EXPLORATORY RESEARCH

Refined CNS Criteria

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DACUS

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Abstract

This document reviews the CNS Requirements evaluated in the DACUS Deliverables D3.3 and D4.2, based on the Collision Risk Model for the Strategic Phase (random trajectories) and analyses to what extend they remain applicable for the Pre-Tactical Phase (real trajectories based on flight plans), considering different traffic scenarios.

Table of Contents

List of Tables

List of Figures

Executive Summary

The acceptable capacity of an airspace volume is limited, among others, by the collision risk, which depends on the ability of the UAS to follow the intended trajectories, which depends on the navigation capabilities and the ability of U-Space systems to detect and prevent conflicts, which depends on the update rate of the UAS' position reports and the tracking accuracy.

In summary, the collision risk depends on the CNS infrastructure performances, so it is essential to identify the acceptable CNS performance requirements on a certain U-space volume, which will be more or less stringent, depending on the likelihood of fatalities due to UAS falling as a result of a collision.

This document analyses the CNS performance requirements identified in DACUS D4.2 [1], by means of the Collision Risk model for the Strategic Phase, and evaluates their applicability in the Pre-tactical phase, considering different traffic scenarios. The study addresses the impact of Communications Update Rate and Navigation Accuracy.

It is worth noting that the collision risk also depends on other factors such as the category of the operation, the type of flight (VLOS and BVLOS) or the information provided to the U-space Services Provider by the operator. However, these factors are beyond the scope of this study.

1. Introduction

1.1 Purpose of the document

The aim of this document is to define a method to review the CNS Requirements evaluated in the DACUS Deliverables D3.3 and D4.2, based on the Collision Risk Model for the Strategic Phase (random trajectories) and to analyse to what extend they remain applicable for the Pre-Tactical Phase (real trajectories based on flight plans).

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.

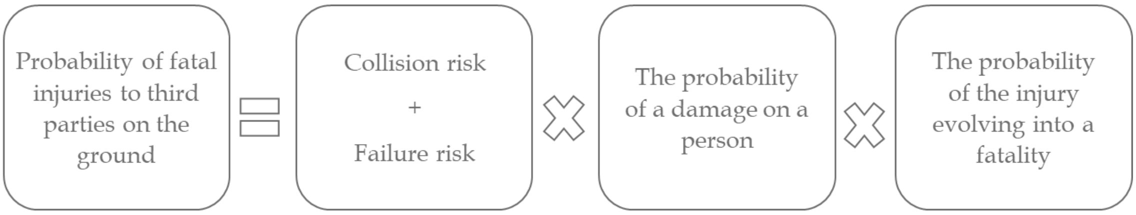
The DACUS consortium will publish this document at the project's website, share findings with any interested party.

1.3 Background

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, airspace structures, etc.), processes (such as separation management), and services (such as Strategic and Tactical Conflict Resolution) into a consistent DCB solution.

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.

It is essential to keep such level of risk below a given value to ensure operations are carries out safely. In this approach, it is taken as a reference the target level of safety (TLS) proposed in the SORA methodology, with the established value being 1E-6 fatalities on the ground per flight hour. Below it is presented the formula followed to obtain the number of fatalities to third parties on the ground.



As it can be seen in the formula, the fatal injuries on the ground will depend on three main factors: collision + failure risk, probability of damage to a person and probability of the injury evolving into a fatality. The first term depends on several factors: characteristics of the airspace, number and performance of the aircraft, structuration of the airspace, CNS performances, etc. The second one depends on the density of population on the ground (level of occupation will determine the probability of falling over an "occupied" zone) and on the sheltering factor, that measures the protection that trees, buildings, cars, etc., offer to people. Lastly, the probability that an injury evolves into a fatality depends on the characteristics of the drone and the energy of impact.

Therefore, the acceptable capacity is limited, among others, by the collision risk, which depends on:

- the ability of the UAS to follow the intended trajectories, which depends on the navigation capabilities and
- the ability of U-Space systems to detect and prevent conflicts, which depends on the update rate of the UAS' position reports and the tracking accuracy.

In summary, the collision risk depends on the CNS infrastructure performances, so it is essential to identify the acceptable CNS performance requirements on a certain U-space volume, which will be more or less stringent, depending on the likelihood of fatalities due to UAS falling as a result of a collision.

1.4 Structure of the document

As introduced before, the objective of this document is to present the process followed to validate the CNS Criteria in the Pre-Tactical Phase. For that, the document is divided in four sections to introduce the concept, present the criterion identified for the Strategic Phase, and finally evaluate the performances in the Pre-Tactical Phase:

- 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 concept, and the role of the collision risk model; furthermore, it presents the CNS Requirements identified for the Strategic Phase model.
- Chapter 3 applies the defined requirements to the Pre-Tactical Phase, considering different scenarios with a number of flight plans defined.
- Chapter 4 summarises the factors affecting the CNS Performances and the main conclusions obtained from the application to the Pre-Tactical Phase.

1.5 List of Acronyms and abbreviations

Acronym	Definition
CNS	Communication, Navigation and Surveillance
CV	Control Volume
DACUS	Demand and Capacity Optimisation in U-Space
DCB	Demand and Capacity Balancing
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 Augmentation System
TLS	Target Level of Safety
UAS	Unmanned Aircraft System

Table 1: List of acronyms and abbreviations

2. Context

The operation of UAS introduces risks both in the air (collision of aircraft with people on board) and on the ground (falling onto people). To ensure safety, a risk assessment process for UAS operations - the Specific Operations Risk Assessment (SORA) concept developed by JARUS [2] –specifies to keep the overall risk below a given Target Level of Safety (TLS). This concept states that the number of fatal injuries to third parties on ground is the best parameter that can embody the equivalence of risk, setting a TLS of 1E-6 fatalities per flight hour. Many other sources as the NATO standard STANAG-AEP4671 [3] follow a similar approach.

With this reference value in mind, a Collision Risk Model can be applied to calculate the probability of Mid-air collisions between UAS and the derived fatality risk within a given area. Capacity must be reduced until the total fatality risk of the persisting traffic scenario is below the aforementioned TLS. The Collision Risk Model developed in the DACUS project calculates the ground fatality risk derived from potential collisions between UAS or from catastrophic failures of individual UAS. In our model, we assess potential collisions between UAS as a factor of the number of vehicles, their performance limitations, the time to react in case of conflict, the capability of detecting a conflict as well as CNS performances. On the other hand, potential for catastrophic failures of the UAS while flying is already identified via its determined "Mean Time Between Failures" (MTBF), and, consequently, is directly proportional to flight time.

Therefore, the acceptable capacity in a given volume of airspace is limited, among others, by the collision risk, which depends on:

- the ability of the UAS to follow the intended trajectories, which depends on the navigation capabilities and
- the ability of U-Space systems to detect and prevent conflicts, which depends on the update rate of the UAS' position reports and the tracking accuracy.

Testing different CNS performance is essential to set the maximum capacity or minimum separation between aircraft because, depending on how good CNS performances are, the greater the capacity of the airspace will be for a given TLS (1E-6 fatalities/flight hour, as per SORA methodology. On the other hand, defining different airspace structures and the risk associated to them will be useful to find the structure which allows the greatest capacity while maintaining an acceptable level of safety.

In summary, the collision risk depends on the CNS infrastructure performances, so it is essential to identify the acceptable CNS performance requirements on a certain U-space volume, which will be more or less stringent, depending on the likelihood of fatalities due to UAS falling as a result of a collision.

