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# Improving the Kill Chain for Prosecution of Time Sensitive Targets

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## 1. Introduction

Command and control (C2) is an essential part of all military operations and activities. It is the means by which a commander recognises what to achieve and the means to ensure that appropriate actions are taken. C2 helps the commander achieve organised engagements with the enemy through the coordinated use of soldiers, platforms and information. However, war is a poorly understood phenomenon characterised by one complex system interacting with another in a fiercely competitive way. In order to effectively control such a dynamic and complex environment, the commander needs at their disposal a C2 system that can capture the battlespace dynamics and be capable of reacting and undertaking actions that produce desired effects. Through planning (whether immediate or deliberate), the commander determines the aims and objectives of the operation, develops concepts of operation, then allocates resources and provides for necessary coordination accordingly.

The term "fog of war" succinctly describes the level of ambiguity in situational awareness in military operations. Good C2 aims to deal with uncertainty so that the commander can decide on an appropriate course of action to positively shape the campaign. One may break through the fog of war by acquiring more knowledge of the situation, but it takes time to gain and process information. Unfortunately, any C2 system also needs to be fast, at least faster than the adversary's OODA (Observe, Orient, Decide and Act) loop (Brehmer, 2005). The resulting tension between coping with uncertainty and time constraints presents a fundamental challenge of C2 (Department of the Navy, 1996).

An essential element of a C2 system is its organisation of people (Wilcox, 2005) working to achieve the commander's intent through formal processes, networks, and the application of sensors and weapons systems. C2 staff gather information, make decisions, take action, communicate and cooperate with one another in the accomplishment of a common goal. Not surprisingly, a C2 system sometimes fails to respond to clear opportunities because the people lack the coordinating abilities required to manage resources effectively and efficiently. The cognitive and cooperative skills of such a C2 organisation prosecuting the mission could ultimately determine the success or failure of military operations (Bakken *et al.*, 2004).

### 1.1 Air power and targeting

Application of air power is a primary element of modern military campaigns. Central to successful application of air power is the selection and prosecution of targets that represent

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critical vulnerabilities of an adversary. Responsibility for planning, tasking and controlling assigned air and space assets is typically assigned to an Air and Space Operations Centre (AOC). Targeting is a central function of an AOC, selecting and prioritising targets and matching appropriate actions to those targets to produce desired effects (Royal Australian Air Force, 2008).

An AOC is a high tempo multitask environment staffed by a dedicated team of specialists who exercise multiple responsibilities to ensure that air assets are coordinated to achieve maximum effect. Two forms of targeting are used in an AOC. Execution of present-day air campaigns is based on a systematic process, called the air tasking cycle, to conduct deliberate targeting. The air tasking cycle consists of six phases, as shown in Fig. 1, in which the first four involve planning and tasking, followed by force execution and completed by operational assessment (US Air Force, 2006). The product of planning is an Air Battle Plan (ABP) containing an Air Tasking Order (ATO) for scheduling sorties.

Fig. 1. Phases of the air tasking cycle.

The air tasking cycle is the central mechanism employed by an AOC that translates the commander's intent into actions against targets. The intent informs strategy development that is used to decide on the desired effects together with the military orders (actions) consisting of the best available means to achieve the stated objectives. Through this cyclical process, an AOC plans, tasks and controls joint air missions to coordinate and synchronise joint fires (Air Force actions in conjunction with other force element strike capability) executed by individual components under the control of the Joint Force Commander.

The air tasking cycle spans multiple days and is useful against fixed targets like buildings and infrastructure. Typically, the air tasking cycle is a three-day process from strategy development up to the end of the force execution phase. Of these, two days are devoted to planning and tasking while one day is allocated to execution (Department of Defence, 2006). Multiple overlapping air tasking cycles can be scheduled one day apart to allow for daily force execution.

While the air tasking cycle is appropriate for static targets, it lacks the responsiveness needed to engage dynamic and emergent targets (Hinen, 2002; Hazlegrove, 2000), as witnessed in recent conflicts where coalition forces encountered both mobile targets and an

adversary strategy of concealment, dispersal and deception. An important function of an AOC is prosecution of targets requiring immediate response, known as time-sensitive targets (TSTs); these include mobile SCUD launchers, surface-to-air missiles and high-payoff targets. Prosecution of such targets is facilitated through the use of a dynamic targeting process, a procedure whose successful implementation depends on timely and accurate decision making by key players. The dynamic targeting process has six distinct phases: Find, Fix, Track, Target, Engage and Assess (F2T2EA), also known as the kill chain or the F2T2EA process.

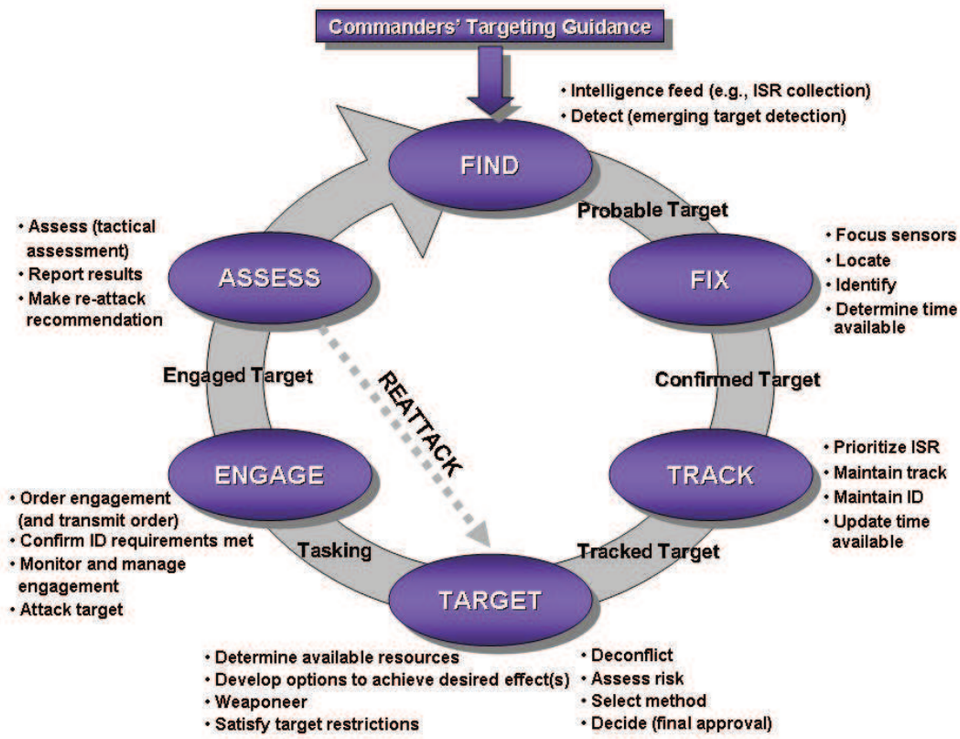



Fig. 2. Phases of the dynamic targeting process (US Air Force, 2006).

