Dynamic Separation Minima

Deliverable ID:	D3.3
Dissemination Level:	PU
Project Acronym:	DACUS
Grant:	893864
Call:	H2020-SESAR-2019-2
Topic:	SESAR-ER4-31-2019 -- U-space
Consortium Coordinator:	CRIDA, A.I.E.
Edition Date:	21 December 2021
Edition:	00.01.00
Template Edition:	02.00.03

Founding Members
EUROPEAN UNION
EUROCONTROL
SESAR JOINT UNDERTAKING

Authoring & Approval

Authors of the document

Name/Beneficiary	Position/Title	Date
Marina Jiménez	INECO	03/12/2021
Víctor Gordo	INECO	03/12/2021

Reviewers internal to the project

Name/Beneficiary	Position/Title	Date
Pablo Sanchez Escalonilla/ CRIDA	DACUS PCo	17/12/2021
Hugo Eduardo/TUDA	TUDA PoC	17/12/2021
Jan Kleikemper/TUDA	TUDA	17/12/2021

Approved for submission to the SJU

Name/Beneficiary	Position/Title	Date
Pablo Sánchez-Escalonilla / CRIDA	Company PoC	23/12/2021
Maron Kristofersson / AHA	Company PoC	23/12/2021
Nicolás Peña / BRTE	Company PoC	23/12/2021
Andrew Hately / ECTL	Company PoC	23/12/2021
Eduardo García / ENAIRE	Company PoC	23/12/2021
Víctor Gordo / INECO	Company PoC	23/12/2021
Sandrine Molton / ISA	Company PoC	23/12/2021
Anna-Lisa Mautes / Jeppesen	Company PoC	23/12/2021
Yannick Seprey / SSG	Company PoC	23/12/2021
Rohit Kumar / TM	Company PoC	23/12/2021
Hugo Eduardo / TUDA	Company PoC	23/12/2021

Rejected By - Representatives of beneficiaries involved in the project

Name/Beneficiary	Position/Title	Date

Document History

Edition	Date	Status	Author	Justification
00.00.01	03/12/2021	Draft	Marina Jiménez	Creation of the document
00.01.00	21/12/2021	Final	Victor Gordo	Final version for official submission

DACUS

This deliverable is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 893864 under European Union's Horizon 2020 research and innovation programme.

Abstract

The aim of this document is to define a method to set the Dynamic Separation Minima in DACUS Project. For that, the steps followed to achieve it and the models developed to this end are presented as well as the results of the experiments carried out. The Dynamic Separation concept is part of the Separation Management Process, that plays an important impact in the Demand and Capacity Balance process that is being developed by DACUS.

Table of Contents

List of Tables

List of Figures

Executive Summary

The aim of this document is to provide an approach to set the minimum separation necessary to keep the risk below the target level of safety in an airspace with a given conditions. To set the TLS, several parameters can be taken as a reference; in DACUS, the parameter chosen is the number of fatalities to third parties on the ground following the approach developed by JARUS in the SORA methodology [1].

The concept of Dynamic Separation Minima refers to the ability of adapting the minimum separation depending on the characteristics of the airspace; this dynamic character gives the opportunity to react better to the demand or at certain temporal timeframe.

To set the required separation minima, the collision risk model used in WP3 of the DACUS Project has been applied to study the risk reduction when separation is introduced. These results and the conclusions obtained are presented through this document.

1. Introduction

1.1 Purpose of the document

The purpose of this document is to describe the method followed to define the Dynamic Separation minima that fits into the DCB process designed in DACUS project. The main goal of setting a minimum separation is to reduce the probability of collision during the flight. This would reduce the capacity so it will have an important impact on the demand and capacity balancing process.

1.2 Intended readership

The document is intended for all DACUS partners as a reference for the separation management linked to the Dynamic Capacity Management (DCM) that will be demonstrated in the project. All partners are encouraged to use the findings of this deliverable as input to any further work that they may perform related to DCM.

The SESAR Joint Undertaking is invited to use the findings of this document for advancing U-space and Dynamic Capacity Management. It may be used in discussions with other ongoing projects focused on separations.

A number of external readers to SESAR such as EASA, DG MOVE, EUROCONTROL, and ICAO, are invited to use this report as input to support collaboration on their activities related to UAS separation and DCM.

For the same reason, it may concern people in charge of drone operations development or people who will have to deal with drone operations: U-space service providers, local authorities at the level of city or region, operators, Air navigation Service Provider, just to name a few.

The DACUS consortium will publish this document at the project's website, share findings with any interested party.

1.3 Background: Separation Management Process

In the DACUS project the separation management is delimited as the process of defining the set of Separation Techniques (rules and responsibilities) associated with maintaining separation minima, as well as of defining the conditions of application of the appropriate technique.

This process monitors the operational and environmental situation and compares the relevant parameters with the conditions of application of each Separation Technique. This comparison leads to a decision on the applicable Separation Scheme2 (rules and responsibilities) during operations.

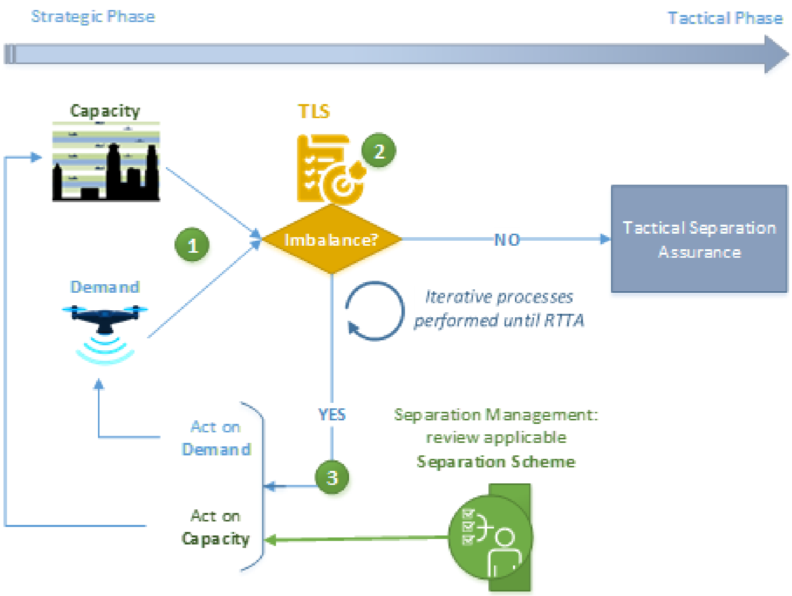


Figure 1. Separation Management within drone DCB Dynamic Capacity Management [2]

