rate indicates that the TIC enhanced strategies have potentials to effectively detect and neutralize potential terror threats. This implies that the system is becoming more proficient in identifying and stopping terrorist activities, resulting in a higher rate of interdiction and a faster flow of legitimate traffic. It suggests an improved security posture and a more efficient response to potential threats.

In summary, the above performance characteristics suggest that the deployment of TIC enhanced strategies has the potential to guarantee positive CT environment. As the decrease in system size and queue length, along with the increase in the number of terrorist cells interdicted and the system effective flow rate, indicates an enhanced ability to detect, intercept, and neutralize potential threats. These characteristics suggest a more efficient and effective CT strategy, resulting in a reduced risk of terrorist activities and a safer environment.

4.3. System Abandonment Distribution

The TQS abandonment distribution refers to the scenario where by a terrorists (active or inactive) decide to evade detection, or if already detected, evade subsequent targeting for interdiction, due to the severity or intensity and effectiveness of the CT efforts. In CT environment, terrorist abandonment is often driven by a desire to escape the immediate danger or impending apprehension or mitigate potential harm. The decision to abandon the queue can be influenced by various factors, such as the severity of the security threat, the credibility of the warning or information received, personal risk assessment, availability of escape routes - amnesty for voluntary surrendered and repented terrorists, as well as the perceived capability of the CT strategy to protect the individuals.

The overall TQS abandonment distribution measures the ***System Balking probability*** - the probability that a new terrorist will not enter the CT environment (escape detection), given that there are $n \geq k$ detected terrorists in the system, and, the ***Queue Reneging probability*** - the probability that a detected and targeted terrorist will escape interdiction, given that there are $n \geq k$ interdicted terrorists in the system.



With the mean recruitment rate of 8.9 terrorists per CT cycle, Figure 4.2 above shows the variability of key parameters of the system abandonment distribution with TIC of the deployed strategies. The correlation coefficient $(r_i; i = 1,2)$ analyses of the variability indicate that:

(i)The probability that a new terrorist will balked on a busy CT environment (escape detection), is positively correlated with the TIC of deployed Strategies $(r_1 = 0.9121, p < 0.001)$. In a TQS, the term "terrorist balking" refers to a situation in which undetected terrorists decides not to proceed with their intended malicious activity due to the presence of security measures or CT efforts. In other words, terrorists "balk" or abandon their plan when they perceive a high risk of detection or apprehension. In the context of SD-TQS, the positive correlation implies that the deployment of TIC enhanced strategies has the potential to guarantee a higher likelihood of terrorists abandoning their plans and not attempting to carry out a terrorist act. The coefficient values of 0.9121, indicates a very strong positive relationship between TIC of deployed Strategies, and the probability that a terrorist balking from the system.

(ii)While the probability that a detected and targeted terrorist will renege (escape interdiction) on a busy CT environment is negatively correlated with the TIC of deployed Strategies $(r_2 = -0.8943, p < 0.001)$. In a TQS, the term "terrorist reneging" take account of a situation in which a detected and targeted terrorist escaped uninterdicted, and hence, complete his/her terror attacks. This can be as a result of some preferential interdiction policy (e.g., prioritization of leadership decapitation or Sacred Cow syndrome) or intelligence lapse or system failure. In the context of SD-TQS, the negative correlation implies that, the deployment of TIC enhanced strategies, has the potential lead to guarantee a lesser likelihood of a detected and targeted terrorists escaping interdiction. The coefficient values of -0.8943, indicates a very strong negative relationship between TIC of deployed Strategies and the probability that a terrorist reneging from the system.

4.3.1. Security implications of the Variability of System Abandonment with TIC of Deployed Strategies: In an SD-TQS, if the probability of a terrorist balking from the CT environment increases with the deployment TIC enhanced strategies (S_0, SC, SS_0, CS_0, & SCS_0), while terrorist renege probability decreases, the following security implications can be applicable:

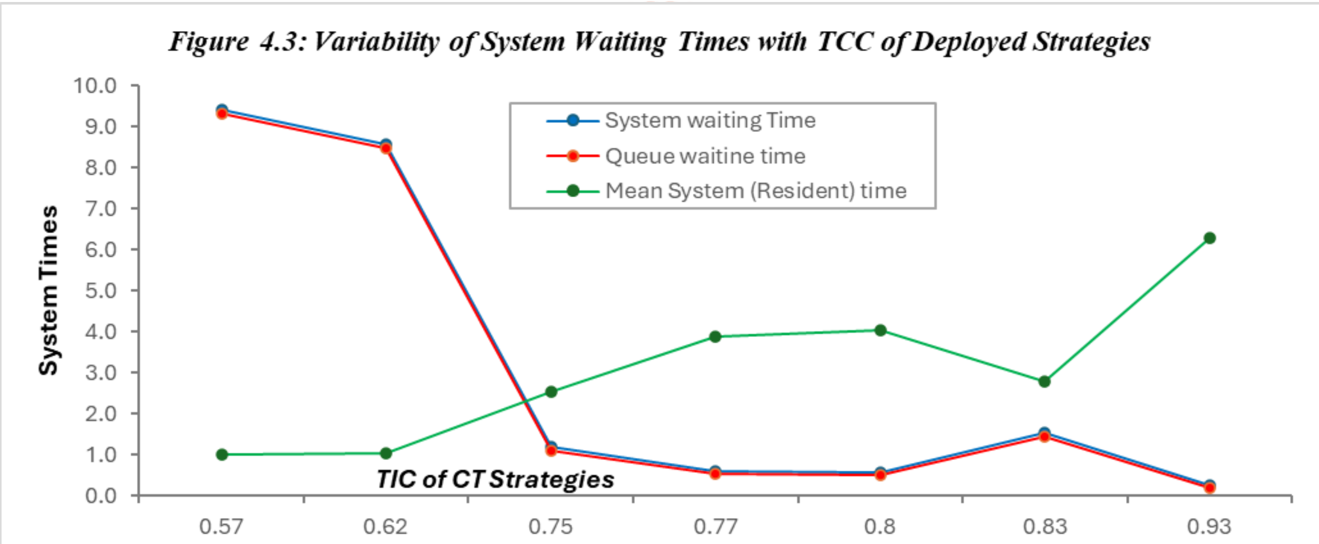
A. ***Probability of a Terrorist Balking Increases with the TIC of Deployed Strategies*:** An increase in the probability of a terrorist balking suggests that the deployment of TIC enhanced strategies can makes it more difficult for terrorists to carry out their intended activities. This could lead to potential terrorists deciding not to proceed with their plans due to the increased risk of detection or interdiction. It implies that the implemented CT strategies are effective in deterring or discouraging terrorist actions.

B. ***Probability of a Terrorist Reneging Decreases with the TIC of Deployed Strategies***: A decrease in the probability of a terrorist reneging indicates that the deployment of TIC enhanced strategies, can reduces the likelihood of detected and targeted terrorists escaping interdiction, and thus complete their plans or withdrawing from the system. This suggests that the implemented CT strategies are effective in detecting and deterring potential threats, making it less likely for detected terrorists to escape interdiction, and thus, complete their intended actions.

In summary, the above performance characteristics suggest that the deployment of TIC enhanced strategies has the potential to guarantee positive security implications**.** As the increased probability of a terrorist balking and the decreased probability of a terrorist reneging indicate that the presence of a CT strategies with an enhance TIC, that guarantee effective and efficient determent of potential terrorists and reduce their willingness to carry out their plans. This implies a stronger security posture and a higher likelihood of detecting and preventing terrorist activities within the system.

4.4. System Waiting/Resident Times Distribution

The system waiting times of TQS is a measure of the total amount of time a terror-related event or incident spends must have spent in CT environment before and after detection, targeting and finally interdiction - from the moment it's detected until it is targeted and interdicted.



With the mean recruitment rate of 8.9 terrorists per CT cycle, Figure 4.3 above shows the variability of key parameters of the system waiting times distribution with TIC of deployed strategies. The correlation coefficient $(r_i; i = 1,2,3)$ analyses of the variability indicate that:

*(i)*Both the system and the queue waiting times are all negatively correlated with the TIC of deployed Strategies $(r_1 = -0.9027;\ r_2 = -0.9024, p < 0.001)$

The system waiting time refers to the total time a terror-related event or incident spends in the CT environment, including both the time spent in the queue and the time spent being processed or interdicted. While the queue waiting time is the time a detected event or incident spends waiting in the queue before procession or interdiction. In the context of SD-TQS, the negative correlation, suggests that the deployment of TIC enhanced strategies, has the capability to limit both the time a terror-related events spent in the CT environment before and during interdiction. That is both the overall time an event remains and the time events spend waiting in the queue before being processed tend to decreases. The coefficient values of -0.9027, and -0.9024 respectively, indicates a very strong negative relationship between TIC of deployed Strategies and the system waiting and queue waiting times respectively.

(ii)The resident time is positively correlated with TIC of deployed Strategies $(r_3 = 0.9628, p < 0.001)$. The resident time, or system sojourn time, is a measure of the total time a terror-related event or incident spends in the CT environment, from the moment it's detected until it is targeted and interdicted. It includes both the time spent waiting in the queue and the time spent being serviced or interdicted. In the context of TQS, the positively correlation suggests that with the deployment TIC enhanced strategies, the average time that terror-related events or incidents spend within the CT environment tends to increase - increase duration of terror-related events or incidents within the CT environment. The coefficient values of 0.9628, indicates a very strong positive relationship between TIC of enhanced strategies and the system resident time. In the complex terrain of CT operations, such positive correlation is expected, considering the additional time required for a detailed screening, investigation, checking, and processing of terror-related events before the final interdiction. This is necessary, not only to enhanced interdiction accuracy, system fairness, and the overall efficiency of the CT strategy but also to uphold sound legal and ethical standards nationally and internationally.