### 1.2 A dynamic modelling approach

Due to the inability to experiment with the kill chain during live exercises and the difficulty of human-in-the-loop simulations, we have constructed an executable dynamic model of human interaction and tasks engaged in the F2T2EA process. We used the simulation and analysis tool C3TRACE (Command, Control and Communications: Techniques for the Reliable Assessment of Concept Execution) developed by the US Army Research Laboratory to represent the operators, the tasks and functions they perform, and their communications patterns. The process model developed is able to quantify task performance and human workload for various organisational configurations.

In modelling the kill chain, it is necessary to capture the activities and measure the duration of tasks performed by operators while engaging in the dynamic targeting process. While technology plays an important role, the kill chain is essentially a human-centric activity involving complex (work-related) social interactions over a limited period of time. For this reason, we capture and study this process through a social network analysis (SNA)

approach. Traditional SNA techniques seek to describe the underlying network structure between individuals through communication links. The resulting network can then be subjected to mathematical analysis using graph theory. Nevertheless, when analysing dynamic targeting we regard exclusion of timing and other contextual information as a shortcoming of the basic SNA approach.

To quantify the variety of social interactions over time, we enriched the traditional methodology of social network analysis by capturing and time-stamping dynamic information. Specifically, this included speech utterances, chat messages, operator actions and changing levels of situational awareness. This extension allowed us to capture in detail the dynamic targeting process as used in an AOC. A software tool we developed that can replay the team's dynamic interactions helps not only in the construction of the dynamic model but also in further analysis of activities within the kill chain.

The goal of our endeavour is to use this multi-faceted dynamic modelling approach to facilitate improvements in the kill chain. The network of tasks performed by the team can be analysed by executing the process model to generate typical outcomes, operator utilisation and durations as well as rates of output in the kill chain. Subjecting the F2T2EA process to stress tests helped us identify possible information-processing bottlenecks and overloads. Subsequent to the simulation, we could usually suggest modified work arrangements to address any identified shortcomings. These proposals, including techniques adapted from those typically used to address resource constrained workflows, led to positive outcomes when tested in a recent exercise.

This paper is divided into six sections. Section 2 following introduces the concept of dynamic targeting used in an AOC and describes how it fits into the deliberate targeting process. Section 3 covers process modelling and simulation and its application to analysis of C2 systems. Section 4 examines our approach for capturing the dynamic targeting sequence and briefly describes C3TRACE, the tool employed herein for modelling and analysis. Section 5 illustrates steps in building a dynamic targeting model in C3TRACE using publicly available data, together with the approach used for analysing the process using the simulation results. Section 6 summarises our work here and discusses how human-in-the-loop experiments could be used to assess alternatives for improving the dynamic targeting process.

## 2. Dynamic targeting in an air and space operations centre

Spanning multiple days makes the air tasking cycle suitable for prosecuting fixed targets but unsuitable for those targets requiring immediate response. Time-sensitive targets (TSTs) requiring immediate response are prosecuted using a separate dynamic targeting process. An AOC coordinates this process while the air tasking cycle is in its execution and assessment phases. The dynamic targeting process provides the command authority with a decision to engage a TST using a compressed timeframe.

### 2.1 Command and control structure for dynamic targeting

An AOC has an offensive operations team and a defensive operations team, organised, in part, around the dynamic targeting process, with most of the activities related to offensive operations. The goal of the dynamic targeting process is to provide the command authority with a correct decision, even if the decision is not to engage the target. It is very dependent on the situation, available resources, the theatre, and the commander's specific intent. One

aspect of the process that demands high workload and time is the need to coordinate activities with the rest of the campaign (execution of the air tasking cycle).

We modelled the dynamic targeting process by considering a command and control structure comprising the following roles (Department of Air Force, 2005; US Air Force, 2006; Case *et al.*, 2006; Air Land Sea Application Center, 2001):

- CCO: Chief of Combat Operations
- DTO: Dynamic Targeting Officer
- SIDO: Senior Intelligence Duty Officer
- SODO: Senior Offensive Duty Officer
- SADO/C2DO: Senior Air Defence Officer / Command & Control Duty Officer (a dual-hatted role)
- Liaison Officers:
  - BCD: Battlefield Coordination Detachment (from Army)
  - SOLE: Special Operations Liaison Element (from Special Operations Command)
  - NALE: Naval and Amphibious Liaison Element (from Navy)
  - MARLO: Marine Liaison Officer (from Marine Corps Forces)

The CCO has prime responsibility for monitoring and directing the current air situation with assistance from the offensive operations team. Within the offensive operations team, the DTO has the key role in the AOC for coordinating the dynamic targeting process.

### 2.2 The dynamic targeting process

The dynamic targeting process has six distinct phases of Find, Fix, Track, Target, Engage and Assess (F2T2EA) (see Fig. 2). The find phase involves detection of an emerging target that fits the description of an expected TST. This detection results in an alert received by the DTO to proceed in coordinating the decision making process to determine whether or not to prosecute the target. The Fix phase commences when positive identification of the target is requested by the DTO and accomplished by the intelligence cell through the SIDO (Case *et al.*, 2006). During the Track phase, a track is maintained on the target while the desired effect is confirmed against it (US Air Force, 2006). The formulation of the desired effect and the targeting solution against the target takes place during the target phase of the dynamic targeting process. During this phase, the current Air Tasking Order (ATO)[1] is searched for suitable weapons platforms that can engage the TST and a collateral damage estimate performed (to prevent fratricide) (Department of Air Force, 2005). The mission package is reviewed against the rules of engagement (ROE) and then submitted to the CCO or higher level commander for engagement approval (Case *et al.*, 2006). The target phase is often the lengthiest process due to the large number of requirements that must be satisfied (US Air Force, 2006).