1.4 Structure of the document

As introduced before, the objective of this document is to present the process followed to set a Dynamic Separation Minima criteria. For that, the document is divided in five sections to introduce the concept, describe its link with other relevant concepts such as the demand, the performance of the services, the available airspace and, finally, try to set a separation minima and test out how the risk is reduced.

- Chapter 1, the current one, introduces the document, the purpose and its organization. It also includes the list of terms, definitions and acronyms or abbreviated terms that may be useful for the understanding of the document. The introduction outlines the purpose, scope and intended audience for the deliverable
- Chapter 2 presents the scope for the separation minima concept; furthermore, it is explained the relation between separation minima and the relevant concepts Collision Risk and DCB.
- Chapter 3 describes how to achieve the separation minima value based on the results obtained in the collision risk model simulations. In this section, it also described the impact of the main influence factor of the collision risk in the separation minima.
- Chapter 4 summarises the Platforms features.
- Chapter 5 presents the factors affecting the collision risk and the fatality risk per collision, to understand how different separation minima will have to be applied.

1.5 List of Acronyms and abbreviations

Acronym	Definition
CNS	Communication, Navigation and Performance
CV	Control Volume
DACUS	Demand and Capacity Optimisation in U-Space
DCB	Demand and Capacity Balance
DCM	Dynamic Capacity Management
EASA	European Union Aviation Safety Agency
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
ICAO	International Civil Aviation Organization
SESAR	Single European Sky ATM Research
SBAS	Satellite Based Augmented System
TLS	Target Level of Safety
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle

Table 1: List of acronyms and abbreviations

2. Scope

2.1 Dynamic Separation Minima and Collision Risk

Separation Minima concept refers to the minimum separation that must be maintained between two aircraft in a given operational environment to keep the operations safe. Even though assuring safety is always the main goal, operations also must be carried out in an efficient way. Therefore, separation minima should be adapted depending on the characteristics of the airspace; this is what dynamic separation minima concept pretends. This dynamic character gives the opportunity to react better on the demand or at certain temporal timeframe.

The main reason to set a minimum separation between aircraft is to assure that the risk of collision is kept low enough to meet a given target level of safety (TLS). This TLS could be set attending to different criteria. JARUS-SORA [1] states that the number of fatal injuries to third parties on the ground (per flight hour) is the best parameter that can embody the equivalence of risk, setting a TLS of 1E-6 fatalities/fh. Many other sources as the standard STANAG-AEP 4671 [3] follow a similar approach. Therefore, collision risk would be the input to determine the lethality risk on the ground (or in the air, in case aircraft with people on board are not segregated from drone operations) which is the value that must be kept below the defined TLS.

2.2 Dynamic Separation Minima as part of Separation Management Process

The DACUS project aims to develop a service-oriented Demand and Capacity Balancing (DCB) process to facilitate drone traffic management in urban environments. The project intends to integrate relevant demand and capacity influence factors (such as CNS performances availability), definitions (such as airspace structure), processes (such as separation management), and services (such as Strategic and Tactical Conflict Resolution) into a consistent DCB solution.

Dynamic separation minima play an important role in the separation management process defining what is the minimum distance the aircraft should keep between each other in every moment. The U-space DCB process spans over various time frames from long-term planning to post-operations. Processes and measures at each frame are decided upon the analysis of a rolling demand and capacity picture increasing in accuracy up to the day/ time of operations (tactical phase). The Figure 2 represents the U-space services and main processes involved in U-space DCB [4]

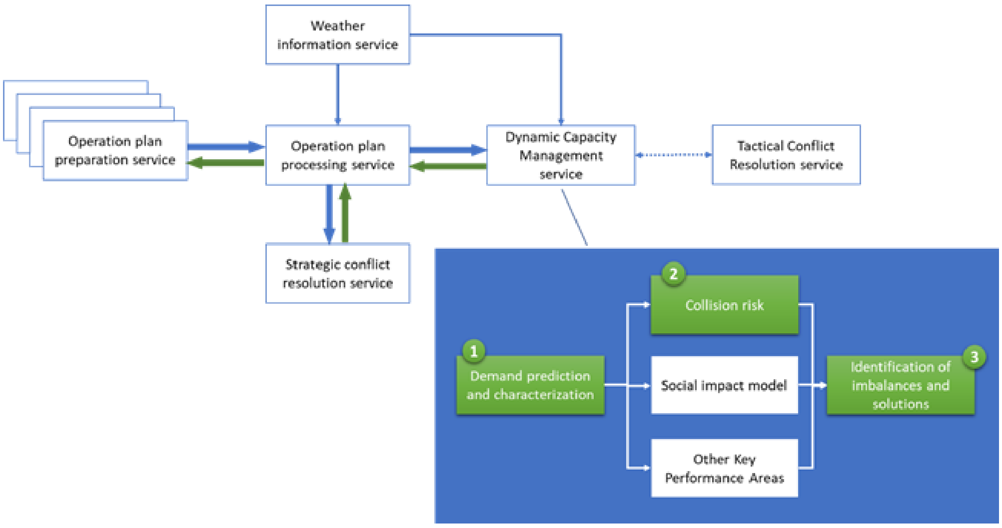


Figure 2: U-space services and main processes involved in drones DCB

Within the blue box are the main internal processes of the Dynamic Capacity Management service, that lead to the identification of demand and capacity imbalances and the selection of solutions. Highlighted in green is finally the particular path that is relevant for separation management in terms of identification of applicable separation scheme.

