

# Rules of the Road Applied to Collision Avoidance Autonomy

Clean Space Industry Days 2024

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ESTEC

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40<sup>TH</sup>

Excellence and beyond

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FOUR DECADES **PUSHING THE LIMITS**

# Agenda

- Introduction
- Automated give-way decision making
- Conclusions

# Introduction

# Introduction

❑ Increase of the Active Vs. Active conjunctions

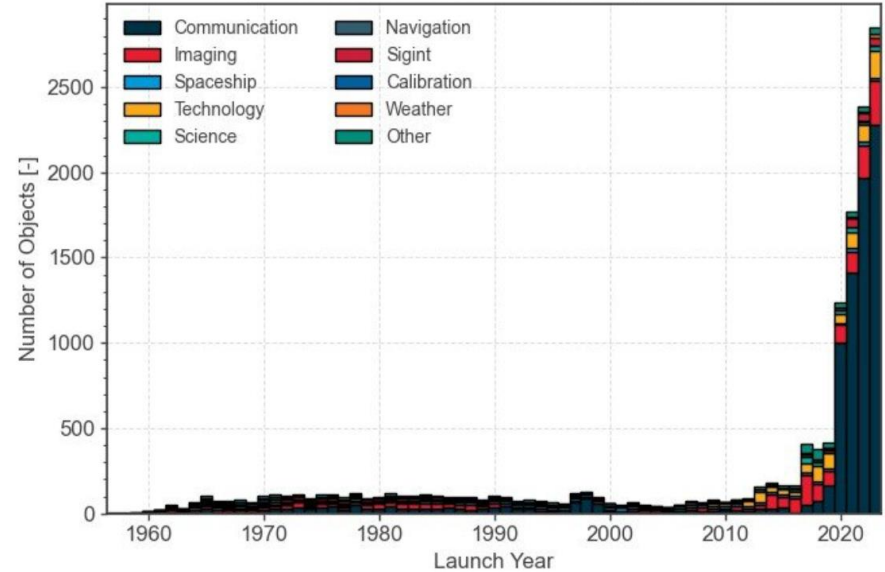
❑ **Need** for coordinate who give way



❑ **Need** to automate the process



Payload Launch Traffic into  $200 \leq h_p \leq 1750\text{km}$



— ESA Space Environment 2024 figure 2: Payload launch traffic into low-Earth orbits over time

Spatial density is increasing!

## Collision Frequency of Artificial Satellites: The Creation of a Debris Belt

DONALD J. KESSLER AND BURTON G. COUR-PALAIS

NASA Johnson Space Center, Houston, Texas 77058

As the number of artificial satellites in earth orbit increases, the probability of collisions between satellites also increases. Satellite collisions would produce orbiting fragments, each of which would increase the probability of further collisions, leading to the growth of a belt of debris around the earth. This process parallels certain theories concerning the growth of the asteroid belt. The debris flux in such an earth-orbiting belt could exceed the natural meteoroid flux affecting future spacecraft designs. A



# Automated decision making process

# Decision Making Process (DMP)



## Three different DMPs

### Rules-of-the-road



- Define the **right of way** in active-active conjunctions
  - Inspired by air, sea and road traffic
- Compare **unambiguous parameters** to define priority
  - Simple and easily **automated**

### Shared Manoeuvre



- Both satellites manoeuvre to **share the CAM cost**
  - **Communication** between operators
- **Coordination** of the design strategy to ensure **safety**
  - Fair and **efficient**

### Negotiation and Trading



- Satellite operators **negotiate and agree** on a conjunction **resolution**
  - **Communication** between operators
  - Needs improvement and regulation

