THREAT EVALUATION IN AIR DEFENSE SYSTEMS USING ANALYTIC NETWORK PROCESS

(HAVA SAVUNMA SİSTEMLERİNDE ANALİTİK AĞ SÜREÇLERİ YARDIMIYLA TEHDİT DEĞERLEME)

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LIST OF SYMBOLS

AA	: Anti-aircraft guns
ALT	: Altitude
ANP	: Analytic Network Process
C2	: Command and Control
CPA IUOT	: CPA in Units of Time
CM	: Countermeasures
DA	: Defended Asset
DWTA	: Dynamic Weapon-Target Assignment
FCR	: Fire Control Radar
GL	: Geographic Location
IFF	: Identification Friend or Foe
JDL	: Joint Directors of Laboratories
MNB	: Maneuverability
MRO	: Maximum Radius of Operation
NMI	: Nautical Miles
OODA	: Observe, Orient, Decide, Act
ORG	: Origin
PC	: Political Climate
PW	: Platform Weapons
RoE	: Rules of Engagement
SAM	: Surface-to-air Missile
SPD	: Speed
SWTA	: Static Weapon-Target Assignment
TA	: Threat Assessment
TBH	: Time Before Hit
TCPA	: Time to CPA

TE : Threat Evaluation

TEWA : Threat Evaluation and Weapon Assignment

WA : Weapon Assignment

WCO : Weapon Control Orders

WER : Weapon Engagement Range

WS : Weapon System

WTA : Weapon-Target Assignment

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ABSTRACT

One of the most crucial steps of air defense domain is evaluation of targets. The function of the threat evaluation component is to compare the threats of known target candidates (tracks) in order to determine which targets shall be engaged first. Threat level depends on track classification and the defended asset, e.g. a bomber is a larger threat against ground units than a fighter. Also it depends on position, course and speed of the target relative to a defended asset.

In this study, our objective is to apply the Saaty's well-known multi criteria decision making method, Analytic Network Process to threat evaluation process and interpret the results. To do so, some scenarios are created with a number of aircrafts approaching to a defended asset from different directions. Some of them are ignored regarding their intent with the help of our intent estimation model, while the rest are evaluated and assigned with a target value. By that, obtained values can be used in sequencing or prioritizing the targets in a war environment.

RÉSUMÉ

Une des étapes les plus cruciales du domaine de la défense aérienne est l'évaluation des cibles. La fonction de la composante d'Évaluation de Menace est de comparer les menaces de cibles candidats connues (*tracks*) pour déterminer quelles cibles seront visées d'abord. Niveau de menace dépend de la classification de la cible et de l'actif défendu, par exemple un bombardier est une plus grande menace contre les unités terrestres qu'un chasseur. En outre, cela compte sur la position, la trajectoire et la vitesse de la cible par rapport à un actif défendu.

Dans cette étude, notre objectif est d'appliquer une des méthodes très connues de prise de décision à multicritères de Saaty, « Analytic Network Process (ANP) » au processus d'Évaluation de Menace et d'interpréter les résultats. Pour ce faire, un scénario est créé avec un certain nombre d'avions approchant à un actif défendu de différentes directions. Certains d'entre eux sont ignorés concernant leur intention à l'aide de notre modèle d'estimation d'intention, pendant que le reste est évalué et attribué avec une valeur cible. Par cela, les valeurs obtenues peuvent être utilisées dans le séquençage et priorisation des cibles dans un environnement de guerre.

ÖZET

Hava savunma sistemlerinde, ilk ve en önemli adımlardan birisi hedeflerin değerlenmesi işlemidir. Tehdit değerleme bileşeninin işlevi, tespit edilmiş olan potansiyel tehdit unsurlarının oluşturdukları tehdidin derecesine göre karşılaştırılarak sınıflandırılması ve sıranalması şeklindedir. Bu yapılan sınıflandırma neticesi ile savunulan unsurlar birlikte ele alındığında oluşan tehdidin seviyesi netleşmiş olur. Örnek vermek gerekirse, savunulan yer unsurlarına karşı bir bombardıman uçağı bir savaş uçağından daha fazla tehdit teşkil etmektedir. Ayrıca, hedefin savunma unsurlarına göre konumu, hızı ve izlediği yol da burada etkin rol oynamaktadır.

Bu çalışmada amacımız, Saaty'nin bilinen çok ölçütlü karar verme yöntemlerinden yöntemlerinden biri olan Analitik Ağ Süreçlerini tehdit değerleme sürecine uyarlayıp sonuçları gözden geçirip yorumlamaktır. Bunu göstermek üzere savunma unsurlarının ve bu savunma unsurlarına farklı yönlerden saldırı gerçekleştirmeyi amaçlayan çeşitli potansiyel saldırı unsurlarının bulunduğu senaryolar oluşturulmuştur. Bu potansiyel saldırı unsurlarından bazıları, amaçları belirlendikten sonra gözardı edilmiştir ve kalan saldırı unsurları hedef olarak belirlenip birer hedef değeri ile eşleştirilmiştir. Böylece elde edilen değerler ışığında herhangi bir savaş ortamında hedeflerin öncelik derecelerinin ve sıralamalarının belirlenebildiği gösterilmiştir.

1. INTRODUCTION

The most crucial problems with which countries struggle in these days are related to security and defense. Every year, huge amount of resources are spent on defensive and offensive weapons and systems to maintain the atmosphere of peace both in and out of the countries. Main purpose on this matter is to be ready to counter the attacks that aim to destroy valuable assets. These assets can be citizens of the country, government buildings, dams, bridges, warships and other military equipments. For most countries, the main effort has tended to be "homeland defense".

Air defense is one of the fastest-evolving area of military operations reseach, responding to the evolution of aircrafts and exploiting various enabling technological advancements, particularly radar, guided missiles and computing (especially electromechanical analog computing from the 1930s). Air defense evolution influenced the areas of sensors and tracking systems, weapons, and command and control. These were either very elementary or unavailable in the beginning of the 20th century.

Decision-making under stress is a hard task for human beings. It requires strong mental capability and years of experience to apply a decision-making process in times like war, natural disasters, etc. The examples also include air defense decision-making applications. Air defense decision-making is an extremely complex process and it can only be performed by experienced and skilled experts in the field. Air defense personnel are often engaged in challenging tasks. In addition to being responsible for all aircraft in their surveillance area, they must also maintain awareness of available resources, monitor audio and verbal messages, and prepare situation reports. In this environment, it can be difficult for air defense team members to notice or identify key pieces of information that may enable them to better understand the tactical situation (Liebhaber and Feher, 2002). Along with the development in technology, difficult tasks are performed easily by autonomic systems. Information sharing, cooperation and command and control of forces become more important than ever. However, critical processes such as these must be performed attentively and to do so, autonomic systems requires exact and specific data to operate. Also the usage of autonomic systems helps increase in human survivability and safety during volatile combat situations.

Informally, the goal of threat evaluation (TE) in air defense is to rank observed enemy aircraft according their threatening activity with respect to a number of Defended Assets (DA). Theoretically, it is self-explanatory that the TE process provides decision support (which improves command and control as well as situation awareness) and is dedicated to improving the operational tempo of operators. In the last two decades, threat assessment and intent assessment subjects have been studied intensely. However, complicated atmosphere of war and considerable amount of variables makes it difficult for researchers to obtain an exact solution method.

According to the data fusion model proposed and maintained by the Joint Directors of Laboratories' (JDL) Data Fusion Group, TE involves capability assessment and intent assessment (Nguyen, 2002). Capability refers to the ability of the target to inflict injury or damage to the DAs. Factors considered in assessing target capability include the composition and size of any group (formation) of targets to which it belongs, its proximity to the related DA, and attributes of its weapon systems (WS) and surveillance systems with relation to various attack techniques. Intent refers to the will or determination of the target to inflict injury or damage. Unlike capability (which is rather straight forward to assess because of its procedural nature), intent is generally more difficult to assess, since deciding whether a target is exhibiting intent is often very subjective (residing in the cognitive domain) (Paradis et al., 2005).

On the other hand, the purpose of Weapon Allocation or Weapon Assignment (WA) is making optimization while satisfying some particular constraints. The objective function of this optimization problem can either be maximization or minimization. When it is a maximization problem, our objective is to maximize the number of destroyed targets or surviving assets. But when it is a minimization problem, the objective is to minimize the damage that targeted to DA or surviving targets.

In the literature, some heuristic algorithms, such as Greedy Algorithm, Stable Marriage Algorithm and Auction Algorithm, are used to do the assignment part of the problem. Threat values of targets and weapon index of WSs are used to match the best possible pairs of weapons and targets.

The motivation behind this thesis is the need for a decision tool, which takes environmental weapon and threat related-characteristics into account, and suggests an effective course of action for air defense in a complex attack environment. Unlike former studies, which proposed mainly heuristic algorithms for TE phase, we use The Analytic Network Process (ANP) for calculating threat values of targets.

Furthermore, we propose a network-based model for TE which considers relations between parameters and produces a final threat value for targets. Our method is based on different aircraft types and we evaluate them according to their technical specifications, behaviors and arriving times to certain points in a number of scenarios.

The rest of the study is as follows: in Chapter 2, a brief overview of literature is given. Since the TE and WA problems have been studied to great extend, the most relevant work are mentioned only. Chapter 3 contains problem definition and decision making model developed for the problem. A short description of ANP and applied work examples are given in Chapter 4. In Chapter 5, the established method is tested on number of scenarios and quality of acquired solutions are reviewed. Finally, Chapter 6 concludes the thesis by discussing the proposed method for TE process and suggests future work.

2. BACKGROUNG: THE TEWA PROCESS

Basically, TEWA stands for TE and WA processes. TEWA is mainly used in military domain but also can be seen in risk management, medical applications as well. It is a process where number of targets which poses threat to some DAs are evaluated or assessed based on some criteria, then a decision making process is performed with these evaluation results. This decision making process will also be the matching process between our defensive mechanisms and evaluated targets. The aim of this process is to assign a number of defensive systems to a number of targets and eliminate the threat factor as much as possible.

Famous military strategist John Boyd's "Observe, Orient, Decide, Act" (OODA) Loop (Figure 2.1) is a very effective decision making tool which is used commonly in military operations (Richards, 2004).

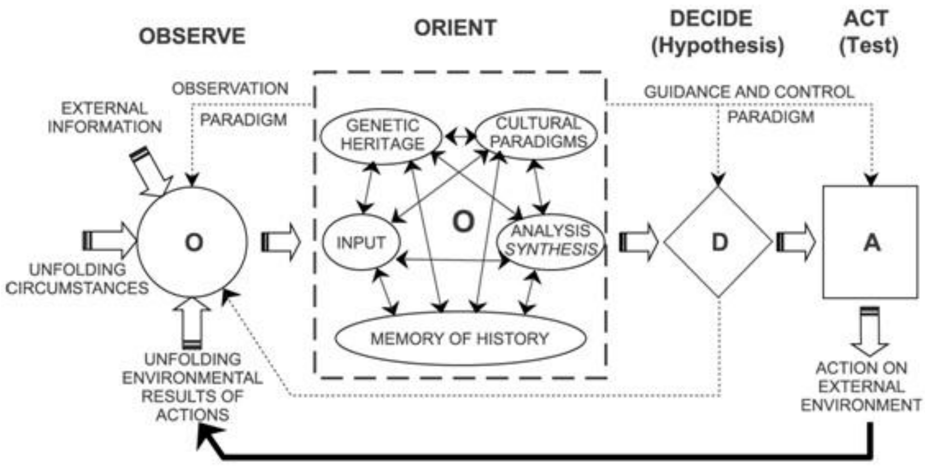

Figure 2.1: The OODA Loop

TEWA process can easily be iterated in OODA Loop as a dynamic and repetitive structure. This can be achieved by:

- Observing the entities and actions of the enemy, determining still alive threats and still remaining weapons.
- Orienting resources to tackle current situation, evaluating targets.
- Deciding actions on basis of current situation, assigning weapons.
- Acting seamlessly on the decision made, neutralizing targets.

During this decision process, there are some elements of surface-to-air defense such as DAs, threat elements and WSs which are needed to be considered according to their attributes:

Defended Assets: In defensive counterair operations, this represents a listing of those assets from the critical asset list prioritized by the Command and Control (C2) center to be defended with the resources available. Thus, some of the DAs have higher priority than the others and need better protection. These DAs might be:

- Command and Control (C2) centers,
- Government buildings,
- Radars and sensors,
- Arsenal buildings
- Communication centers. etc.

Threat Elements: Generally in air defense, threat means all enemy forces attempting to attack or penetrate the friendly air environment. In other words, threats are elements with the intention of damage or injury to the DAs, or making suspicious movements and maneuvers. Threat can be missiles (ballistic, guided. etc.) or aircrafts which drop bombs or fires directly to the ground targets.