The engage phase commences once the engagement is ordered by the commander. A fifteen-line brief drafted by the DTO and the C2DO is transmitted to the pilot of the designated weapons platform who acknowledges both the receipt of the message and comprehension of its contents. This phase concludes once the pilot engages the target. A successful battle damage assessment report completes the dynamic targeting (F2T2EA) process (Case *et al.*, 2006).

[1] The ATO defines the actions during the execution phase of a specific air tasking cycle and is the basis for the monitoring of execution and the assessment of results from sortie action.

Success in dynamic targeting requires timely and accurate decisions. Any delay in the process will ultimately affect the outcome of any dynamic targeting endeavour. There is often very little time allowed between detection of a TST and its possible engagement and execution. The timeliness of this process varies widely. Newman *et al.* (2005) reports an average duration of 20 minutes for dynamic targeting whereas it took approximately one hour by Molan's (2008) account.

An inherent delay in engaging TSTs is the human element of the decision-making process. In making decisions, the AOC has to consider several important factors to make sure that the best possible plan is carried out. Under such time constraints, the command team might make errors due simply to the complexity of the environment or the stress that such a situation generates.

## 3. Prior work of C2 modelling

Model building is useful in gaining an understanding of C2 systems because it involves abstracting the salient aspects of the underlying process (Aslaksen & Belcher, 1992). Our focus is on modelling the functional aspects of the process in terms of the sequence of tasks performed. Simulation is the act of executing the model to produce typical results expected from undertaking real world activity; it can be quite useful in predicting how a system might behave outside of its usual operating environment (Hannon & Ruth, 1994). The modelling and simulation paradigm through process modelling is thus used herein to study the dynamic targeting process.

### 3.1 Process modelling and simulation

A dynamic model expresses the behaviour of a system over time. While mathematical models have been used to model dynamic systems, these approaches have generally been applicable to problems where an analytical solution exists (Law & Kelton, 1991). More complex systems require alternative approaches such as process modelling (Hlupic & Robinson, 1998), which is the focus of this chapter.

The underlying technology behind process modelling is discrete-event simulation. A discrete-event simulation models the evolution of a system over time by a representation in which the state variables change only at specific moments in time (Law & Kelton, 1991). These points in time are when events occur and cause an instantaneous change to the system's state. While the model is being executed, the discrete-event simulation keeps track of simulated time and advances the clock as required. Simulation time is typically managed through the next-event approach to time advance. On commencement, the scheduler initialises simulation time to zero then determines the trigger times of subsequent events. Model execution occurs by advancing the simulation clock to when each event occurs in time order and modifying the state variables as required.

In process modelling, the functions of an organisation are encoded as a network of tasks. Simulation involves triggering activities in the workflow with entities that flow through the system. The invocation and completion of tasks gives rise to events that are executed by the discrete-event simulation. There may be times when tasks lack sufficient resources to immediately service requests, resulting in queuing of entities. Process modelling has direct underpinnings from queuing theory (Law & Kelton, 1991) and thus is useful for analysing how well an organisation services its work requirements.

### 3.2 Process modelling of C2 systems

Kalloniatis and colleagues (Kalloniatis *et al.*, 2009; Kalloniatis & Wong, 2007) have used Websphere Business Modeler Advanced to construct executable models of operational level Joint military headquarters for assessing appropriate staff numbers and structures. Their estimation of relative risk in terms of backlogs in the simulation of processes and cyclic activities indicated areas with the greatest need of augmentation when dealing with a surge in workload.

Newman *et al.* (2005) used the Extend process modelling tool (Krahl, 2003) to model the dynamic targeting process. The model was built from information gained through interviews, observations and system logs. They evaluated the effects of process modifications by comparing the simulation results against a baseline model. At the macro level, they assessed process timeliness and throughput while at the individual level they examined queue rates, actual process time and utilisation rates. Their quantitative analysis enabled their team to suggest recommendations for improving the dynamic targeting process. Extend has also been used in modelling the Standing Joint Force Headquarters (SJFHQ) concept (Hutchins *et al.*, 2005). Findings from the simulation results were used to support decisions on structuring the emerging command centre.

## 4. Capturing and modelling the dynamic targeting process

The US Army Research Laboratory developed a tool called Command, Control and Communications: Techniques for the Reliable Assessment of Concept Execution (C3TRACE) that combines dynamic modelling with human workload modelling (Kilduff *et al.*, 2005). They successfully used C3TRACE to understand how technology affects decision quality in an infantry company (Kilduff *et al.*, 2006). Their analysis revealed that these troops suffered from information overload and occasionally made decisions based on poor information quality.

C3TRACE provides the capability to represent different organisational levels, the staff assigned to them, the tasks and functions they perform, and the communications patterns within and outside the organisation, all as a function of the frequency, criticality, and quality of incoming information. In our study, we used C3TRACE to model human interaction and tasks within the dynamic targeting sequence. The executable model helps us identify communication bottlenecks, workload peaks, and decision-making vulnerabilities so that the overall effectiveness of a proposed configuration change can be assessed.

Three main input categories are required to build a C3TRACE model: the organisational structure (i.e., personnel), the functions and tasks that are executed by the personnel (i.e., sequencing, decisions and queues), and the communication events (messages in the form of face-to-face, digital, voice, etc.). The output of the model includes operator utilisation and performance, decision quality and workload. The advantage of C3TRACE over other process modelling tools (Kalloniatis *et al.*, 2009; Krahl, 2003) is its support for integrating human operators and its ability to account for the human aspect in a work process (Keller, 2002). The analysis of workload allows one to determine the utilisation of operators based on multiple resource theory (Bierbaum *et al.*, 1987). It assumes that workload is the result of several processing resources described by four components: visual, auditory, cognitive, and psychomotor (VACP). The visual and auditory components refer to external stimuli. The cognitive component relates to the level of information processing required and the psychomotor component refers to physical actions. Tasks performed by an operator are therefore broken down into these four components. Workload according to each component

is measured on a scale from 0.0 (no activity) to 7.0 (maximum activity). This allows us to capture operator activities including: reading, listening to speech, evaluating between options, speaking, writing and typing on the keyboard (Bierbaum *et al.*, 1987).