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# CREAM#3 - AutoSTM

## ❑ Collision Risk Estimation and Automated Mitigation – CREAM

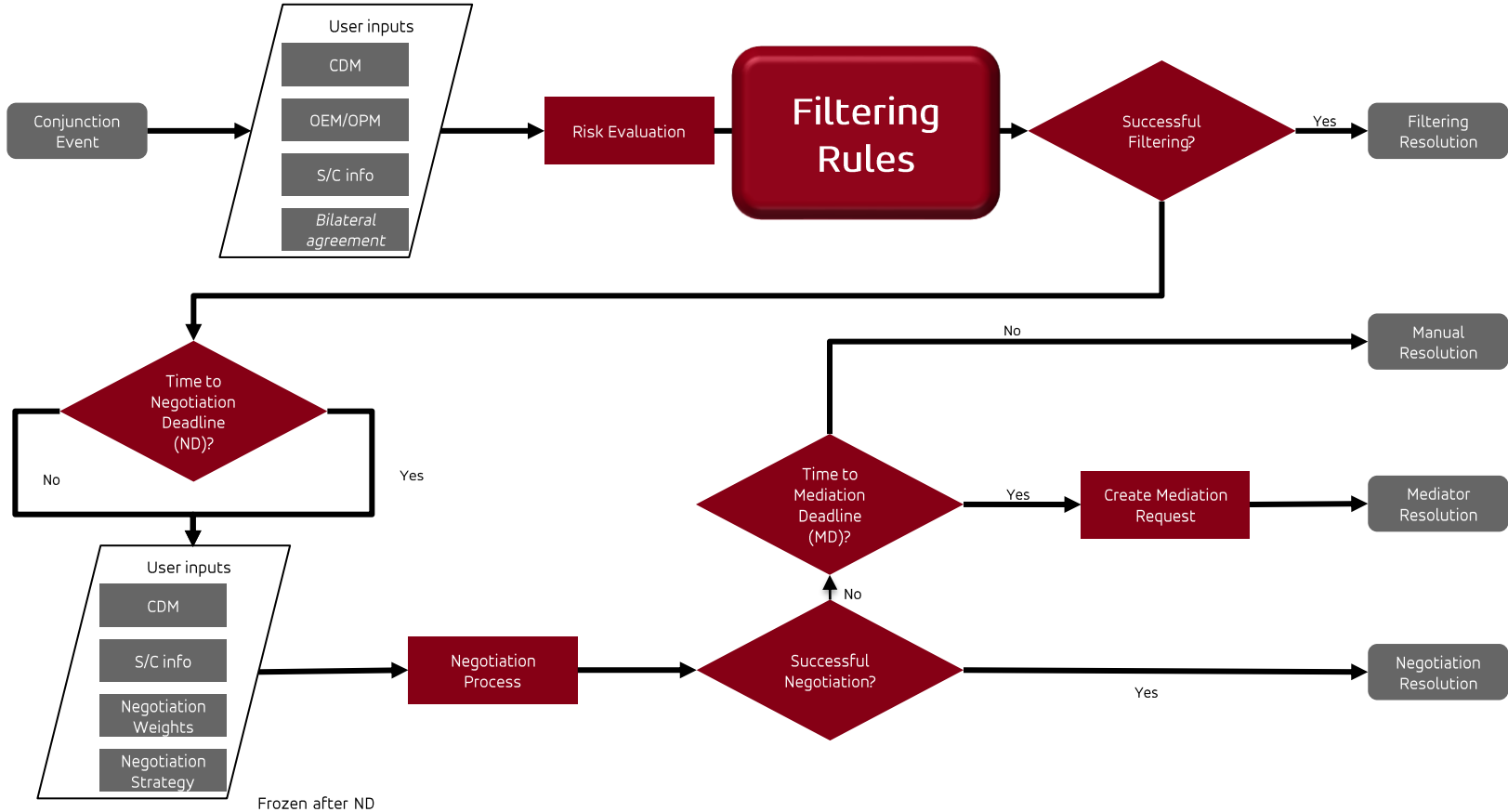
### ❑ Objectives:

- Automated Collision Avoidance
- Reduction of the time between Manoeuvre decision and closest approach
- Assessment of coordination strategies
- Impact of different conjunction resolution rules on the operation of satellites
- Definition of safe communication protocols

CREAM#3



# AutoSTM – Work flow



# Filtering Rules

**This analysis is not part of CREAM#3.** GMV's internal work through Master's Thesis<sup>(\*)</sup>

- ❑ Filtering rules -> set of collection of pre-defined rules (Ruleset) to determine the right-of-way.
- ❑ Several approaches are possible. **AutoSTM** Platform Administrator can enable / disable rules.
- ❑ Evaluated Ruleset (among others):