Weapon Systems: Weapons such as Anti-aircraft (AA) guns or Surface-to-air (SAM) missiles are used in air defense to eliminate targets. Generally, these systems are statationary ground-to-air defense mechanisms but there are also mobile defense systems. At first, the acquisition radar detects a target and when identified as hostile, it is designated to a target tracking radar. The target tracking radar acquires and tracks the target and sends this data to the computer. The computer, given the location of the target, continuously computes a kill point[1]. And so, according to this point, WSs are fired at the optimum point with the maximum possible kill probability. The critical issue is to hit a target moving in three-dimensional space. This means that projectiles either have to be guided to hit the target, or aimed at the predicted position of the target at the time the projectile reaches it, while speed and direction of both the target and the projectile are taken into account.

The complexity of the environment is shown in Figure 2.2. Rules of Engagement are crucial in order to prevent engaging friendly or neutral aircrafts. Different rules can apply to different types of air defense covering the same area at the same time. NATO calls these rules as Weapon Control Orders (WCO) (NATO, 2014), they are:

- **Weapons free:** A weapon control order imposing a status whereby weapons systems may be fired at any target not positively recognized as friendly,
- **Weapons hold:** A weapon control order imposing a status whereby weapons systems may only be fired in self-defense or in response to a formal order,
- **Weapons tight:** a weapon control order imposing a status whereby weapons systems may be fired only at targets recognized as hostile.

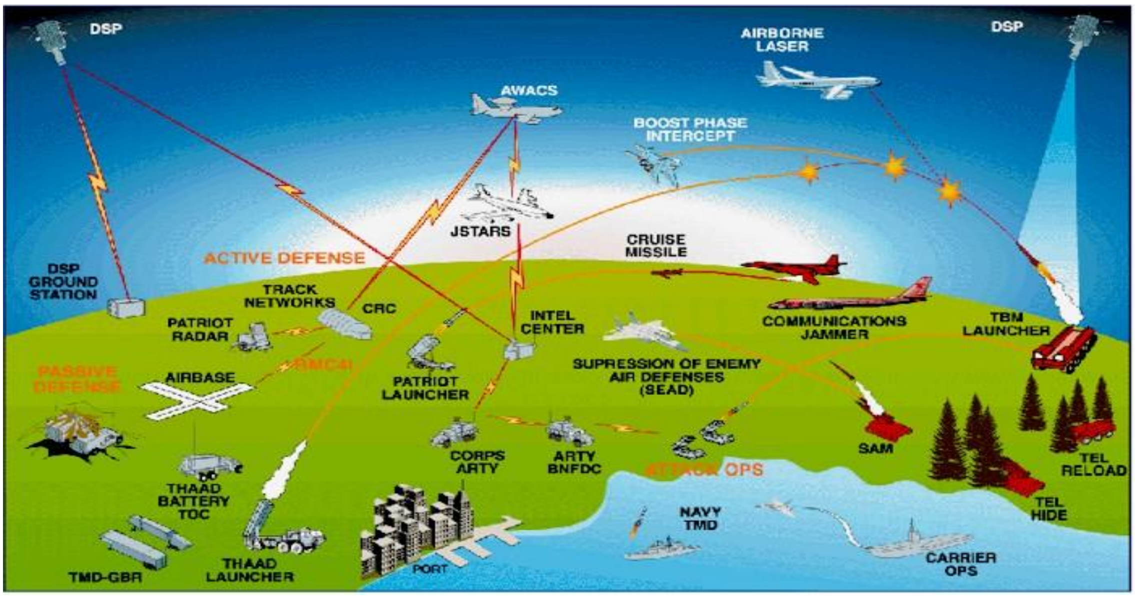

Figure 2.2: Air defense environment

[1] US Army Air Defense Digest, 1972

2.1 Threat Evaluation

TE is a pre-deployment process by which a commander and his staff draw on their encyclopedic knowledge of the enemy, including doctrine, tactics and capabilities, to deduce the nature of the threat they face (Army, 1994). It also refers to the part of threat analysis concerned with the ongoing process of determining if an entity intends to inflict evil, injury, or damage to the defending forces and its interests, along with the ranking of such entities according to the level of threat they pose (Paradis et al., 2005).

Liebhaber and Smith (2000a) reported their results of an investigation into the cognitive aspects of threat assessment (TA). Their aims were to identify and describe the factors and cognitive processes that an Air Defense team onboard ship uses to assess and prioritize aircraft contacts, and to provide preliminary specifications for a cognitively-based threat assessment model. They collected data from experienced Naval Air Defense personnel as they interacted with a realistic, computer-based scenario. After that Liebhaber and Feher (2002) reviewed previous studies to describe a model of threat assessment that was created from the research data, and proposed guidelines for a threat assessment display within the context of an air defense decision support system.

Nguyen (2002) reported in his study the results of a research program on target threat assessment. A discussion of a process of threat assessment is followed by a Cognitive Work Domain analysis on threat assessment. An intent assessment problem using Bayesian Networks is modeled and tested. Following that, Nguyen and Cutler (2003)(2003)(2003)(2003) provided details of a preliminary rule-based model which takes account of the most significant parameters used by operators making asset allocation decisions. They took the approach to automated asset allocation that involves the use of a computational model to provide real-time allocation of friendly controlled assets to cover or engage targets.

Many methods were studied for assessment of threats. Some of them are Rule-based systems (Harris, 1988, Liebhaber and Smith, 2000b), Bayesian networks (Endsley, 1995, Okello and Thorns, 2003, Johansson and Falkman, 2008), Neural networks (Jan, 2004, Hua and Ke, 2012, Azak and Bayrak, 2008), Multi-criteria decision analysis

(Qu and He, 2002) and Fuzzy logic (Yawei, 2007, Dongfeng et al., 2012).

Three main criteria of the TE process are *Capability*, *Intent* (Hall and Llinas, 2008) and *Proximity* (Roy et al., 2002).

Capability: It refers to the identification of threat and its ability to destroy or cause damage to the DAs. Radar cross-section, answer to Identification Friend or Foe (IFF)-interrogation, etc. can give us information about target's identity. The capability of a target depends on its platform capability whether, for example, it can maneuvre fast or it is a stealth platform and on the armament it carries for the mission. Fuel capacity of a target is another parameter that can give us information about target's maximum range of operation. Basically, the target must be identified first; then its capability can be inferred.

Intent: Unlike capability, intent is a bit more subjective term in TE process. Knowing the intent of a target is essential for an operator since intent refers to the predicted activities of a target, in order to prioritize the processing of a target and to choose suitable tactics and appropriate weapons to engage the target. Target intent is one of the main discriminators for classifying whether a target is friend or foe since a particular type of aircraft may be in service in both forces. For example, typical commercial aircrafts tend to fly with steady speed, constant altitude and in a straight line. If a target maneuvers more than normal indicates more threat than a non-maneuvering target. Other indications of hostile intent may be the use of radar-jamming units or if the target's fire control radar is on.

Proximity: Proximity is a class of parameters that are measuring the target's proximity to the DA. One of the most important parameter to define the distance of target to the DA is the Closest Point of Approach (CPA). CPA is point where the distance between asset and the direction of velocity of target will be the shortest (Figure 2.3). CPA can easily be used as a measure of threat level. Targets in far distances can be considered less threatening, while targets in shorter distances indicate more potential threat. Given *n* possible threats and *m* DAs, some of the parameters related to the CPA are:

- Time to CPA (TCPA): Target's approaching time to the CPA.

$$TCPA_{ij} = \frac{d(CPA_{ij})}{v_i} \quad \forall i = 1, \dots, n \quad \forall j = 1, \dots, m \tag{2.1}$$

Where d(CPA_{ij}) represents the distance of target *i* to CPA of DA_j and v_i is the speed of target *i*.

- CPA in Units of Time (CPA IUOT) : Means the time it takes the target to hit the DA after arriving the CPA.

$$CPAIUOT_{ij} = \frac{d(dCPA_{ij})}{v_i} \quad \forall i = 1, \dots, n \quad \forall j = 1, \dots, m \tag{2.2}$$

Where d($dCPA_{ij}$) represents the distance of target *i* to DA_j after arriving CPA.

- Time Before Hit (TBH): TBH is an estimate of the time it takes the target to hit or reach the DA.

$$TBH_{ij} = TCPA_{ij} + CPAIUOT_{ij} = \frac{d(CPA_{ij}) + d(dCPA_{ij})}{v_i} \quad \forall i = 1, .., n \quad \forall j = 1, .., m \tag{2.3}$$

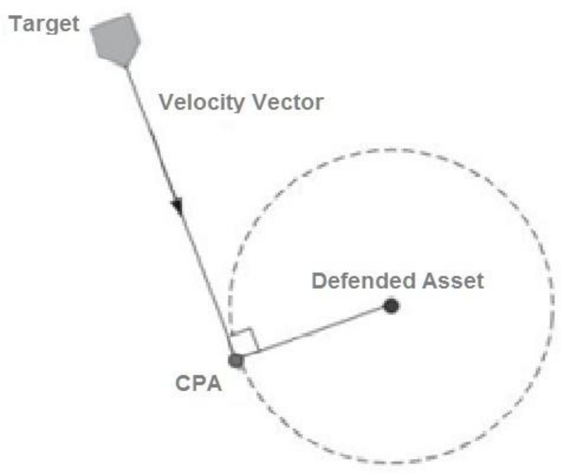

Figure 2.3: Closest point of approach

These calculations are made under the assumption of constant target velocities. This is a reasonable assumption for many platforms and conventional weapons, since they seldom make rapid maneuvers between two track updates (Oxenham, 2003).

A list of commonly used parameters is presented below. Six ot these parameters are identified as critical based on their relative weights. They were, in order of importance: Origin, IFF Mode, Intelligence Report, Altitude, Proximity to an Airlane, and ESM (Liebhaber and Feher, 2002).

Parameter	**Definition**
Altitude	Approximate feet above ground or an indication of change (e.g.,climbing).
Coordinated Activity	Track is communicating with, or nearby, another track.
Countermeasures	Using techniques or tools to avoid radar signals, thermal or infrared guided systems.
Course	Heading - Exact compass heading or indication of heading relative to the DA (i.e., opening or closing).
CPA	Closest Point of Approach - Estimated distance that track will pass by own ship if the track and own ship remain on their current courses.
ESM/Radar	Electronic Support - Electronic emissions from the track (typically indicates the type of radar system the track is using).
Feet Wet/Dry	A Feet Dry track is flying over land. A Feet Wet track is flying over water.
Fire Control Radar	A system that is used by an attacker to track a target by intense radio beams.
IFF Mode	Identify Friend or Foe. Signals from a track that indicate if it is a friendly, or perhaps neutral, aircraft.
Flight Plan/Airlane	A published or otherwise known commercial air route.
Intel	Intelligence reports.
Maneuvers	Indicates the number of recent maneuvers.
Number/Composition	Number of aircraft in the formation.
Origin/Location	Indicates the country from which the track most likely

	originated.
Own Support	Availability of nearby friendly ships or patrol aircraft.
Platform Weapons	Armaments on track.
Range/Distance	The track's distance from the DA.
Speed	Approximate airspeed or an indication of change (e.g. increasing).
Visibility	Approximate number of miles, or an indication of atmospheric conditions (e.g., haze).
Weapon Envelope	The track's position with respect to its estimated weapons envelope.
Wings Clean/Dirty	A track without armament is designated Wings Clean. A track with armament is designated Wings Dirty.

2.2 Weapon-Target Assignment

Weapon-target assignment (WTA) problem is a classical combinatorial optimization process where *m* weapons and *n* targets are matched against each other under various constraints and particular rules. This process requires decision-making in real-time that are consistent with the mission's objectives, and compliant with the rules of engagement (ROE), platform and environmental constraints. The WTA problem entailed by single-platform perspective, which refers to a single platform protecting itself from threats, where assignment relates to selecting the most suitable WS to counter a threat; and the force coordination perspective, where assignment relates to identifying the most suitably armed platform to engage or counter a threat (Paradis et al., 2005).

The problem has two versions; Static WTA and Dynamic WTA (Hosein and Athans, 1990b). In static WTA (SWTA), all the assignments are made in a single stage, so the parameters that are used in the problem are known and the goal is to find the optimal solution for a single assignment. However, in dynamic WTA (DWTA), the goal is to find the global optimum solution for a multi-stage process. In other words, running the STWA multiple times gives the problem a dynamic form. The output of the first stage becomes the input for the second stage and the process evolves into a circulation of processes. But DWTA is a more complicated process due to increasing number of constraints. In DWTA, there are also stage-based constraints which show the status of parameters in every stage of the problem. Thus, this causes the problem to have more constraints than the SWTA and consequently, it takes more time and resources to solve the problem.