To calculate the dynamic separation minima, several inputs must be considered, but all of them are referred to the collision and fatality risk: type and size of drones, non-segregated aircraft with people on board, population density and sheltering of the area overflown, CNS performances, etc.. Other elements like social impact or efficiency, could have an impact on the acceptable capacity, but not on separation which is established for safety reasons.

2.3 Application of Collision Risk Model to the definition of a Dynamic Separation Minima

The process of balancing the capacity and demand in the airspace is an iterative process which pretends to continuously adapt to the environment where operations are going to happen. In this sense, if manned aircraft or other air vehicles carrying people on board are segregated from the rest of UAS, the only risk of common drone operations will be the ground risk, i.e., the likelihood of killing uninvolved people on the ground due to a drone failure or to a collision; therefore, the total capacity of a certain volume of airspace can be estimated by means of a collision risk model.

However, as explained, the acceptable capacity would not only depend on the collision risk, but also on the population density and sheltering factor on the ground, and the features of the drones (size, weight, speed). When combining these factors and comparing to the TLS, we can determine the maximum acceptable collision risk in a certain volume of airspace.

Additionally, the collision risk will depend on the ability of the drones to follow the intended trajectories and on the capability of U-Space systems to detect and prevent conflicts, which depends on the update rate of the drones' position reports and the tracking accuracy. In summary, the collision risk depends on the CNS infrastructure performances.

Therefore, in the context of the DACUS Project, **Dynamic Separation Minima defines the way to cope with temporary variations. These variations may be the result of changes in weather, changes on the population density in a certain area[1], CNS performances degradations or type of drones overflying the area**, among others. In this document, the definition of separation minima will be focused on CNS performance, population density and type of drones.

On the other hand, Separation Minima is usually considered as a pairwise distance between two aircraft. Logically, the minimum distance required to avoid a conflict between two aircraft depends on their relative speed-vectors; i.e. the distance required between two aircraft flying in parallel would be much lower than for two aircraft flying in opposite directions.

This concept of separation based on the relative speeds of aircraft is perfectly applicable for manned aircraft, as they fly usually following fixed routes and in structured air spaces. However, drone operations are very different from manned aviation: in many cases, the objective of the flight is not to go from one place to another, but to follow a specific trajectory to gather the required data; the size and maneuverability of drones (usually multirotor) is very different from fixed wing manned aircraft, etc… Therefore, structured airspaces and predefined routes are not easily applicable for drones, which obtain the maximum benefits when flying free-routesas there would be many contradictory requirements with surrounding aircraft (see Figure 3 below). This is why, **the DACUS project will consider common separation minima for a whole airspace, as a reference framework to keep the fatality risk below the TLS, while increasing the capacity**.

As a consequence, trying to keep a certain separation minima depending on the relative speed of each pair of drones is not really feasible in a congested drone airspace.

[1] Sheltering factor, i.e., the structures protecting the population from drones falling over them (e.g. buildings, trees, etc.), is assumed to be static.

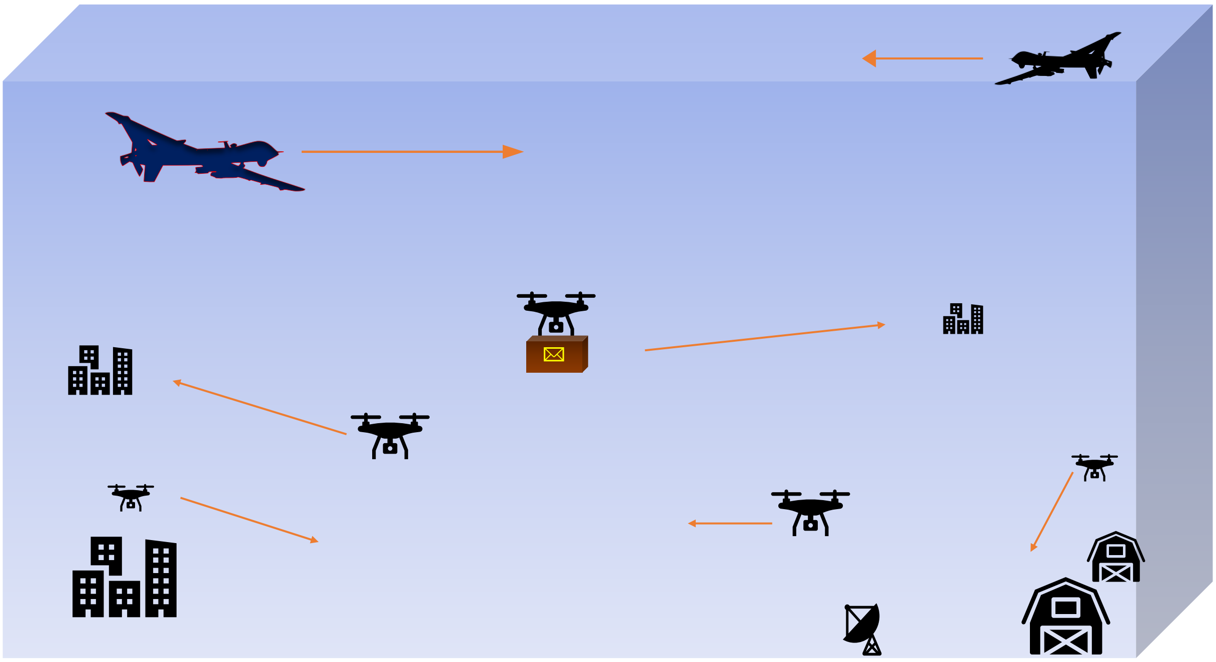


Figure 3. Complexity of applying pairwise separation in high-density drone operation environment

3. Analysis of the Separation Minima Impact on Collision Risk

The DCB process has different stages along the time and, at each of them, the separation minima must be set using different methods. Regarding that, two approaches can be followed: on the one hand, a large minimum separation and highly structured airspace can be considered from the beginning and gradually reduced it based on the demand until the risk reaches the TLS. On the other hand, a non-structured scenario with no separation minima can be considered and, as the density of aircraft rises or the conditions worsen, minimum separation requirements are established. The first one could be safer but not actually efficient, so it is very conservative, as shown in the Metropolis project [5]. For that, and since the objective of the DACUS project is creating an efficient and balance process, the latter is the one followed in this document.

