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A Tactical Separation Assurance System for Terminal Airspace

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A tactical separation assurance prototype system is evaluated for its fitness to support the Standard Terminal Automation Replacement System (STARS) in a complex terminal airspace environment that includes a mix of visual- and instrument-approach aircraft, Mode C intruders, and limited trajectory-intent data. Fast-time simulation experiments using air traffic data from human-in-the-loop simulations and live Terminal Radar Control (TRACON) operations featuring a mix of visual and instrument approaches and Mode C intruders are performed to assess the performance and benefits of the system in a near-term national airspace system (NAS). It is found that nuisance alerts attributable to aircraft on visual approach are eliminated with a high-severity alerting option. With a normal low-severity alerting option, Mode C intruder alerts are reduced more than 50% as compared to the Conflict Alert system, a legacy function in STARS. The trajectory intent information that is most effective in reducing false alerts is identified and found to be available in STARS or easily adapted from existing NAS automation.

I. Introduction

Today air traffic controllers hold the responsibility for separation of air traffic, utilizing decision support tools at their disposal. Conflict Alert (CA),[1] an automated system in Common ARTS (Automated Radar Terminal System) and the newer STARS (Standard Terminal Automation Replacement System), alerts the air traffic controller when it projects that an aircraft will come into dangerous proximity of another aircraft in the US terminal airspace. The dangerous proximity refers to a horizontal separation of about 1 NM and vertical separation of 200 to 300 ft and is not related to the standard separation defined in FAA Order JO 7110.65S.[2] Losses of standard separation have been a significant safety concern. It would be safer for the STARS to have a reliable functionality that alerts the air traffic controller to potential losses of standard separation for the terminal airspace.

The inherent complexities of terminal airspace operations pose a number of challenges in the development of tools that automatically alert the air traffic controller to potential separation conflicts. Routine large-angle turns before final approaches can lead to a proliferation of nuisance alerts. Spacing aircraft near standard separation minima to maximize arrival and departure throughput increases the difficulty of predicting separation conflicts without causing too many false alerts. The difficulty also stems from the dynamic and complex nature of the standard separation criteria, which depend on relative heading, weight classes, locations along the localizer, and other factors.[2] Further challenge comes from the need to provide alerts to enhance safety in situations where standard separation minima may or may not apply. These include the routine practice of sequencing visual- and instrument-approach aircraft together to maximize arrival throughput, as well as the common encounters between IFR (Instrument Flight Rules) and VFR (Visual Flight Rules) flights outside class B airspace, where controllers desire alerts as early as possible to inform the IFR pilot of the VFR traffic before a resolution advisory is triggered from TCAS (Traffic Alert and Collision Avoidance System).[3] To cope with some challenges of terminal airspace, CA is often inhibited by air traffic controllers in busy areas where false alerts would otherwise be common.[4] However, direct inhibition of alerts for some aircraft pairs or suppression of alerts for some particular terminal areas may not be desired for safety reasons because it would eliminate potentially useful alerts needed in some situations.

Previous work established that incorporation of flight-intent information and the use of a single-trajectory approach in the detection of separation conflicts are effective in addressing terminal-airspace challenges.

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Incorporation of flight intent information in the trajectory and conflict predictions has been advocated in en-route Tactical Separation Assured Flight Environment (TSAFE),[5-6] where dual trajectories of dead-reckoning (DR) and flight plan are used. Tests in a prototype system of en-route TSAFE on documented operational error cases showed that TSAFE could provide timely warnings of imminent separation conflicts more consistently than the CA system.[7] Based on the basic operational concepts of TSAFE, a conflict detection algorithm for terminal airspace was recently proposed, which used a single trajectory that incorporates available flight intent information.[8] Comparison with a DR model and a dual trajectory model similar to the en route TSAFE indicated that the new single-trajectory algorithm had fewer false alerts while maintaining a useful average alert lead time of more than 30 seconds. The low false-alert rate was based on somewhat subjective analysis of the actual tracks of aircraft to look for indications of controller or pilot interventions to avoid potential conflicts. More recently, the single-trajectory algorithm was enhanced to include conflict severity in the detection and declaration of separation conflicts to explore ways that potentially reduce nuisance alerts in mixed operations.[9] Ref. 9 also determined objectively that the false alert rate of the new algorithm was only about 10% of the total number of alerts based on recorded air traffic data with available controller interventions from Human-In-The-Loop (HITL) air traffic control experiments. HITL simulation experiments[10] with the Terminal TSAFE (T-TSAFE) algorithms supporting the Human Computer Interface have received positive feedback from participating air traffic controllers, which help verify and improve the detection and resolution algorithms as well.

The recorded live traffic used in previous work contained large percentage of visual-approach flights that were assumed to be instrument-approach flights. As a result the number of alerts observed was large and most of them were nuisance alerts. How to remove those nuisance alerts in practice has not been fully addressed. Furthermore, the live traffic data did not contain tracks unassociated with a flight plan. Thus, how the system performs when Mode C Intruder (MCI) alerts are considered needs to be addressed as well. Here MCI alerts refer to those involving an aircraft associated and another one unassociated with a flight plan. Finally, for the system to be of operational use, it must be integrated with STARS, which has limited available intent information. Therefore, it is important to address if such integration is feasible with worthwhile benefits for the near term.

This work focuses on addressing the above issues. Fast-time simulation of traffic data from HITL air traffic control experiments with mixed operations is performed to demonstrate the effectiveness of the high-severity alerting option for visual-approach aircraft conflicts. Fast-time simulation of a full-day of real-world air traffic data including both associated and unassociated tracks is performed to determine the performance of T-TSAFE in handling MCI alerts. This leads to a more complete performance comparison with the real Conflict Alert in the field than previous work. Four models based on different levels of intent information that may be available in STARS are compared with the baseline in which all intent information available today (such as altitude clearances, nominal interior routes, and flight plan routes) are used. Thus, the dominant intent information in reducing false alerts is identified, which helps to address the feasibility of integrating T-TSAFE with STARS given its available intent information today being limited.

The rest of this paper is organized as follows. Section II summarizes the main features of the T-TSAFE system including the underlying conflict detection and declaration algorithms, the complexity involving visual-approach clearances, and the rules for MCI alerts. Section III describes the fast-time simulation experiments and the results of analyzing the experimental data. Section IV summarizes the findings.

II. The T-TSAFE System

T-TSAFE is a system capable of providing the functionality of tactical conflict detection and resolution for terminal airspace. The inputs to T-TSAFE include TRACON radar tracking data, Mode-C barometric altitude data, and flight intent information such as static arrival and departure routes, altitude amendments, and flight-plan route data. The outputs include aircraft predicted trajectories, conflict and resolution information, and aircraft sequences for different runways. The output may be saved in XML files for post analysis. As T-TSAFE is expected to only provide the function of alerting the air traffic controller to imminent separation conflicts in the near term, the basic features of this function are described in this section. The separation criteria and trajectory prediction algorithm[8] are included for completeness.

A. **Separation Criteria**

The separation criteria for aircraft in terminal airspace are complex and dynamic because they depend on multiple factors such as aircraft weight classes and course headings. The separation minima for determining loss of separation of IFR flights used in T-TSAFE are summarized in this subsection. When visual-approach, non-class-B-airspace VFR, and MCI flights are involved, no separation minima are currently required.[2] However, the air traffic controller still desires to be alerted ahead of potential TCAS resolution advisories. The alerting criteria involving these flights are explained in Sections II.D and II.E and are used in the experiments discussed in Sec. III.