4.4.1. Security Implications of the Variability of System Waiting Times with TIC of Deployed Strategies:

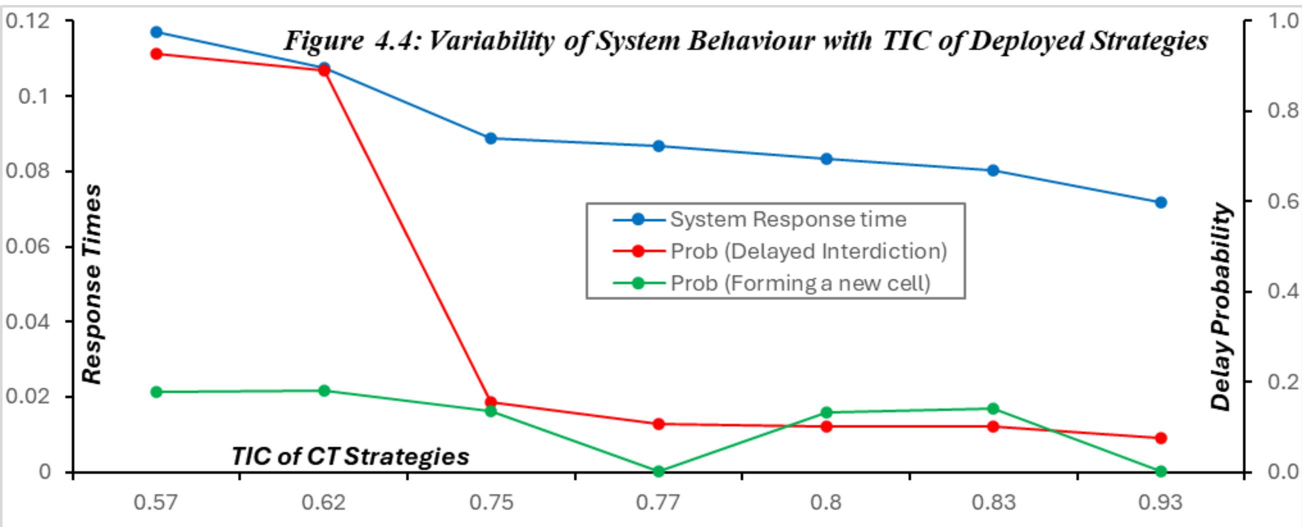
In an SD-TQS, if the both the system and the queue waiting times decreases, while the resident time increases with the deployment of TIC enhanced strategies (S_0, SC, SS_0, CS_0, & SCS_0), the following security implications can be applicable:

A. ***Both the System Waiting and Queue Waiting Times Decrease with TIC of Deployed:*** A decrease in the system waiting and queue waiting times suggests that the deployment of TIC enhanced strategies can improves the efficiency of the system in processing potential threats. This implies that the system is becoming more effective in identifying and addressing terrorist activities, resulting in shorter waiting times for both the system as a whole and the individual queues. It indicates a more streamlined and responsive CT strategies.
B. ***The System Resident Time Increases with the TIC of Deployed CT Strategies:*** An increase in the system resident (sojourn) time indicates that the deployment of TIC enhanced strategies has the potential to successfully detect and address potential terror threats, but with increased processing time for identified threats. This could be due to the necessity for more thorough inspections, screening or investigations of all terror-related events in a privacy protecting and ethically compliance CT strategies. While it may result in longer processing times, it also implies that the system is taking the necessary steps to ensure a comprehensive and effective response to potential threats.

In summary, the above performance characteristics suggest an efficiency and effectiveness security implications as the decrease in waiting times indicates a more efficient processing of potential threats, while the increase in system resident time suggests a more thorough and comprehensive response. These characteristics imply an improved security posture and a more effective handling of potential terrorist activities within the system.

4.5. System Behaviour/Delay Distribution

The overall TQS behaviour and its delay distribution is a measure of terrorist flow-in and flow-out of the system, during the busy and less busy period of CT environment, respectively. These include: (i) The probability that a new terrorist cell will be formed in the CT environment, given that there are $n \leq k$ cells in the system - represent the probability of a terrorist entering a community under the influence of a given CT strategy, (ii) The probability that the interdiction of a newly formed terrorist cell will be delayed, given that there are $n \geq k$ detected cells in the CT environment - represent the efficiency of the CT strategy deployed. (iii) The system response time.



With an average recruitment rate of 8.9 operatives per CT cycle, Figure 4.4 above shows the variability of key parameters of the SD-TQS behavioural distribution with TIC of the deployed strategies. The correlation coefficient $(r_i; i = 1,2,3)$ analyses of the variability indicate that:

(i)Both the probability of forming a new terrorist cell in the CT environment and the system delayed probability are negatively correlated with TIC of deployed Strategies $(r_1 = -0.8459; r_2 = -0.8929, p < 0.001)$. The probability of forming a new terrorist cell refers to the likelihood or chance that a new terrorist organization or group will emerge and establish itself within the operational area or region covered by the CT efforts. The system delay probability refers to the likelihood that the interdiction of a detected terrorist or a terror-related event or incident will experience delays or excessive waiting times within the CT environment. In the context of SD-TQS, the negative correlation suggests that with the deployment of TIC enhanced strategies, the likelihood of a new terrorist cell forming or new group or organizations emerging, as well as the chance of its interdiction being delays decreases, if peradventure one is formed. This implies that with the deployment an enhanced TIC strategy, the chances of experiencing delays or bottleneck or prolonged waiting times in terrorist's interdiction after detection decreases in the CT environment. The coefficient values of -0.9167, and -0.8929, both indicate a very strong negative relationship between TIC of deployed Strategies and the probability of forming a new terrorist cell, as well as with the probability of delayed interdiction, respectively.

(ii)The system response time is negatively correlated with TIC of deployed Strategies $(r_3 = -0.9167, p < 0.001)$. The system response time refers to the time it takes for the CT forces to respond to or take action after a terrorist or terrorist related-events or incident has been detected in the CT environment. In the context of TQS the negative correlation implies that, with the deployment of TIC enhanced strategies, the system's ability to respond to or take action on incoming events or incidents can improves, resulting in shorter response times. The coefficient values of -0.9167, and -0.9167, indicate a very strong negative relationship between TIC of deployed Strategies and the system response time.

4.5.1. Security Implications of the Variability of System Behaviour with TIC of Deployed Strategies:

In an SD-TQS, if the probability of forming a new terrorist cell and the system delayed probability decreases, while the system response time increases with the deployment of TIC enhanced strategies (S_0, SC, SS_0, CS_0, & SCS_0), the following security implications can be applicable:

A. ***Both the probability of forming a new terrorist cell and the system delay probability decrease with the deployment of TIC Enhanced Strategies:*** A decrease in the probability of forming a new terrorist cell suggests that the deployment of TIC enhanced strategies has the potential to effectively detect and prevent the formation of such cells. This implies a stronger security posture and a reduced risk of terrorist activities within the CT environment. Additionally, a decrease in the system delay probability indicates that the TIC enhanced strategies can successfully minimize delays in processing potential terror threats, thus, resulting in a more efficient and responsive CT strategy.

B. ***The system response time decreases with the deployment of TIC enhanced strategies:*** A decrease in the system response time suggests that the deployment of TIC enhanced strategies would results in faster processing times for identified threats. This indicates an improvement in the efficiency and effectiveness of the CT system. A shorter response time allows for quicker detection, assessment, and mitigation of potential threats, leading to a more proactive and agile security posture.

In summary, the above performance characteristics suggest positive security implications, as the decrease in the probability of forming a new terrorist cell, the system delay probability, and the system response time all indicate an enhanced ability to detect, prevent, and respond to potential threats. These characteristics suggest a more efficient and effective security system, resulting in a reduced risk of terrorist activities and a safer CT environment.

4.6. System Discrimination/Unfairness Coefficient

By system discrimination/unfairness coefficient, the analysis underscores the potential of a CT strategy to optimize the available CT resources toward maximizing terrorist interdiction, while minimizing response time and queue length within the CT environment. The Tables 4.1 and 4.2 below, present a summary statistic of the analysis of the discrimination and unfairness characteristics of the SD-TQS under the sampled CT strategies.