The ability for the model to provide meaningful insights into the dynamic targeting process is dependent on how accurately salient aspects of the underlying process are captured. Our close engagement with an AOC has provided an opportunity to observe details of the dynamic targeting process during major joint military exercises. The model we created was constructed from doctrine and procedure manuals, as well as analyses of the data from:

- Capturing the interactions and work practices in the AOC,
- Interviews and workshops with operators,
- Conducting surveys,
- Documents produced during the dynamic targeting process, and
- Logs from computer applications and the Chat application.

Once built, the model was checked by AOC specialists to ensure the process was correctly modelled and that valid simulation results were being produced. The following section describes in further detail the approach used to capture the dynamic targeting process.

### 4.1 Capturing social interactions during dynamic targeting

Our approach to data collection sought to capture fine-grain events in the AOC down to interactions between operators (Stanton *et al.*, 2008). Our observations included recording operators' speech utterances, passing of information and comments on observed events and activities. Additional timing data (hh:mm) was appended to each entry to allow post processing and evaluation of work efficiency. Collecting data this way documented the sequence of events and the decision making process, and identified the activities undertaken by operators during dynamic targeting. Over 50 hours of observations were recorded this way, some captured from multiple vantage points by different observers (Lo *et al.*, 2009).

Information contained in the Chat logs was extracted to supplement the observer notes. The Chat logs provided time-stamped messages exchanged between operators in the AOC during the exercise activities (Joint Warfighting Center, 2002). Chat helped facilitate the communication between different functional entities in the AOC and often triggered respective coordinating activities. Manual observations were synchronised to the system time observed in Chat to facilitate merging of Chat messages with other records. Logs from a specialised AOC status tool provided timed information about the state of progress by operators on each TST.

### 4.2 Merging the disparate sources of data

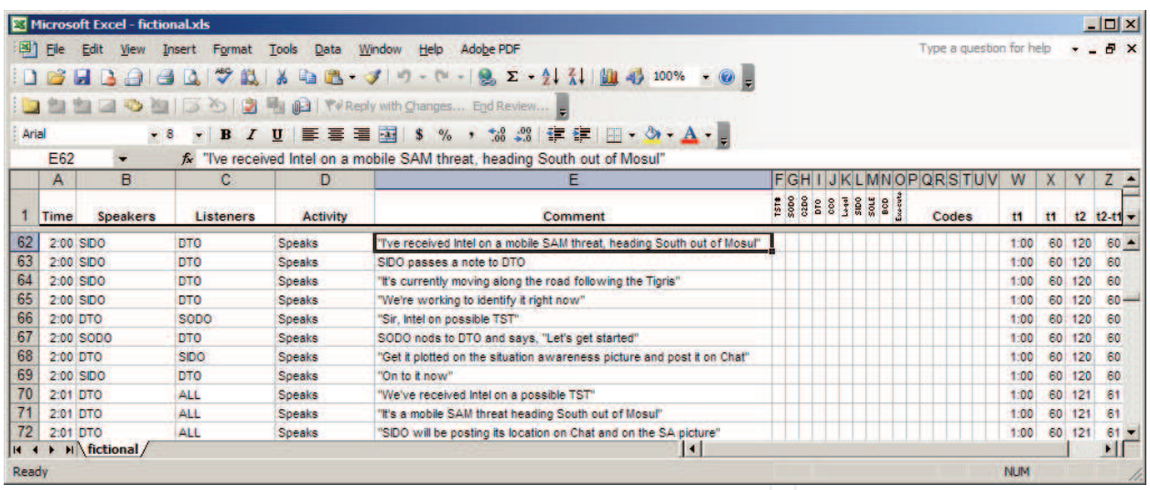
Disparate sources of data were merged into a single consolidated view for each time step. This was facilitated through a spreadsheet, as illustrated using a fictitious scenario and data in Fig. 3. For our purpose, observations were categorised into different activities and annotated with the following keywords in the columns of the spreadsheet:

- 'Speaks' in *Activity* column denotes a speech event between operator(s) in *Speakers* column and those in *Listeners* column. To simplify entry of broadcasts, the ALL keyword in *Listeners* column was used to represent all operators on the floor. Actual speech utterances were stored under *Comment* column,
- ROIP (radio over IP) indicates a speech event through the radio communications system. Due to difficulty in ascertaining the identity of the operator on the other end of the line, that operator was simply denoted as 'Radio',

- Chat describes a message transfer using the Chat application,
- *Comment* column contains observer comments,
- Progress specifies an event relating to the progress observed in prosecuting a TST in terms of the traffic light colour scheme. Column F identifies the TST (1 – 4), while the fields under columns G – O annotates the current state, either R, Y or G (Red, Yellow or Green), and
- <software application> indicates an observed use of a software application. The software application name was recorded in *Activity* column while user name was recorded in *Speakers* column.

Merging data from disparate sources can involve a degree of data deconfliction. In the case of merging records from two or more observers, there may be a need to remove duplicate observations of the same event. Similarly, events recorded in Chat or other software application logs may also have been recorded by observers (glanced from computer terminals or projected onto shared displays). The codes field in the spreadsheet of Fig. 3, allows the analyst to tag each line with user defined codes that annotate the data. A possible use is to assign a letter identifying the observer who produced the entry. Such an approach aided data deconfliction.