According to FAA Order JO 7110.65S,[2] aircraft in terminal airspace are required to be separated by some general separation minima. Most generally, aircraft are required to maintain a separation minimum of 3 NM horizontally or 1000 ft vertically. However this rule is superseded by wake turbulence requirements. When an aircraft (1) operates directly behind, that is, horizontally within 2500 ft of the flight path of the leading aircraft, and either at the same altitude as, or within 1000 ft below, the leading aircraft, or (2) follows another aircraft conducting an Instrument Landing System (ILS) approach, the wake turbulence separation minima in Table 1 are required. In addition, the aircraft must maintain the separation minima in Table 2 when the leading aircraft is over the runway threshold.

Table 1 General wake separation minima for different weight classes

Leading Aircraft	Heavy	B757	Heavy	B757
Trailing Aircraft	Heavy	Large/B757/Heavy	Small/Large/B757	Small
Sep. Minima, NM	4	4	5	5

Table 2 Wake separation minima at runway threshold when the trailing aircraft is small

Leading Aircraft	Large	B757	Heavy
Sep. Minima, NM	4	5	6

There are many special situations that require only reduced separation minima. When the leading aircraft's weight class is the same or less than the trailing aircraft while both are established on the final approach course within 10 NM of the runway threshold with certain conditions on the airport satisfied,[2] the required separation minimum is reduced to 2.5 NM. When two aircraft are on parallel dependent ILS approaches to runways with a runway center-line separation of at least 2500 ft but no more than 4300 ft, the required separation minimum is 1.5 NM. If the runway center-line separation is between 4300 ft and 9000 ft, the required separation minimum becomes 2 NM. If the horizontal separation minima above are violated, the 1000 ft vertical separation minimum must be maintained. In the case of an arrival trailing a departure, a minimum of 2 NM or 1000 ft must be maintained between the aircraft if the separation will increase to a minimum of 3 NM within one minute after the takeoff. Between a VFR aircraft and an IFR aircraft in class B airspace, the general separation minima are reduced to 1.5 NM and 500 ft. No separation minima are required if two aircraft are on diverging courses, or are successive departing aircraft separated by more than 1 NM, or are both established on their independent final approach courses. When one of the aircraft is transitioning from terminal to en-route airspace, the required separation minimum is still 3 NM but the separation must be increasing, the leading aircraft must maintain faster speed than the following aircraft, and the courses must be diverging.

B. **Trajectory Prediction**

Accurate predictions of aircraft trajectories are the key to accurate conflict predictions. The general trajectory prediction algorithm used in T-TSAFE is as described in Ref. 8 and is summarized as follows.

1. *Flight-Intent Information*

In the Next-Generation Air Transportation System (NextGen), accurate flight-intent information such as a detailed end-to-end route or 4-dimensional trajectory may become available for trajectory prediction from the current position of the aircraft. However, currently-available flight-intent information may improve conflict predictions significantly when used properly.

For arrival flights, nominal interior routes provide details of flight intent near the runways. Most aircraft generally follow the same nominal paths that have some common flexibility in the TRACON. Past air traffic automation efforts have used these prescribed nominal TRACON paths from the arrival meter fixes down to the runways for traffic management,[11] and they are also in the adaptation of the Traffic Management Advisor (TMA),[12] a time-based automated tool used to maximize airport efficiency. These nominal paths are referred to as nominal interior routes (NIRs). The NIR for an aircraft is usually unique given the airspace configuration and the engine type, meter fix, airport, and assigned runway. A typical NIR is shown in Fig. 1, where the squares on the center line are waypoints. The last two waypoints indicated in the final leg are the final approach fix (FAF) and runway threshold fix (RWY). Most arrival aircraft are observed to follow the NIRs except that a base extension or “trombone” is common for downwind approaches. The shaded region is a conformance region defined by a conformance threshold. An aircraft is in conformance or on track if its cross-track distance to the center of the NIR is within the conformance threshold, which is typically 0.5 NM.

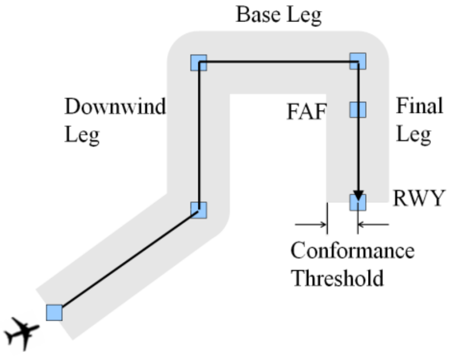

Figure 1. A static nominal interior

There is useful flight-intent information available in other stages of flight as well. For departure flights, the flight-intent information available today includes the RNAV (Area Navigation) departure routes as illustrated in Fig. 2, where an aircraft departs from the runway and makes a left departure turn towards a departure meter fix. The squares indicate waypoints and the shaded region again indicates a conformance region within which the aircraft is considered on track. When available, RNAV departure routes are often closely adhered to. For over-flights, the aircraft flight plan is usually sufficient. Other flight intent information includes the speed upper bound at initial departure waypoints, the speed lower bound at final approach waypoints, as well as altitude restrictions at some common waypoints and level altitudes to be discussed in the next subsection.

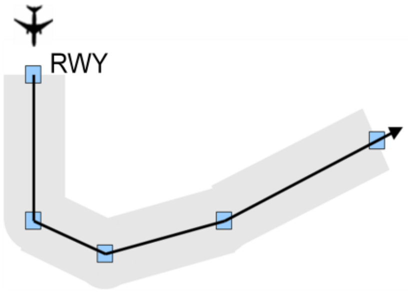

Figure 2. An illustration of the RNAV departure route.

2. Flight-Intent Trajectory

To build a flight-intent trajectory of an aircraft, a horizontal track is first constructed with straight lines and circular arcs based on some simple rules. The flight-plan route, the RNAV departure route, and the nominal interior route are merged to form a flight-intent route, which is used to create the ground (horizontal) track of the aircraft with segments of straight lines and circular arcs. The underlying assumption is that, whenever possible, an aircraft attempts to conform to its flight-intent route and other available intent information. Thus, when in conformance (on track), it will stay in conformance; otherwise it will move along a straight line along its current course. However, the aircraft is assumed to be aware of its flight intent information in the sense that, when possible, it joins smoothly back with the next segment in its flight-intent route. This is summarized in the following general rules:

1) If the aircraft is on track, capture the next waypoint in the flight-intent route.
2) If the aircraft is off track, start with a straight line along its current course and then, if possible, join the flight-intent route when it is intercepted; otherwise continue along the straight line.

Figure 3 shows an example of applying the above rules to predict the ground track of an initially off-track aircraft. The aircraft starts off with a straight line track since it is off track. It then joins the flight-intent route along a circular-arc segment, becomes on track, and moves forward.

Some special rules should be noted concerning the base and final turns. The radius of the circular-arc segments, assuming a coordinated turn, is generally estimated from the aircraft's current ground speed, V, and a bank angle, ϕ_B, by $r_c = V^2/(g \tan \phi_B)$, where g is the acceleration of gravity and we use ϕ_B = 30°. Because base extensions are common and turns onto the finals are constrained, we apply the following rules to the downwind-to-base and base-to-final turns. Here some numerical values are based on engineering experience.