Ruleset	Rules
Main RS	Op. Status > Mission Phase > Man. Level
Orbit RS-1	Orbit Type > Heading
Orbit RS-2	Orbit Type > Altitude
Mission RS	Mission Users > Mission Purpose
Asset RS	Constellation > Fairness

(\*) "Analysis of strategies for active vs active collision avoidance and Space Traffic Management"

**Author:** Fausto Biondi

**Advisor:** Prof. Pierluigi Di Lizia (Politècnico di Milano)

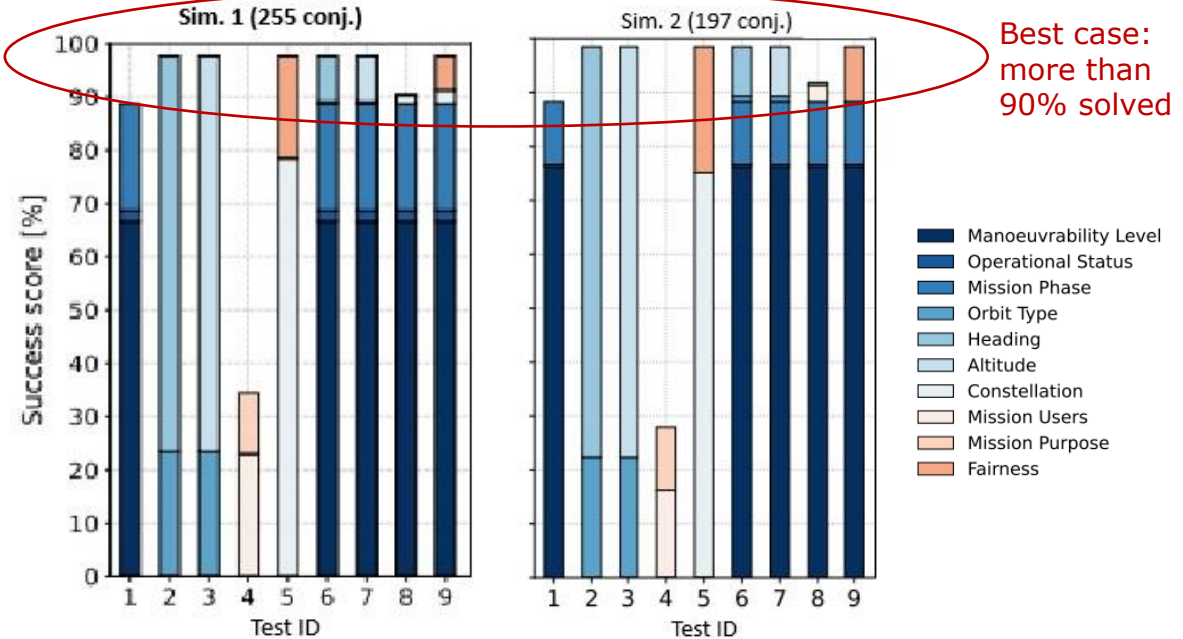
**Co-advisors:** Diego Escobar Antón (GMV), Jorge Rubio Antón (GMV)

Rule	Priority
Operational Status	Partially Operational > Backup > Spare > Operational > Extended Mission
Mission Phase	Design > Transit
Manoeuvrability	Minimally Manoevrable > Manoevrable > Aut. COLA > Crewed
SSC Orbit Type	SSO > Polar > Equatorial > Non-polar inclined
Heading	Right > Left
Altitude	Lower > Higher
Users	Government > Civil > Commercial > Military
Purpose	Science > EO > Nav. > Communications > Technology > Unknown
Constellation	Spare satellite > small constellation > mega-constellaiton
Fairness	Higher > Lower

# Filtering Rules Results - Effectiveness

This analysis is not part of CREAM#3. GMV's internal work through Master's Thesis(\*)