Our approach extends that used by Dietz (2006) in capturing the individual interactions between operators during the decision making process, in addition to capturing the traffic patterns between command posts. Through use of multiple data sources and observers the risk of missing key event data was minimised.



| | Time | Speakers | Listeners | Activity | Comment | Codes | t1 | t1 | t2 | t2-t1 |
|---|---|---|---|---|---|---|---|---|---|---|
| 62 | 2:00 | SIDO | DTO | Speaks | "I've received Intel on a mobile SAM threat, heading South out of Mosul" | | 1:00 | 60 | 120 | 60 |
| 63 | 2:00 | SIDO | DTO | Speaks | SIDO passes a note to DTO | | 1:00 | 60 | 120 | 60 |
| 64 | 2:00 | SIDO | DTO | Speaks | "It's currently moving along the road following the Tigris" | | 1:00 | 60 | 120 | 60 |
| 65 | 2:00 | SIDO | DTO | Speaks | "We're working to identify it right now" | | 1:00 | 60 | 120 | 60 |
| 66 | 2:00 | DTO | SODO | Speaks | "Sir, Intel on possible TST" | | 1:00 | 60 | 120 | 60 |
| 67 | 2:00 | SODO | DTO | Speaks | SODO nods to DTO and says, "Let's get started" | | 1:00 | 60 | 120 | 60 |
| 68 | 2:00 | DTO | SIDO | Speaks | "Get it plotted on the situation awareness picture and post it on Chat" | | 1:00 | 60 | 120 | 60 |
| 69 | 2:00 | SIDO | DTO | Speaks | "On to it now" | | 1:00 | 60 | 120 | 60 |
| 70 | 2:01 | DTO | ALL | Speaks | "We've received Intel on a possible TST" | | 1:00 | 60 | 121 | 61 |
| 71 | 2:01 | DTO | ALL | Speaks | "It's a mobile SAM threat heading South out of Mosul" | | 1:00 | 60 | 121 | 61 |
| 72 | 2:01 | DTO | ALL | Speaks | "SIDO will be posting its location on Chat and on the SA picture" | | 1:00 | 60 | 121 | 61 |

Fig. 3. Different sources of data merged into a single spreadsheet (based on fictitious data).

### 4.3 Analysing the social interactions in dynamic targeting

To replay events captured for dynamic targeting a software tool, simply called SNA Viewer, was developed (Lo *et al.*, 2009). Written in Java, SNA Viewer displays social network diagrams produced by the Pajek network analysis package (Batagelj & Mrvar, 2003), together with relevant contextual information from the spreadsheet and an indicator of the progress of activity for the TST being prosecuted (see Fig. 4). This combination of views enables after-action study of the dynamic targeting process by playing out, in time sequence, the captured events in detail.

The slider at the bottom of the user interface (see Fig. 4) enabled us to quickly navigate through the events by time sequence. Positioning the slider updates each of the three views with information relating to the selected time. Activities are assessed by browsing through events of interest in the recorded comments and reviewing key information, such as actors and duration. The additional comments provide an account of the information flows and the decision making process that took place during prosecution of a TST. Together, the timing data and comments enable decision effectiveness to be assessed.

Progress of the dynamic targeting process is represented with traffic light colours (Newman *et al.*, 2005) in Fig. 4 where red, yellow and green denotes halted, in-progress and approved, respectively. The state of each operator is triggered by the value in columns F – O in Fig. 3 (R, Y or G) while the identifier in column F identifies the TST being prosecuted (1 – 4 for identifying multiple targets). This feature can be used to measure the level of shared situational awareness because individual operators might not update their responsible traffic lights immediately to reflect their work progress in the dynamic targeting process. Recording the changing traffic lights in this way facilitates the assessment of teamwork for dynamic targeting at the indicated time.

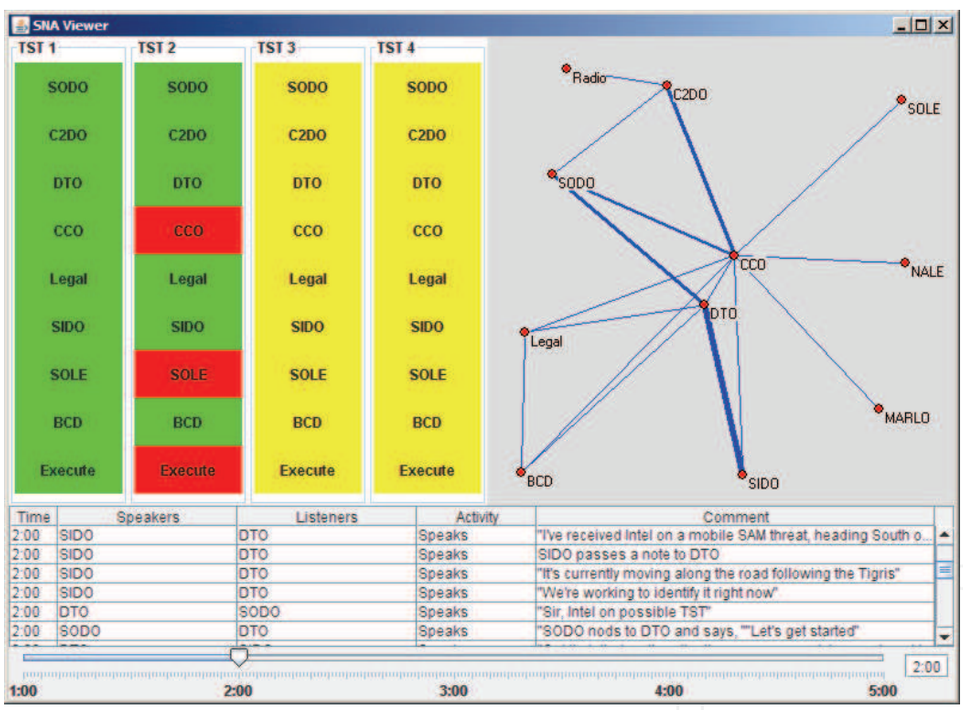



Fig. 4. Screen capture of the Temporal SNA model (based on fictitious data).

The purpose of the social network diagram is to provide a pictorial representation of the evolving interactions between operators when prosecuting a TST. In isolation, SNA allows an analyst to determine the frequency of communication between operators (through verbal communication, ROIP and Chat). Operators in Fig. 4 have been laid out according to the Kamada-Kawai model (Kamada & Kawai, 1989), which positions highly connected operators (over the entire session) in the centre of the diagram. Recorded events (comments, speech utterances and messages from Chat) in the table below, together with the view of TST progress complement the social network diagram with important contextual information.