1) Downwind-to-Base: First, before a turn is detected, the aircraft is predicted to continue along its velocity vector. That is, a downwind-to-base turn will not commence until an actual turn of the aircraft has been detected. This rule is based on the observation that the base leg of the NIR is extended in most cases. Figure 4 shows an example prediction of an on-track aircraft turning into the downwind leg and continuing along a straight line without making a base turn because the aircraft is not predicted to make the base turn until it has been detected to be turning. The detection of a turn is defined as three consecutive course changes in the same direction (left or right). After a turn towards the base is detected, the actual turn radius is calculated based on the current rate of course change, ω, and the current ground speed by $r_a = V/\omega$. If the current heading of the aircraft is more than 150 degrees from the final approach course, the aircraft is assumed to continue turning for 10 seconds or about two radar update cycles with the current actual turn radius r_a, and then continue along a straight-line projection at the end of the turn. If the current course of the aircraft is within 150 degrees of the final approach course, the aircraft is assumed to continue turning with radius r_a, to a course perpendicular to the final approach course. If the turn is not possible because r_a is too large, the coordinated turn radius r_c, is tried. If the turn is still not possible, a straight line is used.
2) Base-to-Final: An aircraft approaching the final approach course with some angle is generally assumed to turn and start to intercept the final approach course at some minimum perpendicular distance *d*. Figure 5 shows a prediction of the ground track for a typical base-to-final turn scenario. Based on visual inspection of many actual trajectories, we take *d* = 1 NM. Circular arcs and straight lines are used to construct the trajectories of interception. An interception angle θ = 30° before the final approach fix is assumed. If an aircraft is already closer than 1 NM to the final approach course, it is assumed to turn and intercept right away. If it is not possible to turn onto the final with one circular arc, it may overshoot and intercept the final with two turns or two circular arcs.[13]

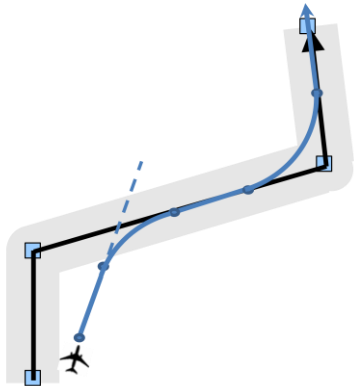

Figure 3. Prediction of the ground track of an initially off-track aircraft.

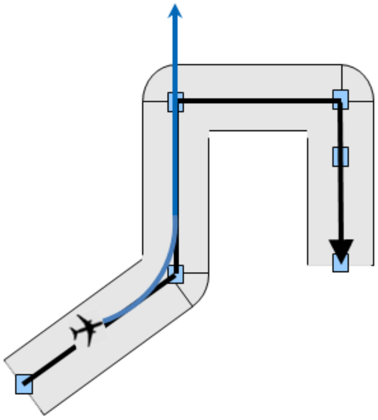

Figure 4. Prediction of the ground track of an on-track aircraft turning into a downwind leg.

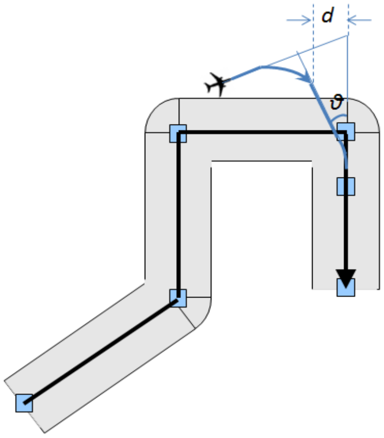

Figure 5. Prediction of the ground track of an aircraft making a base turn and a typical intercept of the final approach course.

Once the ground track is predicted, a ground speed profile is then generated for the aircraft to fly along the track. Our experience from comparing the trajectory predictions with the actual ground tracks of aircraft in the TRACON suggests that the ground speed changes significantly enough that it is not sufficient to use constant ground speed but acceleration needs to be modeled as well. However, since the actual duration of deceleration of an aircraft is not known, the rate of the deceleration may be so large that the aircraft may be predicted to reduce its speed unrealistically to zero within the look-ahead period. Thus, a lower bound for the ground speed is necessary, especially during base leg and final approach phases. Similarly, the acceleration of a departing flight may be so large that an upper bound on the ground speed needs to be imposed. In this paper, ground speed lower bounds near the final approach and runway threshold fixes are imposed, and an upper bound is imposed on certain departure flights. Other bounds may be added in the future. When a ground speed bound is imposed, the aircraft is projected to fly at constant speed once the bound is reached.

The speed bounds we used are reasonable values based on observations of a large set of flight data. The results are not sensitive to the precise values. The lower bound on the ground speed near the final approach fix is set at 160 knots. The bound at the runway threshold is 130, 115, or 95 knots depending on whether the engine type of the aircraft is jet, turboprop, or piston, respectively. The ground speed upper bound for departure flights is 260 knots for flights below 6500 ft. In terms of the current ground speed, the length of the predicted ground track, and the speed bound, a required acceleration may be calculated. In the case of a deceleration, if the magnitude of the required deceleration is larger than the current measured value, the required value will be used. Otherwise, current ground deceleration is used. Note that whereas wind effects are not explicitly taken into account, they are implicitly considered through modeling the ground acceleration.

Finally, an altitude profile is formed for the trajectory. The altitude profiles for climb or descent are modeled in three phases: an initial acceleration phase, a constant-rate phase, and a final deceleration phase. A vertical constant acceleration of magnitude 0.1g, where g is the acceleration of gravity, is assumed for the initial and final phases. With this acceleration, it takes about 10 seconds for an aircraft to increase its climb rate by 2000 fpm. Figure 6 illustrates the model of a three-phase climb. The following rules are used to determine the phase of a flight:

1) When the vertical distance to the cleared altitude is more than 200 ft, and its climb or descent rate is more than 500 fpm, it is in the constant-rate phase.
2) When the distance is more than 200 ft and the climb or descent rate is less than 500 fpm, it is in the acceleration phase. (It is not in a deceleration phase since the speed would have to be larger for a stopping distance of 200 ft if the deceleration is 0.1g.)
3) Otherwise the aircraft is in the deceleration phase.

It should be noted that the numbers above are adjustable. They yield reasonable predicted altitude profiles when compared with actual trajectories, and the conflict prediction results are not sensitive to the precise values. If an aircraft is in the constant-rate phase, its constant vertical rate is given by its current vertical rate. If an aircraft is in the initial acceleration phase, its vertical speed at the constant-rate phase is obtained by looking up the nominal climb or descent rate in the Base of Aircraft Data (BADA) from Eurocontrol.[14]

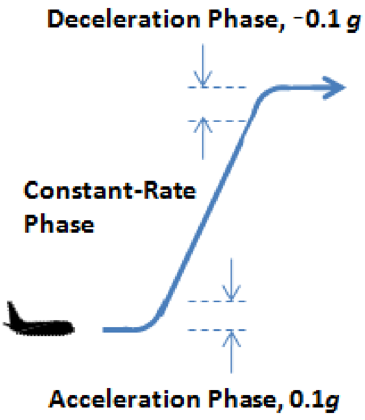

Figure 6. The three-phase climb of an aircraft.

It is important to obtain cleared altitude, the intent information on which the altitude profile relies heavily. Altitude clearances are entered into the Host computer at each Air Route Traffic Control Center (ARTCC or Center) but not in the TRACON, where the altitude clearances usually are communicated to the pilots by voice only. However, it is already possible for controllers to enter cleared altitudes in STARS today. HITL experiments show that participating controllers are willing to enter the altitudes when the traffic is not too busy, especially when they see the benefits of entering them.[10] As in Ref. 8, for recorded real-world data, we may extract the location and duration of level segments from the recorded data file of aircraft tracks and use them to generate simulated entry of altitude clearances. The resulting cleared altitudes are referred to as Inferred Altitude Clearances (IACs). Ref. 8 shows that IACs reduce the number of false alerts significantly.