2.1 Collision Risk Model

As starting point to identify potential collisions, the model [4] applies the equations concerning relative velocities and distances between aircraft (as explained further on) from *Annex 1* of the *"Manual on airspace planning methodology for the determination of separation minima*" [5] developed by ICAO. To achieve an estimation of ground fatality risk, a Monte Carlo simulation approach using Python language is applied. A large number of traffic samples are simulated in order to calculate the risk of collision and failures. Once the collisions and failures are calculated, the probability of fatal injuries to third parties on the ground can be determined, considering an inelastic collision between the UAS 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 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 UAS would fall on a person (as a function of population density) and the probability that the injury provokes a fatality (as a function of UAS characteristics and sheltering factor). This concept is based on the SORA [2] likelihood of harm estimation.

The model can be applied in the Strategic and the Pre-tactical phases. In the strategic phase, the trajectories considered are random and as flight plans are submitted, the trajectories will be fixed. The model calculates the expected ground fatality risk of a given scenario. This scenario is defined using random trajectories and other parameters such as CNS systems performances and characteristics times. In the pre-tactical phase, submitted flight plans and their trajectories are used to build the nominal scenario. Based on these scenarios, uncertainties in time and position/headings are introduced to calculate the risk of the "real" scenarios. These two models are explained in detail below.

As introduced before, the strategic phase model calculates the overall expected ground fatality risk by considering random trajectories and introducing uncertainties in position and headings. Uncertainties in time are not introduced as they are random trajectories. A control volume is defined and conflicts and collisions occurring within the volume are calculated. Conflicts and collisions are calculated based on characteristic times and CNS performances.

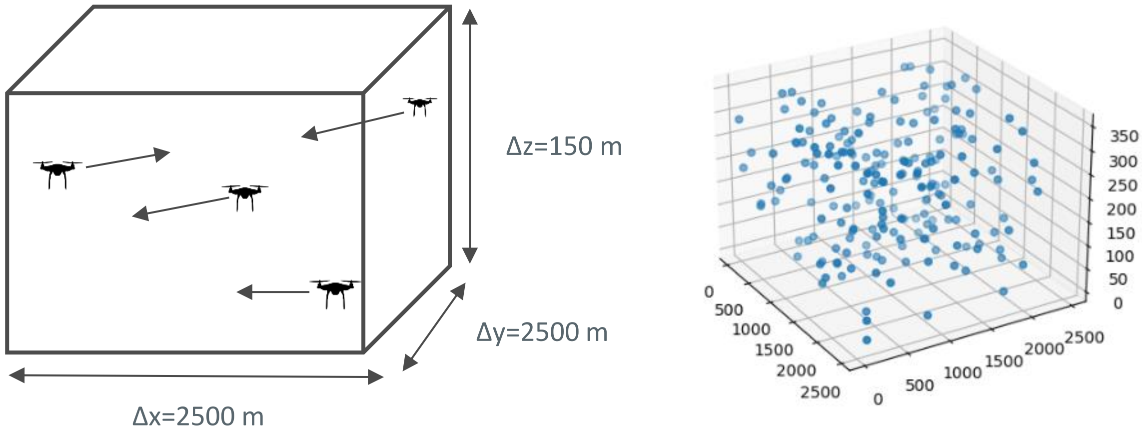


Figure 1: Example of trajectories considered by the Collision Risk Model in the Strategic Phase

Similarly, the pre-tactical phase model calculates the expected ground fatality risk, per cell and in the whole studied volume, considering the 4D nominal trajectories provided by the demand model. The trajectories defined by the demand model are deterministic, however, the real execution will present uncertainties both in time (delay or advance with regard to the nominal case) and in position/heading (navigation system error, i.e., difference between the position calculated and the real position of the UAS); therefore, different uncertainties in terms of time, position and headings must be introduced to assess the real ground risk associated with the foreseen operations. To that end, given the scheduled trajectories in a period of time ($\boldsymbol{t_{initial}}, \boldsymbol{t_{final}}$), N different iterations introducing errors are generated for each $\boldsymbol{t_i}$ and the risk of each of these iterations is calculated and then averaged, to obtain the expected ground risk, in the considered time period.

The ground risk is then compared with a Target Level of Safety (1E-6 fatalities per flight hour, as defined by JARUS/SORA) to identify if the number of operations scheduled are acceptable or not.

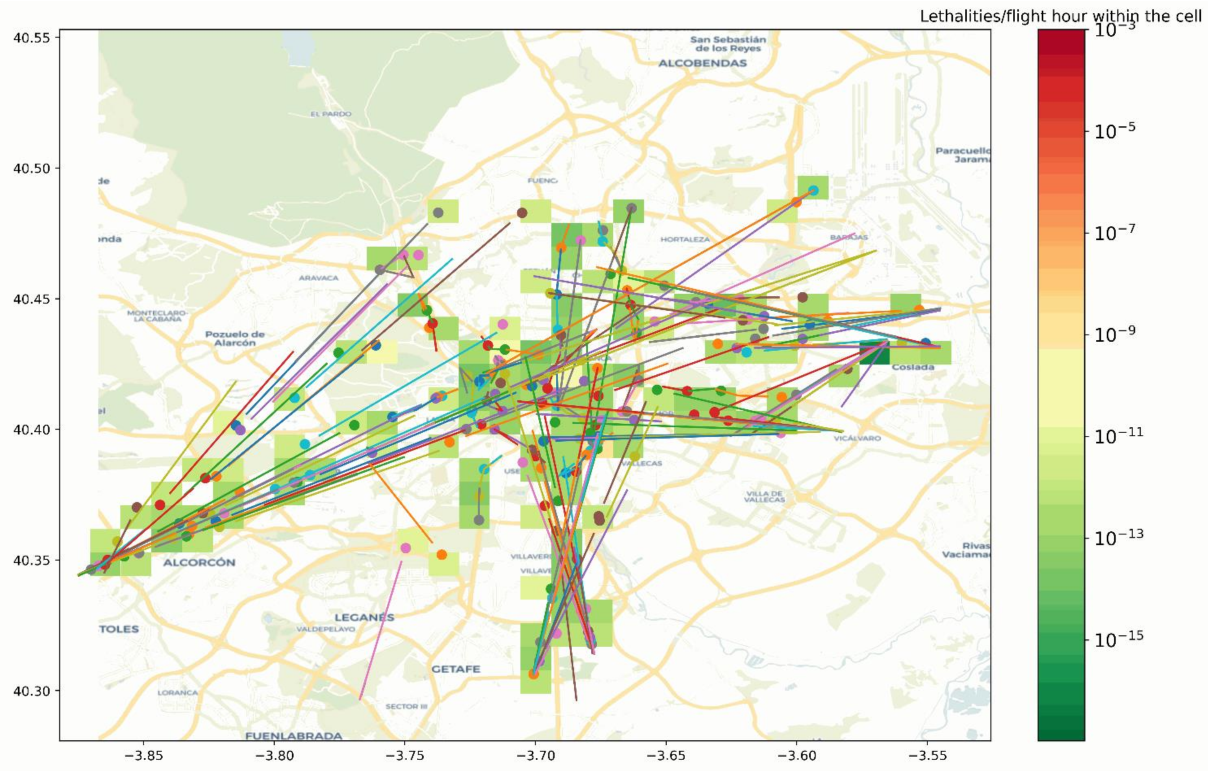


Figure 2: Example of trajectories considered by the Collision Risk Model in the Strategic Phase

2.2 CNS Performances considered in the analysis

The next independent variables concern CNS performance. In particular, two fundamental aspects for detecting potential collisions are considered. The first is the accuracy of the navigation system, which considers a position error following a normal distribution [4]. The second is the update rate, i.e. how often the position of the UAS is reported.