The procedure therefore is, as starting point, no minima separation is considered in the DCB process until the risk reach the TLS. Once the demand is expected to be high enough to reach the acceptable level of safety, some mitigations are applied. However, this process is complex when the operations are not defined but only predicted; which is the case at strategic phase. Therefore, the way to proceed is using a collision risk model at strategic phase which simulates a large number of random scenarios in order to have a representative picture of the expected scenario. Once the model is run, the output must be analyzed and translated into a required minima separation. To achieve that, it is essential to study and understand how each factor present in the scenario impacts on the collision risk and, therefore, how they impact on the separation minima.

The collision risk model developed in DACUS has the main goal of identifying the maximum acceptable capacity of a given airspace. This model is further detailed in the deliverable D3.2 (reference); however, the primary characteristics of the model are described below in order to understand the effect it has in the definition of separation minima.

3.1 Impact of Initial Separation and Time to minimum closing distance on the Collision Risk

To evaluate the impact of the initial separation and the time to minimum closing distance on the collision risk, firstly, a fully random scenario is simulated as depicted hereafter in Figure 4 (left). After obtaining the results of the simulations, different initial separations are applied between UAVs to evaluate the impact the initial separation has in the collision risk Figure 4 (right).

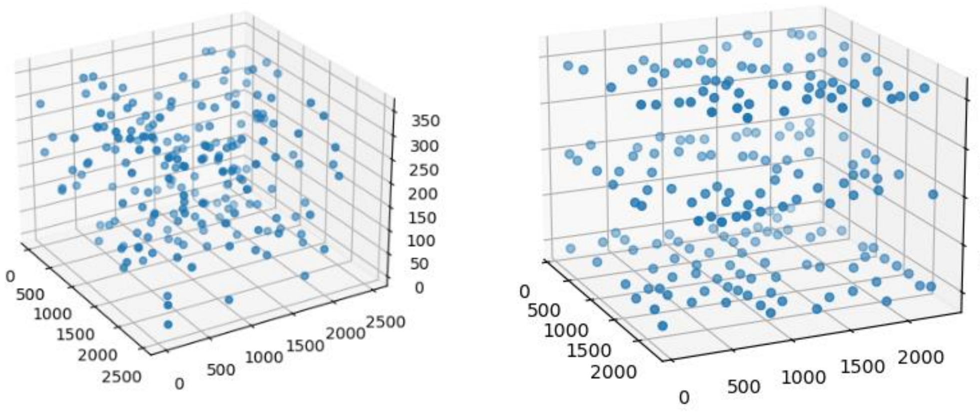


Figure 4. Position of UAVs at t=0 with no separation (left) and with separation (right)

Before continuing with the results and the application of the measurements, some key concepts are introduced:

- **Time to minimum closing time**: It is the time elapsed since the simulation begins until the aircraft are at the point of minimum distance between them. In the

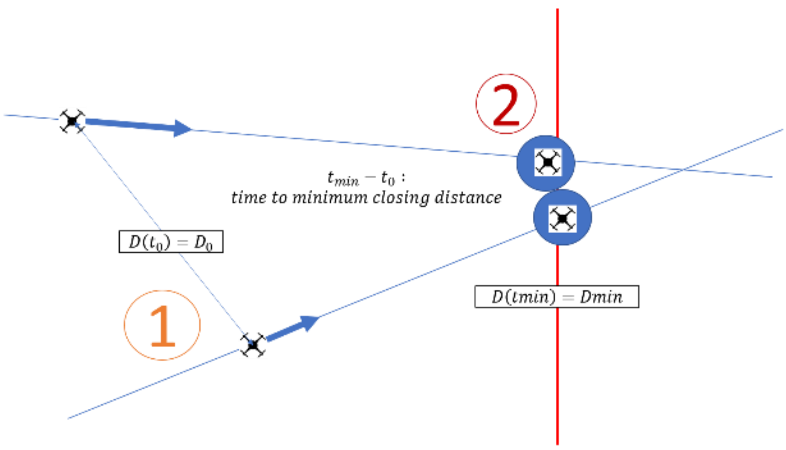


Figure 5. Graphical representation of time to minimum closing point

- **Initial separation:** It is the distance between the UAVs in the beginning of the simulations (t=0).

As part of the process to obtain the required minimum distance, we start simulating a totally random scenario with no separation as depicted in Figure 4 (left), free flight trajectories, within the control volume and number of collisions is obtained. Table 2 presents the inputs considered in these simulations:

<table>
<tr><th></th><th>Position (x, y, z)</th><th>Speed (v)</th><th>Horizontal direction (θ)</th><th>Vertical direction (ϕ)</th><th>Safety Margin</th></tr>
<tr><td>Without separation</td><td>Random</td><td rowspan="2">Random up to 25 m/s</td><td rowspan="2">Random between 0° and 360°</td><td rowspan="2">0°-5°when v<25m/s

5°-90° when v>5m/s</td><td rowspan="2">10 m</td></tr>
<tr><td>With separation</td><td>Random within cells defined to assure the minimum separation considered</td></tr>
</table>

Table 2: Inputs considered in separation simulations

Next, the results of the simulations are presented for the scenario without separation and with separation. More detailed description of the collision risk model could be found in deliverable D3.2 Capacity Models in support of DCB [6].