C. Conflict Prediction and Declaration

1. Conflict Prediction

Conflict prediction uses the predicted trajectories to project into the future within some look-ahead time, determine the separations between pairs of aircraft in the airspace, and compare them with the separation criteria. To avoid missing the prediction of a potential conflict or to increase the prediction lead time to a potential conflict, one may probe in multiple possible paths to account for uncertainty of pilot intent. However, this multiple-path approach is at the expense of increasing the chance of false predictions of conflicts. A dual-trajectory approach has been adopted in en route TSAFE[5-7] where both the flight-plan and dead-reckoning trajectories are used. The complexity of terminal airspace calls for reducing overall trajectory prediction uncertainty to minimize false predictions. Thus, an intent-based single-trajectory approach to conflict prediction is used for terminal airspace.[8]

The intent-based single-trajectory approach will always be able to predict a real conflict with a lead time greater or equal to zero. The predicted trajectory becomes more accurate closer to the potential conflict because the needed look-ahead time becomes smaller. Thus, while the approach may fail to predict a real conflict far in the future, it will eventually catch all conflicts and it may only have a slightly smaller average lead time than the dual-trajectory approach.

In addition to the predicted trajectories, track history is needed for conflict predictions involving wake turbulence. When wake turbulence must be considered, one needs to determine if the trailing aircraft is operating directly behind (within 2500 ft of the flight path of) the leading aircraft. Thus, a track history for at least a period equal to the look-ahead time for each aircraft must be maintained. To check whether wake separation applies to a pair of in-trail aircraft, the cross-track position of the trailing aircraft with respect to the track history of the leading aircraft must first be located. Then, if the altitude of the trailing aircraft is within 1000 ft below that of the leading aircraft at the perpendicular cross-track position, wake separation criteria apply.

Because of uncertainties in the predicted trajectories, to minimize the number of false alerts, the detection algorithm relies on other conditions to determine whether to declare a predicted conflict with a conflict alert. The concept of conflict severity is useful in conflict declaration.[9]

2. Conflict Severity

First let us introduce the concept of separation conformance categorization for classifying operational errors as defined in FAA Order JO7210.56C.[15] Four classes of operational errors, A, B, C, and PE (Proximity Event), known as Separation Conformance Category (SCC), are defined for non-wake separations. Figure 7 highlights the regions of different SCC classes in the plane where the horizontal axis is the horizontal separation retained and the vertical axis is the vertical separation retained. The horizontal separation retained is defined by $H_{\mathrm{r}} = r/r_{\mathrm{min}}$ where r is the horizontal separation at closest proximity and r_{min} is the required horizontal separation minimum. The vertical separation retained is defined by $V_{\mathrm{r}} = h/h_{\mathrm{min}}$ where h is the aircraft vertical separation at closest proximity and h_{min} is the required vertical separation minimum. The closest proximity is defined as the point at which the combined lateral and vertical separation results in the lowest slant range (straight line distance between two aircraft). Thus, if one defines a conformance separation $s = \sqrt{V_r^2 + H_r^2}$, then classes A and B operational errors correspond to the region specified by the ranges of $s \leq 34\%$ and $34\% < s \leq 75\%$, respectively; class C operational errors correspond to the region with the ranges of $s > 75\%$ and $V_{\mathrm{r}} \leq 90\%$ and $H_{\mathrm{r}} \leq 90\%$; and class PE errors correspond to the region with the ranges of either $V_{\mathrm{r}} > 90\%$ or $H_{\mathrm{r}} > 90\%$. For wake separations, only the horizontal separation is used and there are only A, B, and C classes, which correspond to regions specified

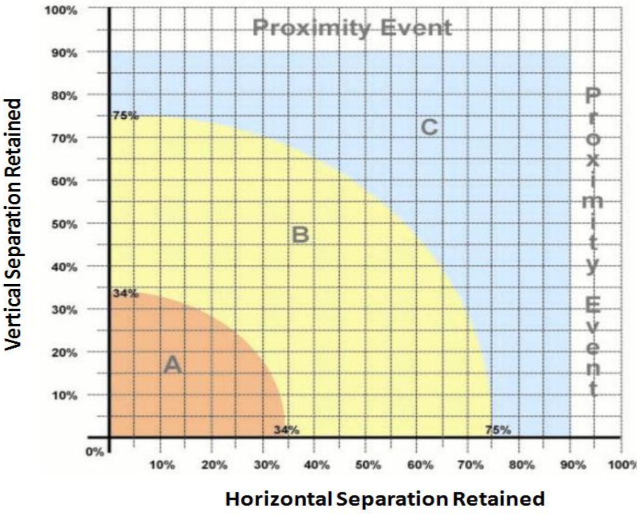

Figure 7. Categorization of operational errors in A, B, C, and PE categories for non-wake separations.

by the ranges of $H_\mathrm{r} \leq 70\%$, $70\% < H_\mathrm{r} \leq 85\%$, and $85\% < H_\mathrm{r} < 100\%$, respectively.

Next we define the criticality state of a predicted loss of separation (LOS). An operational error causes an LOS. The SCC concept of operational errors can thus be directly adopted to define the SCC class of an LOS. That is, we can classify the LOS states into classes A, B, C, and PE based on the same ranges of the conformance separation. The smaller is the conformance separation of the LOS, the more severe is the SCC class of the LOS. On the other hand, the time to the predicted LOS indicates how urgent it needs to be dealt with and is thus important to be taken into account. We combine these two factors to define the criticality state of a predicted LOS with three discrete values of high, medium, and low, as shown in Table 3. We may also refer to the criticality state of a potential LOS as *none* (not listed in Table 3) if it is of class PE with a time to LOS greater than 70 seconds. In general, a conflict may develop into various criticality states of LOS. The LOS gets more critical as the aircraft converge toward each other, becomes less critical as they diverge from each other, and may eventually disappear. For example, a high criticality LOS state refers to a situation in which the time to the predicted LOS is less than 40 seconds and the SCC class of the LOS is either A or B. The two time durations of 40 and 70 seconds are adjustable parameters. These two values are based on engineering experience although the result is not sensitive to the precise values. Subject matter experts (SMEs) have suggested that a 20 seconds alert lead time in the terminal area would provide sufficient time for the controller to take action in most conflict situations.

Table 3 Definition of the criticality state of a loss of separation

Time to LOS: t (seconds)	$t < 40$	$t > 40$	$T < 70$	$t < 40$	$t > 70$	$40 < t < 70$
SCC class of LOS	A or B	A or B	C	PE	C	PE
Criticality	**High**	**Medium**			**Low**	

Finally we define the severity of a predicted conflict based on the highest criticality state of the impending LOS. If the highest criticality state of an impending LOS is high, medium, or low based on the time to the most severe SCC class into which the LOS can develop within the look-ahead period, the conflict severity is correspondingly high, medium, or low. A high-severity predicted conflict thus refers to an impending LOS which is expected to develop into a high criticality state within the look-ahead period. Similarly, a medium-severity predicted conflict refers to an impending LOS that is expected to develop at most into a medium criticality state within the look-ahead period, whereas a low-severity predicted conflict can at most develop into a low criticality state. If the highest criticality of an impending LOS is *none* then its conflict severity is *none*. Note that it is not a good criterion to use the closest proximity to define the severity of a conflict since it may take a long time for a pair of aircraft to achieve their closest proximity for encounters of a slow closure rate.