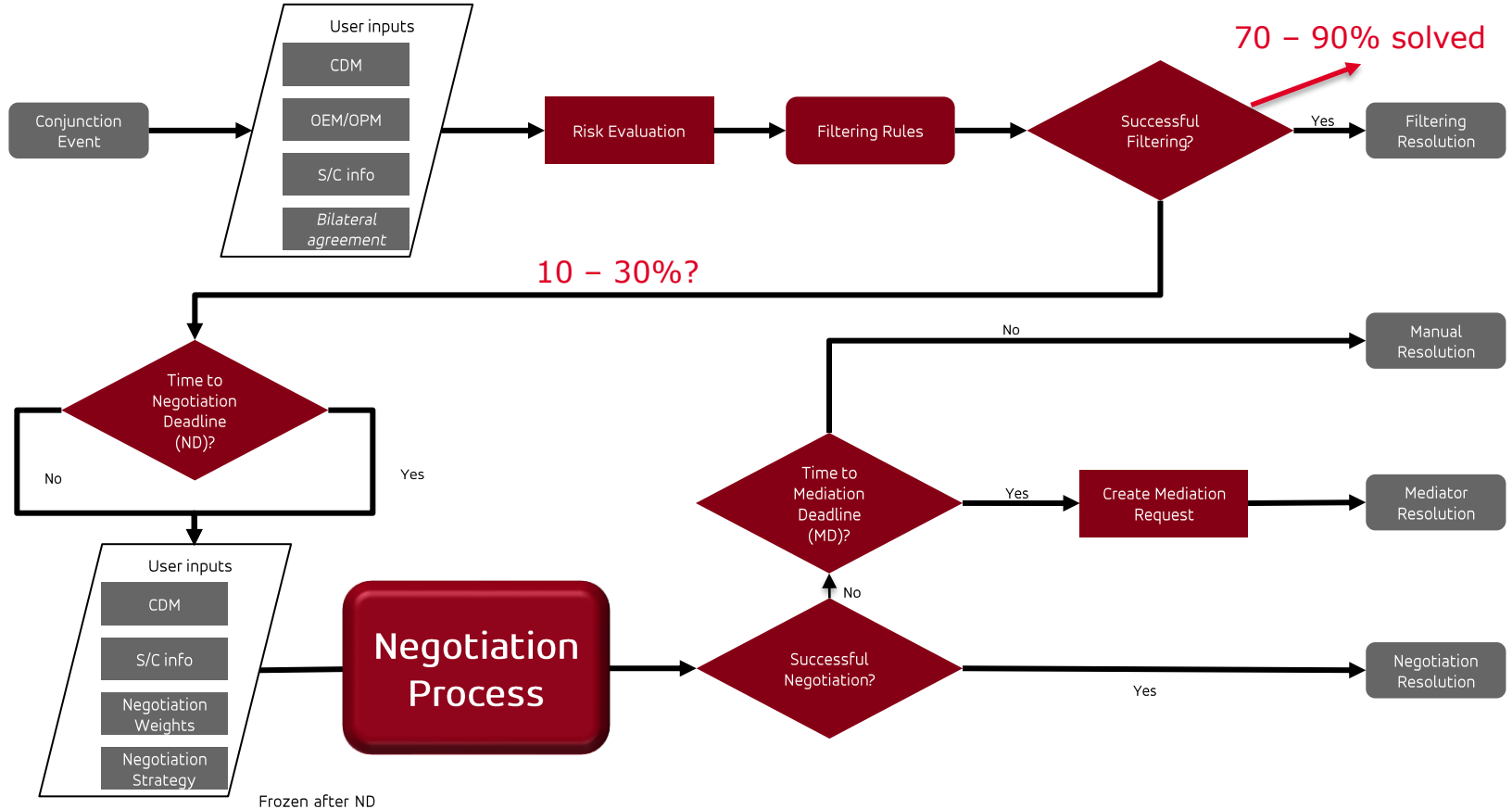
Test ID	Decision-making processes
1	Main RS
2	Orbit RS-1
3	Orbit RS-2
4	Mission RS
5	Asset RS
6	Main RS > Orbit RS-1
7	Main RS > Orbit RS-2
8	Main RS > Mission RS-1
9	Main RS > Asset RS-1