3.1.1 Without separation

Once the simulations are run, histograms are generated that allow to know what was the distance at which most of the aircraft which collided were from each other at the beginning of the simulation and how much time (in seconds) it took to get the closest point.

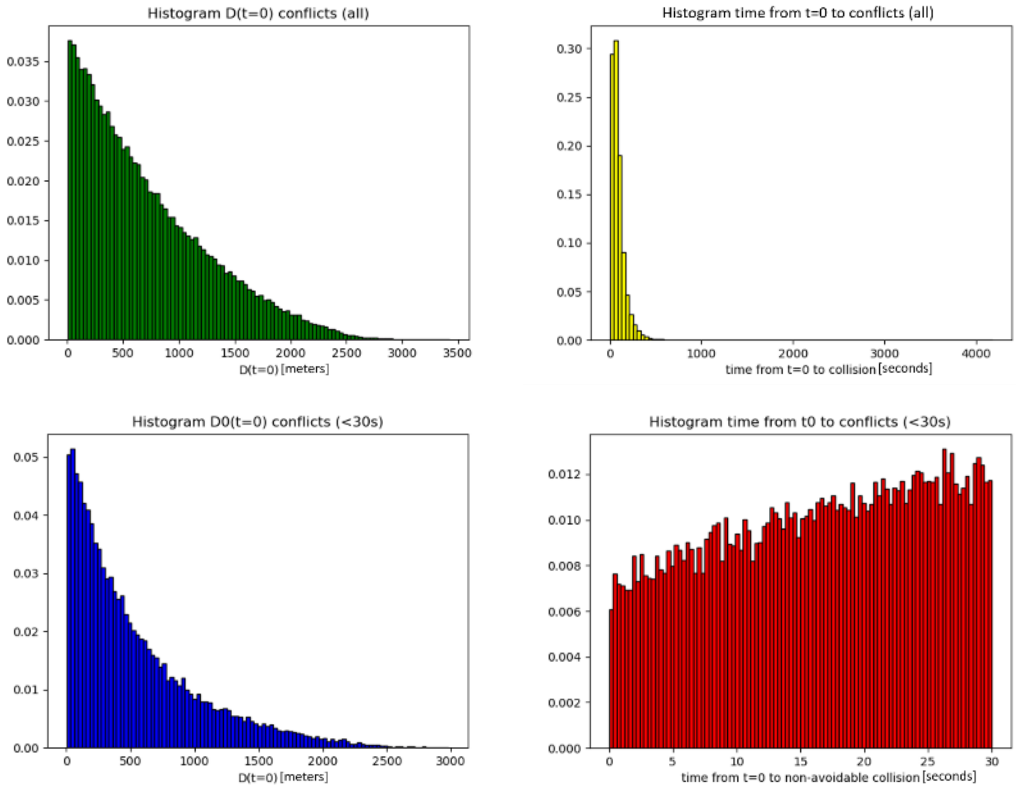


Figure 6. Results without separation

It can be observed that most of the collisions occur in the first seconds of the simulation given that separation is not applied. The objective of setting a minimum separation is to delay them in time so they can be detected and then avoided. In the next section, it is explained the process followed to set the separation and the improvements introduced by it.

3.1.2 With separation

Hereafter, the process to set the separation is explained and some relevant concepts are introduced. To place the aircraft in the control volume, it is divided in small cells. To set a minimum separation, the dimensions of the control volume are determinant, so the maximum capacity or the minimum separation can be established but not at the same time.

In the simulations carried out, the dimensions of the control volume are:

$$LENGTH_{CV} = 2500\ m$$

$$WIDTH_{CV} = 2500\ m$$

$$HEIGH_{CV} = 2500\ m$$

Therefore, the number of cells in each direction will be:

$$NUM_{CELLSx} = int\left(\frac{LENGTH_{VC}}{CELL_X}\right)$$

$$NUM_{CELLSy} = int\left(\frac{LENGTH_{VC}}{CELL_Y}\right)$$

$$NUM_{CELLSz} = int\left(\frac{HEIGTH_{VC}}{CELL_Z}\right)$$

where $CELL_X, CELL_Y, CELL_Z$ are the dimensions of the cells in each direction. In case the aircraft are placed in the center of the cells, the separation will be equal to the dimensions of the cells.

It is evident that the dimensions of the control volume will determine the maximum number of cells that can be placed, it is, the maximum number of aircraft that will be able to keep the minimum separation between them. On the other hand, to emplace a given number of aircraft keeping a determined minimum separation, a certain volume of airspace is needed.

$$NUM_{AC}(CELL_X CELL_Y CELL_Z) = L_{CV}, W_{CV}, H_{CV}$$

Since the objective is keeping the scenarios random, the separation is applied at t=0 but the aircraft can fly in all directions. The process followed to place the aircraft is the following:

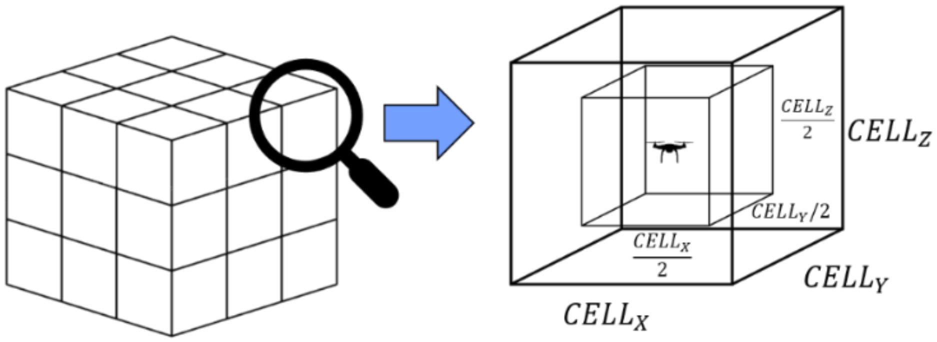
- Each aircraft is placed in the center of a cell so that there is only one aircraft per cell
- Starting from the center of the cell, the position of aircraft will be a random position within the cube with dimensions: $\frac{CELL_X}{2}\frac{CELL_Y}{2}\frac{CELL_Z}{2}$ so the aircraft are not completely ordered but keeping a minimum distance.

