Close encounter decision-making: comparing CASSANDRA and CNES operational processes

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Introduction. At the Aerospace Centre of Excellence (ACE), a system to support operators in Space Traffic Management (STM) tasks is being developed: CASSANDRA, *Computational Agent for Space Surveillance and Debris Remediation Automation*[1]. One of its functionalities is the Intelligent Decision Support System module (IDSS), which performs close encounter risk assessment and provides robust decision-making support to operators, [2, 3]. At CNES operational centre, the follow-up of an encounter risk assessment is performed by the analysts using JAC software[4] after receiving a sequence of CDMs. This system is currently in operation and tested in several real-case scenarios.

In this work, we propose a new capability of CASSANDRA's decision-making process to handle a series of CDMs associated with encounter events, as done in CNES operational centre. CDMs are the standard to share information about a space encounter. A comparison between CASSANDRA's and CNES's decision-making systems is made over some virtual and real scenarios.

CASSANDRA approach. CASSANDRA's approach is based on Dempster-Shafer's theory of evidence (DSt)[5], allowing modelling both epistemic and aleatory uncertainty, data fused information from different sources, and providing robust decisions. The IDSS system performs the decision-making using a classification criterion that considers the proximity of the event, the confidence in the correctness of the PoC value, and the Degree of Uncertainty affecting the available information[2]. In order to use the DSt approach, the information has to be provided as sets of intervals for the uncertain variables. When considering CDMs, the information included on them only accounts for aleatory uncertainty and the information is single-valued.

The novelty of this work is in the inclusion of sequences of CDMs as inputs. From CDMs, we can extract the uncertain variables used by the IDSS (miss

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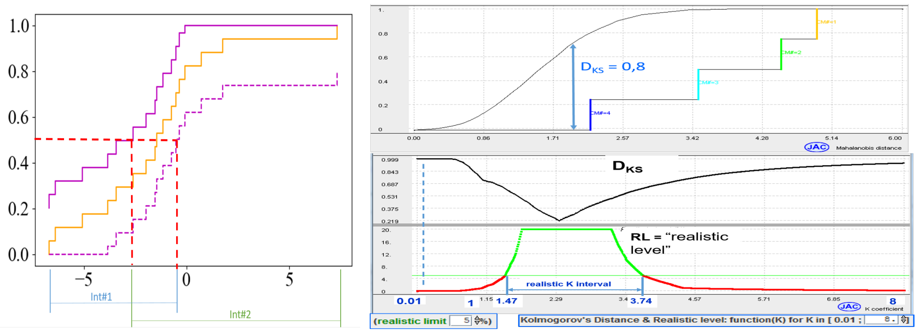
distance and covariance matrix components in the impact plane) and compute the empirical Cumulative Distribution Function (eCDF). According to Dvoretzky–Kiefer–Wolfowitz (DWT) inequality [6], it is possible to define the region within the actual Cumulative Distribution Function (CDF) will be located with (1-ε)% confidence. With the resulting set of curves, similar to the p-boxes used in probability theory[7], it is possible to define the intervals of the variable by executing a number of α *cuts* along the vertical axis, so the intersections with the DWT bands define the bounds of the intervals (see Figure 1a). Once obtained the intervals, the IDSS decision-making approach can be executed as usual.

CNES approach. On the other hand, CNES decision-making process is based on the concept of Scaled PoC, sPoC[8]. Acknowledging that the information contained in the CDM can be affected by further uncertainty, the objects' covariance matrices are scaled by multiplying them by the factors $k_p \in [\underline{k_p}, \overline{k_p}]$ and $k_s \in [\underline{k_s}, \overline{k_s}]$. The sPoC is defined as: $sPoC = max_{kp,ks}(PoC)$.

In order not to overestimate the sPoC, the range for k_p and k_s is shrunk so that the level of realism, α, of the Kolmogorov–Smirnov distance between the empirical distribution function and the (assumed) theoretical 3DoF ξ^2 distribution of the Mahalanobis distance between the previous uncertain ellipses and the reference one (i.e. the most recent information on uncertainty) is above the selected *realistic limit)* [9].

Then, the operator bases the final decision on the highest sPoC, the proximity of the event, and the minimum miss distance.

Study cases. We propose to compare both decision-making processes in a number of cases, both virtual, with a known outcome (collision or on collision), and real cases provided by CNES.



(a) (b)

Fig. 1: (a) CASANDRA approach: (purple) DWT bands and (red) α *cut* at 0.5. (b) CNES approach: Theoretical vs empirical Mahalanobis distance distribution, and k_p range of values for above the *realistic level* (green).

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