Table 4.1: System Discrimination/Unfairness with Respect to Terrorist Interdiction

Variables	C $P_n = 0.002$	S $P_n = 0.002$	S_0 $P_n = 0.173$	SC $P_n = 0.18$	SS_0 $P_n = 0.206$	CS_0 $P_n = 0.212$	SCS_0 $P_n = 0.149$
D(t)	-4.7485	-4.1979	0.9472	1.056	1.0057	0.5524	0.8915
$E[D^2] = r_j D_j^2 P_n$	150.911	117.9429	519.4064	671.7044	697.2396	216.4816	396.2841
$[E[D]]^2 = [r_j D_j P_n]^2$	19.3169	15.09711	5751.22	7738.545	9193.051	2937.412	3779.213
Var[D]	**131.5941**	**102.8458**	**-5231.81**	**-7066.84**	**-8495.81**	**-2720.93**	**-3382.929**

With an average recruitment rate of 8.9 operatives per CT cycle, Figure 4.1 above shows the variability of the interdiction dependent discrimination/unfairness characteristics with the deployed CT strategies. The correlation coefficient $(r_i; i = 1,2,3)$ analyses of the variability indicate that: both the accumulative discrimination, $D(t)$ and the general system Discrimination coefficients $E[D^2]$ are positively correlated with the TIC of deployed Strategies $(r_1 = 0.8705; r_2 = 0.4839, p < 0.001)$. While the overall system unfairness coefficient, $Var[D]$ is negatively correlated with the TIC of the deployed CT strategies, $(r_3 = -0.5492, p < 0.001)$.

The accumulative discrimination index measures the interdiction discrimination experienced by terrorists over the entire cycle of CT operations. It takes into account the cumulative effects of interdiction discrimination throughout the duration of the entire queue process - the overall number of terrorists interdiction discriminated from the beginning to the end of CT operations. The system discrimination coefficient on the other hand, evaluates the overall interdiction discrimination within the SD-TQS, assessing the extent to which the system as a whole optimizes terrorist interdiction processes. Hence, providing an indication of fairness or unfairness of the TQS as a whole. By RAQFM[47] principle, the positive correlation of both coefficients indicates that with the deployment of enhanced TIC strategies, the system interdiction exceeded its established IT. The coefficient values of 0.8705, and 0.4839, indicate a very strong, and strong positive relationship between TIC enhancing CT strategies and the accumulative and system discrimination coefficients, respectively.

Similarly, the system unfairness coefficient quantifies the level of unfairness within the SD-TQS, as it takes into account both the system discrimination and other factors that contribute to unfairness, such as queue length, waiting time, and service allocation. Thus, providing a comprehensive measure of the overall unfairness or efficiency of the SD-TQS. In the context of RQFM[47] principle, the negative correlation, implies that the deployment of TIC enhanced strategies, has the potential to optimize effective terrorists' interdiction, resource utilization, waste reduction, and better throughput in handling terror-related events or incidents. The coefficient values of -0.5492, indicate a strong positive relationship between TIC enhanced strategies and the system unfairness coefficients.

Table 4.2: System Discrimination/Unfairness with Respect to System Waiting Time

Variables	C $P_k = 0.002$	S $P_k = 0.002$	S_0 $P_k = 0.173$	SC $P_k = 0.18$	SS_0 $P_k = 0.206$	CS_0 $P_k = 0.212$	SCS_0 $P_k = 0.149$
D(t)	-49.2635	-49.269	1.9635	0.7755	3.696	3.861	3.6795
$E[D^2] = r_j D_j^2 P_n$	5.4980	5.4992	0.7555	0.1226	3.1875	3.5798	2.2850
$[E[D]]^2 = [r_j D_j P_n]^2$	0.0979	0.0979	1.1632	0.1964	5.844	6.4737	3.0302
Var[D]	**5.4001**	**5.4013**	**-0.4077**	**-0.0738**	**-2.6565**	**-2.8939**	**-0.7452**

With an average recruitment rate of 8.9 operatives per CT cycle, Table 4.2 above shows the variability of waiting time dependent discrimination/unfairness characteristics under the sampled CT strategies. The correlation coefficient $(r_i; i = 1,2,3)$ analyses of the variability indicate that: while the accumulative discrimination, $D(t)$ is positively correlated with the TIC of deployed Strategies $(r_1 = 0.8883, p < 0.001)$, both the system discrimination $E[D^2]$ and the overall system unfairness $Var[D]$ coefficient are negatively correlated with the TIC of the deployed CT strategies, $(r_2 = -0.5808; r_3 = -0.8531, p < 0.001)$.

Under the waiting time threshold, the system discrimination/unfairness coefficients measure the discrimination with respect to the system waiting or response times over the entire cycles of CT operations. It takes into account the cumulative effects of waiting or response time discrimination throughout the duration of the entire queue process. Hence, providing an indication of fairness or unfairness of the SD-TQS as a whole, in terms of time management. By RAQFM[47] principle, the positive correlation of accumulative discrimination with TIC of deployed CT strategies, indicates that the deployment of TIC enhanced strategies, has the potentials to enhance the system waiting/response times above the system threshold value. While the negative correlation of the system discrimination and unfairness coefficients, indicate that, though the deployment of TIC enhancing CT strategies may lack in system waiting time management, however, its response time management is fairer than otherwise. The coefficient values of -0.5808, and -0.8531, indicate a strong, and very strong negative relationship between TIC enhancing strategies and the system discrimination and unfairness coefficients, respectively.

4.6.1. Time-Dependent Variability of System Discrimination Coefficient:

Analysing the time dependent discrimination of the SD-TQS, Figure 4.5(a) below shows that, the system accumulative interdiction discrimination tends to decreases linearly over time under the individual Sticks and Carrots CT strategies *(see red & blue curves).* While the accumulative interdiction discrimination of their combined or TIC enhanced variants tends to increases linearly over time *(see green, black, yellow and purple curves*. In the context of RAQFM principle, the linear decrease of the accumulative discrimination index, indicates that, though the Sticks and Carrots CT strategies may be necessary to impede the numerical strength of a given terrorist organization in the short term, however, in the long term, the individual deployment of these strategies (in isolation of each other) may not be sufficient to sustain maximum terrorist interdiction in the CT environment. Therefore, their combination or deployment of TIC enhanced variants, is necessary and sufficient to guarantee maximum acceleration of terrorist interdiction in the CT environment than the individual Sticks and Carrots strategies.