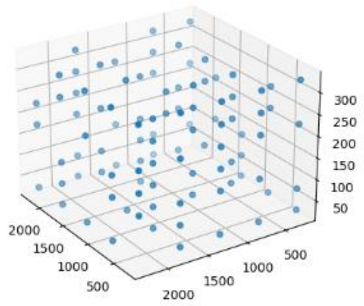
Therefore, the **minimum separation** between the aircraft in direction x, y, z will be:

$$minimum\ SEP_X = \frac{CELL_X}{2}$$

$$minimum\ SEP_Y = \frac{CELL_Y}{2}$$

$$minimum\ SEP_Z = \frac{CELL_Z}{2}$$





Hereafter in Table 3, it is presented the results without separation and with different separations for 100 aircraft and 100000 simulations:

Separation (x,y,z)	Number of conflicts	Number of conflicts in the first 30 seconds	Risk of conflict	Risk of conflicts in the first 30 seconds
Without separation	57284	4539	0.15000175	0.011885656
25,25,25	57487	4567	0.15053331	0.011958976
50,50,25	56479	4119	0.1478938	0.01078586
50,50,50	60946	4684	0.15843847	0.012176776
100,100,25	54262	3647	0.14208845	0.009549898
100,100,50	57136	4058	0.1496142	0.010626127
250,250,25	49480	2634	0.12956648	0.006897294

250,250,50	50021	2519	0.13098312	0.006596159
500,500,25	45292	1658	0.11859994	0.004341577
500,500,50	42590	984	0.11152459	0.002576666

Table 3: Conflicts calculated for different separation values

In the table, several trends could be highlighted:

- As the horizontal distance increases, the overall collision risk decreases.
- However, for the same horizontal separation, when vertical separation increases too much, the collision risk increases. The reason is that, as the scenario is defined, horizontal trajectories ($\phi \leq 5°$) are more likely than vertical ones. Therefore, since the vertical separation is enough (provided that the minimum separation is higher than the safety margin), it is preferable to have more flight levels with less vertical separation but less congested.
- The trend presented before is reversed when the horizontal separation increases very much (500 m). This is because, even having less levels, the dimensions of the cells are bigger so there are less overlaps vertically.

After, the results for the best (500 m, 500 m, 50m) and the worst scenario (50 m, 50 m, 50 m) according to the previous table are presented and analysed. The results depicted are the distances between the aircraft which enter in conflict and the time it takes to the conflict are presented. These two outputs are represented for all the potential conflicts and for those which occur within the first 30 seconds. Several things could be appreciated in them:

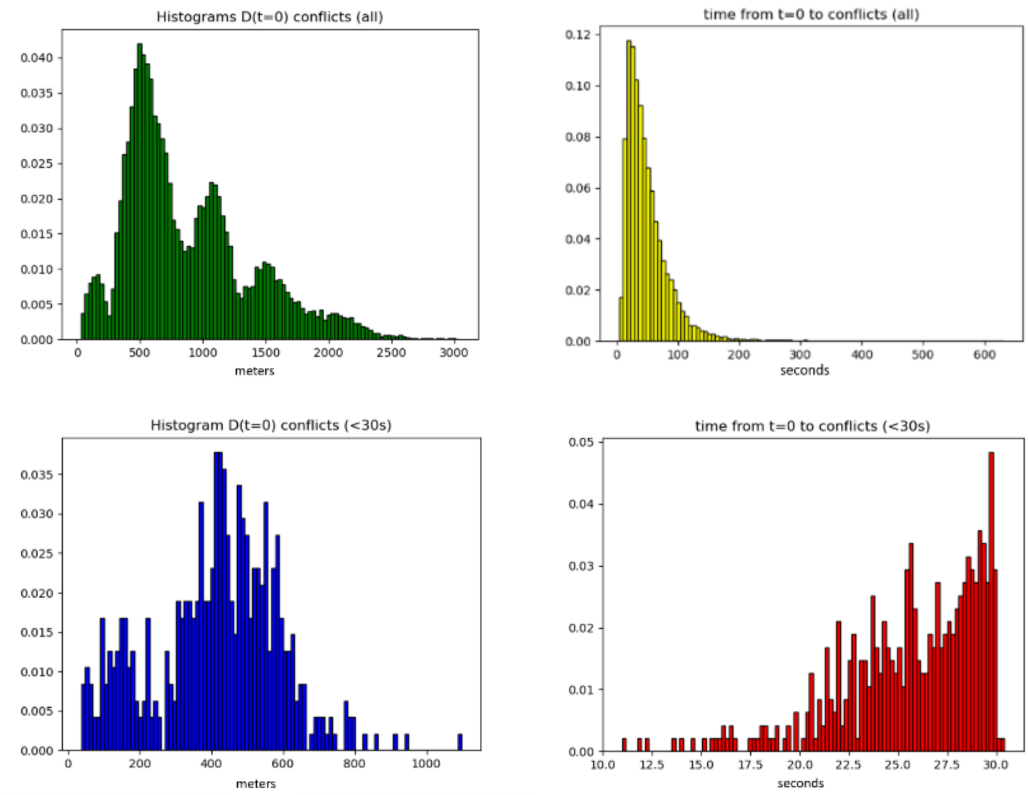


Figure 7. Results with initial separation of 500 m, 500 m and 50 m

Firstly, in the first graph, it is represented the distance at which the aircraft that have a conflict were in the beginning of the simulation. Since the dimensions of the cells were 500m, 500m, 50m, most of the aircraft were at distances multiple of minimum separation. The ones below 500m are these that enter in a conflict in the vertical direction.