Navigation accuracy	**Description**
GPS L1	Deviations: $\sigma_x, \sigma_y = 1.633\text{m}, \sigma_z = 2.55\text{m}$
GPS+SBAS	Deviations: $\sigma_x, \sigma_y = 1.02\text{m}, \sigma_z = 1.1\text{m}$
Communications update rate	**Description**
1 s	High, one update every second
3 s	Medium, one update every 3 seconds
5 s	Low, one update every 5 seconds

Table 2. Overview of CNS performance-related variables: Navigation accuracy and update rates.

2.3 CNS Performance Analysis Results for the Strategic Phase

The evaluation of CNS Performance Requirements in the Strategic Phase has already been presented in the previous DACUS Deliverable D4.2 [1] and are summarised below.

2.3.1 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 3 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 3: 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.

2.3.2 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 UAS 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 4). 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 4: Collision risk (collisions/flight hour) results for 20 UAS/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 UAS's navigation equipage. In case of GNSS service degradation, separation would have to be increased accordingly.

3. CNS Performance Requirements applicability in the Pre-Tactical Phase

The assessment of applicability to the Pre-tactical Phase of the CNS Performance Requirements identified with the Collision Risk Model for the Strategic Phase has been developed analysing the effects on different traffic scenarios of the impact of the variations in Communications Update Rate and Navigation Accuracy.

3.1 Traffic Scenarios

Traffic Scenarios have been taken from DACUS D4.2 [1] Experiment 2 (Frankfurt) and 4 (Madrid). The main features of these scenarios are described below.

3.1.1 Madrid Scenarios

DACUS D4.2 [1] Experiment 4 aims to represent the UAS traffic in Madrid city that is expected to take place in a typical day of the year 2035 and focuses on the effectiveness of DCB measures in the pre-tactical and tactical phases. The experiment uses the UAS Traffic Characterization data that is forecasted in Europe for the horizon 2030-2050 and adapts these predictions to the characteristics of this European city.

Operations are concentrated within a 30Km x 30Km region covering the main part of the city. Noise, visual and collision risk services are used to analyse the impact of the initial 4D UAS Operation plans for all the traffic that is planned to operate in a 24-hour period using 1Km x 1Km grid cells as illustrated in the screenshot below:

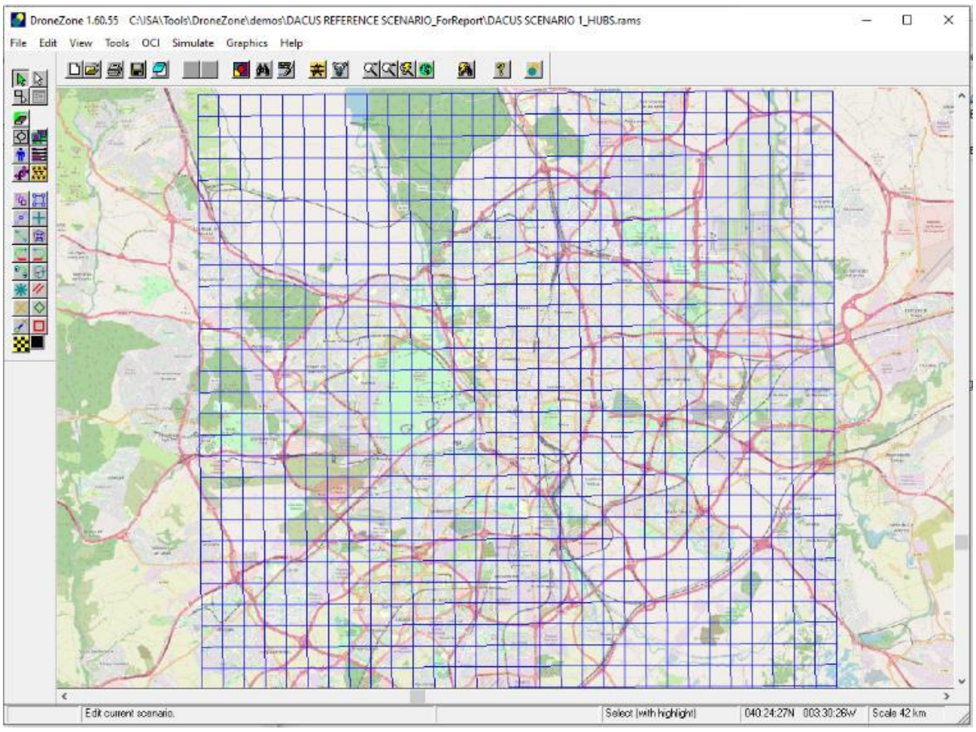


Figure 3: Madrid scenario analysis region

The scenarios considered in the present document are:

1. **Reference Scenario**: it is used to provide baseline metrics and hotspot measures using the DACUS DCM services and the RAMS Plus, *UASZone* variant which can model UAS operations using a detailed commercial UAS performance database with more than 2000 available vehicle types included.

2. **Speed controlled zones**: this scenario takes the baseline traffic demand and the identified Collision Risk and Social Impact hotspots due to the planned operations and assigns one hour speed restrictions to each of the zones where a hotspot is identified

3. **Altitude organization using directional flight layers to traverse hotspot cells**: a strategic DCB mechanism was used which separates traffic in hotspot areas into different vertical layers, depending on the direction of flight for each operation as it crosses the hotspot region.

4. **Organization using routes (organised per flight layers depending on the courses)**: each UAS joined a flight layer based on their course and in addition to this, a route grid was defined over those zones where hotspots are identified.

3.1.2 Frankfurt Scenario

The baseline scenario only includes nominal 4D trajectories and shall represent a significant traffic demand, meaning that a considerable number of hotspots are expected from the analysis of the resulting demand and capacity situation. Furthermore, within the scope of the experiments only a 3-hour timeframe (4pm – 7pm) was examined. For every application type a specific rationale was followed and assumptions were met to come up with an initial traffic estimation in the city of Frankfurt.

Furthermore, the shape of the grids was defined as a *square* shape. For the temporal resolution, both DCM model prototypes provide hotspot results with a 1-minute rate.