Mainly, there are two approaches for the assignment problem; asset-based and target-based (Wacholder, 1989, Hosein and Athans, 1990b). In asset-based models, the objective is to assign weapons to targets so as to maximize the expected total value of the assets surviving after all weapon-target engagements and all target impacts. In contrast, target-based models aim to minimize expected total value of the targets surviving after all engagements. Following notation will be used to describe these two models:

$|T|$: Total number of targets,

T: Set of targets $(T_1, T_2, \ldots, T_{|T|})$,

$|A|$: Total number of assets,

A : Set of DAs $(A_1, A_2, \ldots, A_{|A|})$,

v_i: Estimated target value of target i,

ω_j: Value of the asset j .

$|W|$: Total number of weapons,

W: Set of Weapons $(W_1, W_2, \ldots, W_{|W|})$,

p_{ik}: Probability of weapon k to destroy target i if assigned,

q_i: Probability of target i to destroy or do harm to asset j,

G_j: Set of targets aimed at the defended asset j,

$$X_{ik}: \begin{cases} 1 & \text{if weapon } k \text{ is assigned to target } i, \\ 0 & \text{otherwise.} \end{cases}$$

2.2.1 The Asset-Based SWTA Problem

The asset-based SWTA problem is a nonlinear integer programming problem where W weapons matched against T targets in order to maximize the number of surviving assets.

It is more suitable for ballistic missile defense problems where aims of targets assumed to be known(Murphey, 2000).

$$\max J = \sum_{j=1}^{|T|} \omega_j \prod_{i \in G_j} \left(1 - q_i \prod_{k=1}^{|W|} (1 - p_{ik})^{X_{ik}}\right), \quad (2.4)$$

subject to

$$\sum_{i=1}^{|T|} X_{ik} = 1, \quad \forall k, \quad (2.5)$$

$$X_{ik} \in \{0.1\}, \ \forall i \forall k. \quad (2.6)$$

In this formulation, the inner product of (2.4) gives us the expected survival probability of target T_i when it is matched against weapon W_k, and the outer product gives us the expected survival probability of DA A_j. In conclusion, the sum over the outer product gives us the maximized total expected protection value of the DAs.

2.2.2 Target-Based SWTA Problem

The main difference between target-based and asset based SWTA problems is that the target-based formulation is more appropiate when the intended aim of the targets are unknown (Murphey, 2000). The general frame of the formulation is similar to the asset-based one.

$$\min Z = \sum_{i=1}^{|T|} v_i \prod_{k=1}^{|W|} (1 - p_{ik})^{X_{ik}}, \quad (2.7)$$

subject to

$$\sum_{i=1}^{|T|} X_{ik} = 1, \quad \forall k, \quad (2.8)$$

$$X_{ik} \in \{0.1\}, \ \forall i \forall k. \quad (2.9)$$

Also in this formulation, the inner product of (2.7) gives us the expected survival probability of target T_i when it is matched against weapon W_k. However, sum over the outer product gives us the minimized total expected survival probability of targets.

Some of the assumptions which are made in the target-based SWTA problems:

- All firing units have to be assigned to targets,
- A firing unit need to be assigned to exactly one target,
- Many firing units can be assigned to the same target in order to decrease the survival probability of target,
- All firing units have to be assigned simultaneously.

Den Broeder et al. (1959) investigate the WTA problem with identical weapons. Their purpose is to assign *m* missiles to *n* targets in order to neutralize at least *k* targets. In the first version of the problem, all targets have the same value but each target has a different probability of getting killed, independent of the missile type attacking. In the second version, it is assumed that the value of each target is known. This second version is also referred to as the Flood's Assignment Problem.

Multi-stage version of the WTA problem, where the offense launches a number of rounds aimed at assets of the defense, is investigated by Hosein and Athans (1990c). In each stage of the engagement, the defense observes the outcomes of the assignments made in the previous stage before assigning a subset of the remaining weapons in the present stage. Under suitable assumptions, as the number of targets approaches infinity, the problem can be treated as a deterministic one in which the number of targets that survive over a stage equals its expected value. This result can be used to provide lower bounds on the optimal cost for problems with a finite number of targets.

An extensive study to develop exact methods for solving WTA problems is carried out by Ahuja et al. (2004). They try to assign *n* weapons to *m* targets such that the total expected survival value of the enemies after the engagement is minimum. The main aim of their work is to deliver an exact method for the solution of the problem. They propose several approaches such as linear programming, integer programming, network flow based lower bounding methods, network flow-based construction heuristic, as well as a very large-scale neighborhood search algorithm.

2.3 Dynamic Aspect

The SWTA problem deals with the optimal assignment of the targets and WSs to minimize the damage done to the DAs when there is only single opportunity to engage the enemy and all other input of the problem are fixed. If multiple engagements can be made during the attack, then the assignments can be done dynamically by using "OODA Loop" or "Shoot-Look-Shoot" strategy. Note that the problem will be re-solved after each stage because the results of that stage can be observed. This means that one is only interested in obtaining assignments for the present stage. By the principle of optimality, it is implicitly assumed that optimal assignments will be used in all subsequent stages (Hosein and Athans, 1990b).

In the dynamic problem, the time duration of the offense's attack is divided into a number of time segments. Each segment is of sufficient length to allow the defense to fire a subset of its weapons and observe (perfectly) the outcomes of all of the engagements of the weapons. With the feedback of this information the defense can make better use of its weapons, since it will no longer engage targets which have already been destroyed (Hosein and Athans, 1990a).

3. MODELING

3.1 Problem Definition

The main aim of air defense is to defend the assets by using weapons to neutralize the threats. Threats are generally airplanes flying at very high speeds. They send rockets to or drop bombs onto assets (Figure 3.1). During the engagement period, radars supply information to C2 center on velocity, position and type of threats. C2 center checks the weapon availability, decides on the best engagement strategy and sends engagement orders to weapons. If the weapon accepts the order, it prepares to fire. This engagement period as a whole is called *weapon setup time*, which may be different for each weapon. This preparation includes:

- loading ammunition,
- turning the muzzle,
- watching and tracking the threat, and
- engaging and firing.

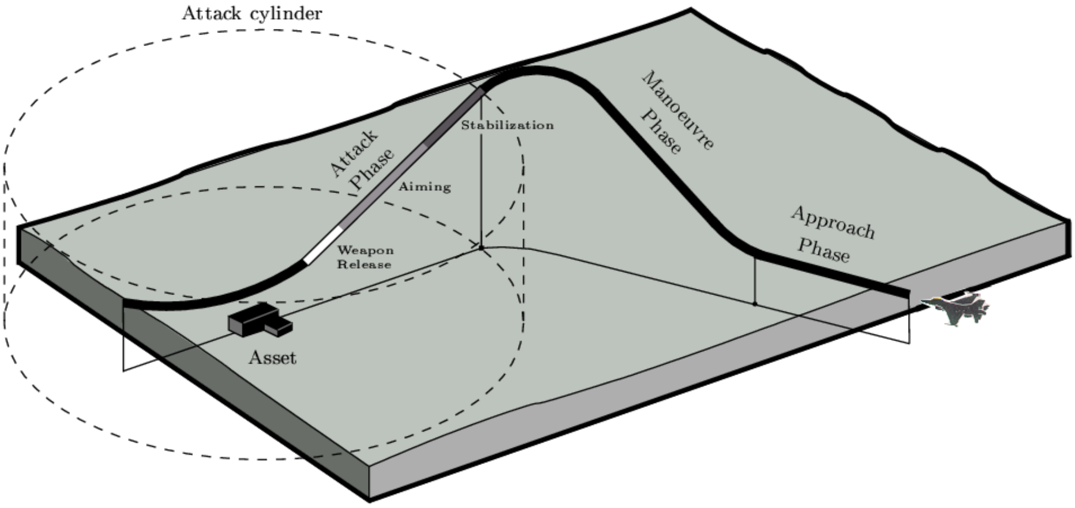

Figure 3.1: Attack procedure of an aircraft

In the beginning of the process, we need to determine the intent of the possible threats whether they have hostile intent or they are neutral. Then we may treat them as targets and assign their target values. To do so, some clues about threats considering their past and present conditions need to be gathered.

3.2 Intent Estimation

Usually, intent of a target cannot be observed directly. However, signs of which the enemy is engaged in particular actions or behavior can be observed. Therefore, to read the intent of a target, operators get as many clues as possible from different information sources such as radar, IFF-interrogation, intelligence reports, visual inspection, etc. Operators perform a number of sequential activities within the overall task. These activities include recognition that the target exists, assessment of the environment in which the target is operating, and assessment of the target behavior within the environment, leading to an assumption about its intentions. A conclusion about the intent of a target may lead to actions of further investigation or to intercepting and neutralizing the target(Nguyen, 2002).

Our intent estimation model is mainly based on logical approach. We consider some of the clues such as:

- Heading,
- Known or agreed flight plan,
- Platform type,
- Fire control radar,
- Countermeasures.

These clues are chosen based on visibility, measurability and detectability by sensors or radars in a state of area scaning (Figure 3.2.). For instance, a track is detected by our radar systems and is heading towards one of our DAs and there is no data on a flight agreement plan, we check whether it is a commercial aircraft or a fighter/bomber. If we detected that the track is a bomber and the fire control radar on the track is enabled, we suppose that a track detected by our radars and is heading to a different direction with

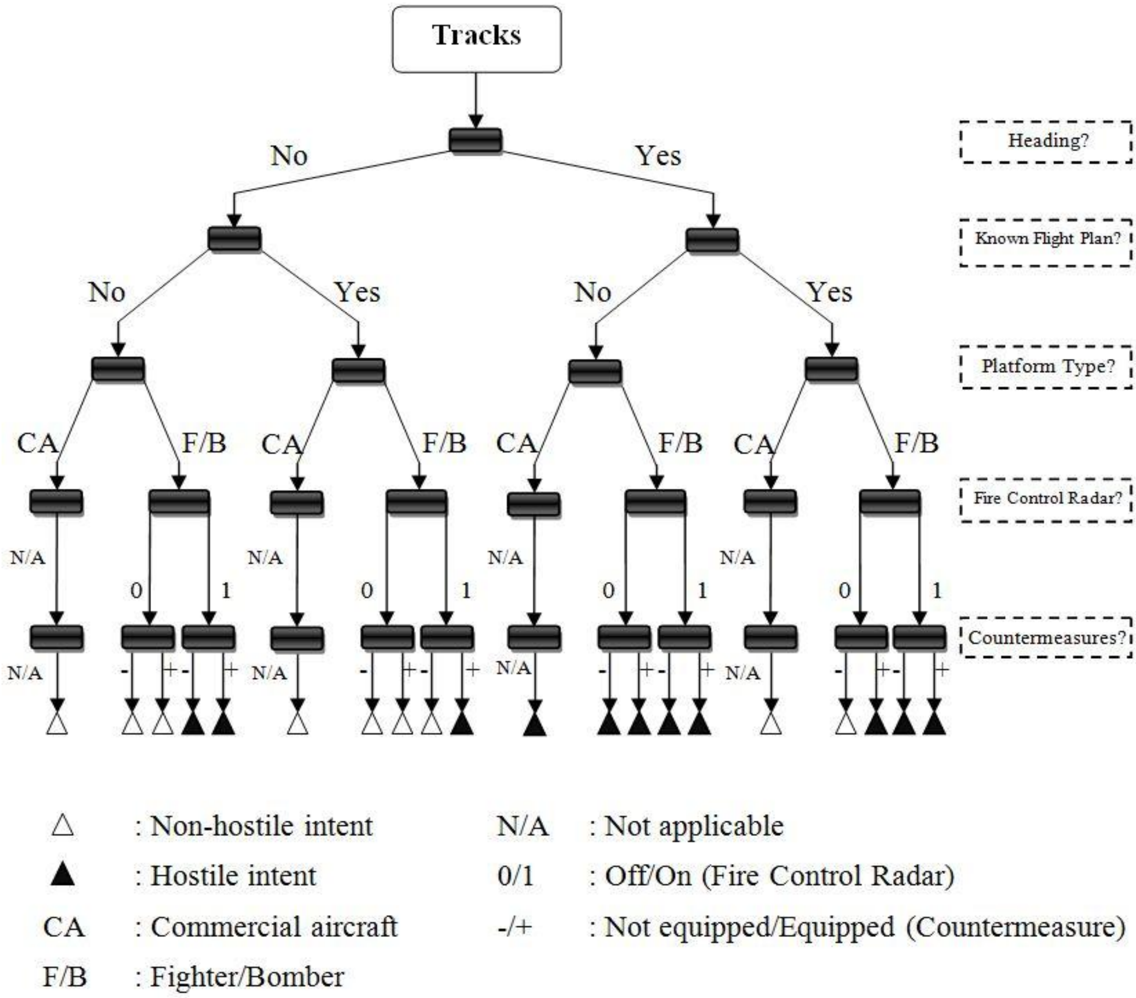

Figure 3.2: Intent estimation model

fire control radars on and not equipped with countermeasures. If we have a clue on a flight agreement plan, we ignore the track, otherwise, it becomes a suspected target.