Regarding the conflicts which occur before 30 s, most of them occur after 20 seconds, so it is a considerable time to react.

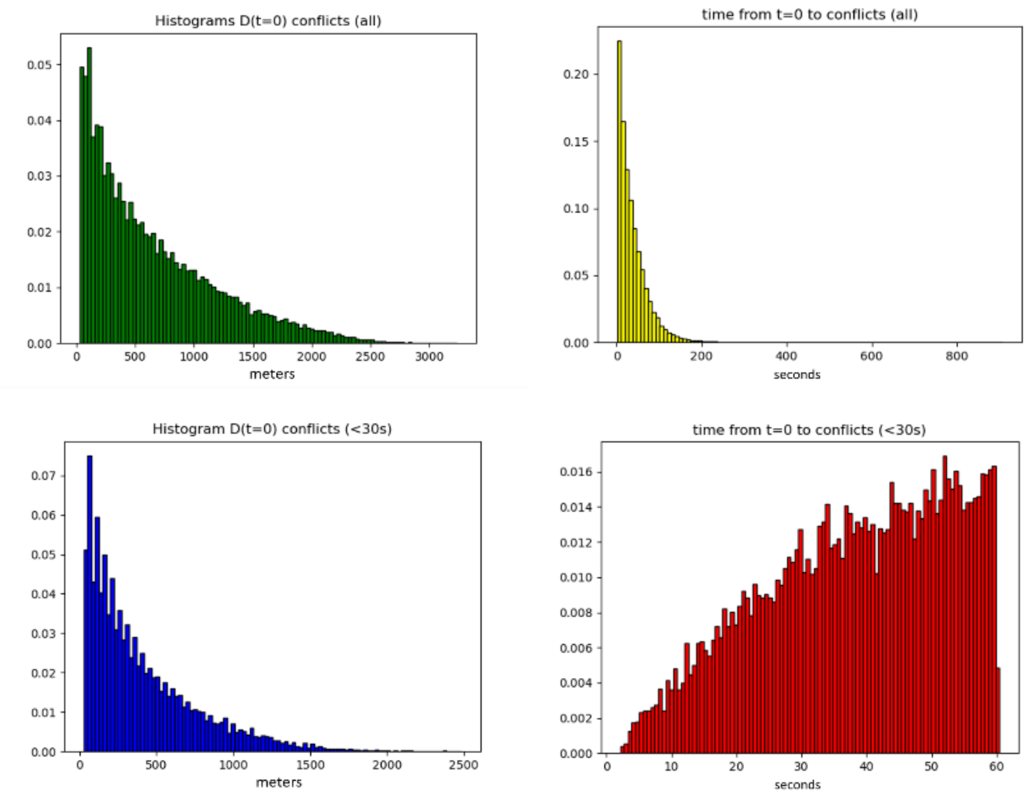


Figure 8. Results with initial separation of 50 m, 50 m and 50 m

It can be observed that these separations are not enough since most of the collisions occur in the first seconds of the simulation. The trend of the graphs is similar to the case without separation.

4. Impact of main influence factors on fatality risk

As explained, the collision risk is not the only factor which determines the maximum acceptable capacity. The lethality per collision is the second part of the total risk, so it will have a critical impact on the separation requirements to assure that the total fatality risk is below the TLS.

The probability of fatal injuries to third parties on the ground is, therefore, calculated by multiplying the probability of collision and failure with the probability that, if a collision were to occur, the UAV would fall on a person (as a function of population density [7]) and the probability that the injury provokes a fatality (as a function of drone characteristics and sheltering factor [8]). This concept is based on the SORA [1] likelihood of harm estimation and is represented schematically in Figure 9. Note that collisions between UAVs and manned aircraft were not initially considered in the model, as the DACUS project only considers a fully segregated drone environment with no people on board.

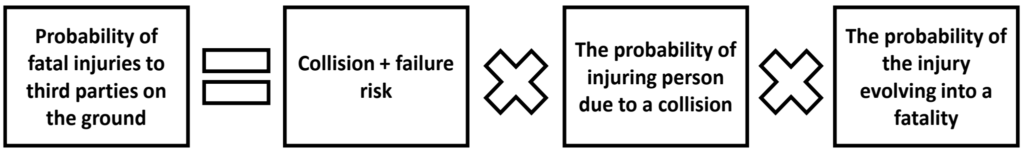


Figure 9. Schematization of the process for calculating the probability of fatal injuries to third parties on the ground

So, once identified the effect of separation on the conflict risk, it is necessary to consider the rest of the factors affecting the collision risk and the fatality risk per collision, to understand how different separation minima will have to be applied in a certain volume of airspace depending on the different factors conditioning the scenario, which are mainly:

- CNS performances, which impacts on the collision risk
- Population density, which impacts on the fatality per collision
- Aircraft features, which also impacts on the fatality per collision

4.1.1 Factors with affect the collision risk: CNS Performance

4.1.1.1 Communications update rate

The collision risk has been obtained for different position report update rates to determine the effect on the risk of this factor. The results are presented in Table 4 which shows that the collision risk increases with the update rate (lower update frequency) when there is U-space in place and that if communication is lost the collision risk is ten times greater.

Communications Update Rate	Non-avoidable collisions (by a U-space Tactical Deconfliction Service)
1 s	2.86E-03
3 s	4.68E-03
5 s	7.60E-03
No communications	3.40E-02

Table 4: Communication update rate impact on collision risk

Therefore, changes in the communications update rate would require different separation minima to absorb the same capacity in a certain volume of airspace and much greater separation if communications are suddenly lost.