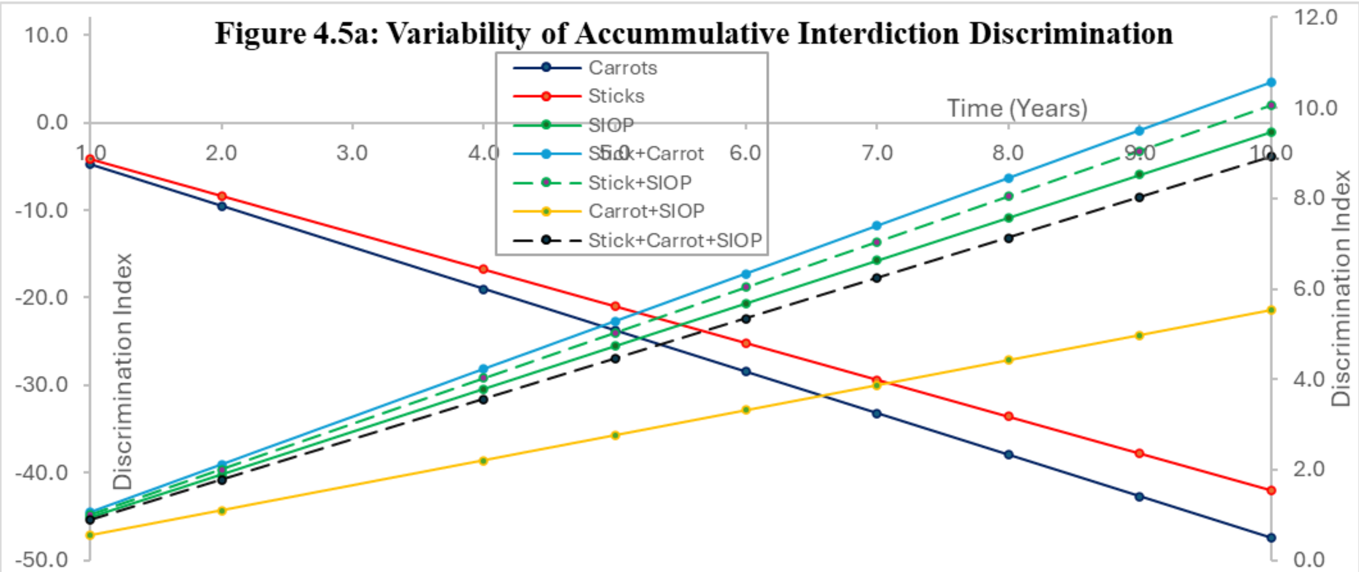


Figure 4.5a: Variability of Accummulative Interdiction Discrimination

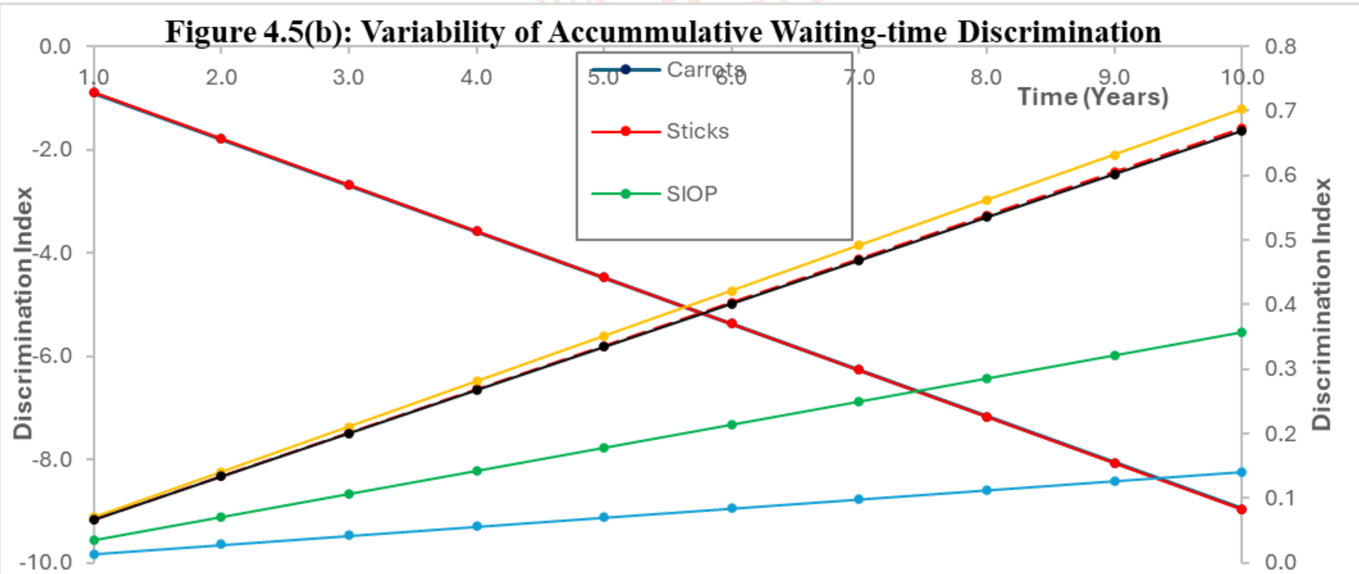
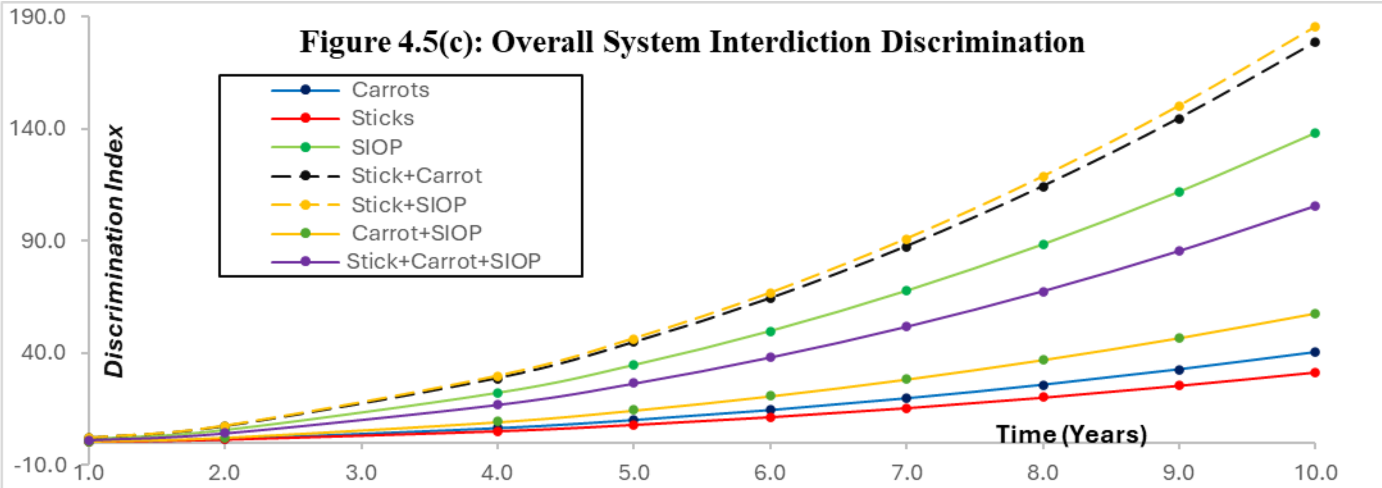


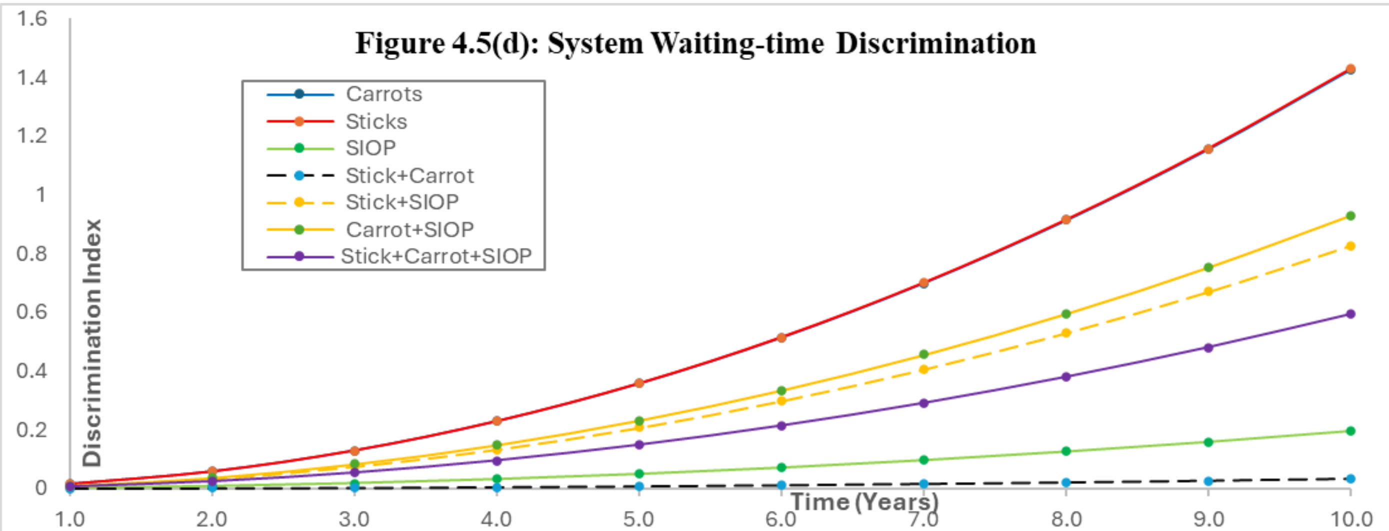
Figure 4.5(b): Variability of Accummulative Waiting-time Discrimination

Similarly, on the waiting time discrimination of the SD-TQS, Figure 4.5(b) above shows that, the accumulative waiting-time discrimination tends to decreases linearly over time under the individual Sticks and Carrots CT strategies *(see red & blue curves)*. While their combined or enhanced TIC variants tends to increases linearly over time *(see green, black, yellow and purple curves)*. In the context of RAQFM[47] principle the linear decrease of the accumulative discrimination over time, indicate that, though the Sticks and Carrots CT strategies may not individually be sufficient to sustain optimal terrorist interdiction for a longer time, however, their individual deployment may be sufficient to minimize the system waiting and response times, and hence long queue length in the system. Therefore, considering the existing positive correlation between the Sticks and the Carrots CT strategies[56], the combination or simultaneous deployment of both CT strategies can complement each other's efforts, while also serving as a balance and comprehensive CT strategy to optimize terrorist interdiction as well as minimize the system waiting time, and long queue length.

On the overall system discrimination of the SD-TQS, Figure 4.5(c) below shows that, the overall system discrimination with respect to interdiction increases exponentially over time; with the combined or TIC enhanced variants exhibiting higher system discrimination coefficients than otherwise *(see red, blue, green, yellow, black, and purple curves)*. In the context of RAQFM[47] principle, the variation of the exponential increase in the overall system discrimination coefficients over time, indicate that the combination or deployment of TIC enhancing variants (S_0, SC, SS_0, CS_0, & SCS_0), has the potential to guarantee maximum terrorist interdiction in a CT environment than the individual Sticks or Carrots CT strategies *(compare red & blue curves with others).*