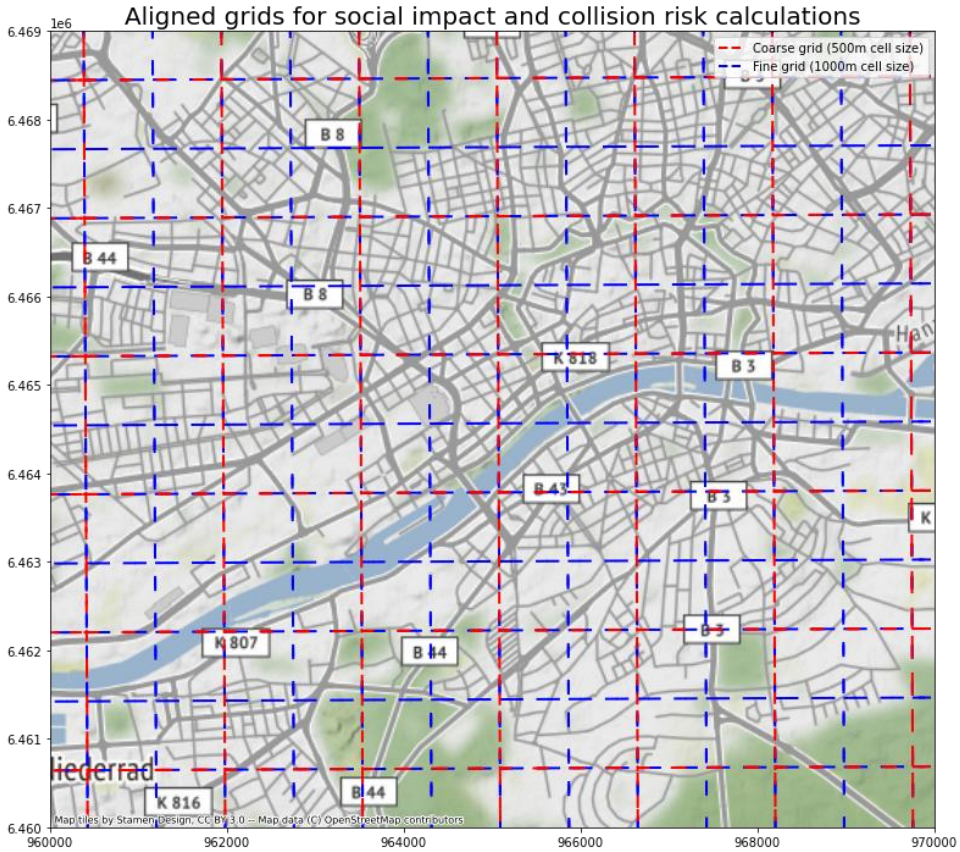


Figure 4: Aligned grids for Social Impact and Collision Risk hotspots

3.2 Communication Update Rate Results

As explained, the traffic samples for the scenarios described in the previous section have been analysed with the Collision Risk Model for the Pre-Tactical Phase, considering different communications update rates (see section 2.2).

Before presenting the outputs, some characteristic times must be presented to explain how the collisions are classified:

- Update time (t_{update}): Update rate of the surveillance system (or "e-Identification" service in U-space terminology).
- Detection and Alert time ($t_{det/alert}$): time required by the U-space Tactical Conflict Resolution service to detect a conflict between two UAS and provide the alerts to avoid the conflict/collision; assumed as 1s in the experiments.
- Manoeuvring time (t_{man}): time required by the UAS to modify their trajectories attending to the alert, avoiding the conflict/collision; estimated as 4 seconds considering FAA recommendations, for UAS remotely piloted [6].

$$t_{total} = t_{update} + t_{det/alert} + t_{man}$$

Finally, after calculating conflicts and collisions and considering the times described above, different parameters are obtained:

- Avoidable collisions: They are those collisions that can be avoided by the U-space system, i.e. when the time until the collision is long enough to detect and avoid it ($t_{min} > t_{total}$)
- Non-avoidable collisions: They are those collisions that can't be avoided by the U-space system, i.e. when the time until the collision is not long enough to detect and avoid it ($t_{min} < t_{total}$)

Considering this criterion for each scenario, a table shows all the pairs of UAS which would suffer at least a collision in the MonteCarlo simulations. Each table presents the following columns:

- PAIR: affected UAS
- Index_t: time sample in which the collision occurs
- Time to collision: mean value and standard deviation of all the times till the collisions occur
- Vel_ac1 & Vel_ac2: mean speeds of the affected UAS
- Total No of collisions for that pair.
- Probability of unavoidable collision, considering the normal distribution of time to collision for an update rate of 1 sec (t_{total}= 7 sec)

3.2.1 Madrid Reference Scenario

The results for the Madrid Reference scenario are shown below. It can be seen that three pairs are responsible for most of the collisions, increasing largely the collision risk average for the scenario, as they have not been strategically deconflicted.

PAIR	Index_t	Time to collision		Vel_ac1	Vel_ac1	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
		mean	std	mean	mean			
(13- 14)	58	6.36165376	3.35991341	2.74347521	0	7	**22**	**57.5%**
(20- 21)	13	23.8310596	9.9701699	12.8328601	1.80E-05	6	**70**	**4.6%**
(20- 23)	15	7.26454964	0	2.74809651	0	7	**14**	**0.0%**
(21- 22)	18	14.0016747	9.39622955	12.8352629	2.37E-05	65	**67**	**22.8%**
(21- 23)	19	29.7885511	6.20424573	12.8549529	12.8506162	5	5	**0.0%**
(22- 23)	22	36.6006803	0	12.8300507	12.857315	5	**42**	**0.0%**
(23- 31)	19	37.8472154		12.8506151	12.8931899	1	**1**	**0.0%**
(25- 27)	10	0		2.74347436	0	1	**11**	**100.0%**
(26- 28)	15	8.36390354	1.01009344	2.74347436	0	17	**30**	**8.8%**
(30- 31)	17	11.1694578	1.58527563	12.8944239	12.8990352	4	**4**	**0.4%**
(32- 33)	26	12.1462251	0	12.8923423	12.9020158	3	**3**	**0.0%**
(32- 36)	10	37.7445001	0.55723599	12.8789758	12.8616756	5	**5**	**0.0%**
(35- 36)	6	2.60032885	4.29469532	4.47289437	1.99E-05	180	**1792**	**84.7%**
(36- 37)	11	0.64148469	1.30972906	1.98502788	1.70949284	347	**3367**	**100.0%**
(37- 38)	16	6.76067375	5.80452479	7.91111988	3.9799964	42	**2949**	**51.6%**
(38- 41)	16	34.9180457		12.8593062	12.8701988	1	**1**	**0.0%**
(45- 47)	10	5.5746113	5.0889006	2.74347456	0	5	**7**	**61.0%**
(46- 48)	14	4.86756056	2.87387775	2.7410074	0	42	**48**	**77.1%**
(55- 58)	15	0		2.74347509	0	1	**1**	**100.0%**
(65- 68)	14	6.08627983	2.88524005	2.74100747	0	65	**66**	**62.4%**
(70- 73)	13	3.89023158	0.5271291	2.74347469	0	13	**13**	**100.0%**
(75- 78)	14	0	0	2.74347471	0	2	**2**	**100.0%**
(80- 83)	14	6.45293743	2.67861987	2.74347494	0	27	**36**	**58.1%**
(85- 87)	9	4.9653455		2.74347592	0	1	**9**	**0.0%**
(86- 88)	14	5.19325317	1.60631245	2.74347592	0	18	**24**	**87.0%**
(90- 93)	14	0		2.74347476	0	1	**1**	**100.0%**
(98- 99)	27	0	0	2.7434757	0	6	**6**	**100.0%**
(98- 103)	23	0	0	0.07837978	0	35	**54**	**100.0%**
(99- 103)	30	8.61983561	8.80432518	2.88086091	2.74254009	60	**66**	**42.7%**
(100- 103)	27	10.1784063	8.95592097	2.74278339	2.77436158	82	**89**	**36.1%**
(101- 102)	47	23.3489494	8.04082545	2.74347454	0	20	**34**	**2.1%**

Table 5: Collision Pairs. Madrid Reference Scenario

Additionally, it can be also seen that most of the collisions will include a stopped UAS (loitering or close to take off), which would also be solved by an adequate strategic and tactical deconfliction.

The following table summarises the probability of unavoidable collision, for each update rate and type and type of collision.