4.1.1.2 Navigation accuracy

The impact of navigation accuracy on the ability to detect conflicts has been also tested by means of the collision risk model. Given that the position reported by the drone will differ its real position, part of the avoidable collisions will not be prevented if the U-space service is not able to detect them. The remaining collision risk will be calculated from the sum of the unavoidable collisions and the non-detected avoidable collisions. This means that the navigation accuracy has no effect in the number of potential collisions (in a free-flight scenario), but it determines the ability to detect avoidable collisions, depending on the conflict margins considered.

Results show a clear reduction of collision risk for SBAS augmented GPS at lower conflict margins (see Table 5). The lowest overall collision risk was found to be situated between the 5 and 10-meter conflict margin for the GPS+SBAS case. As the margin of conflict increases, the improvement introduced by SBAS is attenuated since most of the conflicts are detected even with the highest error (GPS L1). In the case of the conflict margin, for GPS L1, the greater the conflict margin, the lower the collision risk (more potential collisions detected). With GPS+SBAS, the effect is similar, but given that results for 5 m and 10 m conflict margins were equivalent, the smaller margin is enough to detect most of the potential collisions.

Conflict margin	GPS L1	GPS+SBAS
3 m	2.33E-02	1.21E-02
5 m	1.32E-02	3.78E-03
10 m	3.93E-03	3.83E-03

Table 5: Collision risk (collisions/flight hour) results for 20 UAVs/km2 and 1s update rate

Therefore, again, for the same volume of airspace and the same number of operations, different separation minima could be required depending on the drone's navigation equipage. In case of GNSS service degradation, separation would have to be increased accordingly.

4.1.1.3 Traffic mix

The traffic mix will also have an important effect on the collision risk. The size of the aircraft will determine the minimum separation that has to be considered to avoid collisions and keep the risk below the TLS.

On the other hand, the type of UAV, will determine the manoeuvrability and, therefore, the time needed to avoid collisions.

4.1.2 Factors that affect the lethality per collision

4.1.2.1 Population Density and Sheltering Factor

The second part of the equation expressed in Figure 9 depends on the population density and the sheltering factor. The probability of fatal injuries to third parties on the ground is calculated considering an inelastic collision between the drones followed by a free fall (parabolic); this fall determines the impacted area on the ground and then, the fatality risk is calculated depending on the population density and how protected people are in the impacted area. Note that we assume the entire vehicle to remain intact after collision. The probability of fatal injuries is determined using a sheltering factor, which quantifies the level of protection that buildings, trees or vehicles offer to people and therefore reduce the probability of serious injuries. The results for different locations are shown in Table 6, based on the collision risk model explained in D3.2[2] [6].

[2] The probability of fatal injuries to third parties on the ground are determined, considering an inelastic collision between the drones followed by a free fall (parabolic); this fall determines the impacted area on the ground and then, the fatality risk is calculated depending on the population density and how protected people are in the impacted area. Note that we assume the entire vehicle to remain intact after collision. The probability of fatal injuries is determined using a sheltering factor, which quantifies the level of protection that buildings, trees or vehicles offer to people and therefore reduce the probability of serious injuries.

Environment	Population Density (inh/km2)	Sheltering factor [8]	Fatality per collision
Madrid City Centre	12000	High	0.002168529
Toulouse City Centre	5500	High	0.000969634
Toulouse Outskirts - Industrial	5500	Very High	0.000813654
Toledo Outskirts	900	Low	0.000285549
Toulouse Outskirts - Residential	900	High	0.000159806
Toledo City Centre	600	High	0.000132791
Toledo Rural	50	Very Low	3.93394E-05

Table 6: Fatality per collision in different locations

4.1.2.2 Aircraft characteristics (size/weight)

The characteristics of the aircraft will have an impact not only in the collision risk but in the lethality on the ground since the energy transmitted to a person in the impact determines the lethality of the impact. Therefore, the fatality rate will increase for big aircrafts falling over a person without any impact energy reduction system.

5. Conclusions

This document presents the concept of separation minima defined in the DACUS project as part of the collision risk model to determine capacity.

The document explains that a pairwise separation minima is not realistic in a congested drone airspace as there would be many contradictory requirements with surrounding aircraft. Accordingly, the DACUS project considers common separation minima for a whole airspace, as a reference framework to keep the fatality risk below the TLS, while increasing the capacity.

The impact of separation minima on the conflict and collision risk is shown in Section 3, which shows that different horizontal and vertical separation minima requirements will notably reduce the collision and conflict risk, for the same drone density.

Finally, Section 4 explains that as the acceptable capacity depends on the fatality risk and not directly on the conflict risk, different additional factors, beyond of separation, will have to be analyzed to set the separation requirements. Depending on the evolution of these factors in a certain volume of airspace (dynamic population density, drones' size and equipage, CNS degradations), different separation requirements will be necessary to safely absorb the same capacity, so separation will have to be dynamically calculated and applied depending on these factors.

6. References

[1] JARUS, “Specific Operations Risk Assessment - SORA Methodology,” [Online]. Available: http://jarus-rpas.org/sites/jarus-rpas.org/files/jar_doc_06_jarus_sora_v2.0.pdf.

[2] D. Project, *D 5.2 Separation Management Process,* 2021.

[3] NATO, *NATO-AEP-4671 UNMANNED AIRCRAFT SYSTEMS AIRWORTHINESS REQUIREMENTS (USAR),* 2019.

[4] D. Project, “D 1.1-Drone DCB concept and process,” 2021.

[5] METROPOLIS, “Simulation Results and Analysis (D5.2),” 2015. [Online]. Available: https://homepage.tudelft.nl/7p97s/Metropolis/downloads/Metropolis_D5-2_Simulation_Results_and_Analysis_v10.pdf. [Accessed 2021].

[6] D. Project, *D 3.2 Capacity Models in support of DCB,* 2021.

[7] NASA, “Socioeconomic data and applications center (SEDAC),” [Online]. Available: https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11/data-download. [Accessed 2021].

[8] E. Commission, “Copernicus - European Union's Earth observation programme,” [Online]. Available: https://www.copernicus.eu/en/access-data.