3.3 Threat Evaluation Model

Our objective for this model is to assign threat values to the detected targets regarding their hostile intents. The main function of this process is to generate values which are designed to be used as a sequencing factor or to set priorities for the targets. It is crucial that before engagement, threat posed by target should be known in order to waste precious time and resources on weak targets while more dangerous and powerful targets attempts successful attacks on DAs. To apply this, some parameters must be considered and used as criteria in the model.

3.3.1 Criteria

As previously mentioned in section 2, a list of commonly used parameters exists and some of these parameters have critical importance. We design our model with two main criteria, namely: “Capability” and “Proximity”, including the sub-criteria for each one. We use a number of parameters from this list as sun-criteria and we add different parameters beside the list such as:

- *Maneuverability* (MNB): Agility of track and maneuver capacity

- *Weapon Engagement Range* (WER): Varies for the onboard armament, indicates maximum and minimum firing distances.

- *Maximum Radius of Operation* (MRO): Also varies according to platform type and fuel capacity, indicates maximum reach point of track beginning from lift-off.

Other criteria from the list:

- Origin (ORG)
- Platform Weapons (PW)
- Fire Control Radar (FCR)
- Countermeasures (CM)
- Speed (SPD)
- Altitude (ALT)
- Time to CPA (TCPA)
- CPA in Units of Time (CPA UIOT)
- Time Before Hit (TBH)

3.3.2 Moderating Factors

In addition to criteria, there are some factors that affect the parameters indirectly or puts more weight on some criteria. Because of their indirect impacts, they are called as “Moderating Factors”. In this study, two moderating factors have been taken into consideration for their possible effects on criteria:

Political Climate (PC): It corresponds to diplomatic relations between nations. When a target detected by the early warning systems, if the origin of target is known, it automatically affects the threat level of target as a result of diplomatic stage between two sides. For example, consider a case where two fighters approaching our DA from a distance. One is originated in nation A and the other in nation B. With nation A, our diplomatic stage is neutral while it is critical with nation B. Our decision will be automatically affected by this situation and so fighter B will be treated with more caution than fighter A.

Geographic Locations (GL): Both in defense and offense strategies, the surface features of the area have an important role. The attack plans and formations are directed while geographic obstacles and flying distances are taken into consideration.

3.3.3 Relations between Sub-Criteria

In a general context, all the criteria are affected by each other to some degree. There are direct connections between some parameters caused by kinematic effects.

3.3.3.1 Dependence Relations for Capability Sub-Criteria

The Capability sub-criteria which we determined are MNB, PW, ORG, MRO, WER, FCR and CM.

MNB is affected from SPD, ALT, PW, MRO and ORG. The SPD at which an aircraft is capable of its maximum aerodynamic maneuverability is known as the corner airspeed; at any greater SPD the control surfaces cannot operate at maximum effect due to either airframe stresses or induced instability from turbulent airflow over the control surface. At lower SPDs the redirection of air over control surfaces, and thus the force applied to maneuver the aircraft, is reduced below the airframe's maximum capacity and thus the aircraft will not turn at its maximum rate (Gal-Or, 1990). Also, ALT at which an aircraft cruises affects MNB due to the air density. Air density decreases as ALT increases and this causes the airflow on the airframe and wings. The aircraft must compensate this by gaining SPD to increase the force applied to maneuver. Of course, GL of the operation field will directly affect the maximum and minimum barometric altitude according to difference in meters above sea level. Additionally, the PW and fuel tanks means adding extra weight to the aircraft. The MNB of the aircraft decreases while the weight on airframe increases. If we desire to extend the MRO of the aircraft, extra fuel load will be needed and this will also makes the aircraft less maneuverable. ORG of the aircraft can gives us clues about MNB by economical and technological standards in the country which our target is originated. Higher standards mean better education and training opportunity for the pilots of that country. A good pilot can use an aircraft well to the limits and can increase the MNB of the aircraft relatively.

For the PW, SPD is also an affecting factor. Muzzle velocity of guns and rockets tells us more or less about impact depth or maximum penetration when they hit a target. If the SPD of the aircraft increases, so does the damage of weapons automatically because aircraft SPD determines the actual muzzle velocity. Maximum and minimum firing distances are affected from both SPD and ALT. Attacking angle changes according to changes in ALT and geographic shape of the land. Desired CPA of an aircraft may change the choice of weapon and ammunition type. Bombs and rockets with higher area damage effect can serve to extend the closest point of approach. But all the extra weight caused by armament decreases MNB as a result. Also if the extra armament is needed and weight of the aircraft must not exceed limits, this may cause sacrificing some fuel by loading less of it and it means reduction of the MRO. As we mention before, high standarts in a country can also affect the technological developments in military industries. R&D activities result with weapons which are more powerful and well-prepared against countermeasures.

MRO or maximum combat radius refers to the distance from an airbase that a warplane can reach, patrol there for a set amount of time and return to base with minimal fuel left, thus completing a combat mission. Combat radius of an aircraft varies according to the fuel capacity of the aircraft mostly. But other factors such as combat ALT, ordnance weight affect the fuel consumption of the aircraft directly, and combat radius mediately. An aircraft engaged in a low-level combat mission will have a smaller combat radius than the same one engaged in a high-level mission, due to higher fuel consumption at lower ALTs since lower ALTs have higher atmospheric pressure and air density. And also an aircraft with more and heavier ordnance or PW will have a smaller combat radius than the same one with less and lighter ordnance, due to higher fuel consumption at heavier weights (Ruijgrok, 1990). ORG of the aircraft will affect the MRO by the location of the center point.

Typically, the higher and faster the launching aircraft is flying, the wider the WER can be. For long range missiles this difference can be small, but short range missiles (like the AGM-65 Maverick) often dramatically increase in range when launched at high ALT. This gives the attacking aircrafts a standoff distance while the WER increases allowing them to launch the missiles or release bombs outside the most intense air defenses around the DAs. Thus, if the WER of an aircraft is wider, target priority of that aircraft increases same as the target value. The choice of range of weapons can be determined considering RoE applied by both sides. Thus, PC has an effective role here.

The inner and outer relations of capability sub-criteria are summarized in the Figure 3.3.

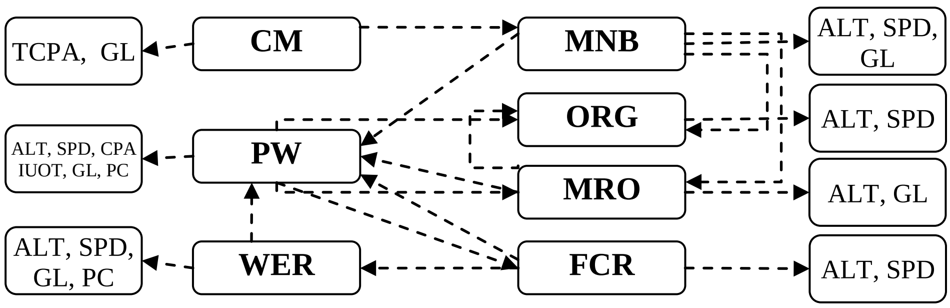

Figure 3.3: Inner relations capability criterion

3.3.3.2 Dependence Relations for Proximity Sub-Criteria

Sub-criteria for the proximity we will be discussing are SPD, ALT, CPA, CPA IUOT and TBH.

SPD combines two factors, the *distance* travelled in a certain amount of *time*. With higher SPD, targets can approach to the DAs in less time. Factors affecting the aircraft SPD are ALT, PW and MRO. As we mentioned before, as the ALT increases, the air density decreases. This means that the air resistance and the total drag effect on aircraft reduces, consequently, the aircraft can reach up to higher airspeed performance. This applies mostly to the jet engine aircrafts naturally. On the other hand, diving or losing ALT causes the aircraft to gain SPD rapidly. In short, to reach higher or maximum SPD, aircrafts must gain ALT before all else. PW and MRO have the weight factor because of the ammunition and fuel tanks. As the total weight of aircraft increases, so does the gravitational pull, but the climb rate and overall SPD decreases. Thus, if the desired MRO is widened, the fuel demand of aircraft will increase and that means extra weight on the aircraft.

As a general definition, ALT is a distance measurement, usually in the vertical or "up" direction, between a reference datum and a point or object. A higher ALT for an aircraft means covering more ground and reaching farther distances. But gaining such ALT requires more engine power and consequently, more fuel. So, aircraft SPD and MRO are affecting factors here. Also, the load on the aircraft (armament weight, fuel load) affects the ALT performance of the aircraft because of the extra weight which they bring and required extra engine power to climb and carry that weight. When attacking, the type of weapon and ammunition on the aircraft determines the WER and thus, attack altitude and attack angle of the aircraft.

TCPA is the duration of an aircraft to reach the CPA. It is a simple measurement of the SPD, ALT and MNB. In a case of changing a straight attack line, MNB gives us the time to change the route and position in another straight attack line.

CPA IUOT is the duration between CPA and discharging weapons to the DAs. CPA IUOT is also measured by SPD, ALT and MNB, but in addition to them, the attack phase is present in this criteria. In the attack phase, PW and WER play the main roles. They determine the distance to discharge and if this distance is long, CPA IUOT will be shorten, and vice versa.

Similarly, inner and outer relations of proximity sub-criteria are shown in the Figure 3.4. below.

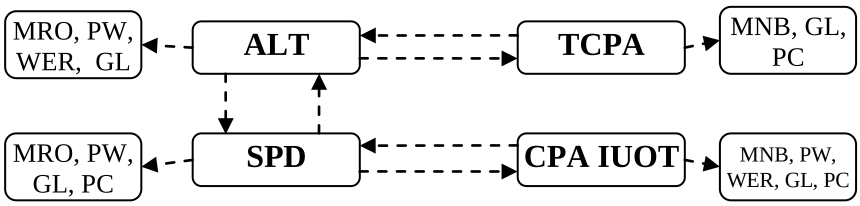

Figure 3.4: Inner relations proximity criterion

3.3.4 Evaluation Model

The general outline of the TE model is shown in Figure 3.5. The "Goal" here is to assign a target value for each target based on evaluation criteria. The arrows on the scheme represents the inner and outer dependencies among clusters.

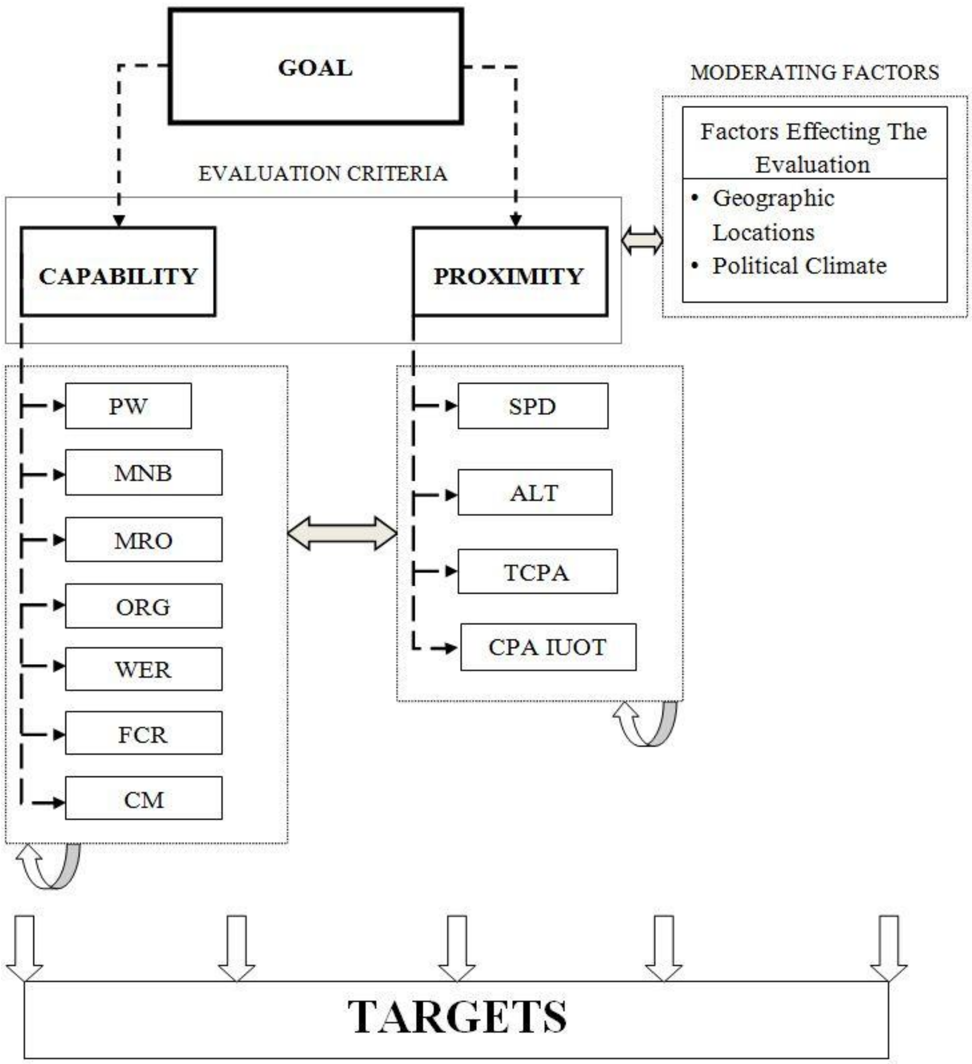

Figure 3.5: Threat Evaluation model

4. ANALYTIC NETWORK PROCESS – ANP

4.1 General Information

ANP is a generalization of Saaty's Analytical Hierarchy Process (AHP), which is one of the most widely used multi-criteria decision support tools. ANP and its supermatrix technique can be considered as an extension of AHP that can handle a more complex decision structure (Saaty, 2001), as the ANP framework has the flexibility to consider more complex inter-relationships (outer-dependence) among different elements.