The current version of SNA Viewer uses the Pajek package to produce the social network diagrams (Batagelj & Mrvar, 2003). Contents of each session were exported in text format and parsed with a program we developed to produce valid Pajek code. Specifically, the code took the form of a time-event network that enumerated and labelled each node and defined when edges were added and removed from the network. Nodes connected with multiple edges are displayed in Pajek using a thicker line. The network diagram for each time sequence was individually exported to an image file for display in SNA Viewer.

The ability to program a time-event network in Pajek enabled the exploration of different ways of representing the social network diagrams. For example, the following options were considered for the network diagram:

- Displaying the communications events at each instance in time,
- Showing the communications events accumulated since start time, and
- Representing the network diagram as a heatmap by allowing edges to remain on the network diagram for a fixed period.

These effects weren't a feature of Pajek but instead were produced in our program that automatically parses captured data to produce valid Pajek code. Of those options, the heatmap approach was assessed as producing the most meaningful social network diagrams for our purpose. In the network diagram in Fig. 4, each edge was set to remain on display for 10 minutes after its inclusion in the graph. The frequency of interaction between operators is indicated by the relative edge thickness.

Capturing the detailed aspects of the dynamic targeting process enabled the workflow to be decomposed, facilitating understanding of its sub-processes. In particular, we were able to deduce task durations for the process from captured recordings and construct the workflow with data in the operator manuals. Furthermore, the collection of multiple observations from several vignettes has helped us to compute the state transition probabilities for branched workflows. This understanding underpinned the construction of an executable dynamic targeting model using C3TRACE (Lo & Au, 2007).

### 4.4 Conducting surveys and interviews with operators

Exercise participants were asked to complete surveys at the end of each shift to assess their own levels of workload and to identify issues faced. Furthermore, interviews with operators conducted during lull periods were useful in eliciting deeper understanding of operator activities and issues related to dynamic targeting. The information received allowed the dynamic targeting process to be decomposed into its component tasks, provided average durations, identified actors in each task and estimated the probability values for each conditional branch in the network of tasks. The operators were also asked to rate their workload according to the VACP scale. The knowledge gained through this approach is invaluable and helps to supplement the observed notes because of our inability to remain cognisant of all activities concurrently being undertaken by operators in the dynamic targeting process, particularly when represented by a single observer.

## 5. Illustrating model development

The dynamic targeting process is modelled herein with publicly available information using the operator configuration described in Section 2.2 with each role filled by a single operator. The process model was generated by capturing the work performed by the operators according to the F2T2EA process (Department of Air Force, 2005; Case *et al.*, 2006).

Simulation of the actual dynamic targeting sequence allows identification of possible bottlenecks in the process. To illustrate the modelling process, the model was populated with fictitious timing and probability to generate simulation results in this chapter that illustrate the concept.

An important part of constructing a process model involves encoding the functions of the workflow as a network of multiple tasks performed by different processing entities (people or machines). During simulation, execution of the process model is controlled by a flow of tokens. A fragment of the process model is illustrated in Fig. 5 and the corresponding sequence of events is as follows (Case et al., 2006):

1. … CCO or SODO approves tasking order
2. Tasking order (15-line text message) is drafted by C2DO and transmitted by ground track coordinator (GTC) via Link-16 or voice to airborne weapons controller, e.g., Airborne Warning and Control System (AWACS)
3. AWACS acknowledges receipt and passes information to weapon platform which either accepts or rejects tasking
4. Acknowledgement is provided to the C2DO with the estimated time-over-target (TOT) from the weapon platform
5. Target is prosecuted

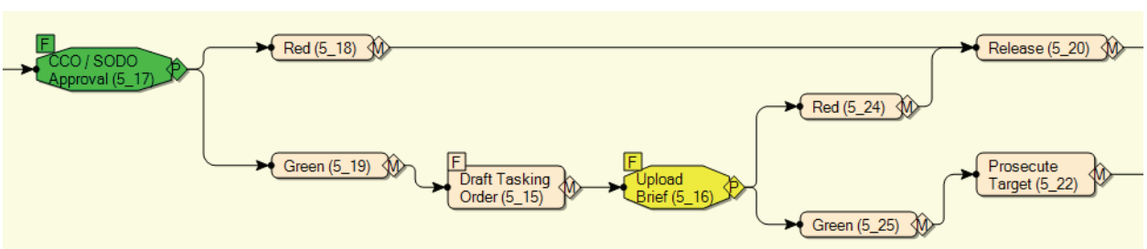



Fig. 5. A fragment of the dynamic targeting process model in C3TRACE.

C3TRACE allows modelling of operators and assignment of operators to tasks. If the required operators become unavailable, tokens queue for service and the corresponding tasks will be delayed. Hence, tasks 5_17, 5_15 and 5_16 in Fig. 5 are each configured with a simple First In, First Out (FIFO) queue (as denoted by the symbol F). The transition to multiple decision outcomes (such as Green denoting success and Red representing failure) are modelled using probabilistic branching (as indicated by the symbol P) and handled appropriately. Task 5_22 captures the inherent delay in the target engagement by the chosen weapons system.

### 5.1 Analysis of the dynamic targeting model

To study process throughput, the dynamic targeting model was subjected to various rates of emerging TSTs so that the process was stressed beyond its normal operating conditions. Each simulation run involved initiating the F2T2EA process using 25 tokens over a range of different rates of occurrence, from a low rate of emerging TSTs sensed 90 minutes apart to a high rate of targets sensed 5 minutes apart. Results were obtained by averaging ten independent runs with each rate and the resultant task timeline was analysed according to the output rate of the process.

Fig. 6 shows the throughput performance in terms of the ratio of output to input rates against a range of initiation rates. An output rate that equals the input rate indicates the

process is working within its limitations. A lower output rate than the input rate shows that the dynamic targeting process is stressed and building up backlogs. For the data employed for this study, the results indicate that the dynamic targeting process works efficiently when the rate of initiation is slower than one TST every 30 minutes. Pushing the process any faster simply results in a backlog of outstanding tasks that cause the delayed prosecution of TSTs. This defeats the purpose of dynamic targeting because the process is designed to enable an immediate targeting response.