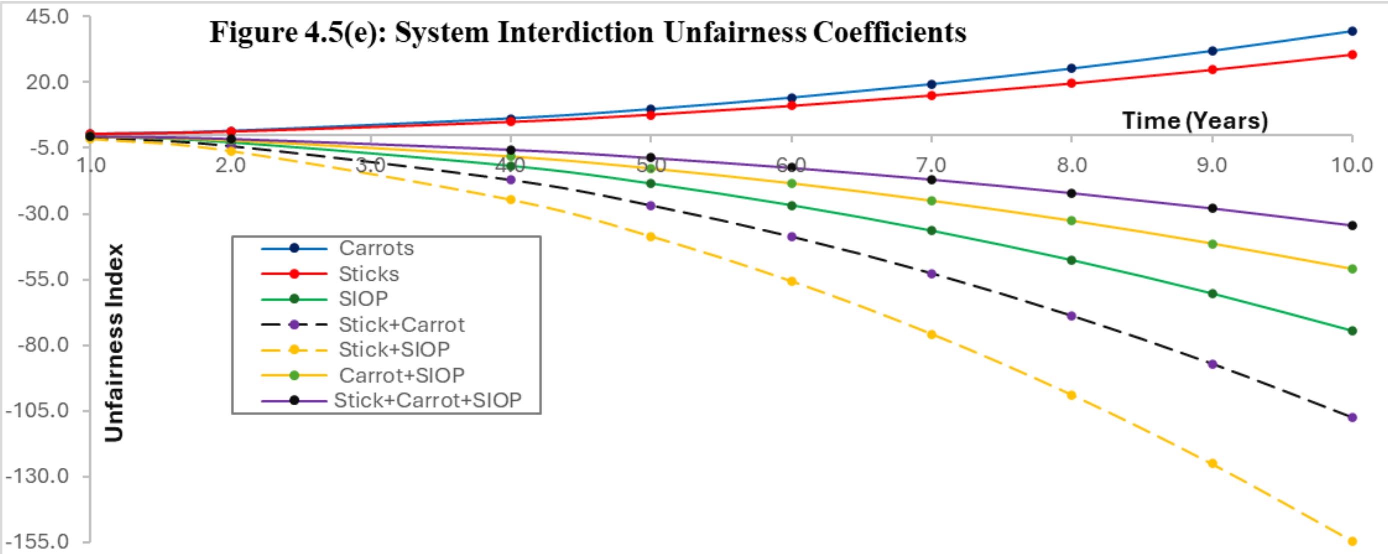


On the overall system waiting-time discrimination coefficient of the SD-TQS, Figure 4.5(d) below shows that, the overall system waiting-time discrimination coefficients tends to increases exponentially over time under the sampled CT strategies *(see red, blue, green, yellow, black, and purple curves)*. However, the individual Sticks *(red curve)* and Carrots *(blue curve)* strategies tends to exhibit higher system discrimination coefficients than their combined or TIC enhanced strategies. In the context of RAQFM[47] principle, the exponential increase of CT strategies indicates that, though the deployment of Sticks and Carrots CT strategies individually may not be sufficient to sustain optimal terrorist interdiction for a long duration, however, their deployment may be necessary to minimize the system waiting and response times, and hence, long queue length in CT environment than their combined or other TIC enhanced strategies.

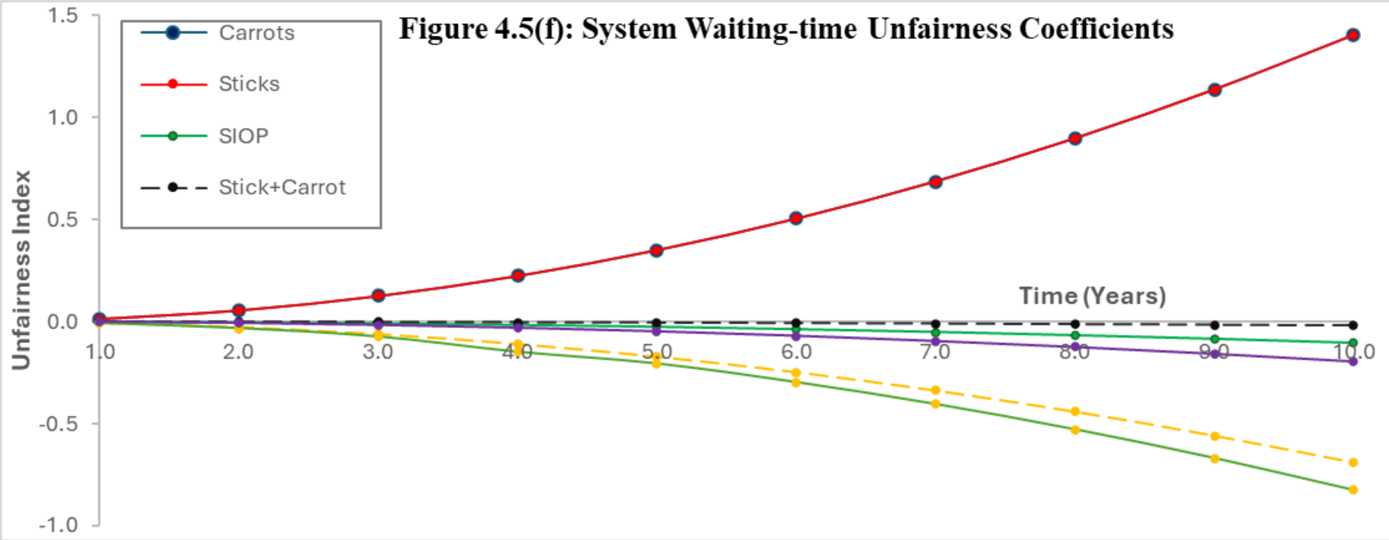


4.6.2 Time-Dependent Variability of System Unfairness Coefficient:

Considering the time dependent unfairness of the SD-TQS, Figure 4.5(e) below shows that, the overall system interdiction unfairness coefficients, tends to increase exponentially over time under the individual Sticks and Carrots CT strategies increases *(see blue and red curves)*, while their combined or TIC enhanced variants tends to decrease exponentially over time *(see green, black, yellow and purple curves)*. In the context of RAQFM[47] principle, the exponential increase of the individual Sticks and Carrots CT strategies with time, indicate that, though the Sticks and Carrots CT strategies may be necessary to temporary impede terrorist numerical strength as well as minimize the system waiting time and, thus, queue length, however, in the long term, the individual deployment of these strategies (in isolation of each other) may not be sufficient to minimize the overall system unfairness coefficient. But their combination or simultaneous deployment with intelligence enhanced variants (SIOP) may culminate in enhanced TIC strategies (SC, SS_0, CS_0, & SCS_0), necessary and sufficient to optimize the overall fairness or efficiency of the system. Therefore, the deployment of TIC enhanced strategies, has the potential to accelerate maximum interdiction, minimized the overall system unfairness, and hence, guarantee efficient system performance for a peaceful and secured CT environment.



Similarly, Figure 4.5(f) below shows that, the overall system waiting-time unfairness coefficients tends to increase exponentially over time under the individual Sticks and Carrots CT strategies *(see red and blue curves)*, while their combined or TIC enhanced variants tends decreases exponentially over time *(see green, yellow, black, and purple curves)*. In the context of RAQFM[47] principle, the exponential increase of individual Sticks and Carrots CT strategies summarily indicate that, though the two strategies may be necessary to impede terrorist numerical strength as well as minimize the system waiting time, and thus, queue length in the short term, in the long term, the individual deployment of these strategies (in isolation of each other) may not be sufficient to minimize the overall system unfairness coefficient. However, their combination or simultaneous deployment with an intelligence enhancing variants (SIOP) may culminate in enhanced TIC strategies (SC, SS_0, CS_0, & SCS_0), necessary and sufficient to minimized the overall unfairness. Therefore, the deployment of enhanced TIC strategies, specifically, combining the Stick and SIOP agents (SS_0), or combined Carrots and SIOP agents (CS_0), has the potential to optimized terrorist interdiction, minimized the overall system unfairness with respect to the waiting, and hence, guarantee efficient system performance, for a peaceful and secured CT environment.



4.6.2. Security Implications of the Variability of Interdiction Discrimination/Unfairness with TIC of Deployed Strategies:

In an SD-TQS, if both the accumulative and the overall system interdiction discriminations index are positively correlated with the deployment of enhanced TIC strategies, while the system interdiction unfairness coefficient is negatively correlated with the deployment of enhanced TIC strategies, the following security implications can be inferred:

A. ***Accumulation Interdiction Discrimination is Positively Correlated with TIC of Deployed Strategies:*** Accumulative interdiction discrimination index, measures the overall discriminatory power of the TQS in identifying and interdicting potential terror-related threats, events or incidents. A higher accumulative discrimination index indicates a higher ability of the TQS to differentiate between potential threats and non-threats at each stage of the queue processes. By RAQFM[47] principle, a positive correlation of the accumulative interdiction discrimination, implies that the deployment of enhanced TIC strategies can enhance the s TQS's ability to discriminate between potential threats and non-threats, leading to a higher accumulative discrimination index. This can result in improved security by effectively identifying and intercepting potential threats.

B. System Interdiction Discrimination Coefficient is Positively Correlated with TIC of Deployed Strategies: The system interdiction discrimination coefficient measures the overall discriminatory power of the TQS at the beginning to the end of the Queueing process. A higher system interdiction discrimination coefficient indicates a higher ability to discriminate between potential threats and non-threats at each stage of the queueing processes. By RAQFM[47] principle, a positive correlation of the system interdiction discrimination coefficient, implies that the deployment of enhanced TIC strategies can enhance the TQS's overall ability to discriminate between potential threats and non-threats, hence, leading to a higher system interdiction discrimination coefficient. This can improve security by effectively identifying and intercepting potential threats at multiple stages of the Queueing process.

C. ***System Interdiction Unfairness Coefficient is Negatively Correlated with TIC of Deployed Strategies***: The system interdiction unfairness coefficient measures the fairness of the TQS in interdicting potential terror-related threats or events or incidents during the Queueing process. A lower system interdiction unfairness coefficient indicates a more equitable treatment of terror-related threats or events or incidents. By RAQFM[47] principle, a negative correlation of the system interdiction unfairness coefficient, implies that the deployment of enhanced TIC strategies can potentially lead to a lower system interdiction unfairness coefficient. This is because deploying enhanced TIC strategies allows for a more targeted and efficient screening process, reducing the need for expensive and time-consuming checks on terror-related threats or events or incidents who may pose a lower risk.

In summary, the above interdiction discrimination/unfairness characteristics suggest positive security implications, as both increase in accumulative and the general system interdiction discrimination, as well as the decrease in the overall system interdiction unfairness coefficient, cumulatively indicate a more equitable treatment of terror-related threats or events or incidents, and improved security by focusing resources on higher-risk threats, or events or incidents. Hence, preventing bias and potential violations of civil liberties, promotes a more inclusive and equitable CT environment, fostering trust and cooperation among different segments of the population.