ANP, incorporates both qualitative and quantitative approaches to a decision problem (Cheng and Li, 2005). It is also capable of capturing the tangible and intangible aspects of relative criteria that have some bearing on the decision making process (Saaty, 2001). Also, ANP can deal with interconnections and inner-dependence between decision factors in the same level.

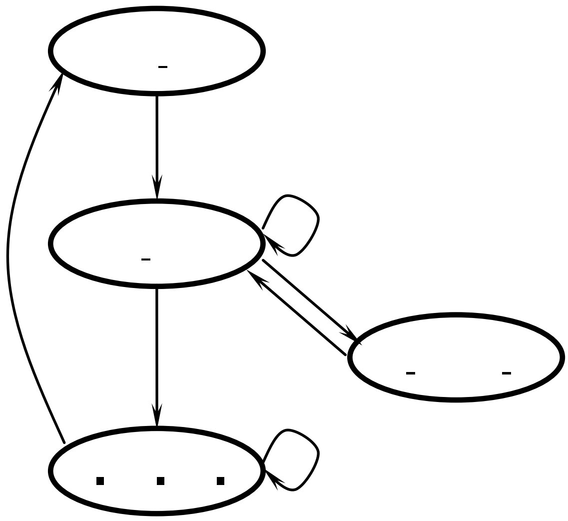

Figure 4.1: Structure of a nonlinear network

ANP has a wide range of applications in the literature. The subject is still quite recent, thus, studies continues increasing in many fields such as strategic policy planning (Ulutaş, 2005, Lee and Kozar, 2006), market and logistic (Meade and Sarkis, 1998, Agarwal et al., 2006, Jharkharia and Shankar, 2007), economics and finance (Niemira and Saaty, 2004, Lu et al., 2015), civil engineering (Neaupane and Piantanakulchai, 2006, Bobylev, 2011), manufacturing systems (Das and Chakraborty, 2011, Milani et al., 2013), territorial and environmental assessment (Promentilla et al., 2008, Aragonés-Beltrán et al., 2010a, Aragonés-Beltrán et al., 2010b), ERP selection (Gürbüz et al., 2012), human resources (Gürbüz, 2010, Lin, 2010, Gürbüz and Albayrak, 2014) and transportation (Tuzkaya and Önüt, 2008).

Table 4.1: Saaty's Fundamental Scale

Value	**Definition**	**Explanation**
1	Equally important	Two decision elements have equal influence on the superior decision element.
3	Moderately more important	One decision element has moderately more influence than the other.
5	Strongly or essentially more important	One decision element has strongly more influence than the other.
7	Very strong or demonstrated importance	One decision element has very strongly more influence than the other.
9	Extremely more important	One decision element has extremely more influence than the other.
2, 4, 6, 8	Intermediate values of judgment	
Reciprocals		If *v* is the judgment value when *i* is compared to *j*, then *1/v* is the judgment value when *j* is compared to *i*.

Thus, ANP consists of three parts: the first part is the control hierarchy for the network of the criteria and sub-criteria, the second part is a network of influences among the elements and clusters, and the third one is the feedback between the various clusters and elements within a cluster.

4.2 Pairwise Comparisons, Eigenvectors and Consistency

In ANP, relative priorities are established in the same way that it is done in AHP. The qualitative aspects are weighted through pairwise comparisons using the fundamental scale given in Table 4.1.

Using the ratings given in Table 4.1, the pairwise comparison matrices $A=(a_{ij})$ are formed as seen below, in order to calculate the relative priorities of the elements forming these matrices in further steps:

$$A\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \text{ where } a_{ij} = {}^{1}\!/_{a_{ji}} \ \ \forall i,j = 1,\dots,n \text{ and } a_{ii} = 1 \ \forall i = 1,\dots,n$$

If the matrix A wouldn't contain errors and the judgments were perfectly consistent, then:

$$a_{kj}.\, a_{kj} = a_{ij} \ \ \forall i,j,k = 1,\dots,n \qquad (4.1)$$

Therefore all the elements in this matrix could be expressed as follows:

$$a_{ij} = {}^{w_i}\!/_{w_j} \ \ \forall i,j = 1,\dots,n \qquad (4.2)$$

And this would yield to the following equality:

$$\begin{bmatrix} {}^{w_1}\!/_{w_1} & {}^{w_1}\!/_{w_2} & \cdots & {}^{w_1}\!/_{w_n} \\ {}^{w_2}\!/_{w_1} & {}^{w_2}\!/_{w_2} & \cdots & {}^{w_2}\!/_{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ {}^{w_n}\!/_{w_1} & {}^{w_n}\!/_{w_2} & \cdots & {}^{w_n}\!/_{w_n} \end{bmatrix} \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} = n \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} \qquad (4.3)$$

If the judgments are not perfectly consistent, the previous equality becomes $Aw=\lambda_{max}\, w$, where λ_{max} is the principal eigenvalue of A. In other words, A is consistent if and only if

$\lambda_{max}=n$ and as Saaty demonstrated, it turns out that the inequality $\lambda_{max} \geq n$ is always true.

The solution can be found by raising the matrix to a sufficiently large power (the Power Method), then performing the column normalization to obtain the relative priority vector $w = (w_1,w_2,...,w_n)$. The process is stopped when the difference between the k^{th} and *k+1st* power of the matrix is smaller than a predetermined small value.

An easy way to get an approximation of the relative priority vector is to make a column normalization of the matrix *A* and then take the arithmetic mean of the rows. Hence:

$$w_i = \sum_{j=1}^{n} \left[a_{ij} / \sum_{k=1}^{n} a_{kj}\right] / n \qquad \forall i = 1, \dots, n \tag{4.4}$$

and

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{\sum_{j=1}^{n} a_{ij} . w_j}{w_i} \tag{4.5}$$

It has to be underlined that for important application; only the eigenvector derivation procedure has to be used because approximations can lead to a wrong ranking of the alternatives.

The consistency index – CI of a comparison matrix is given by:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{4.6}$$

And the consistency ratio – CR is obtained by comparing the CnI value with the random inconsistency – RI values given in the Table 4.2. The judgments in the comparison matrix are said to be consistent and therefore the relative priority vector estimation is accepted if CR value is less than 10%. When greater values are found, the comparison matrix i.e. the judgments in the matrix need to be revised.

Table 4.2: RI Values for Different Size *n* of the Comparison Matrices

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Using these values, the CR value is calculated as follows:

$$CR = CI / RI \qquad (4.7)$$

4.3 Supermatrix

The priorities derived from pairwise comparison matrices are placed into a supermatrix. The supermatrix represents the influence priority of an element on the left of the matrix on an element on the top of the matrix with respect to a particular control criterion. Every element of a component doesn't need to impact an element in another component. Thus those who don't impact are given a zero value for their contribution. Assuming *n* components, C_j where $j = 1, \ldots, n$, with each one having n_j elements, the supermatrix will be as follows:

$$W = \begin{matrix} & \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{matrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{matrix} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1n} \\ W_{21} & W_{22} & \cdots & W_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ W_{n1} & W_{n2} & \cdots & W_{nn} \end{bmatrix} \end{matrix}$$

$$\text{where} \quad W_{ij} = \begin{bmatrix} w_{i1}^{j1} & w_{i1}^{j2} & \cdots & w_{i1}^{jn_j} \\ w_{i2}^{j1} & w_{i2}^{j2} & \cdots & w_{i2}^{jn_j} \\ \vdots & \vdots & \ddots & \vdots \\ w_{in_i}^{j1} & w_{in_i}^{j2} & \cdots & w_{in_i}^{jn_j} \end{bmatrix} \quad \forall i, j = 1, \ldots, n$$

Here, $w_{in_i}^{jn_j}$ represents the impact of the n_i^{th} element of the component *i* on the n_j^{th} element of the component *j*. Therefore, each column in the matrix W_{ij} is a principal eigenvector that represents the impact of all the elements in the i^{th} component on each of the elements in the j^{th} component.

The resulting matrix needs to be stochastic, i.e. the columns have to sum up to one, in order to continue the calculations and obtain meaningful limiting results. It is necessary to compare the components themselves to ensure that. The pairwise comparisons of the components are made with respect to each of the components or according to some attribute presented in a separate control hierarchy for that system. The resulting priorities are used to weight the column vectors of the supermatrix previously obtained. Hence the resulting supermatrix is column stochastic.

The overall priorities of each element of each cluster are given by the solution to:

$$\lim_{n\to\infty} W^{2k+1} \tag{4.8}$$

Now what is desired, if it exists, is the limiting priority of impact of each element on every other element. It has to be noted that if the matrix is positive or if it becomes positive after raising it to some power; it turns out that a unique answer can be obtained. But when no power of the matrix is strictly positive, there may not be a unique limit as in oscillating powers of the matrix where different limits are obtained.

4.4 ANP Procedure

The outline of ANP steps as follows:

i. Describe the decision problem in detail.
ii. Determine all the inter and inner-dependencies that exist in the decision problem and thus construct the general network of the decision problem.
iii. Build the supermatrix by performing the pairwise comparisons.
iv. Perform pairwise comparisons on clusters in order to find the weighted supermatrix.
v. Perform consistency analysis of all the pairwise comparisons.
vi. Find the weighted supermatrix.
vii. Find the limit supermatrix from which the overall score for the alternatives is retrieved.
viii. Make the final decision.

5. NUMERICAL APPLICATION – TEST SCENARIOS

In this section, our objective is to create scenarios to test our model and later, evaluate and comment on the results. The scenarios are based on the aerial attack examples in the past and reformed with the consultation of field experts. Attacking aircraft types and models are selected according to their availability and commonness. There will be a number of detected tracks and one DA in the test models. According to the scenarios, our radar systems detects these tracks with their velocity vectors traverse into or pass nearby our national air space. Some of these tracks will target our DA and approach it from different directions.

After estimating the intent of detected tracks, the ones with hostile intent are taken into consideration as targets. To evaluate these targets using ANP, we need to obtain data to assign to the parameters and use them in the model. Detecting and tracking systems obtain these data and C2 center processes them in a usable form. Some parameters are connected directly to each other. For example, if an aircraft is identified as brand name and model, then it's armament and specifications of these armament such as weight, firing range, blast radius etc. can be retrieved from database.

After identifying the attackers, we extract the data of platform weapons, maneuverability (which is calculated by using thrust-to-weight ratio of aircraft), maximum radius of operation, weapon engagement range from database by reason of these aircrafts have certain specifications and they may vary in an insignificant rate.

5.1 Scenario Assumptions

Some assumptions are made at this point in order to standardize the input data and simplify the evaluation process. They are listed below:

i. The input data for ALT, SPD, TCPA, CPA IUOT, ORG, FCR and CM are randomly generated while the data for PW, MNB, MRO and WER are assumed as maximized based on aircraft specifications.
ii. All commercial aircrafts have the same specifications.
iii. The defending side has borders with attacking sides and the aircrafts are detected out of the borders of defending side.
iv. Commercial aircrafts with unknown fligth plans are assumed to be an element of the side which they are detected within.
v. ORG values of the attacking sides are evaluated by percentage, 0% corresponds to having poor standards while 100% corresponds to having high standards.

5.2 Scenario Elements

To use as input in scenarios, we defined three different aircraft model, one being attack aircraft and other two being multirole fighters. Also, we used Superdecisions software to apply the model to these scenarios. The Superdecision software allowed us to implement the model with dependence and feedback.

Eurofighter Typhoon

The Eurofighter Typhoon is a twin-engine, canard-delta wing, multirole fighter. The Eurofighter Typhoon is a highly agile aircraft, designed to be an effective dogfighter when in combat with other aircraft; later production aircraft have been increasingly more well-equipped to undertake air-to-surface strike missions and to be compatible with an increasing number of different armaments and equipment. Eurofighter Typhoon is ideally suited to Close Air Support as it can remain on task for long periods with large, flexible weapon loads, such as Paveway IV and the Brimstone Air-to-Surface precision attack weapon[2].