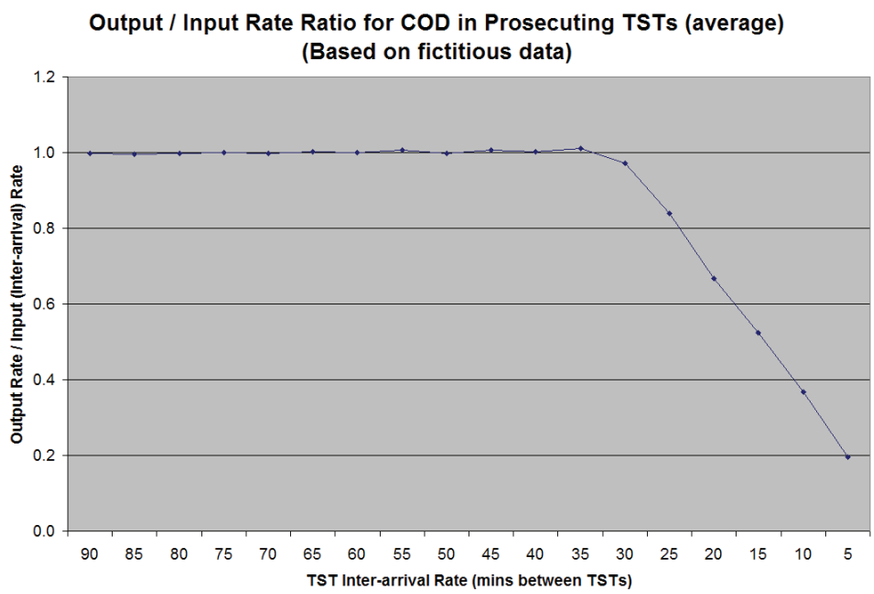



Fig. 6. Performance of the dynamic targeting process over a range of input rates.

Fig. 7 plots the utilisation of operators in prosecuting TST requests arriving 30 minutes apart. This is the maximum capacity at which the process can manage to respond to

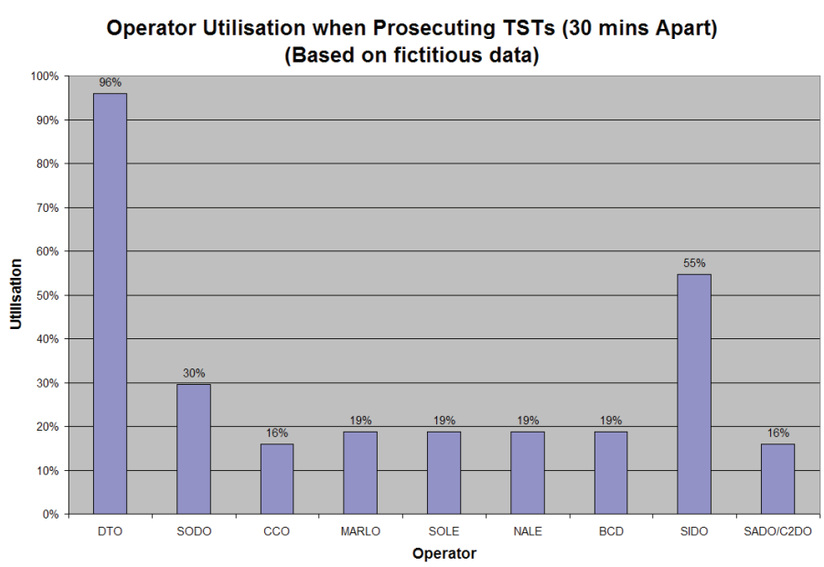



Fig. 7. Operator utilisation when prosecuting TSTs spaced 30 minutes apart.

incoming requests immediately. Note that the graph only plots the utilisation of operators undertaking the dynamic targeting process and does not account for their routine work during the execution phase of the air tasking cycle. Clearly the DTO is highly utilised in the dynamic targeting process at the indicated input rate. The SIDO is another operator who is substantially utilised in the prosecution of TSTs.

To investigate potential process bottlenecks, we present in Fig. 8 utilisation of the DTO over a range of input rates in prosecuting TSTs. This reveals that utilisation of the DTO is highly correlated with the input rate of TST requests. The maximum DTO utilisation is reached when the input rate reaches one TST every 30 minutes and 100% utilisation is maintained at higher input rates at the expense of prolonged process time. This knee point corresponds to the input rate that maximises the throughput performance in Fig. 6. This correlation indicates that the DTO is the likely cause of the bottleneck in process performance.

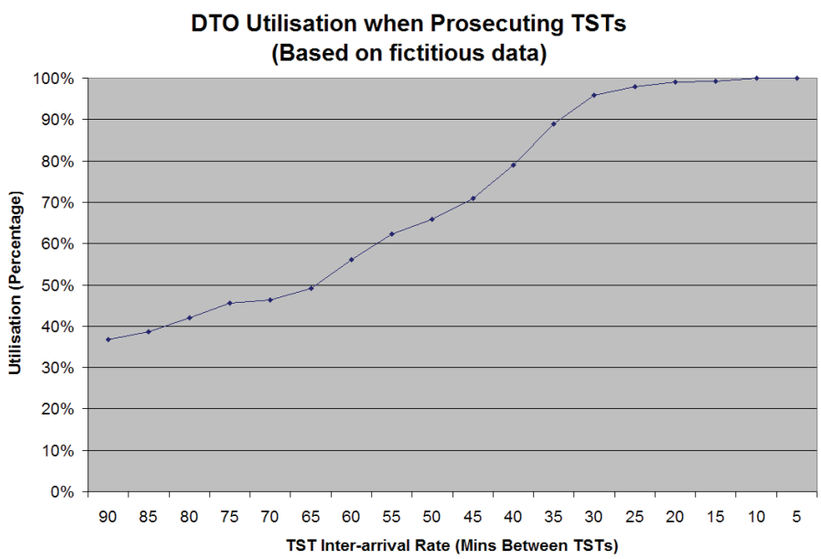



Fig. 8. Utilisation of the DTO over a range of input rates for the prosecution of TSTs.