4.6.3. **Security Implications of the Variability of Waiting-time Discrimination/Unfairness with TIC of Deployed Strategies**: In an SD-TQS, if both the accumulative waiting-time discriminations index is positively correlated with the deployment of enhanced TIC strategies, while the overall system waiting-time discrimination and the system waiting-time unfairness coefficients are negatively correlated with the deployment of enhanced TIC strategies, the following security implications can be inferred:

1. ***Accumulation Waiting-time Discrimination is Positively Correlated with TIC of Deployed Strategies:*** The accumulative waiting-time discrimination index refers to the measure of waiting-time discrimination experienced by potential terror-related threats or events or incidents in the TQS based on their characteristics, such as race, religion, political, or ethnicity. By RAQFM[47] principle, where security screening is conducted, the positive correlation of the accumulative waiting discrimination index can have several security implications:

A. ***Increased Targeting Time***: A higher accumulative waiting-time discrimination index suggests that certain terror-related threats or events or incidents are being disproportionately targeted for security screening. This can lead to a concentration of resources on specific profiles, potentially overlooking other potential threats that do not fit the targeted profiles.

B. ***Perception of Bias:*** A positive correlation of accumulative waiting discrimination index can create a perception of bias and unfair treatment among individuals who are consistently subjected to heightened security scrutiny. This perception can erode trust in the security system, leading to increased tensions between different communities.

C. ***Missed Potential Terror-related Threats:*** If the focus of CT strategies is primarily on specific profiles, it may result in missed potential terror-related threats from individuals or groups who do not fit the targeted profiles. Terrorists can adapt and exploit gaps in security measures by using individuals who are less likely to be subjected to intense scrutiny.

2. ***System Waiting-time Discrimination Coefficient is Negatively Correlated with TIC of Deployed Strategies:*** The system waiting-time discrimination coefficient measures the overall level of waiting discrimination within the TQS. By RAQFM[47] principle, a negative correlation between the system waiting-time discrimination coefficient and the deployment of enhanced TIC strategies can have the following security implications:

A. ***Enhanced Fairness:*** A decrease in the system waiting discrimination coefficient indicates a reduction in overall waiting-time discrimination within the TQS. This can lead to a fairer distribution of security screening measures, ensuring that terror-related threats or events or incidents are not unfairly targeted based on their characteristics.

B. ***Improved Perception of Security:*** When the system waiting-time discrimination coefficient decreases, it can contribute to a perception of fairness and equal treatment among all terror-related threats or events or incidents. This can enhance public trust in the security system and promote cooperation and support from the community in identifying potential threats.

C. ***Comprehensive Threat Assessment:*** By reducing waiting-time unfairness, CT measures can be more inclusive and comprehensive in assessing potential threats. This can help identify terror-related threats or events or incidents that may not fit traditional profiles, but still pose a risk, thereby enhancing the effectiveness of counterterrorism efforts.

3. ***System Waiting-time Unfairness Coefficient is Negatively Correlated with TIC of Deployed Strategies:*** The system waiting-time unfairness coefficient measures the level of waiting-time unfairness within TQS. By RAQFM[47] principle, a negative correlation of the system waiting-time unfairness coefficient with the deployment of enhanced TIC strategies can have the following security implications:

A. ***Enhanced Public Perception:*** A decrease in the system waiting-time unfairness coefficient indicates a reduction in overall waiting-time unfairness within the CT environment. This can contribute to a positive public perception of the CT strategies, fostering trust and cooperation between the public and CT agencies.

B. ***Mitigation of Tensions:*** By reducing waiting-time unfairness, the CT system can help mitigate tensions between different communities that may feel disproportionately targeted or discriminated against. This can contribute to a more harmonious social environment and reduce the potential for radicalization or alienation.

C. ***Strengthened Security Partnerships***: When the system waiting-time unfairness coefficient decreases, it can encourage communities to actively participate in CT efforts, such as reporting suspicious activities or individuals. This collaboration can enhance the overall CT posture by increasing the availability of information and intelligence.

In the overall, the above waiting-time discrimination/unfairness characteristics suggest positive security implications, as increase in accumulative waiting-time discrimination, and the decrease in both the overall system waiting-time discrimination and unfairness coefficient, cumulatively indicate an equitable treatment of terror-related threats or events or incidents, and improved security by focusing resources on high-risk threats, or events or incidents. Hence, preventing bias and potential violations of civil liberties, while promotes a more inclusive and equitable CT environment, fostering trust and cooperation among different segments of the population.

4.7. SUMMARY OF RESULTS OF THE ANALYSES

In summary, the analysis of the performance measures of the SD-TQS under the sampled CT strategies, shows that the deployment of TIC enhanced strategies, (S_0, SC, SS_0, CS_0, & SCS_0), has greater utility and potentials to optimize CT operations through advancing synergistic effects, integrated intelligence capacity, and interdiction accuracy within the CT environment. Such CT strategies are likely to achieve a higher terrorist interdiction rate, rapid response to emerging threats and improve detection capability. With improved detection capabilities, there would be fewer terror-related threats or events or incidents entering or remaining within the CT environment. Hence decreasing the probability of terrorist cells formation or existing in an undetected manner. Enhanced interdiction accuracy also allows for reduced delays in identifying and intercepting terrorist cells. It helps ensure thoroughness in due process and protection of citizens' fundamental rights and liberties. A lower chance of terrorist cell formation and higher likelihood of disrupting imminent terrorist incursions can be expected compared to the alternatives lacking robust intelligence integration. Additionally, deployment of enhanced TIC strategies helps to promotes positive discrimination in interdicting genuine threats, while limiting unfair treatment. This can lead to wiser allocation and matching of CT resources according to actual risks and intelligence indicators. Overall, an intelligence-driven CT strategies with optimized interdiction capabilities appears best positioned to achieve CT objectives while upholding legal and ethical standards nationally and internationally.

Table 4.3: Comparison of SD-TQS Performance Characteristics

SD-TQS Performance	C (%)	S (%)	S_0(%)	SC (%)	SS_0(%)	CS_0(%)	SCS_0(%)
Terrorist Interdiction	57.00	62.00	75.00	77.00	80.00	83.00	93.00
System Traffic/Utilization	63.25	67.84	79.7	80.99	83.8	87.17	95.69
System Size/Queue Length	59.07	66.28	87.06	65.59	69.74	94.05	85.21
System Abandonment	59.13	63.61	72.46	77.93	80.69	80.24	92.95
System Waiting Times	57.93	61.16	74.14	74.08	78.4	81.09	88.92
System Behaviour/Delay	61.88	66.4	74.07	74.88	78.47	81.39	89.91
System Discrimination/Unfairness	35.25	48.42	60.85	82.54	95.02	94.11	89.98
Mean System Performance	**56.22**	**62.24**	**74.75**	**76.14**	**80.87**	**85.86**	**90.81**

In the overall, by SD-TQS performance measures, Table 4.1 above shows the performance ratings of the systems' performances.

A. With respect to Terrorist Interdiction capacity, the Carrots strategy can be rated 57% efficient; Sticks strategy can be rated 62% efficient; SIOP agents can be rated 75% efficient; combined Stick and Carrot strategy can be rated 77% efficient; combined Stick and SIOP agents can be rated 80% efficient; combine Carrot and SIOP agents can be rated 83% efficient; and combine Stick, Carrot and SIOP agents can be rated 93% efficient.

B. With respect to the System Traffics management, the Carrots strategy can be rated 63.25% efficient; Sticks strategy can be rated 67.84% efficient; SIOP agents can be rated 79.7% efficient; combined Stick and Carrot strategy can be rated 80.99% efficient; combined Stick and SIOP agents can be rated 83.8% efficient;

combine Carrot and SIOP agents can be rated 87.17% efficient; and combine Stick, Carrot and SIOP agents can be rated 95.69% efficient.

C. With respect to the System Size management, the Carrots strategy can be rated 59.07% efficient; Sticks strategy can be rated 66.28% efficient; SIOP agents can be rated 87.06% efficient; combined Stick and Carrot strategy can be rated 65.59% efficient; combined Stick and SIOP agents can be rated 69.74% efficient; combine Carrot and SIOP agents can be rated 94.05% efficient; and combine Stick, Carrot and SIOP agents can be rated 85.21% efficient.

D. With respect to System Abandonment management, the Carrots strategy can be rated 59.13% efficient; Sticks strategy can be rated 63.61% efficient; SIOP agents can be rated 72.46% efficient; combined Stick and Carrot strategy can be rated 77.93% efficient; combined Stick and SIOP agents can be rated 80.69% efficient; combine Carrot and SIOP agents can be rated 80.24% efficient; and combine Stick, Carrot and SIOP agents can be rated 92.95% efficient.

E. With respect to System waiting-times management, the Carrots strategy can be rated 57.93% efficient; Sticks strategy can be rated 61.16% efficient; SIOP agents can be rated 74.14% efficient; combined Stick and Carrot strategy can be rated 74.08% efficient; combined Stick and SIOP agents can be rated 78.4% efficient; combine Carrot and SIOP agents can be rated 81.09% efficient; and combine Stick, Carrot and SIOP agents can be rated 88.92% efficient.