Probability of unavoidable collision	Update rate 1 sec	Update rate 3 sec	Update rate 5 sec
In flight UAS	**17.9%**	**22.5%**	**26.6%**
One stopped UAS	**58.1%**	**60.5%**	**61.8%**

Table 6: Probability of Unavoidable Collisions. Madrid Reference Scenario

If we discard the most likely collision pairs (non-strategically deconflicted aircraft pairs) the results are the following ones:

Probability of unavoidable collision	Update rate 1 sec	Update rate 3 sec	Update rate 5 sec
In flight UAS	**8.3%**	**10.2%**	**12.3%**
One stopped UAS	**33.8%**	**42.7%**	**47.4%**

Table 7: Probability of Unavoidable Collisions. Madrid Reference Scenario – Strategic Deconfliction

3.2.2 Madrid Speed Control Zones Scenario

The results for the Madrid SCZ scenario are shown below.

PAIR	Index_t	Time to collision		Vel_ac1	Vel_ac1	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
		mean	std	mean	mean			
(10- 11)	26	56.3670269	5.78258753	4.17798808	12.8991009	2	**6**	**0.0%**
(13- 14)	58	3.66874567	4.71631879	2.74347531	0	4	**12**	**76.0%**
(20- 21)	13	35.5172897	5.36507457	12.8322266	0	24	67	**0.0%**
(20- 23)	15	1.51171361		2.74248123	0	1	**12**	**0.0%**
(21- 22)	18	21.7834123	8.36893465	12.8322005	0	73	**91**	**3.9%**
(21- 23)	19	34.2462586		12.8550053	12.8526729	1	**1**	**0.0%**
(22- 23)	22	43.1002871	2.09369324	12.8319933	12.8556735	5	**35**	**0.0%**
(25- 27)	10	0	0	2.74347436	0	6	14	**100.0%**
(26- 28)	15	1.41380966	2.68949005	2.74347436	0	13	**24**	**98.1%**
(30- 31)	17	14.0288469	5.32455482	12.8922155	12.9017398	14	14	**9.3%**
(35- 36)	5	13.2961848		12.8573213	9.24595332	1	40	**0.0%**

PAIR	Index_t	Time to collision mean	Time to collision std	Vel_ac1 mean	Vel_ac1 mean	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
(36- 37)	10	11.7463722	1.82898636	12.8640572	9.2619957	7	180	**0.5%**
(37- 38)	16	7.03226302	7.12101537	11.5878339	6.84761984	42	82	**49.8%**
(38- 41)	16	40.7534189		9.22136145	12.8694697	1	**1**	**0.0%**
(41- 43)	16	0	0	2.7410073	4.56971532	3	**3**	**100.0%**
(45- 47)	10	2.75103933	3.95819723	2.74347447	0	6	14	**85.8%**
(46- 48)	14	6.26394707	3.28353472	2.74347447	0	35	45	**58.9%**
(51- 52)	16	0	0	12.8585304	12.8739325	2	**2**	**100.0%**
(51- 53)	17	0		2.7410089	4.56971799	1	1	**100.0%**
(61- 63)	17	0		2.74347467	0	1	**1**	**100.0%**
(65- 68)	14	4.34245922	3.28933195	2.74347465	0	15	**34**	**79.0%**
(70- 73)	13	6.7428048	1.40936166	2.74100757	0	7	7	**57.2%**
(75- 78)	14	0	0	2.74347463	0	3	**4**	**100.0%**
(80- 83)	14	6.43710894	2.75518619	2.74347485	0	39	46	**58.1%**
(85- 87)	9	8.8328161	0.59807477	2.74347568	0	8	33	**0.1%**
(86- 88)	14	7.01184806	2.9095093	2.74347568	0	10	**20**	**49.8%**
(90- 93)	14	0	0	2.74347463	0	3	3	**100.0%**
(98- 99)	27	4.8282229	3.86614877	2.74453154	4.26737784	45	**45**	**71.3%**
(98- 100)	21	0	0	4.15636419	0.41563642	11	21	**100.0%**
(98- 103)	23	3.10574567	3.74739534	2.65904213	3.85750003	32	60	**85.1%**
(99- 103)	30	4.24429829	2.55993572	4.57374778	2.7432429	7	**9**	**85.9%**
(100- 103)	27	16.9328835	8.82299514	2.7424296	1.52294506	9	**20**	**13.0%**
(101- 102)	47	30.1791977	1.75263291	2.74347462	0	2	**23**	**0.0%**

Table 8: Collision Pairs. Madrid Speed Control Zone Scenario

Additionally, it can be also seen that most of the collisions will include a stopped UAS (loitering or close to take off), which would also be solved by an adequate strategic and tactical deconfliction.

The following table summarises the probability of unavoidable collision, for each update rate and type and type of collision.

Probability of unavoidable collision	Update rate 1 sec	Update rate 3 sec	Update rate 5 sec
In flight UAS	**14.7%**	**18.3%**	**25.3%**
One stopped UAS	**19.1%**	**25.1%**	**28.7%**

Table 9: Probability of Unavoidable Collisions. Madrid Speed Control Zone Scenario

3.2.3 Madrid Layers Scenario

The results for the Madrid Layers scenario are shown below. It can be seen that two pairs are responsible for a greater number of collisions, but the share of total collisions is not very relevant.

PAIR	Index_t	Time to collision mean	Time to collision std	Vel_ac1 mean	Vel_ac1 mean	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
(7- 8)	22	0	0	0	12.8963989	2	**2**	**100.0%**
(10- 11)	26	72.9987853	20.0019352	4.17679367	12.9001201	2	**9**	**0.0%**
(13- 14)	58	7.9606429	1.61113312	2.74347509	0	5	**13**	**27.6%**
(20- 21)	13	34.103076	7.4372702	12.8322032	0	12	**68**	**0.0%**
(20- 23)	16	0.11045674	0.17111884	2.74248119	1.52400003	6	**6**	**100.0%**
(20- 30)	14	38.1949643	0	12.8549118	12.8883027	3	**3**	**0.0%**
(21- 22)	18	14.9873498	11.4606694	12.8356406	0	46	**69**	**24.3%**
(22- 23)	22	40.7944083		12.8321714	12.855659	1	**41**	**0.0%**
(25- 27)	10	4.90882706	0.46296596	2.74347438	0	7	**20**	**100.0%**
(26- 28)	15	6.26458933	3.8668703	2.74347438	0	5	**19**	**57.5%**
(30- 31)	17	16.9279614	5.74555041	12.898347	12.9018567	11	**11**	**4.2%**
(32- 36)	10	44.9758403	1.57088767	10.5243015	12.8629031	7	**7**	**0.0%**
(35- 36)	6	8.96813745	3.90729896	12.7805156	0	43	**51**	**30.7%**
(36- 37)	10	11.8437478	0.49372468	12.8206008	8.84280126	2	**197**	**0.0%**
(37- 38)	16	8.07376703	4.76620174	11.0962898	8.43935084	66	**100**	**41.1%**
(38- 41)	16	37.2757353		8.83970332	12.8705352	1	**1**	**0.0%**
(40- 43)	13	0	0	2.74100737	0	4	**4**	**100.0%**
(45- 47)	9	8.45825734		2.74347457	0	1	**42**	**0.0%**
(46- 48)	14	2.80100076	2.95357085	2.74347457	0	17	**30**	**92.2%**
(50- 53)	14	0	0	2.74347586	0	3	**3**	**100.0%**
(51- 52)	14	30.1039461	0	12.8584224	12.8742684	2	**2**	**0.0%**
(65- 68)	14	7.10848109	3.27651191	2.74347462	0	18	**32**	**48.7%**
(70- 73)	13	6.54302149	3.40850548	2.74100765	0	22	**23**	**55.3%**
(75- 78)	14	0		2.74347477	0	1	**4**	**100.0%**
(80- 83)	14	6.57266616	3.55497237	2.74347498	0	22	**35**	**54.8%**
(85- 87)	9	7.27390276	1.06141902	2.74347578	0	4	**28**	**39.8%**
(86- 88)	14	6.21594363	2.55375533	2.74347578	0	25	**35**	**62.1%**
(96- 105)	15	2.41084842	2.96405154	2.26242067	1.41501696	95	**111**	**93.9%**
(96- 106)	19	0		0	0	1	**7**	**100.0%**
(99- 101)	19	0	0	1.27E-05	1.27E-05	18	**40**	**100.0%**
(99- 103)	23	26.5791149	2.71785843	2.68935732	4.25E-05	4	**267**	**0.0%**

Table 10: Collision Pairs. Madrid Layers Scenario

Additionally, it can be also seen that most of the collisions will include a stopped UAS (loitering or close to take off), which would also be solved by an adequate strategic and tactical deconfliction.