Technical Specifications (I.H.S., 2013):

- Type: Multirole fighter
- Empty weight: 11,000 kg (24,250 lb)
- Loaded weight: 16,000 kg (35,270 lb)

[2] Benefits to Industry. Available from: http://www.eurofighter.com/advantages

- Powerplant: 2 × Eurojet EJ200 afterburning turbofan
- Dry thrust: 60 kN (13,490 lbf) each
- Thrust with afterburner: >90 kN (20,230 lbf) each
- Maximum speed:
    - At altitude: Mach 2 class
    - Supercruise: Mach 1.5
- Service ceiling: 19,812 m (65,000 ft)
- Range: 2,900 km (1,565 nmi)
- Thrust/weight: 1.15
- Hardpoints: Total of 13: 8 × under-wing; and 5 × under-fuselage pylon stations; holding up to 7,500 kg (16,500 lb) of payload. For air-to-ground attacks, Eurofighter carries:
    - 4x laser guided GBU-16 Paveway II – Mk 83 1000 lb (454 kg) bombs.
- Maximum firing range: Over 14.8 kilometres (8.0 nmi)

Lockheed Martin F-22 Raptor

The Lockheed Martin F-22 Raptor is a single-seat, twin-engine, all weather stealth tactical fighter aircraft developed for the United States Air Force (USAF). The result of the USAF's Advanced Tactical Fighter program, the aircraft was designed primarily as an air superiority fighter, but has additional capabilities including ground attack, electronic warfare, and signals intelligence roles (Reed, 2009).

Technical Specifications (Ayton, 2008):

- Type: Multirole fighter
- Empty weight: 19,700 kg (43,340 lb)
- Loaded weight: 29,300 kg (64,460 lb)
- Powerplant: 2 × Pratt & Whitney F119-PW-100 pitch thrust vectoring turbofans
- Dry thrust: 104 kN (23,500 lb) each
- Thrust with afterburner: 156+ kN (35,000+ lb) each
- Maximum speed:
    - At altitude: Mach 2.25 (1,500 mph, 2,410 km/h) [estimated]
    - Supercruise: Mach 1.82 (1,220 mph, 1,960 km/h)
- Service ceiling: >20,000 m (65,000 ft)

- Range: >2960 km (1,600 nmi) with 2 external fuel tanks
- Thrust/weight: 1.09
- Hardpoints: 4× under-wing pylon stations can be fitted to carry 600 U.S. gallon drop tanks or weapons, each with a capacity of 2,270 kg (5,000 lb). For air-to-ground attacks, F-22 carries:
  - 2x 1,000 lb (450 kg) JDAM
- Maximum firing range: Up to 28 kilometers (15 nmi)

Sukhoi Su-34

The Sukhoi Su-34 (Russian: Сухой Су-34) (export designation: Su-32, NATO reporting name: Fullback) is a Russian twin-seat fighter-bomber. It is intended to replace the Sukhoi Su-24.

Based on Sukhoi Su-27 'Flanker', the two-seat Su-34 is designed for tactical deployment against air, ground and naval targets (including small and mobile targets) on solo and group missions in daytime and at night, under favourable and adverse weather conditions and in a hostile environment with counter-fire and EW counter-measures deployed, as well as for air reconnaissance[3].

Technical Specifications:

- Type: Fighter/Bomber
- Empty weight: 22,500 kg (49,608 lb)
- Max. takeoff weight: 45,100 kg (99,425 lb)
- Powerplant: 2 × 13,500 kgf (132 kN, 29,762 lbf) afterburning thrust Lyulka AL-31FM1 turbofans
- Maximum speed:
  - High altitude: Mach 1.8+ (≈2,000 km/h, 1,200 mph)
  - Low altitude: Mach 1.2 (1,400 km/h, 870 mph) at sea level
- Service ceiling: 15,000 m (49,200 ft)
- Range: 1,100 km (680 mi) at low level altitude
- Thrust/weight: 0.68

[3] Sukhoi Su-34. Available from: http://www.sukhoi.org/eng/planes/military/su32

- Hardpoints: 12× wing and fuselage stations with a capacity of 8,000–12,000 kg and provisions to carry combinations of air-to-ground attack armaments:
  - 6× Kh-29L air-to-ground missile 660 kg (1,460 lb) each
  - 3× KAB-1500L guided bombs 1500 kg (3,306 lb) each
- Maximum firing range:
  - Kh-29L: 10 km (5.4 nmi)
  - KAB-1500L: 1 to 15 km (0,5 to 8 nmi) depending on speed and altitude

5.3 Test Scenario 1

In this scenario, 5 generated tracks are detected near the border of defending side and checked for their intents. As seen in Table 5.1, all five tracks are identified as hostile intended according to our intent estimation model. Implementation phase of the model can be seen in Figure 5.1.

Table 5.1: Scenario 1 estimated intents of detected tracks

Tracks	**Heading**	**Known Flight Plan**	**Platform Type**	**Fire Control Radar**	**Countermeasures**	**INTENT**
Track 1	No	No	F	1	Positive	Hostile
Track 2	No	Yes	F	1	Positive	Hostile
Track 3	Yes	No	CA	0	Negative	Hostile
Track 4	Yes	No	F	0	Negative	Hostile
Track 5	Yes	Yes	F	1	Negative	Hostile

In Table 5.2, it is shown that these five targets are originated from two different attacking sides. Both sides have two Eurofighter Typhoon approaching to the defending side. There is a commercial aircraft detected approaching from the second attacking side which identified as hostile intended by the reason of flight plan of the aircraft is unknown. ORG values of the first and second attacking sides are 80% and 50%, respectively.

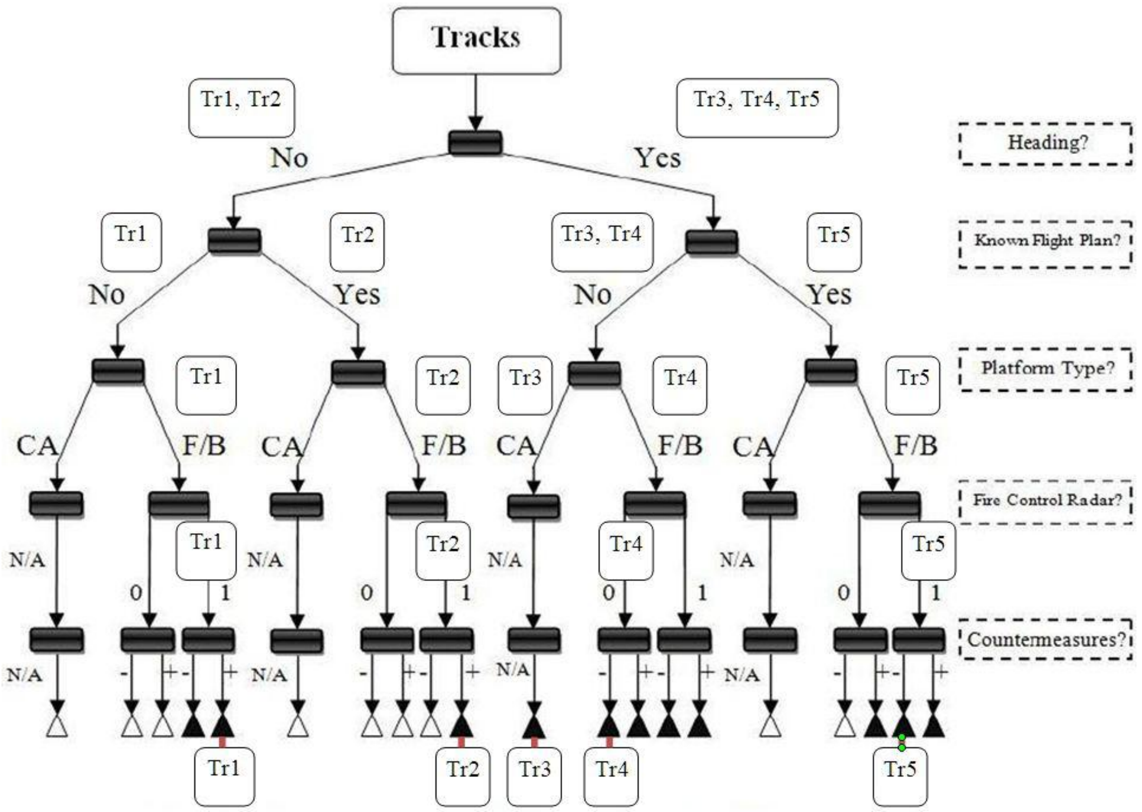

Figure 5.1: Scenario 1 intent modeling of tracks

Table 5.2: Scenario 1 track data

Targets	ID	ALT (m)	SPD (Km/h)	TCPA (mins)	CPA IUOT (mins)	PW (kg)	MNB (t/w)	MRO (Km)	ORG	WER (Km)	FCR	CM
T1	EUT	10500	1100	24	21	1816	1.15	2900	1	15	1	1
T2	EUT	9500	1050	59	23	1816	1.15	2900	1	15	1	1
T3	CA	8800	840	38	30	0	0.15	7500	1	0	0	0
T4	EUT	13000	1270	25	1	1816	1.15	2900	2	15	0	0
T5	EUT	12500	1240	27	1	1816	1.15	2900	2	15	1	0

The result in Table 5.3 shows that Track 4 has the biggest target value among other tracks. Track 5 follows it with the second biggest target value. They both have the lowest ORG and CPA IUOT values and the lowest TBH values consequently. Hence, this causes widening the gap between them and other tracks. The commercial aircraft has the only superiority in MRO value and has no PW or WER values naturally. So the value of Track 3 seems reasonable considering the rest of the target values.

Table 5.3: Scenario 1 target values

Alternatives	Total	Normal	Ideal	Ranking
Target 1	0.0065	0.1916	0.737	3
Target 2	0.0059	0.1751	0.6735	4
Target 3	0.0039	0.1144	0.44	5
Target 4	0.0088	0.2599	1	1
Target 5	0.0088	0.2591	0.9967	2

5.4 Test Scenario 2

This scenario has also five generated tracks (Table 5.4), one of them is a bomber but CAs are absent in this instance and implementation phase of the model can be seen in Figure 5.2.

Three different attacking sides are present and ORG values of the first, second and third sides are 30%, 50% and 80%, respectively (Table 5.5). The first side has one F-22 Raptor and one Sukhoi SU-34, the second side has only one Eurofighter Typhoon and the third side has two F-22s as it is perceived.

Table 5.4: Scenario 2 estimated intents of detected tracks

Tracks	Heading	Known Flight Plan	Platform Type	Fire Control Radar	Countermeasures	INTENT
Track 1	Yes	No	F	1	Negative	Hostile
Track 2	No	No	F	1	Negative	Hostile
Track 3	Yes	No	B	1	Positive	Hostile
Track 4	Yes	Yes	F	0	Positive	Hostile
Track 5	Yes	No	F	1	Positive	Hostile

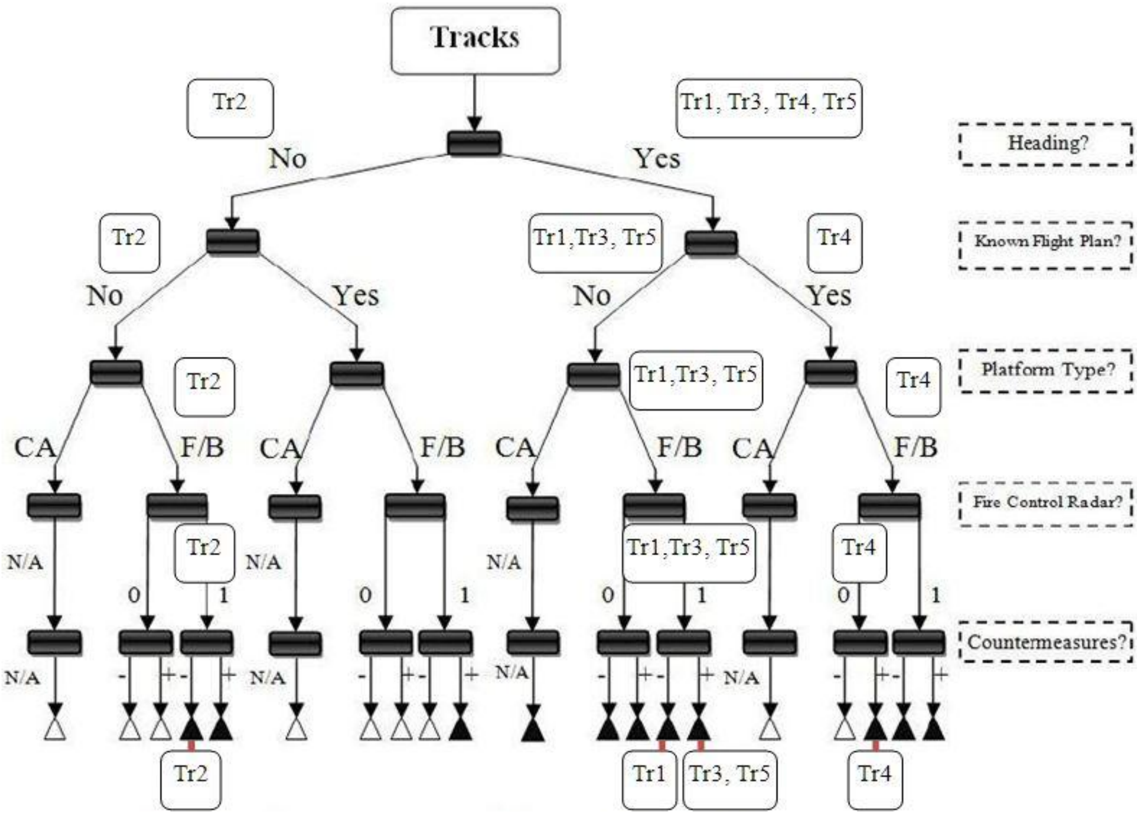

Figure 5.2: Scenario 2 intent modeling of tracks

Track 1 and Track 3 have the biggest target values in results of scenario 2 as seen in Table 5.6. They have the same ORG values but their aircraft types differ, one fighter and one bomber. SU-34 is a heavy fighter and is not rapid and agile as F-22. The reason they have fractional diference in target values is that SU-34 is a heavy bombardment aircraft and has much more armament capacity compared to F-22. Thus, it compensates the lower values which SU-34 gets from ALT, SPD, MNB, etc.