Fig. 9 is another representation of utilisation of the DTO using the TST inter-arrival rate in terms of the number of TST requests per hour. Utilisation of the DTO is highly correlated with the rate of TST inputs until the input rate reaches two TSTs per hour, i.e., one TST arriving every 30 minutes.

### 5.2 Relieving bottlenecks and improving performance

The increasing prevalence of TSTs in recent operations necessitates improvement in the performance of the dynamic targeting process. Prosecution of TSTs involves a race against the clock. Some avenues that might be pursued to relieve existing shortfalls of dynamic targeting include:

- Additional human resources (augmentees) to assist dynamic targeting when the rate of emerging TSTs increases
- Specialised training to ensure that operators are able to meet performance targets
- Appropriate training to produce multi-skilled operators who are capable of taking on different roles to help balance workloads in overstressed situations

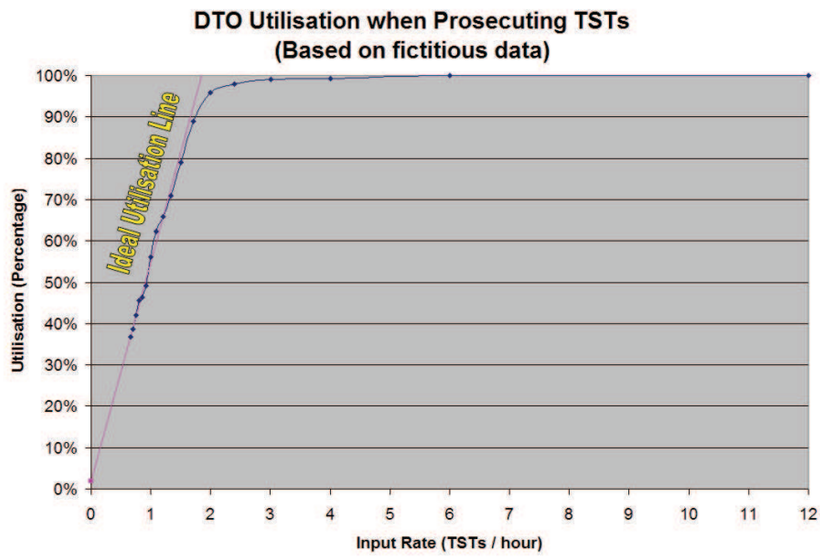



Fig. 9. Ideal utilisation range of the DTO when prosecuting TSTs.

- Use of technology to facilitate human operations
- Simplifying the dynamic targeting process to enable faster decision making

As the DTO is highly utilised in the dynamic targeting process, forming a dynamic targeting cell (DTC) with a team of multiple operators performing the functions of the overworked DTO can relieve any bottlenecks here (Department of Air Force, 2005). The decision of when to use augmentees is mainly based on anecdotal evidence resulting from observations and feedback during exercises.

## 6. Conclusion and future work

Although C2 is a critical component of military forces, C2 systems are complex and may exhibit unpredictable behaviour. Even with clearly established goals and defined limitations, it is not straightforward to provide coordinated engagement reliably in an efficient manner. Dynamic targeting is an important C2 process in the AOC because it is used to rapidly engage high value time-sensitive targets. This process is subject to a highly dynamic environment due to differences and variations in such variables as:

- The target to prosecute
- Battlespace conditions
- Red force capability
- Operator workloads in an AOC
- Outcomes of decision making
- Order and timing for tasks undertaken

Prosecuting time-sensitive targets is inherently difficult and complex because the process involves choosing among geographically distributed assets and personnel. The need to coordinate actions throughout a theatre of combat is constantly in tension with the need to prosecute quickly and efficiently.

In this chapter we report studies of dynamic targeting in an AOC by capturing the social interactions involved in the process and using C3TRACE as a simulation and analysis tool.

An advantage of C3TRACE is that it allows for limitations of human operators in developing executable process models. Our model has incorporated the human aspect in the work process because humans are central to C2 in terms of decision making and collaboration. The initial model was based on a baseline configuration in which only one DTO is involved in coordinating every TST prosecution. The limits of dynamic targeting with this model were found by stress testing the process over a range of rates of initiation. Stressing the process beyond its inherent capacity results in a failure to prosecute targets in a timely manner. A study of operator workload revealed the cause of the performance bottlenecks correlates strongly with an overworked DTO in the process.

The model in this chapter was constructed from publicly available information describing the dynamic targeting process and populated with representative but fictitious data and probabilities. Therefore, the actual results of our analysis are for illustrative purposes only. In this respect the aim here is to describe how modelling and simulation using C3TRACE can reveal insights about organisational processes using a quantitative approach. The results generated provide confidence in applying C3TRACE modelling and simulation to assess potential AOC refinements before committing to actual process evaluations on the operations floor.

Related, but necessarily classified work, has extended to the analysis of data captured from observing real processes in an AOC. We plan human-in-the-loop experimentation to evaluate the effectiveness of different options for overcoming issues identified through such analysis. The environment described by Case *et al.* (2006) provides a reference for establishing our own instrumented facility. In particular, we are keen to employ this environment to assess how augmentees can be tasked to overcome the throughput limitations of the process and to determine whether changes to the workflow can improve timeliness. We expect that video and audio capture will supplement manually observed data and help to further reduce the risk of missing important events.

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**Dynamic Modelling**

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When talking about modelling it is natural to talk about simulation. Simulation is the imitation of the operation of a real-world process or systems over time. The objective is to generate a history of the model and the observation of that history helps us understand how the real-world system works, not necessarily involving the real-world into this process. A system (or process) model takes the form of a set of assumptions concerning its operation. In a model mathematical and logical assumptions are considered, and entities and their relationship are delimited. The objective of a model – and its respective simulation – is to answer a vast number of “what-if” questions. Some questions answered in this book are: What if the power distribution system does not work as expected? What if the produced ships were not able to transport all the demanded containers through the Yangtze River in China? And, what if an installed wind farm does not produce the expected amount of energyt? Answering these questions without a dynamic simulation model could be extremely expensive or even impossible in some cases and this book aims to present possible solutions to these problems.

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