The following table summarises the probability of unavoidable collision, for each update rate and type and type of collision.

Probability of unavoidable collision	Update rate 1 sec	Update rate 3 sec	Update rate 5 sec
In flight UAS	**11.9%**	**13.6%**	**15.6%**
One stopped UAS	**18.4%**	**23.7%**	**26.8%**

Table 11: Probability of Unavoidable Collisions. Madrid Layers Scenario

3.2.4 Madrid Routes Scenario

The results for the Madrid Routes scenario are shown below. It can be seen that two pairs are responsible for a greater number of collisions, but the share of total collisions is not very relevant.

PAIR	Index_t	Time to collision		Vel_ac1	Vel_ac1	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
		mean	std	mean	mean			
(10- 11)	26	77.2775084	1.95622426	4.17725346	12.9004175	3	**11**	**0.0%**
(10- 12)	32	0	0	4.17853006	12.8994779	4	**6**	**100.0%**
(10- 13)	36	0		4.17808132	12.9068234	1	**1**	**100.0%**
(12- 13)	19	0	0	0	12.9050128	2	**3**	**100.0%**
(13- 14)	58	5.80618468	0	2.74347561	0	3	**10**	**0.0%**
(20- 21)	13	29.3831859	9.65304531	12.8319184	0	25	**51**	**1.0%**
(20- 23)	16	0.4250584	0.55767002	2.73835049	3.32717091	11	**17**	**100.0%**
(21- 22)	18	18.5106919	9.0802181	12.8343024	0	53	**73**	**10.2%**
(21- 23)	19	10.5178367	0	12.8548652	12.8526727	3	**3**	**0.0%**
(22- 23)	22	40.5614334	0.09458396	12.8319292	12.8556155	4	**38**	**0.0%**
(25- 27)	10	4.54116276	2.44470903	2.74100729	0	8	**15**	**84.3%**
(26- 28)	15	4.54375541	2.59375182	2.74347445	0	13	**24**	**82.8%**
(30- 31)	17	9.7125191	3.63374316	12.8821092	12.9007441	11	**11**	**22.8%**
(32- 36)	10	43.4270748		10.5245677	12.863464	1	**1**	**0.0%**
(35- 36)	6	12.7288888	3.02909466	12.7864508	0	20	**31**	**2.9%**
(36- 37)	10	11.4119684	4.74932416	12.8630363	8.85136076	7	**246**	**17.6%**
(37- 38)	16	8.4366374	5.22443463	10.5510102	8.83983191	39	**64**	**39.2%**

(40- 43)	13	0	0	2.74100766	0	4	**4**	**100.0%**
(45- 47)	10	7.15722301	3.62665827	2.74347475	0	11	**12**	**48.3%**
(46- 48)	14	5.82893988	3.74673085	2.74347475	0	16	**36**	**62.3%**
(51- 52)	15	0.48286199	0	12.8586287	12.8741442	3	**3**	**0.0%**
(55- 58)	14	0	0	2.74347559	0	2	**2**	**100.0%**
(65- 68)	14	4.22093677	3.28579901	2.74347438	0	13	**22**	**80.1%**
(70- 73)	13	5.02155094	2.86337621	2.74347448	0	39	**42**	**75.5%**
(75- 78)	14	0	0	2.74347476	0	8	**12**	**100.0%**
(80- 83)	14	5.68447762	2.96285255	2.74347549	0	26	**44**	**67.1%**
(85- 87)	9	6.72796909	3.45486074	2.74347677	0	13	**19**	**53.1%**
(86- 88)	14	7.29553956	3.48268553	2.74347677	0	14	**15**	**46.6%**
(95- 105)	13	0	0	47.0101718	51.4062128	3	**3**	**100.0%**
(95- 106)	16	0	0	0	0	3	**19**	**100.0%**
(99- 103)	24	5.58754018	3.78716751	2.37059331	0	81	**144**	**64.5%**

Table 12: Collision Pairs. Madrid Routes Scenario

Additionally, it can be also seen that most of the collisions will include a stopped UAS (loitering or close to take off), which would also be solved by an adequate strategic and tactical deconfliction.

The following table summarises the probability of unavoidable collision, for each update rate and type and type of collision.

Probability of unavoidable collision	Update rate 1 sec	Update rate 3 sec	Update rate 5 sec
In flight UAS	**10.0%**	**14.4%**	**19.6%**
One stopped UAS	**30.4%**	**37.6%**	**42.3%**

Table 13: Probability of Unavoidable Collisions. Madrid Routes Scenario

3.2.5 Frankfurt Baseline Scenario

The results for the Frankfurt Baseline scenario are shown below. It can be seen that there are a large number of pairs involved in collision but there are very few of them for each single pair. So the scenario is deconflicted strategically, but the load of traffic is beyond the airspace capacity limit, so most collisions are unavoidable by a Tactical Deconfliction Service.