F. With respect to System Behavioural management, the Carrots strategy can be rated 61.88%) efficient; Sticks strategy can be rated 66.4% efficient; SIOP agents can be rated 74.07% efficient; combined Stick and Carrot strategy can be rated 74.88% efficient; combined Stick and SIOP agents can be rated 78.47% efficient; combine Carrot and SIOP agents can be rated 81.39% efficient; and combine Stick, Carrot and SIOP agents can be rated 89.91% efficient.

G. With respect to System Discrimination/Unfairness management, the Carrots strategy can be rated 35.25% efficient; Sticks strategy can be rated 48.42% efficient; SIOP agents can be rated 60.85% efficient; combined Stick and Carrot strategy can be rated 82.54% efficient; combined Stick and SIOP agents can be rated 95.02% efficient; combine Carrot and SIOP agents can be rated 94.11% efficient; and combine Stick, Carrot and SIOP agents can be rated 89.98% efficient.

H. With respect to General system performance management, the Carrots strategy can be rated 56.22% efficient; Sticks strategy can be rated 62.24% efficient; SIOP agents can be rated 74.75% efficient; combined Stick and Carrot strategy can be rated 76.14% efficient; combined Stick and SIOP agents can be rated 80.87% efficient; combine Carrot and SIOP agents can be rated 85.86% efficient; and combine Stick, Carrot and SIOP agents can be rated 90.81% efficient.

5. RECOMMENDATIONS

Considering the above arrays of security implication that may arose from the performance measures of the SD-TQS, to optimize the SD-TQM for effective and efficient CT operations the study strongly recommends: The maximization of terrorist interdiction rate through robust intelligence and proactive TIC enhanced strategies. The deployment of TIC enhancing CT strategies would help to harness optimal interdiction discrimination, by accurately and efficiently differentiating terror-related threats from non-terror-related threats. Thus, giving high priority to potential terror-related threats, or events, or incidents than otherwise. The system efficiency and resource utilization need to be optimized, while minimizing waste. Timely intelligence integration and information sharing between CT stakeholders is highly recommended. The unfairness coefficient should be minimized to avoid bias and unfair treatment of terror-related threats, or events or incidents in the CT environment. False positives and negatives factors also need minimizing to avoid wrongly identifying individuals with non-terror related threats. Th system processing time and queue length should be minimized to streamline operations and reduce public inconvenience and also restored public trust and confidences.

In view of the strong positive correlation between the Stick and Carrot CT strategies[56], and the above arrays of security implications, the study strongly recommend the combination or simultaneous deployment of Stick and Carrot CT strategies, as well as their enhanced TIC variants, for a balanced, coordinated and enhanced CT strategy. It suggests combining the Sticks CT strategy - focused on law enforcement with the Carrots CT option - emphasizing conciliation initiatives. Trust, collaboration and information sharing among CT agencies, communities and stakeholders is critical to a well-coordinated CT environment. Coordinated and enhanced intelligence-driven CT operations are also highlighted, with specialized intelligence-optimizing pseudo-terrorist (SIOP) agents playing a key role in gathering tactical insights, infiltrating networks and disrupting activities to optimize CT strategy and decision-making. Measuring and optimizing these various factors and deploying a balanced, intelligence-led, collaborative whole-of-society strategy can help maximize effectiveness and efficiency of CT operations.

CONCLUSION

The research study on appraising the Nigerian CT strategies using a state-dependent terror queueing model (SD-TQM) provides valuable insights into optimizing CT efforts through this mathematical lens. The study examines key performance measures of key CT strategies, with respect to maximizing terrorist interdiction rate, discrimination rate, system efficiency and intelligence integration. Maximizing these parameters, ensures successful identification and interception of terror-related threats, accurate differentiation of terror-related threats from non-terror related threats, and optimizing CT resources deployed, as well as proactive intelligence-driven actions. The research also emphasizes minimizing factors like system unfairness, false positives/negatives, processing time and queue length. Doing so reduces biases, errors in identification, delays and congestion in the system. The paper underscores combining CT strategies, especially the positive correlation between aggressive law enforcement and interventionist/conciliatory initiatives. Simultaneously deploying correlated strategies including intelligence-driven variants leads to a balanced, coordinated and intelligence-enhanced CT strategy as well as maximizing effectiveness the CT strategies.

The study argues against over dependent solely on the coercive CT strategies, and emphasizes credible intelligence guiding operations. It recommends leveraging specialized pseudo-terrorist agents for enhanced intelligence and conciliatory oversight while respecting privacy through robust safeguards, strict protection policies and adherence to legal/ethical standards. Overall, the research provides a comprehensive assessment through the queuing model lens, contributing to CT literature, while offering insights on optimization, maintenance of trust, confidence and upholding legal and ethical standards in CT operations. It underscores continual evaluation, adaptation and developing efficient, and adaptive CT strategies to combat terrorism.

REFERENCES

[1] Aaron C. and Kristian S. G., (2011): "The Developmental Dynamics of Terrorist Organizations". *Santa Fe Institute, Santa Fe, NM 87501, USA and Centre for the Study of Civil War, Oslo, Norway.*

[2] Agnieszka Joanna Janicka (2020): 2-class Terror Queue model: Analysis and optimal Assignment of agents. *Student thesis: Eindhoven University of Technology research portal https://research.tue.nl/files/172591869/BEP_report_Janicka.pdf.*

[3] Alex. P. Schmid (2021): Handbook of Terrorism Prevention and Preparedness. *International Centre for Counter-Terrorism – ICCT Press Publication, First published: July 2021 DOI: 10.19165/2020.6.01 ISSN: 2468-0486 ISBN: 9789090339771, https://www.icct.nl/handbook-terrorism-prevention-and-preparedness.*

[4] A.M. Lee, (1968): Applied queuing theory, *MacMillan, London, 1968.*

[5] Andrea Seidl, Edward H. Kaplan, Jonathan P. Caulkins, Stefan Wrzaczek, Gustav Feichtinger (2015): Optimal Control of a Terror Queue. *Operations Research and Control Systems Institute of Statistics and Mathematical Methods in Economics Vienna University of Technology, (Research Report 2015-12) September, 2015. Pp 1-22.*

[6] Asal, Victor, Brian J. Phillips, R. Karl Rethemeyer, Corina Simonelli, and Joseph K. Young (2018): Carrots, Sticks, and Insurgent Targeting of Civilians. *Journal of Conflict Resolution, August (2018). http://journals.sagepub.com/doi/abs/10.1177/0022002718789748*.

[7] Baskett, F., Chandy, K. M., Muntz, R. R., & Palacios, F. G. (1975): Open, closed, and mixed networks of queues with different classes of customers. *Journal of the ACM*, 22(2), 248-*260.*

[8] Bronwyn Reid (2020): The Problem with the Carrot and the Stick. *https://www.linkedin.com/pulse/problem-carrot-stick-bronwyn-reid.*

[9] Building Resilience Against Terrorism: Canada's Counter-terrorism Strategy *https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/rslnc-gnst-trrrsm/index-en.aspx.*

[10] Butler, L.B. (2011): Hezbollah: The Dynamics of Recruitment. *US Marine Corps, School of Advanced Military Studies. US Army Command and General Staff College, Fort Leavenworth, Kansas AY 2011-01.*

[11] Commission Act of 2007. *https://www.congress.gov/110/plaws/publ53/PLAW110publ53.htm*

[12] Counter-Terrorism Module 2 Key Issues: Drivers of Violent Extremism. *https://www.unodc.org/e4j/en/terrorism/module-2/key-issues/drivers-of-violent-extremism.html.*

[13] Okoroafor, (2015): 'Boko Haram is Costing Nigeria Much More than Borno's $1 billion', *Ventures (10 September 2015). http://www.venturesafrica.com/boko-haram-is-costing-nigeria-much-more-than-bornos-1-billion>/*

[14] Wang, Y. Li, and X. Zhang (2023): State-dependent Queuing Models for Service Systems. *https://www.mdpi.com/2071-1050/14/21/14104.*

[15] Don Rassler (2021): Commentary: Data, AI, and the Future of U.S. Counterterrorism: Building an Action Plan. *Combating Terrorism Centre at West Point. October 2021, Volume 14, Issue 8. https://ctc.westpoint.edu/commentary-data-ai-and-the-future-of-u-s-counterterrorism-building-an-action-plan/*

[16] Erlang, A. (1909): The theory of probabilities and telephone conversations. *Nyt Tidsskrift for Matematik B 20 (1909), 33–39.*

[17] Kelly and R. J. Williams (1991): Optimal Control of a State-Dependent Queuing System with Applications to Traffic Signal Control. *Journal of Advances in Applied Probability in the year 1991.*

[18] Guiora, A. N., (2008): Fundamentals of Counterterrorism. *Aspen Publishers, New York.*

[19] Gutfraind, A. (2009): Mathematical Terrorism: "Understanding Terrorist Organizations with a Dynamic Model." A PhD dissertation. *Studies in Conflict & Terrorism* 32: 45-59, *SIAM Journal, October 2009.*

[20] Hossein Abouee-Mehrizi, Opher Baron, and Joseph L. Rotman (2015): State-Dependent $M/G/1$ Queueing Systems. *https://www-2.rotman.utoronto.ca/opher.baron/files/A21_state-dependent%20MG1%20queueing%20systems.pdf .*

[21] Horgan, J. (2005): The Psychology of Terrorism. *New York, NY: Routledge, Sept 2005.*