3. *Conflict Declaration*

After the prediction of a potential conflict, the detection algorithm may decide whether to declare the conflict depending on how reliable the prediction is and how severe the conflict is. The ultimate objective is to reduce false alerts while maintaining reasonable alert lead time, which is the time to first LOS. To assure a certain level of reliability, we adopt a conventional rule of "*m* of *n*" cycles, which is commonly used in Conflict Alert and elsewhere. The rule of "*m* of *n*" cycles here is in terms of the 4.8 second TRACON radar track update cycle and it means that there are *m* predictions of violation of the separation criteria out of *n* cycles. We will not consider the prediction of a conflict with a severity of *none* as a violation. The *m* and *n* values in the "*m* of *n*" cycles are chosen empirically based on the time to predicted first LOS as shown in Table 4. The precise values may be adjusted somewhat and the rules may be relaxed when the track data contains less noise in the future. The conflict severity of the prediction refers to the severity of the most recent of the *m* conflicts of the "*m* of *n*" cycles. After the rule of "*m* of *n*" cycles is applied, a severity threshold on the conflict severity is used to eventually determine if the conflict prediction is going to be declared with an alert. Three severity thresholds are defined here. When the severity threshold is high, the first declaration of a conflict will not commence until the conflict prediction that survives the "*m* of *n*" cycles rule is of high severity. Once a conflict prediction is declared, a lower-severity prediction will not clear the conflict and it will continue to be declared as long as the rule of "*m* of *n*" cycles is satisfied. Similarly, when the severity threshold is medium (low), the first declaration of a conflict will not commence until the conflict prediction that survives the "*m* of *n*" cycles rule is of medium (low) or higher severity. The low-severity alerting option should generally be used.

Table 4 "*m* of *n*" cycles for conflict declaration

Time to Predicted First LOS *t* (seconds)	$t = 15$	$15 < t \le 35$	$35 < t \le 60$	$60 < t \le 90$	$t > 90$
"*m* of *n*" cycles	1 of 2[†]	2 of 3	3 of 5	4 of 6	5 of 7

[†] If neither of the two predictions is of high severity, use the rule of "2 of 3" cycles instead.

A rule affecting conflict declaration, similar to the standard altitude rounding rule used in the Host computer at each Center, is also adopted here. Any aircraft flying nominally level within 100 ft of its cleared altitude is considered to be exactly at its cleared altitude for the purposes of separation requirements. Note the value is 200 ft for en route. Furthermore, the first or second radar updates are excluded as the course is usually not accurate yet.

D. Visual Approach Flights

There are generally a number of different visual approaches to runways in a large airport. According to SMEs, a large airport is divided into different "complexes," where a complex may consist of just a single runway or two parallel runways separated by a distance of 2500 ft or less. An aircraft approaching a runway in one complex is said to be on VS if it is cleared for visual approach to follow the aircraft in front that approaches a different parallel runway in a *different* complex. An aircraft approaching a runway in one complex is said to be on VV if it is cleared for visual approach to follow the aircraft in front that approaches a different parallel runway (less than 2500 ft apart) in the *same* complex. An aircraft approaching a runway in one complex is said to be on VA if it is cleared for visual approach to follow the aircraft in front within the *same* complex. For example, Figure 8 shows that runways 24L and 24R in Los Angeles International Airport (LAX) form Complex 24 and runways 25L and 25R form Complex 25. Aircraft A1 is on ILS approach to runway 24R and is thus said to be on I4R. Aircraft A2 is cleared on Visual Approach to runway 24R following aircraft A1 in front and aircraft A2 is thus said to be on V4R and A1 and A2, boxed with the same color, form a VA pair. Aircraft A4 is cleared for visual approach to runway 25L following aircraft A3 which is on ILS approach to runway 25R and aircraft A4 is thus said to be on VV and A3 and A4 form a VV pair. Aircraft A6 is cleared for visual approach to runway 25L following aircraft A5 in front, which is on ILS approach to runway 24R, and aircraft A6 is thus said to be on VS and A5 and A6 form a VS pair. For LAX, VA thus includes V4R, V4L, V5R, and V5L.

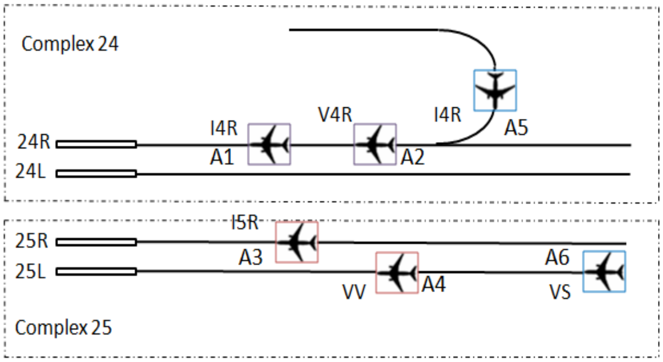

Figure 8. Two complexes in LAX with three visual approach aircraft pairs: (A1, A2), (A3, A4), and (A5, A6).

The concept of conflict severity can be applied to the declaration of potential conflicts involving visual approach aircraft to ensure safer operations. As seen from Fig. 8, the varieties of visual approaches mixed with ILS approaches may make the overall separation rules in large airports quite complex. Officially there are no separation requirements for visual-approach pairs such as those in Fig. 8, although standard separation minima are still required between non-visual pairs such as the pair of A2 and A5. In practice some safety protections should be provided to prevent potential errors. According to SMEs, a visual aircraft pair will generally maintain some unpublished safe separation which is typically slightly above 2 NM horizontally. Also, the controllers have moral responsibility to prevent collisions, so they watch out for this safe separation. There is always the potential error of a visual-approach aircraft unintentionally following the wrong leading aircraft as well. It is therefore important to alert the controller if serious compression of the visual approach pairs is developing. In this way potential errors can be avoided and the controller may inform pilots before TCAS alerting occurs. A high severity threshold will serve the purpose in this case. Here the standard separation requirements are assumed, but a conflict will not be declared unless the severity of the potential conflict becomes high. This approach does not increase controller workload since it generates few alerts under normal circumstance. However it does provide alerts to the controller before safety is compromised.

The high-severity alerting option for visual-approach aircraft pairs assures that there are no alerts when the visual-approach pairs are predicted to maintain about 75% of the standard separation minima. With consensus from SMEs, the high-severity rules for visual-approach aircraft pairs are as follows. First, the VA pairs are subject to the high-severity alerting option. Next, there will *not* be any alert between a VS aircraft pair or a VA aircraft and another VA or ILS aircraft that is in a different complex unless one of the aircraft crosses its localizer toward the other aircraft, in which case a high-severity alert may be declared. Finally, there will be no alert at all between a VV aircraft pair no matter how close they may get unless the aircraft on VV overtakes the aircraft in front, in which case they no longer form a VV pair. Thus, only TCAS might provide collision alerting protection for VV aircraft pairs if it is not turned off.

E. **VFR and MCI Flights**

Alerts on potential conflicts involving an IFR flight and a VFR flight outside class-B airspace are desired as well, though the separation minima are different from those inside class-B airspace. There are generally no standard separation minima involving VFR flights outside class-B airspace.[2] However, the controller needs to inform pilots of IFR flights of potential VFR traffic, preferably before any TCAS traffic alerts or resolution advisories. Discussions with participating controllers and SMEs in HITL experiments suggest that the class-B-airspace minima of 1.5 NM horizontally and 500 ft vertically are too small to allow early enough alerting when the aircraft involved are not flying level. It appears that the horizontal minimum needs to be increased to 2 NM and vertical minimum to 1500 ft when one or both aircraft are climbing or descending.