Table 5.5: Scenario 2 track data

Targets	**ID**	**ALT (m)**	**SPD (Km/h)**	**TCPA (mins)**	**CPA IUOT (mins)**	**PW (kg)**	**MNB (t/w)**	**MRO (Km)**	**ORG**	**WER (Km)**	**FCR**	**CM**
T1	F22	12500	1170	16	1	900	1.09	3000	1	28	1	0
T2	EUT	11000	1020	48	15	1816	1.15	2900	2	15	0	0
T3	S34	9500	990	28	1	8460	0.68	1100	1	10	1	1
T4	F22	10000	1130	23	5	900	1.09	3000	3	28	0	1
T5	F22	9500	1040	24	1	900	1.09	3000	3	28	1	1

Table 5.6: Scenario 2 target values

Alternatives	Total	Normal	Ideal	Ranking
Target 1	0.0082	0.2484	0.9323	2
Target 2	0.005	0.1521	0.571	4
Target 3	0.0088	0.2664	1	1
Target 4	0.0049	0.148	0.5556	5
Target 5	0.0061	0.185	0.6944	3

5.5 Test Scenario 3

Four fighter, two bomber and four commercial aircrafts, with a total of ten detected tracks given in Table 5.7 which are put in the intent estimation process in scenario 3 as it can be seen in Figure 5.3. There is also three different attacking sides here and ORG values are 50%, 80% and 30% for side 1, 2 and 3, respecticely.

Table 5.7: Scenario 3 estimated intents of detected tracks

Tracks	Heading	Known Flight Plan	Platform Type	Fire Control Radar	Countermeasures	INTENT
Track 1	No	Yes	CA	0	Negative	Non-Hostile
Track 2	Yes	No	F	1	Positive	Hostile
Track 3	Yes	No	F	0	Positive	Hostile
Track 4	No	No	CA	0	Negative	Non-Hostile
Track 5	Yes	No	B	1	Positive	Hostile
Track 6	Yes	No	B	1	Positive	Hostile
Track 7	Yes	No	CA	0	Negative	Hostile
Track 8	Yes	No	CA	0	Negative	Hostile
Track 9	Yes	No	F	1	Positive	Hostile
Track 10	Yes	No	F	1	Positive	Hostile

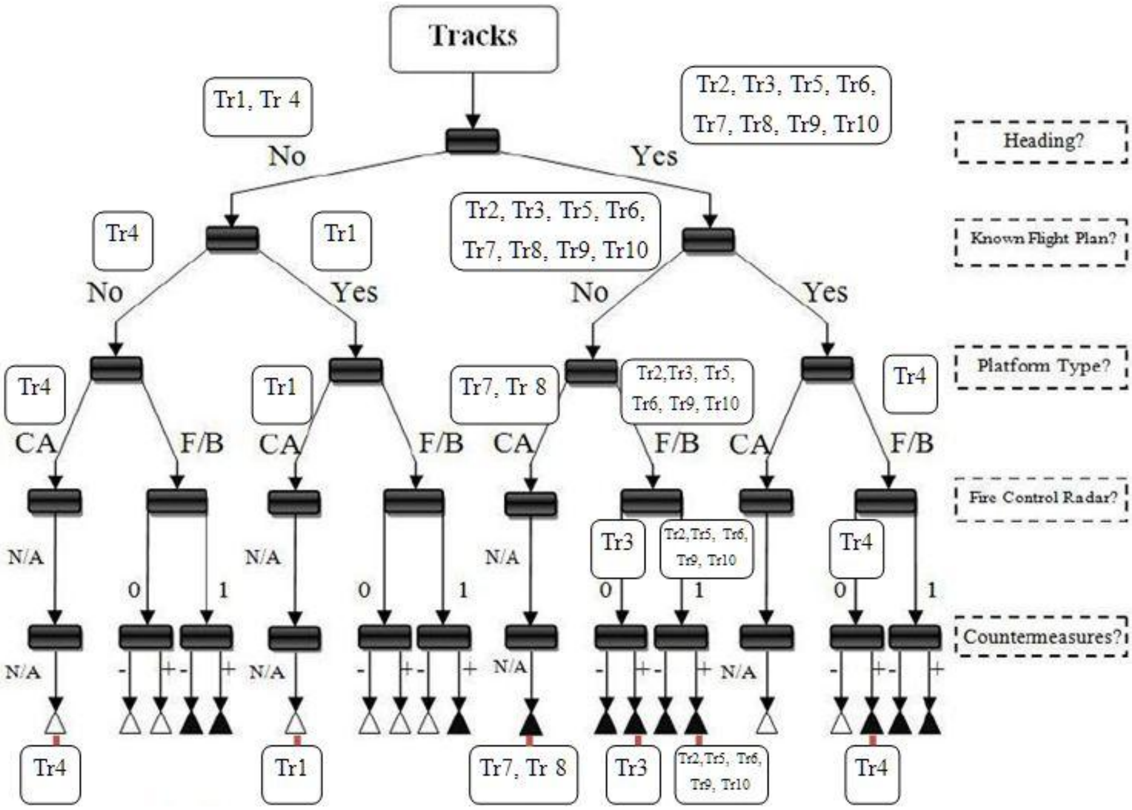

Figure 5.3: Scenario 3 intent modeling of tracks

Table 5.8: Scenario 3 track data

Targets	ID	ALT (m)	SPD (Km/h)	TCPA (mins)	CPA IUOT (mins)	PW (kg)	MNB (t/w)	MRO (Km)	ORG	WER (Km)	FCR	CM
T1	-	-	-	-	-	-	-	-	-	-	-	-
T2	EUT	8700	1080	31	3	1816	1.15	2900	1	15	0	1
T3	F22	14000	1360	16	5	900	1.09	3000	3	28	0	0
T4	-	-	-	-	-	-	-	-	-	-	-	-
T5	S34	8000	850	28	1	8460	0.68	1100	1	10	1	1
T6	S34	6500	780	23	1	8460	0.68	1100	2	10	1	0
T7	CA	8700	910	48	20	0	0.15	7500	3	0	0	0
T8	CA	8230	780	52	24	0	0.15	7500	1	0	0	0
T9	F22	7000	885	18	4	900	1.09	3000	2	28	0	1
T10	EUT	13000	1110	19	1	1816	1.15	2900	3	15	1	1

The two bomber aircrafts, Track 5 and Track 6, has the biggest target values as a result of the estimation process (Table 5.9). Their short TBH and high PW values have put

Table 5.9: Scenario 3 target values

Alternatives	Total	Normal	Ideal	Ranking
Target 2	0.0039	0.1138	0.6153	6
Target 3	0.004	0.1168	0.6316	5
Target 5	0.0056	0.1656	0.8957	2
Target 6	0.0063	0.1849	1	1
Target 7	0.0023	0.0686	0.3708	8
Target 8	0.0026	0.0776	0.4199	7
Target 9	0.0045	0.1326	0.7173	4
Target 10	0.0048	0.1401	0.7577	3

them as the primary targets on the list. The CAs have the lowest target values but not a major differentiation for not keeping track of. The two bomber aircrafts are assigned with the highest values and become primary targets in the process.

Using the relative importance vectors obtained from the cluster comparison matrices, the cluster matrix is formed as shown below in Table 5.10 and the priorities of the criteria can be seen in Table 5.11. After making all the pairwise comparisons, the unweighted, weighted supermatrices and the limit supermatrix are constructed by using "Super Decisions" software as shown in appendix section.

Table 5.10: Cluster matrix

	Proximity	Capability	Moderating Factors	Alternatives
Proximity	0.619	0.235	0.333	0
Capability	0.275	0.655	0.667	0
Moderating Factors	0.074	0.081	0	0
Alternatives	0.031	0.028	0	0

Table 5.11: Relative priorities of criteria

	Normalized By Cluster	Limiting
Altitude	0.257	0.127
CPA in Units of Time	0.205	0.101
Speed	0.372	0.184
Time to CPA	0.166	0.082
Countermeasures	0.024	0.009
Fire Control Radar	0.085	0.033
Maneuvrability	0.082	0.032
Maximum Radius of Operation	0.053	0.020
Origin	0.297	0.115
Platform Weapons	0.355	0.137
Weapon Engagement Range	0.105	0.040
Geographic Locations	0.527	0.045
Political Climate	0.473	0.041

6. CONCLUSION

This thesis study presents a new approach to the TE by defining the parameters widely and using them in an ANP model as a network structure. TEWA process is defined briefly as a beginning. TEWA is a two-phase process and TE is the first step of it and described with details in earlier sections. By doing so, we clarified why TE is important and where and how it is used in the process of WA.

After 9/11 attacks on World Trade Center buildings, commercial aircrafts has been under a lot of suspicion and investigation. In all of aviation history, commercial aircrafts have never been this much of a center of attention and have not been considered as a possible threat to national defense. Considering this and previous studies that did not take CAs into consideration, we added CAs to our TE process as possible threats and assign them threat values as a result.

Our main objective in this study is to eliminate targets that do not pose a threat and evaluate real threats. Intent estimation is the first step we take in this process. Intent estimation model in this study is based on observations and eliminations and used for determining actual targets. Then these actual targets are evaluated via our ANP model.

Many methods are used in TE concept in the past studies. Saaty's ANP is not yet experienced in the field and so we applied this method in order to extend the past studies and define the relations between parameters more thoroughly. In earlier studies, TE process deeply investigated and a number of parameters are stated as the commonly used parameters and most of the researches are made on the basis of them. We used these parameters as well with a different perspective. We mainly focused on the relations between parameters and their direct effects on each other. A network is created to show these relations, degrees of effects weights of the criteria. Considering the promising and purposeful results that are obtained, it can be said that ANP is a preferable method for this concept. After that, these values can be easily integrated into the WA process both static and dynamic form as further studies.