[22] Human Rights Watch (2016): 'They set the Classrooms on Fire: *https://org/report/2016/04/11/they-set-classrooms-on-fire/attacks-education-northeast-nigeria> accessed 16 February 2019.*

[23] Israel Udoh; Oluwadamire Alabi; Oluwaseun Fatoba & Ukoh, Eno Obong Effiong (2021): The Counter-terrorism Resource Allocation Queuing Fairness Appraisal of Leadership Decapitation Approach. *Journal of Emerging Technologies and Innovative Research (JETIR) (8)12, December 2021, pp 480-501. www.jetir.org (ISSN-2349-5162).*

[24] Israel J. Udoh, Michael O. Oladejo and Hycienth O. Orapine (2019): Assessing the Effectiveness of Carrots and Sticks Approach on Terrorists' Strength and Sustainability: A Mathematical Deterministic Model. *International Journal of Research and Innovation in Applied Science -IJRIAS Vol.4 issue 2 February 2019, pp.11-27. https://www.rsisinternational.org/journals/ijrias/DigitalLibrary/Vol.4, Issue2/11- 27.pdf.*

[25] Institute for Economics and Peace, 'The Global Terrorist Index 2015'. *http://economicsandpeace.org/wp-content/uploads/2015/11/Global-Terrorism-Index-2015.pdf> accessed 20 March 2019.*

[26] JCAT Counterterrorism Guide for Public Safety Personnel. *https://www.dni.gov/nctc/jcat/index.html*

[27] John O. Brennan (2012): The Efficacy and Ethics of U.S. Counterterrorism Strategy. *Wilson Centre, https://www.wilsoncenter.org/event/the-efficacy-and-ethics-us-counterterrorism-strategy.*

[28] van der Wal, M. van der Heijden, and R. van der Mei (2022): Validating state-dependent queues in health care. *Queueing System 100, 505–507 (2022). https://doi.org/10.1007/s11134-022-09827-x. https://link.springer.com/article/10.1007/s11134-022-09827-x.*

[29] J.D. Little (1961): A proof of the queuing formula $L = \lambda W$, *Opns. Res., 9 (1961), pp. 383–387*.

[30] Julia Chirkova, Vladimir Mazalov, and Evsey Morozov (2022): Equilibrium in a Queueing System with Retrials. *Mathematics* 2022, *10*(3), *428; https://doi.org/10.3390/math10030428*.

[31] Kaplan, E. H. (2010): Terror Queues, Operations Research, *INFORMS, vol. 58(4-part-1), pages 773-784,RePEc:inm:oropre:v:58:y:2010:i:4-part-1:p:773-784,DOI: 10.1287/opre.1100.0831*.

[32] Kaplan, E.H. and Feinstein, J.S. (2012): Intel Queues. *Military Operations Research, V17, pp17-30, N1 2012, doi 10.5711/1082598317117*.

[33] Kaplan, E. H. (2013): Staffing models for covert counterterrorism agencies. *Socio-Economic Planning Sciences, 47(1):2–8*.

[34] Kaplan, E. H. (2015): Socially efficient detection of terror plots. *Oxford Economic Papers, 67(1):104–115*.

[35] Kress, M., & Szechtman, R. (2009): Why defeating insurgencies is hard: The effect of intelligence in counterinsurgency operations - A best case scenario. *Operations Research 57*(3), 578-585.

[36] Linda Green (1984): A Multiple Dispatch Queueing Model of Police Patrol Operations. *Management science Vol. 30, No. 6, June 1984 Printed in U.S.A.*

[37] L. Nwabughiogu, (2016): '$9 bn Needed to Rehabilitate North-East', *Vanguard (Lagos, 13 April 2016), http://www.vanguard-ngr.com/2016/04/9bn-needed-to-rehabilitate-north-east/, accessed 16 February 2019.*

[38] L. Westcott, (2013): 'Boko Haram Violence Has Displaced an Estimated 800,000 Children in Nigeria', *Newsweek (Lagos 13 April 2013) <http://www.europe.newsweek.com/boko-haram-violence-has-displaced-estimated-800000-children-nigeria-321921?rm=eu> 16 February 2019.*

[39] Maren Brooks (2021): Irregular Warfare and Counterterrorism *https://policy.defense.gov/OUSDP-Offices/ASD-for-Special-Operations-Low-Intensity-Conflict/Irregular-Warfare-and-Counterterrorism/*

[40] Mona Khechen (2013): Social Justice: Concepts, Principles, Tools and Challenges. *Economic and Social Commission for Western Asia (ESCWA), Distr. LIMITED E/ESCWA/SDD/2013/Technical Paper.9 16 December 2013.*

[41] N. Gans, G. Koole, and A. Mandelbaum (2003): State-dependent Queuing Models for Call Centers. *Journal of Operations Research. https://www.scirp.org/reference/ReferencesPapers.aspx? ReferenceID=210563.*

[42] N. M. Abdullah, (2019): 'FG to spend N121Bn on North-East', *Daily Trust (Lagos). http://www.dailytrust.com.ng/news/general/fg-to-spends-n121bn-on-north-east/183006.html,16 Feb, 2019.*

[43] Olga Nikolić and Igor Cvejić (2017): Social Justice and the Formal Principle of Freedom. *UDK: 316.34 https://doi.org/10.2298/FID1702270N - May 2017.*

[44] Paul K. Davis (2014): Toward Theory for Dissuasion (or Deterrence) by Denial: Using Simple Cognitive Models of the Adversary to Inform Strategy. *International Security and Defense Policy Centre, RAND NSRD WR-1027, January 2014. http://www.rand.org/nsrd/ndri/centers*.

[45] Peter J. Kolesar, Kenneth L. Rider, Thomas B. Crabill and Warren E. Walker (1975): A Queueing-linear programming Approach to Scheduling Police Patrol Cars. *Reproduced by the RAND Corporation, City of New York.*

[46] People, Countries Impacted by Climate Change Also Vulnerable to Terrorist Recruitment, Violence, Speakers Tell Security Council in Open Debate. *Meetings Coverage and Press Releases, https://press.un.org/en/2021/sc14728.doc.htm.*

[47] Raz D., Levy H. and Avi-Itzhak, (2004): A Resource Allocation Queuing Fairness Measure. *In Proceedings of Sigmetrics 2004/Performance 2004 Joint Conference on Measurement and Modeling of Computer Systems, pp 130-141, New York, NY, June 2004. Performance Evaluation Review, 32(1):130-141).*

[48] R. D. Braun and R. E. Schumacher (1988): Patrol Allocation in Law Enforcement: A *Queueing Approach. NASA Technical Reports Server.*

https://ntrs.nasa.gov/api/citations/19760016996/

[49] Sasaki, T., Brännström, Å, Dieckmann, U. & Sigmund, K. (2012): Institutional delivery of incentives and assessment of voluntary participation. *Proc. Natl Acad. Sci. USA 109, 1165–1169 (2012).*

[50] S. Amuwa (2015): 'Boko Haram and Food Security in Nigeria', *Economic Confidential (Lagos), http://www.economicconfidential.com/2015/01/boko-haram-and-food-security-in-nigeria/> accessed 16 February 2019.*

[51] S. K. Singh and S. K. Bose (2020): "State dependent queueing models under admission control. *Journal of Ambient Intelligence and Humanized Computing, Original Research, Vol. 11, pg 3873–3891, (2020). https://link.springer.com/article/10.1007/s12652-019-01638-y.*

[52] Stuart Guterman (2013): Wielding the Carrot and the Stick: How to Move the U.S. Health Care System Away from Fee-for-Service Payment. Commonwealth Fund. *https://www.commonwealthfund.org/blog/2013/wielding-carrot-and-stick-how-move-us-health-care-system-away-fee-service-payment.*

[53] Stefan Wrzaczek, Edward H. Kaplan, Jonathan P. Caulkins, Andrea Seidl, Gustav Feichtinger (2016): Differential Terror Queue Games. *Operations Research and Control Systems Institute of Statistics and Mathematical Methods in Economics Vienna University of Technology, (Research Report 2016-02) March, 2016, pp1-16.*

[54] Sztrik, J. (2012): Basic Queuing Theory. *University of Debrecen, Faculty of Informatic http://irh.inf.unideb.hu/user/jsztrik/education/05/3f.html.*

[55] The Cable, 'In Figures: All Boko Haram Attacks in 2015', *The Cable. (Washington, 28 December 2015), http://www.thecable.ng/path-of-aruthless-killer-all-boko-haram-deaths-in-2015, accessed 16 February 2019.*

[56] Udoh, I.J., and Alabi, O.I, (2024): An Assessment of Counter-terrorism Options: A State Dependent Terror Queuing Model Perspective. *International Journal of Research and Innovation in Applied Science (IJRIAS), ISSN 2454-6194, DOI: 10.51584/IJRIAS, Vol IX Issue II February 2024, pp 74- 104, https://doi.org/10.51584/IJRIAS.2024.90209*

[57] USA PATRIOT Act of 2001. *https://www.congress.gov/107/plaws/publ56/PLAW-107publ56.htm*

[58] Victor Asal, Brian J. Phillips, R. Karl Rethemeyer, Corina Simonelli and Joseph K. Young (2018): Carrots, Sticks, and Insurgent Targeting of Civilians. *Journal of Conflict Resolution, 1- 26, DOI: 0.1177/0022002718789748. http://www.journals.sagepub.com/home/jcr*