The separation minima for MCI conflicts between an IFR flight and an unassociated flight are similar to those between IFR and VFR flights. There are many aircraft in terminal airspace that are unassociated with flight plans. Dead Reckoning (DR) trajectories have to be used to predict their positions. The separation minima for potential MCI conflicts are generally 1.5 NM horizontally and 500 ft vertically. Many unassociated flights have low ground speeds near small airports. Reduced separation minima of 1 NM horizontally and 400 ft vertically are thus used when the ground speed is below 90 knots and altitude is below 1500 ft. Also, unassociated tracks with altitudes below 500 ft will be excluded since the IFR flights would be landing.

Unassociated flights are generally VFR flights. However, before an IFR aircraft arrives into terminal airspace its track usually appears as unassociated and becomes associated with a call sign later. As a result, the unassociated track and another associated track may correspond to the same call sign and even coexist for a short period of time. Thus, self alerts between the same aircraft could be generated. Indeed some CA alerts turn out to be self alerts. In another situation, both tracks may have conflicts with another IFR flight, leading to redundant alerts, which turn out to exist in Conflict Alert as well. A preprocessor has thus been introduced in T-TSAFE that stitches identical tracks together in real time by keeping a short history of active aircraft tracks. The stitching mechanism identifies identical tracks based on horizontal positions, altitudes, and time. Thus, T-TSAFE is designed to eliminate self and redundant MCI alerts.

III. Fast-Time Simulation Experiments and Results

The performance of T-TSAFE was evaluated with fast-time simulation experiments focusing on how well T-TSAFE handles conflicts involving visual-approach aircraft pairs, how well it deals with MCI conflicts, and how it may be integrated in the near term with STARS, which has limited intent information. The relevant conflict prediction and declaration mechanisms have been discussed in the previous section.

A. **HITL Mixed Operations**

Two fast-time simulation experiments were performed on two sets of data recorded from two 40-minute "shakedown" runs of HITL air traffic control experiments simulating operations in the Southern California TRACON (SCT). Most arrivals to LAX were cleared for visual approaches. The setup of the shakedown HITL experiments was not for measuring the performance of T-TSAFE but to study the algorithms associated with visual-approach flights and the Computer Human Interfaces (CHI) for the controllers. As a result, there were many alerts intentionally created. In the first run, two parallel arrival runways (24R and 25L) were used, so an aircraft could be cleared to V4R or V5L. In the second run, four parallel runways (24L, 24R, 25L, and 25R) were used, so an aircraft could be cleared to V4L, V4R, V5L, V5R, VS, or VV. The four-runway configuration with visual approaches is used infrequently in actual LAX operations. This configuration is characterized by high throughput and high capacity. The shakedown experiment was performed with the same setup as previous experiments as described in Ref. 10. Thus, many conflicts were intentionally created and many other conflicts resulted from experimental artifacts. Nevertheless, since the visual intent information was recorded, fast-time simulation and analysis of the data still helped to assess the performance of T-TSAFE.

The fast-time simulation of HITL experimental traffic data generated various alerts, with only high-severity alerts for visual-approach pairs. Figure 9 shows the alerts for the configurations of two and four runways, categorized in four categories as described next. VFR/MCI alerts refer to alerts in which one of the aircraft is VFR or MCI flight. Most of these alerts were intentionally created by a dedicated pilot.[10] The non-visual non-VFR/MCI alerts refer to those that do not involve visual-approach or VFR/MCI flights. Many of these alerts were due to simulation artifacts such as when an aircraft cleared for final approach to runway 24R would make a dog-leg approach in which the aircraft was close to but never really on the localizer for lack of pseudo-pilots. Ref. 9 shows that 10% or less of the non-visual-approach alerts may be false alerts. An alert is considered false if it is not followed by an actual loss of separation when there is no controller or pilot intervention. The before-visual-clearance alerts refer to those alerts for which the aircraft were not yet cleared for visual approaches and as soon as they were cleared the alerts disappeared. Thus these are good alerts. These alerts would not appear when the aircraft were issued visual-approach clearance earlier in the real world or after the participating controllers have some training runs. On the four-runway configuration there were some cases with the leading aircraft cleared on VV. These alerts were due to misunderstanding about the VV clearance by one participant controller, again because we did not have a training run before the shakedown experiment. The four categories of alerts account for all the alerts generated. Thus, the high-severity alerting option generates no nuisance alerts. When the high-severity alerts for visual-approach flights were examined separately, SMEs also indicated that those were good and useful alerts to remind the controller.

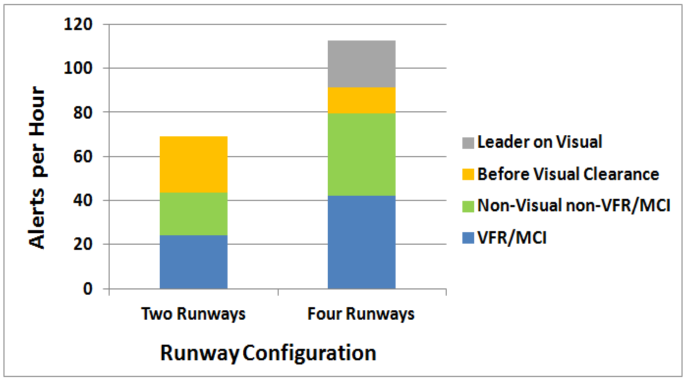

Figure 9. Characterization of various T-TSAFE alerts from simulations of HITL air traffic data for two runway configurations.

Two fast-time simulations of the HITL recorded data sets were also performed assuming no visual clearance intent information so they were similar to simulations of real-world air traffic data with no knowledge of visual clearances. Figure 10 shows the number of alerts per hour averaged over both simulations. The non-visual alerts included the VFR/MCI alerts. The total alerts for mixed operations included the non-visual alerts. If we exclude the non-visual alerts from the first and second bars, we obtained alerts involving visual-approach aircraft. These correspond to 85 and 30 alerts per hour for the first and second bars, respectively. Thus, after excluding the non-visual-approach alerts, about 55 alerts per hour or 65% of the alerts generated when the visual-approach flights are assumed to be on ILS approach, are eliminated when the visual intent information becomes available. The other 30 alerts per hour, as discussed above, are either because visual approaches were not yet declared or the VV clearances were improperly used. The result once again shows that the T-TSAFE high severity alerting option can eliminate all nuisance alerts which would otherwise appear when visual-approach flights were treated as ILS approach flights.

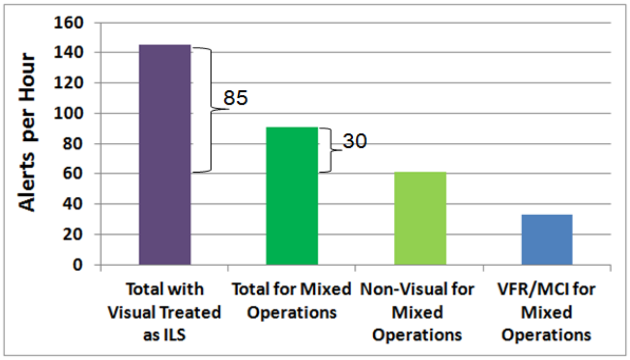

Figure 10. T-TSAFE alerts from simulations of HITL air traffic data.