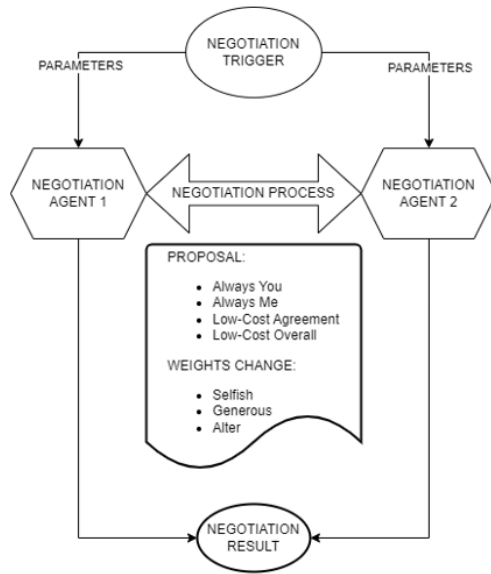
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# AutoSTM – Work flow



# AutoSTM – Negotiation Process Results



❑ Set of dimensionless parameters ( $P_i$ )

❑ Each parameter associated to a weighting factor between [0, 1] ( $W_i$ )

❑ Proposal:

▪ Rigid

- Always you
- Always me

▪ Flexible

- Low-cost agreement
- Low-cost overall

❑ Weights change

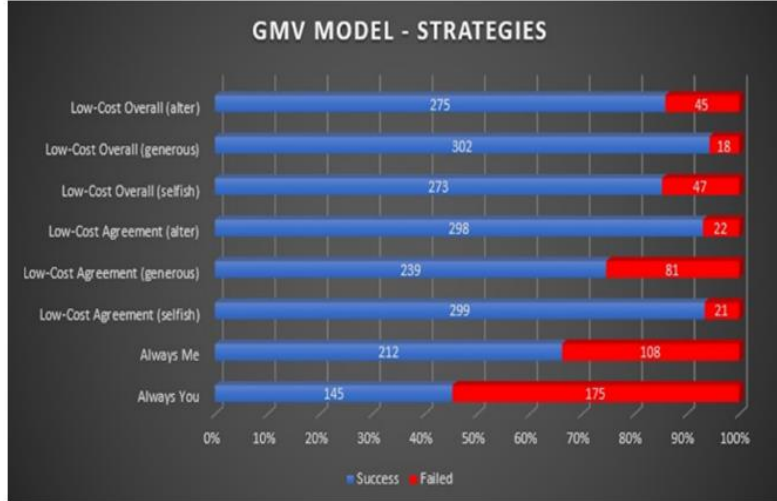
- Selfies
- Generous
- Alter

- Fuel consumed
- Average fuel consumption
- Deviation from design
- Cost of CAM
- Lifetime left
- Dimensionless SMA
- Dimensionless ECC
- Dimensionless INC
- Dimensionless RAAN
- Dimensionless PoC
- Dimensionless covariance matrix

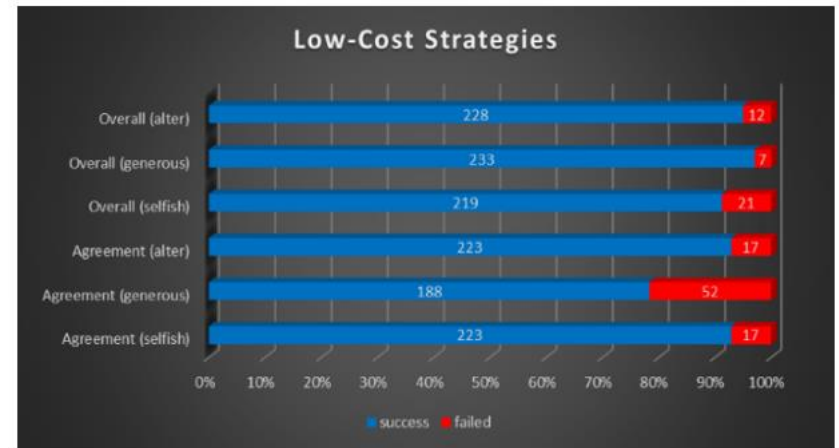


$$\text{Cost} = \sum_{i=1}^n P_i \times W_i$$

# AutoSTM – Negotiation Process Results



Flexible proposal more successful than rigid proposal



Lower success: low-cost agreement with generous weighting



More than 65% of the negotiations are solved in 1 round

# Conclusions



# Conclusions

- ❑ **STM** is key for safe space.
- ❑ **Automation** is mandatory.
- ❑ **Clear Rulesets** are needed to implement the automation.
- ❑ International **collaboration** is a must.

# Thank you

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