PAIR	Index_t	Time to collision mean	Time to collision std	Vel_ac1 mean	Vel_ac1 mean	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
(0- 10)	0	0	0	1.00241658	1.00241144	8	**48**	**100.0%**
(1- 16)	0	0	0	1.47592132	1.47592165	8	**8**	**100.0%**
(3- 31)	0	0	0	1.00456908	1.0045436	8	**8**	**100.0%**
(3- 311)	9	0	0	1.00451985	1.00454846	8	**8**	**100.0%**
(5- 35)	1	0	0	1.76844017	1.76843995	16	**16**	**100.0%**
(5- 379)	10	4.07741134	1.83022925	1.76844017	1.76844016	21	**21**	**94.5%**
(6- 511)	14	0	0	1.01886924	1.01888024	8	**8**	**100.0%**
(8- 27)	1	0	0	1.00566374	1.00568452	8	**8**	**100.0%**
(8- 45)	1	0	0	1.00567677	1.00566129	8	**8**	**100.0%**
(8- 307)	9	0	0	1.00565728	1.00567146	4	**4**	**100.0%**
(8- 363)	10	0	0	1.00568576	1.00570576	14	**14**	**100.0%**
(11- 39)	1	0	0	1.47471189	1.47470799	8	**8**	**100.0%**
(11- 248)	12	0		1.47471604	1.47471013	1	**1**	**100.0%**
(13- 148)	12	0	0	1.08792964	1.08793259	8	**8**	**100.0%**
(13- 356)	13	0	0	1.08787257	1.0879366	8	**8**	**100.0%**
(14- 59)	14	0	0	1.47778543	1.47779026	8	**8**	**100.0%**
(15- 17)	13	7.0865158	0	7.93302225	2.10596309	8	**8**	**0.0%**
(16- 357)	11	0	0	1.47592238	1.47592122	8	**8**	**100.0%**
(18- 245)	7	20.1581603	0	7.76925555	1.47673129	8	**8**	**0.0%**
(18- 331)	10	0	0	1.57367589	1.57367933	8	**8**	**100.0%**
(19- 161)	5	0	0	1.47907841	1.47907815	8	**8**	**100.0%**
(20- 29)	1	0	0	1.02036611	1.02037833	3	**3**	**100.0%**
(20- 50)	1	0	0	1.02038536	1.02036187	8	**8**	**100.0%**
(21- 40)	1	0	0	1.4950312	1.49503124	8	**8**	**100.0%**
(22- 62)	2	8.10996079	0	1.04456387	6.85700187	8	**8**	**0.0%**
(23- 31)	1	2.20038357	2.40568701	4.26689202	3.85401488	17	**17**	**97.7%**
(25- 159)	5	0	0	1.02308816	1.02310411	8	**8**	**100.0%**
(25- 206)	6	0	0	1.02310117	1.02306301	8	**8**	**100.0%**
(26- 320)	9	8.8828221	0	1.49590831	1.4959083	8	**16**	**0.0%**
(28- 77)	11	0	0	7.92054315	7.90436494	7	**7**	**100.0%**
(30- 261)	7	0	0	1.01777816	1.01777821	8	**8**	**100.0%**
(31- 147)	4	2.37740961	2.9934576	1.69431761	1.00455391	10	**18**	**93.9%**
(31- 180)	5	1.76621452	1.0764293	2.2039146	1.00453946	23	**23**	**100.0%**
(32- 347)	10	1.51747818	0.83606899	1.47487778	1.47487825	16	**24**	**100.0%**
(33- 169)	12	0	0	4.47824112	4.33990977	32	**34**	**100.0%**
(36- 40)	1	2.09297246	3.0235713	3.42198257	3.608253	24	**48**	**94.8%**
(36- 326)	10	0	0	1.49503119	1.49503124	16	**16**	**100.0%**

PAIR	Index_t	Time to collision mean	Time to collision std	Vel_ac1 mean	Vel_ac1 mean	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
(37- 276)	10	10.678217	0.03098303	3.70577362	3.03777789	10	**10**	**0.0%**
(37- 443)	13	0	0	1.47592317	1.47592201	16	**16**	**100.0%**
(38- 51)	1	0	0	1.47686884	1.47687875	16	**40**	**100.0%**
(38- 83)	9	0	0	1.4768747	1.47686753	8	**24**	**100.0%**
(38- 288)	9	0	0	1.4768747	1.4768734	8	**8**	**100.0%**
(38- 344)	10	0	0	1.47687515	1.47687278	3	**3**	**100.0%**
(39- 248)	8	0	0	1.47470772	1.47470429	8	**8**	**100.0%**
(39- 281)	8	9.91965665	0	1.47472368	1.47471809	8	**8**	**0.0%**
(39- 321)	9	0	0	1.47471421	1.47471375	8	**8**	**100.0%**
(41- 52)	1	0	0	1.33333333	1.33333333	8	**24**	**100.0%**
(41- 55)	1	0	0	1.33333333	1.33333333	8	**14**	**100.0%**
(42- 131)	4	0	0	1.47460713	1.47460872	8	**8**	**100.0%**
(44- 185)	6	0	0	6.5440763	7.39554281	8	**8**	**100.0%**
(46- 134)	12	0	0	1.33333333	1.33333333	8	**8**	**100.0%**
(46- 358)	11	0	0	1.33333333	1.33333333	11	**11**	**100.0%**
(46- 383)	11	0	0	1.0122889	1.01228467	8	**8**	**100.0%**
(49- 286)	12	0	0	1.47432689	1.47432762	8	**8**	**100.0%**
(49- 446)	13	0	0	1.4743306	1.47432868	8	**8**	**100.0%**
(49- 449)	12	4.33436196	0	1.47432662	1.47432433	8	**8**	**0.0%**
(51- 83)	2	0	0	1.47687353	1.47687806	8	**8**	**100.0%**
(51- 491)	14	7.63588027	0	1.4768712	1.47687304	8	**8**	**0.0%**
(54- 173)	5	0	0	1.60541094	7.85643815	8	**8**	**100.0%**
(54- 184)	5	3.42225637	3.26098449	1.47440478	1.47440515	30	**30**	**86.4%**
(54- 201)	6	0	0	1.47440489	1.47440455	24	**24**	**100.0%**
(57- 165)	9	7.55668863	4.28709549	6.39889572	7.50442939	16	**57**	**44.8%**
(57- 236)	11	0	0	1.05964751	1.05964085	8	**8**	**100.0%**
(58- 177)	5	24.9036256	0	6.91461805	6.01101322	8	**8**	**0.0%**
(58- 240)	7	0	0	1.48322473	1.48322705	7	**7**	**100.0%**
(60- 81)	2	0		1.33333333	1.33333333	1	**1**	**100.0%**
(60- 85)	2	0	0	1.33333333	1.33333333	16	**16**	**100.0%**
(60- 452)	13	3.25344116	2.92727515	1.33333333	1.08944197	19	**19**	**90.0%**
(60- 475)	13	2.38315864	0	1.08943011	1.08947263	8	**8**	**0.0%**
(61- 89)	2	0	0	1.0290866	1.02908664	8	**8**	**100.0%**
(61- 349)	10	0	0	1.0290865	1.02908655	8	**8**	**100.0%**
(64- 84)	2	0	0	1.00241663	1.00241071	8	**8**	**100.0%**
(64- 88)	3	0	0	1.00239334	1.00241661	2	**2**	**100.0%**
(69- 377)	10	2.7436796	1.10061555	1.47794024	1.47793991	11	**11**	**100.0%**