B. Real-World Mixed Operations with MCI

To assess the full benefits of T-TSAFE, we also performed a fast-time simulation of real-world data including both associated and unassociated tracks and compared the performance of T-TSAFE in the low-severity alerting option with the actual Conflict Alert in the field. It has been difficult to obtain real-world data that contain both associated and unassociated tracks together with flight intent information for the associated flights. Air traffic data recorded at NASA has only associated tracks and their flight intent information but does not include unassociated tracks. On the other hand the FAA's CDR (Continuous Data Recording) data recorded from CA does not contain any intent information. We used the full 24 hours data on February 24, 2012 from SCT. We extracted unassociated tracks from the CA data and inserted them into the NASA recorded data. Unassociated tracks with negative and zero altitudes were removed. As explained earlier, a preprocessor of T-TSAFE has been developed that processes the unassociated tracks in real time without knowledge of future tracks and may associate the unassociated track with associated tracks by stitching based on position and velocity to avoid self and redundant alerts. A table that maps unassociated and associated tracks and sometimes two unassociated tracks is generated by the preprocessor. This table helps to identify CA's conflict pairs, especially the MCI alert pairs, in post analysis. Post processing of the XML outputs of T-TSAFE allows comparison of T-TSAFE alerts of conflict pairs including MCI alert pairs with those of the CA alert pairs. The CA conflict pairs were extracted from the CO (System Monitor Console) class of the FAA CDR Editor, a tool for extracting various classes of CA data. The CA alerts from the CO class were displayed to the controllers in the real world.

In simulation of the real-world air traffic data, the low-severity alerting option was used with all arrival aircraft assumed to be performing ILS approaches as far as the conflict criteria were concerned. Inferred altitude clearances were also added as simulated altitude amendments in the recorded traffic data as if the level-off intent were available. Weather conditions on Feb. 24, 2012 and the way most aircraft flew their final approaches with short final legs suggest that a large percentage of the aircraft were on visual approaches. Thus, many of the T-TSAFE alerts were expected to be nuisance alerts. However, as shown in the previous section, these nuisance alerts would all be eliminated when the high-severity alerting option is used on visual approach pairs, given that the visual-approach flight intent information is available in CARTS and STARS.

Analysis shows that MCI alert pairs for T-TSAFE are 55% fewer than those for Conflict Alert, with about 10% of the CA non-MCI and 25% of the CA MCI alerts overlapping with the corresponding T-TSAFE alerts. Figure 11 shows the alerts per hour average over the whole day for both T-TSAFE and CA, separated by MCI and non-MCI as well as LOS and non-LOS alerts.[8] The CA All and T-TSAFE All bars represent the total alerts for CA and T-TSAFE respectively. The LOS and non-LOS portions of the CA alerts represent an overlap of ~12% of CA alerts with the T-TSAFE alerts. Similarly, the LOS and non-LOS portions of the CA non-MCI alerts represent an overlap of ~10% with the T-TSAFE non-MCI alerts. The LOS and non-LOS portions of the CA MCI alerts represent an overlap of ~25% with the T-TSAFE MCI alerts. The overlap of about 10% for the non-MCI alerts is small and is consistent with an 80% false-alert rate[16] for CA non-MCI alerts given a false alert rate of ~10% for T-TSAFE as previously discussed.[9] The overlap of about 25% for the MCI alerts is larger but is still a small overlap. Notice also that T-TSAFE MCI alerts (the TTSAFE-MCI bar) are about 55% fewer than the CA MCI alerts (the CA-MCI bar). The fact the overlap is small and T-TSAFE will eliminate the nuisance alerts associated with visual approaches suggest that T-TSAFE and CA may coexist initially because they have different time horizons and there will not be too many T-TSAFE alerts.

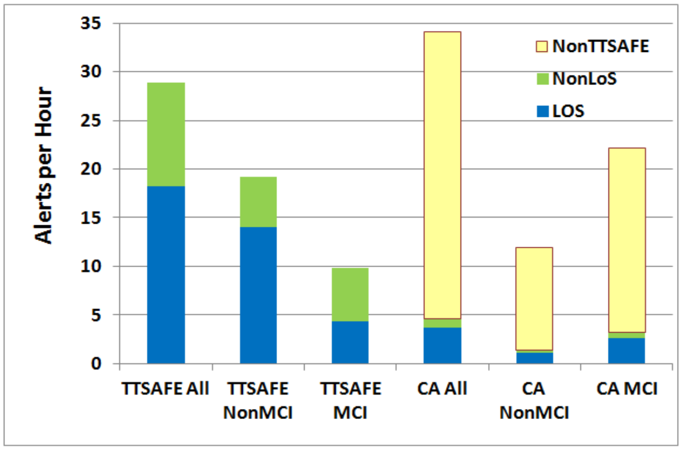

Figure 11. Overlap between various TTSAFE and CA alerts based on the category of LOS, non-LOS, and non-TTSAFE.

A relatively large percentage of CA alerts are MCI alert which contains a small portion of self and redundant alerts. As seen in Fig. 11, about 70% of CA alerts are MCI alerts. We also found that about 7% of CA MCI alerts are self alerts between the same aircraft or redundant alerts of the same aircraft showing up both as associated and unassociated aircraft and being in conflict with another aircraft simultaneously.

It is helpful to classify the alerts into LAX and non-LAX alerts with LAX alerts referring to those alerts in which at least one of the aircraft is an LAX departure or arrival. Figure 12 shows the alerts per hour average over the whole day for both T-TSAFE and CA, separated by MCI and non-MCI as well as LAX and non-LAX alerts. The TTSAFE NonMCI bar indicates about 72% of T-TSAFE non-MCI alerts are LAX alerts whereas the TTSAFE MCI bar indicates that only about 12% of T-TSAFE MCI alerts are LAX alerts. On the other hand, the CA NonMCI bar indicates that only about 13% of CA non-MCI alerts are LAX alerts whereas the CA MCI bar indicates that only 2% of CA MCI alerts are LAX alerts. These results suggest that the majority of LAX alerts were suppressed or inhibited in CA. Thus, T-TSAFE is even more favorable considering that T-TSAFE does not suppress LAX alerts and the nuisance alerts will be eliminated after visual-approach intent information is applied.

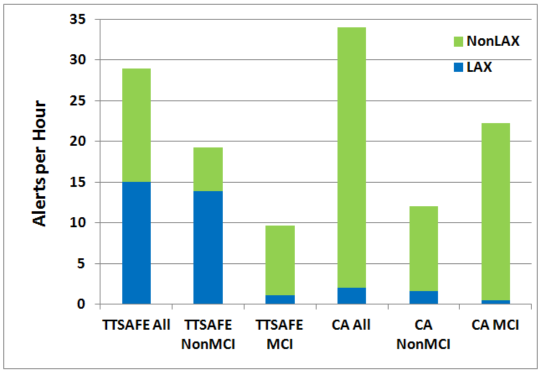

Figure 12. Various TTSAFE and CA alerts classified in terms of LAX and non-LAX alerts.

The fact that CA has inhibition flags on a large portion of predicted conflict pairs can be seen more explicitly from analysis of the CA conflict predictions before applying the "*m* of *n*" filtering and the inhibition flags. Figure 13 shows the CA predictions of potential conflict pairs from the "CA class" of FAA CDR Editor. These are predictions that may or may not result in declarations of conflict alerts so the controllers did not see them. Almost two thirds of these predicted conflict pairs were not declared as conflict alerts due to the filtering and inhibit flags. The ratio of the inhibited portion of a bar in Fig. 13 to the overall high of the bar indicates the percentage of predicted conflict pairs that has inhibition flags. Thus, about 47% of the conflict predictions of CA MCI pairs had inhibition flags and 36% of the conflict predictions of CA non-MCI pairs had inhibition flags.