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APPENDIX: Supermatrices

Unweighted Supermatrix for Scenario 1

	ALT	CPA IUOT	SPD	TCPA	CM	FCR	MNB	MRO	ORG	PW	WER	GL	PC	T1	T2	T3	T4	T5
ALT	0.00	0.40	0.20	0.40	0.00	0.00	0.00	0.09	0.00	0.71	0.21	1.00	0.00	0.19	0.18	0.16	0.24	0.23
CPA IUOT	0.20	0.00	0.80	0.00	0.00	0.00	0.07	0.00	0.00	0.47	0.47	0.90	0.10	0.02	0.02	0.02	0.47	0.47
SPD	0.20	0.40	0.00	0.40	0.00	0.00	0.00	0.14	0.00	0.86	0.00	0.90	0.10	0.20	0.19	0.15	0.23	0.23
TCPA	0.33	0.00	0.67	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.89	0.11	0.27	0.11	0.13	0.26	0.23
CM	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.50	0.50	0.00	0.00	0.00
FCR	0.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.80	0.00	0.00	0.33	0.33	0.00	0.00	0.33
MNB	0.20	0.00	0.80	0.00	0.00	0.00	0.00	0.07	0.53	0.39	0.00	1.00	0.00	0.24	0.24	0.03	0.24	0.24
MRO	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.90	0.00	1.00	0.00	0.15	0.15	0.39	0.15	0.15
ORG	0.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.16	0.16	0.16	0.26	0.24
PW	0.11	0.65	0.24	0.00	0.00	0.35	0.00	0.09	0.56	0.00	0.00	0.20	0.80	0.25	0.25	0.00	0.25	0.25
WER	0.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.80	0.20	0.25	0.25	0.00	0.25	0.25
GL	1.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PC	1.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Weighted Supermatrix for Scenario 1

	ALT	CPA IUOT	SPD	TCPA	CM	FCR	MNB	MRO	ORG	PW	WER	GL	PC	T1	T2	T3	T4	T5
ALT	0.00	0.25	0.12	0.25	0.00	0.00	0.00	0.02	0.00	0.19	0.06	0.07	0.00	0.01	0.01	0.01	0.01	0.01
CPA IUOT	0.12	0.00	0.50	0.00	0.00	0.00	0.02	0.00	0.00	0.13	0.13	0.07	0.01	0.00	0.00	0.00	0.01	0.01
SPD	0.12	0.25	0.00	0.25	0.00	0.00	0.00	0.04	0.00	0.24	0.00	0.07	0.01	0.01	0.01	0.00	0.01	0.01
TCPA	0.21	0.00	0.41	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00	0.07	0.01	0.01	0.00	0.00	0.01	0.01
CM	0.00	0.00	0.00	0.24	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.08	0.00	0.01	0.01	0.00	0.00	0.00
FCR	0.09	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.57	0.00	0.00	0.01	0.01	0.00	0.00	0.01
MNB	0.05	0.00	0.19	0.00	0.00	0.00	0.00	0.05	0.35	0.26	0.00	0.08	0.00	0.01	0.01	0.00	0.01	0.01
MRO	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.59	0.00	0.08	0.00	0.00	0.00	0.01	0.00	0.00
ORG	0.23	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.01	0.01	0.01	0.02	0.02
PW	0.03	0.15	0.06	0.00	0.00	0.23	0.00	0.06	0.37	0.00	0.00	0.02	0.06	0.01	0.01	0.00	0.01	0.01
WER	0.08	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.06	0.02	0.01	0.01	0.00	0.01	0.01
GL	0.33	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PC	0.33	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Limit Supermatrix for Scenario 1

	ALT	CPA IUOT	SPD	TCPA	CM	FCR	MNB	MRO	ORG	PW	WER	GL	PC	T1	T2	T3	T4	T5
ALT	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.01	0.01	0.00	0.01	0.01
CPA IUOT	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.01	0.01	0.00	0.01	0.01
SPD	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.01	0.01	0.00	0.01	0.01
TCPA	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.01	0.01	0.00	0.01	0.01
CM	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.01	0.01	0.00	0.01	0.01
FCR	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.01	0.01	0.00	0.01	0.01
MNB	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.01	0.01	0.00	0.01	0.01
MRO	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.01	0.01	0.00	0.01	0.01
ORG	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.01	0.01	0.00	0.01	0.01
PW	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.01	0.01	0.00	0.01	0.01
WER	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.01	0.01	0.00	0.01	0.01
GL	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.01	0.01	0.00	0.01	0.01
PC	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.01	0.01	0.00	0.01	0.01
T1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Unweighted Supermatrix for Scenario 2

	ALT	CPA IUOT	SPD	TCPA	CM	FCR	MNB	MRO	ORG	PW	WER	GL	PC	T1	T2	T3	T4	T5
ALT	0.00	0.40	0.20	0.40	0.00	0.00	0.00	0.09	0.00	0.71	0.21	1.00	0.00	0.28	0.25	0.02	0.23	0.22
CPA IUOT	0.20	0.00	0.80	0.00	0.00	0.00	0.07	0.00	0.00	0.47	0.47	0.90	0.10	0.31	0.02	0.31	0.06	0.31
SPD	0.20	0.40	0.00	0.40	0.00	0.00	0.00	0.14	0.00	0.86	0.00	0.90	0.10	0.22	0.19	0.19	0.21	0.19
TCPA	0.33	0.00	0.67	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.89	0.11	0.31	0.10	0.18	0.21	0.20
CM	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.33	0.33	0.33
FCR	0.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.80	0.00	0.00	0.33	0.00	0.33	0.00	0.33
MNB	0.20	0.00	0.80	0.00	0.00	0.00	0.00	0.07	0.53	0.39	0.00	1.00	0.00	0.21	0.23	0.13	0.21	0.21
MRO	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.90	0.00	1.00	0.00	0.23	0.22	0.08	0.23	0.23
ORG	0.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.30	0.18	0.30	0.11	0.11
PW	0.11	0.65	0.24	0.00	0.00	0.56	0.00	0.09	0.35	0.00	0.00	0.20	0.80	0.07	0.14	0.65	0.07	0.07
WER	0.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.80	0.20	0.26	0.14	0.09	0.26	0.26
GL	1.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PC	1.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Weighted Supermatrix for Scenario 2

	ALT	CPA IUOT	SPD	TCPA	CM	FCR	MNB	MRO	ORG	PW	WER	GL	PC	T1	T2	T3	T4	T5
ALT	0.00	0.25	0.12	0.25	0.00	0.00	0.00	0.02	0.00	0.19	0.06	0.07	0.00	0.01	0.01	0.00	0.01	0.01
CPA IUOT	0.12	0.00	0.50	0.00	0.00	0.00	0.02	0.00	0.00	0.13	0.13	0.07	0.01	0.01	0.00	0.01	0.00	0.01
SPD	0.12	0.25	0.00	0.25	0.00	0.00	0.00	0.04	0.00	0.24	0.00	0.07	0.01	0.01	0.01	0.01	0.01	0.01
TCPA	0.21	0.00	0.41	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00	0.07	0.01	0.01	0.00	0.01	0.01	0.01
CM	0.00	0.00	0.00	0.24	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.01	0.01	0.01
FCR	0.09	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.57	0.00	0.00	0.01	0.00	0.01	0.00	0.01
MNB	0.05	0.00	0.19	0.00	0.00	0.00	0.00	0.05	0.35	0.26	0.00	0.08	0.00	0.01	0.01	0.00	0.01	0.01
MRO	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.59	0.00	0.08	0.00	0.01	0.01	0.00	0.01	0.01
ORG	0.23	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.02	0.01	0.02	0.01	0.01
PW	0.03	0.15	0.06	0.00	0.00	0.37	0.00	0.06	0.23	0.00	0.00	0.02	0.06	0.00	0.00	0.02	0.00	0.00
WER	0.08	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.06	0.02	0.01	0.00	0.00	0.01	0.01
GL	0.33	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PC	0.33	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Limit Supermatrix for Scenario 2

	ALT	CPA IUOT	SPD	TCPA	CM	FCR	MNB	MRO	ORG	PW	WER	GL	PC	T1	T2	T3	T4	T5
ALT	0.12	0.10	0.18	0.08	0.01	0.06	0.03	0.02	0.09	0.15	0.05	0.04	0.04	0.01	0.01	0.01	0.00	0.01
CPA IUOT	0.12	0.10	0.18	0.08	0.01	0.06	0.03	0.02	0.09	0.15	0.05	0.04	0.04	0.01	0.01	0.01	0.00	0.01
SPD	0.12	0.10	0.18	0.08	0.01	0.06	0.03	0.02	0.09	0.15	0.05	0.04	0.04	0.01	0.01	0.01	0.00	0.01
TCPA	0.12	0.10	0.18	0.08	0.01	0.06	0.03	0.02	0.09	0.15	0.05	0.04	0.04	0.01	0.01	0.01	0.00	0.01
CM	0.12	0.10	0.18	0.08	0.01	0.06	0.03	0.02	0.09	0.15	0.05	0.04	0.04	0.01	0.01	0.01	0.00	0.01
FCR	0.12	0.10	0.18	0.08	0.01	0.06	0.03	0.02	0.09	0.15	0.05	0.04	0.04	0.01	0.01	0.01	0.00	0.01
MNB	0.12	0.10	0.18	0.08	0.01	0.06	0.03	0.02	0.09	0.15	0.05	0.04	0.04	0.01	0.01	0.01	0.00	0.01
MRO	0.12	0.10	0.18	0.08	0.01	0.06	0.03	0.02	0.09	0.15	0.05	0.04	0.04	0.01	0.01	0.01	0.00	0.01
ORG	0.12	0.10	0.18	0.08	0.01	0.06	0.03	0.02	0.09	0.15	0.05	0.04	0.04	0.01	0.01	0.01	0.00	0.01
PW	0.12	0.10	0.18	0.08	0.01	0.06	0.03	0.02	0.09	0.15	0.05	0.04	0.04	0.01	0.01	0.01	0.00	0.01
WER	0.12	0.10	0.18	0.08	0.01	0.06	0.03	0.02	0.09	0.15	0.05	0.04	0.04	0.01	0.01	0.01	0.00	0.01
GL	0.12	0.10	0.18	0.08	0.01	0.06	0.03	0.02	0.09	0.15	0.05	0.04	0.04	0.01	0.01	0.01	0.00	0.01
PC	0.12	0.10	0.18	0.08	0.01	0.06	0.03	0.02	0.09	0.15	0.05	0.04	0.04	0.01	0.01	0.01	0.00	0.01
T1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Unweighted Supermatrix for Scenario 3

	ALT	CPA IUOT	SPD	TCPA	CM	FCR	MNB	MRO	ORG	PW	WER	GL	PC	T1	T2	T3	T4	T5	T6	T7	T8
ALT	0.00	0.40	0.20	0.40	0.00	0.00	0.00	0.09	0.00	0.71	0.21	1.00	0.00	0.12	0.19	0.11	0.09	0.12	0.11	0.09	0.18
CPA IUOT	0.20	0.00	0.80	0.00	0.00	0.00	0.07	0.00	0.00	0.47	0.47	0.90	0.10	0.09	0.05	0.26	0.26	0.01	0.01	0.06	0.26
SPD	0.20	0.40	0.00	0.40	0.00	0.00	0.00	0.14	0.00	0.86	0.00	0.90	0.10	0.14	0.18	0.11	0.10	0.12	0.10	0.11	0.14
TCPA	0.33	0.00	0.67	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.89	0.11	0.10	0.19	0.11	0.13	0.06	0.06	0.17	0.16
CM	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.25	0.00	0.25	0.00	0.00	0.00	0.25	0.25
FCR	0.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.80	0.00	0.00	0.00	0.00	0.33	0.33	0.00	0.00	0.00	0.33
MNB	0.20	0.00	0.80	0.00	0.00	0.00	0.00	0.07	0.53	0.39	0.00	1.00	0.00	0.19	0.18	0.11	0.11	0.02	0.02	0.18	0.19
MRO	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.90	0.00	1.00	0.00	0.10	0.10	0.04	0.04	0.26	0.26	0.10	0.10
ORG	0.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.12	0.08	0.12	0.20	0.08	0.12	0.20	0.08
PW	0.11	0.65	0.24	0.00	0.00	0.35	0.00	0.09	0.56	0.00	0.00	0.20	0.80	0.08	0.04	0.38	0.38	0.00	0.00	0.04	0.08
WER	0.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.80	0.20	0.14	0.26	0.09	0.09	0.00	0.00	0.26	0.14
GL	1.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PC	1.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Weighted Supermatrix for Scenario 3

	ALT	CPA IUOT	SPD	TCPA	CM	FCR	MNB	MRO	ORG	PW	WER	GL	PC	T1	T2	T3	T4	T5	T6	T7	T8
ALT	0.00	0.25	0.12	0.25	0.00	0.00	0.00	0.02	0.00	0.19	0.06	0.07	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
CPA IUOT	0.12	0.00	0.50	0.00	0.00	0.00	0.02	0.00	0.00	0.13	0.13	0.07	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01
SPD	0.12	0.25	0.00	0.25	0.00	0.00	0.00	0.04	0.00	0.24	0.00	0.07	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
TCPA	0.21	0.00	0.41	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00	0.07	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01
CM	0.00	0.00	0.00	0.24	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.08	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.01
FCR	0.09	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.57	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01
MNB	0.05	0.00	0.19	0.00	0.00	0.00	0.00	0.05	0.35	0.26	0.00	0.08	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01
MRO	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.59	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
ORG	0.23	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01
PW	0.03	0.15	0.06	0.00	0.00	0.23	0.00	0.06	0.37	0.00	0.00	0.02	0.06	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
WER	0.08	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.06	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00
GL	0.33	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PC	0.33	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Limit Supermatrix for Scenario 3

	ALT	CPA IUOT	SPD	TCPA	CM	FCR	MNB	MRO	ORG	PW	WER	GL	PC	T1	T2	T3	T4	T5	T6	T7	T8
ALT	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
CPA IUOT	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
SPD	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
TCPA	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
CM	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
FCR	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
MNB	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
MRO	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
ORG	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
PW	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
WER	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
GL	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
PC	0.13	0.10	0.18	0.08	0.01	0.03	0.03	0.02	0.11	0.14	0.04	0.05	0.04	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
T1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

BIOGRAPHICAL SKETCH

Seçkin Ünver was born in 1986 in Kayseri and has finished his high school education in Kayseri Nuh Mehmet Baldöktü Anadolu Lisesi in 2005. Then he was accepted to Yıldız Technical University Industrial Engineering Department and completed his B.Sc. on Industrial Engineering in 2011. He was accepted to Galatasaray University in 2012 and completes his M.Sc. on Industrial Engineering in 2015. His general interest areas are mathematical programming and heuristic algorithms.