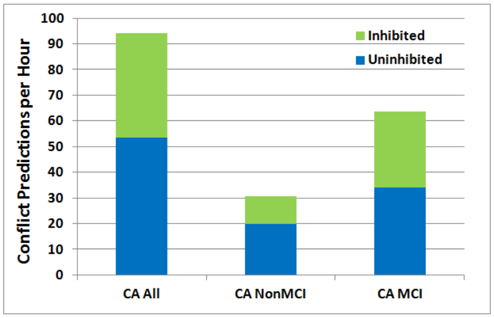

Figure 13. CA predicted conflict pairs per hour separated into inhibited and uninhibited portions.

To summarize, most of the TTSAFE alerts from fast-time simulation of the real-world air traffic data are nuisance alerts that would be eliminated in reality where visual-approach information is available. No explicit suppression of areas of TRACON or inhibition flags on specific aircraft is needed. The high-severity alerting option for visual approach flights will only provide alerts when a visual aircraft pair gets too close to each other. In contrast, CA resorts to explicit suppression or inhibition flags which will also eliminate any useful alerts when aircraft pairs get unexpectedly too close. Even after the suppression, there still appears to be too many alerts and too many false alerts. Thus, T-TSAFE will do a better job of assisting the controller to assure aircraft separation and help to increase the safety of TRACON operations.

C. STARS Intent Models

The T-TSAFE system would fit nicely in STARS as a subsystem to provide a functionality that helps the controller to maintain aircraft standard separation in terminal airspace. However, STARS currently has very limited flight intent information that does not even include the flight plan routes. It is thus necessary to examine the effects of different flight intent information in T-TSAFE as the intent information to be available in STARS is likely to be phased in.

Based on the intent information either available in STARS today or expected to become available in STARS with easy enhancements, four intent models were studied. The total number of alerts T-TSAFE generated for the four models are compared with the baseline (BL) model that includes all intent information available. The main intent information used in T-TSAFE, as explained earlier, includes the Nominal Interior Route (NIR), altitude clearance, RNAV Departure Route (RDR), and the flight plan. The four models studied are those of Dead Reckoning (DR), DR with Level-off (DRL), NIR with Level-off (NL), and NIR with RDR and Level-off (NRL). The DR model corresponds to current STARS without altitude clearance. The DRL model corresponds to current STARS with altitude clearance, which is simulated with inferred altitude clearance here. The NL model corresponds to STARS with altitude clearance and an enhancement in its static adaptation with NIR, which already exists in TMA for most TRACONs. STARS currently can already provide the necessary key information required for NIRs: arrival meter fix, airport, arrival runway, and aircraft type. The NRL model corresponds to STARS with altitude clearance and enhanced adaptation for both static NIR and RDR. STARS can provide the key information required for the RDR as well such as the departure meter fix and runway. Compared with the NRL model, the BL model has the constantly updated flight plan of the aircraft as well.

Figure 14 shows the total number of alerts T-TSAFE generates for the four models and the baseline. As can be seen, the number of alerts in the DR model almost doubles that in the baseline. The level-off intent reduces the number of alerts significantly and so does the NIR intent. The RNAV departure route has a relatively less effect partly because the overall number of alerts on departure flights is small. There is no obvious trend on whether the alerts are related to LAX arrival or departure. Again, the actual number of alerts will reduce significantly when visual-approach intent is available in the real system, and so the difference between the NL model and the baseline will not be great. Thus, the intent information of altitude clearance and NIR is the most significant in reducing the number of false alerts, which only requires a minimal enhancement of STARS adaptation to include existing static NIR available in TMA today.

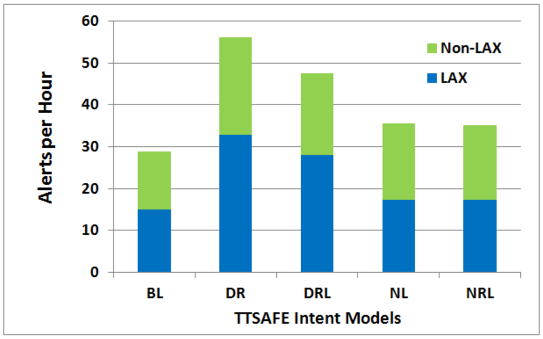

Figure 14. T-TSAFE alerts per hour for the baseline (BL) and four other models of different intent information.

IV. Summary and Conclusions

This paper describes a tactical separation assurance system for terminal airspace called Terminal Tactical Separation Assured Flight Environment (T-TSAFE). T-TSAFE may support a new functionality of the Standard Terminal Automation Replacement System (STARS) that assists air traffic controllers in maintaining aircraft standard separation by alerting them to imminent separation conflicts for the whole terminal airspace. The conflict detection is based on a recently proposed intent- and severity-based single-trajectory algorithm. The conflict severity concept is refined and the commonly used "*m* of *n*" rules of conflict declaration are adopted. The focus has been on three issues not being fully addressed in previous work. The first issue concerns how well T-TSAFE handles potential conflicts involving visual-approach aircraft pairs. A complex variety of those visual pairs are used in practice to increase airport throughput. These visual pairs, as well as how to apply a high-severity alerting option to them to enhance safety, are described. The second issue concerns how well T-TSAFE treats potential Mode-C-Intruder (MCI) conflicts involving an aircraft associated and another unassociated with a flight plan. Normal low-severity alerting option is applied to MCI alerts with separation criteria similar to those for VFR (Visual Flight Rules) flights. The third issue concerns how T-TSAFE may be integrated with STARS which has limited available intent information. Effects of different levels of intent information are thus studied to identify the most important intent information that reduces false alerts.

A fast-time simulation of air traffic data recorded from a preliminary human-in-the-loop experiment on Southern California TRACON was performed. The experiment included one run with two parallel runways and another with four parallel runways and featured higher than normal traffic density with most aircraft being cleared for visual approach to their runways. By simulating the data with and without the visual approach intent information, it was found that the large number of nuisance alerts resulted from treating the visual-approach flights as instrument-approach flights are all eliminated by the high-severity alerting options for visual-approach aircraft pairs.

A fast-time simulation of real-world air traffic data from operations in Southern California TRACON on Feb. 24, 2012 was performed, which included both associated and unassociated tracks and thus allowed an evaluation of T-TSAFE performance on MCI alerts. As before, the real-world data featured mixed operations involving many visual-approach aircraft that were assumed to be making instrument approaches instead. Comparison with results from the real Conflict Alert (CA) in the field shows that T-TSAFE has more than 50% fewer MCI alerts. T-TSAFE also has a slightly smaller total number of alerts even though CA suppresses most of the alerts in LAX whereas T-TSAFE includes the removable nuisance alerts resulting from treating the visual-approach flights as instrument flights. The overlap between CA alerts and T-TSAFE alerts is only about 10%, suggesting that T-TSAFE may coexist with CA initially especially because the two systems have different time horizons.

Different intent models based on what is and what can be available in STARS were studied and compared with the baseline that includes all intent information including the aircraft flight plans. The result suggests that altitude clearances and static nominal interior routes dominate the effects that reduce the number of false alerts. Altitude clearance is already available from STARS today, and static nominal interior routes already exist for most TRACONs in the Traffic Management Advisor (TMA) and can be readily adapted to STARS. The relevant key information required for nominal interior routes such as the arrival meter fix, airport, and runway as well as the aircraft engine type are already available in STARS.

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