PAIR	Index_t	Time to collision mean	Time to collision std	Vel_ac1 mean	Vel_ac1 mean	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
(70- 203)	6	0.16320764	0.30220183	1.48894653	1.48894683	8	**8**	**100.0%**
(72- 203)	11	8.4422342	0	7.73201927	6.5948349	8	**8**	**0.0%**
(74- 92)	2	0	0	1.06265226	1.06266878	8	**8**	**100.0%**
(74- 163)	4	0	0	1.06266424	1.06265089	8	**14**	**100.0%**
(76- 105)	2	0	0	1.47487279	1.4748689	8	**8**	**100.0%**
(76- 303)	8	5.50652865	0	1.47487557	1.47487392	3	**3**	**0.0%**
(77- 131)	11	0	0	1.33333333	1.33333333	12	**19**	**100.0%**
(78- 116)	3	0	0	1.33333333	1.33333333	8	**8**	**100.0%**
(78- 352)	9	0.89015946	0	1.01193101	1.01193768	8	**8**	**100.0%**
(81- 85)	3	0	0	1.21134783	1.21140583	16	**16**	**100.0%**
(81- 495)	14	0	0	1.33333333	1.33333333	7	**7**	**100.0%**
(83- 288)	9	0	0	1.47686753	1.4768734	8	**8**	**100.0%**
(87- 104)	3	0	0	1.47550841	1.4755084	8	**8**	**100.0%**
(87- 219)	7	0	0	1.4755084	1.47550841	16	**16**	**100.0%**
(87- 237)	7	1.05696145	0.45604942	1.4755084	1.47550841	16	**16**	**100.0%**
(87- 238)	7	0	0	1.47550841	1.47550839	5	**5**	**100.0%**
(88- 102)	3	0	0	1.16786028	4.37870517	16	**16**	**100.0%**
(89- 402)	11	0.7962905	0	1.02908653	1.02908669	8	**8**	**100.0%**
(90- 253)	8	0	0	1.47586985	1.47586749	8	**8**	**100.0%**
(92- 301)	9	0	0	1.06265221	1.06264922	23	**23**	**100.0%**
(96- 130)	4	0	0	1.47473579	1.47473799	8	**8**	**100.0%**
(97- 317)	14	0	0	1.47474086	1.47474102	8	**8**	**100.0%**
(97- 342)	14	0	0	1.47474086	1.47474196	8	**8**	**100.0%**
(97- 360)	13	0	0	1.47474273	1.47474501	8	**11**	**100.0%**
(97- 365)	14	0	0	1.47474148	1.47473994	8	**8**	**100.0%**
(97- 457)	13	2.39371149	1.68089293	1.47474496	1.47474346	37	**37**	**99.7%**
(97- 469)	13	4.53190096	3.18801234	1.47474267	1.47474207	38	**38**	**78.1%**
(97- 473)	13	2.57769803	0.1513583	1.47474156	1.47474587	16	**16**	**100.0%**
(97- 476)	13	0.87105778	0	1.47474251	1.4747411	3	**3**	**100.0%**
(98- 99)	3	14.5124894	0	7.67629693	6.48141798	8	**8**	**0.0%**
(98- 490)	13	0	0	1.08928565	1.08919674	8	**8**	**100.0%**
(99- 289)	8	0	0	1.48431262	1.4843139	7	**7**	**100.0%**
(100- 396)	11	4.24182127	0	1.08792663	1.08791581	8	**9**	**0.0%**
(104- 416)	12	0.88406363	0	1.47550839	1.4755084	8	**8**	**100.0%**
(104- 439)	12	3.94130053	0	1.47550839	1.4755084	8	**8**	**0.0%**
(104- 478)	13	0	0	1.4755084	1.47550841	8	**8**	**100.0%**
(105- 347)	11	24.6066653	1.86390082	6.23431493	1.59586343	16	**24**	**0.0%**

PAIR	Index_t	Time to collision mean	Time to collision std	Vel_ac1 mean	Vel_ac1 mean	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
(105- 421)	11	10.2607007	0	6.23276694	1.47488297	8	**23**	**0.0%**
(109- 134)	4	0	0	1.33333333	1.33333333	10	**10**	**100.0%**
(111- 213)	6	2.56114237	3.95910727	1.49590824	1.49590822	23	**23**	**86.9%**
(111- 272)	7	0	0	1.49590815	1.49590815	8	**8**	**100.0%**
(112- 159)	4	0	0	1.33333333	1.33333333	8	**8**	**100.0%**
(113- 118)	3	0	0	1.47561762	1.47561837	8	**8**	**100.0%**
(114- 128)	3	0	0	1.47626373	1.4762573	8	**8**	**100.0%**
(115- 129)	14	0	0	1.47501861	1.47502567	8	**8**	**100.0%**
(115- 158)	12	15.659538	5.26728988	7.52897098	6.00026061	17	**28**	**5.0%**
(115- 423)	13	0	0	1.47502646	1.47502401	9	**9**	**100.0%**
(115- 493)	14	0	0	1.47501261	1.47501769	7	**7**	**100.0%**
(116- 203)	14	12.4082265	0	2.17191085	6.94865646	8	**8**	**0.0%**
(116- 290)	14	12.3889407	0	2.17189016	6.94996488	8	**8**	**0.0%**
(118- 413)	12	0	0	1.47561979	1.47561771	8	**8**	**100.0%**
(120- 132)	4	0		1.47687258	1.47687438	1	**1**	**100.0%**
(121- 155)	4	0	0	1.48894657	1.4889464	8	**8**	**100.0%**
(122- 172)	9	0	0	1.47794341	1.47793851	8	**8**	**100.0%**
(124- 175)	9	11.566662	0	6.23461416	2.66748642	8	**8**	**0.0%**
(125- 279)	9	37.6169705	8.66428541	7.58718663	7.8198841	24	**24**	**0.0%**
(125- 434)	12	0	0	1.474406	1.47440564	8	**8**	**100.0%**
(127- 143)	4	0	0	1.47486684	1.47485917	8	**8**	**100.0%**
(127- 263)	13	0	0	1.47487315	1.47486588	2	**2**	**100.0%**
(127- 448)	12	3.57830067	2.70707678	1.47486406	1.47487095	22	**22**	**89.7%**
(128- 415)	12	0		1.47625678	1.47625823	1	**1**	**100.0%**
(128- 481)	13	0	0	1.47626057	1.47626377	8	**8**	**100.0%**
(129- 158)	14	0		1.47502445	1.47502275	1	**1**	**100.0%**
(130- 135)	4	19.0239497	0	7.65535457	6.92178998	8	**12**	**0.0%**
(130- 234)	9	8.62827228	11.7907475	5.75948641	5.03975638	40	**56**	**44.5%**
(130- 317)	9	8.04201683	3.9866265	2.81376752	1.47474478	32	**43**	**39.7%**
(130- 350)	10	0	0	1.47474099	1.4747408	8	**8**	**100.0%**
(130- 360)	10	0	0	1.47474256	1.47473965	16	**16**	**100.0%**
(131- 146)	4	0	0	1.47460319	2.40226432	16	**16**	**100.0%**
(133- 338)	10	0	0	1.06199925	1.06201073	8	**8**	**100.0%**
(133- 375)	11	0		1.06199791	1.06196504	1	**1**	**100.0%**
(133- 387)	11	0	0	1.0620079	1.06195473	8	**8**	**100.0%**
(133- 395)	11	0	0	1.0620458	1.06198182	8	**8**	**100.0%**
(134- 358)	12	0	0	1.33333333	1.33333333	7	**7**	**100.0%**

PAIR	Index_t	Time to collision mean	Time to collision std	Vel_ac1 mean	Vel_ac1 mean	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
(134- 383)	11	0	0	1.1728135	1.55657248	16	**16**	**100.0%**
(135- 157)	9	0	0	1.47474118	1.47474413	8	**12**	**100.0%**
(135- 317)	9	4.59552292	2.30816255	1.47474269	1.47474519	25	**33**	**85.1%**
(135- 365)	10	0	0	1.47474864	1.474746	6	**6**	**100.0%**
(138- 161)	4	0	0	1.47907857	1.47907832	8	**8**	**100.0%**
(138- 252)	8	0	0	1.47907807	1.47907792	19	**19**	**100.0%**
(139- 436)	12	2.71489919	0.11808654	1.47505926	1.4750591	15	**25**	**100.0%**
(141- 420)	12	0	0	1.47480084	1.47480366	5	**5**	**100.0%**
(144- 145)	5	0		1.47611778	1.47611469	1	**1**	**100.0%**
(146- 391)	11	2.59309713	2.6781392	1.47459997	1.47460331	16	**16**	**95.0%**
(146- 425)	11	5.50757269	0	1.47459402	1.4746024	4	**4**	**0.0%**
(148- 176)	5	0	0	1.08792038	1.08789771	3	**3**	**100.0%**
(148- 315)	9	46.2377469	0	4.01456844	5.7157114	8	**8**	**0.0%**
(148- 396)	12	0	0	1.08794787	1.08788739	8	**8**	**100.0%**
(152- 418)	12	2.26095374	2.6378972	1.476733	1.47673326	36	**44**	**96.4%**
(154- 401)	11	1.59556872	0.35496817	1.03040496	1.0304002	16	**16**	**100.0%**
(155- 252)	8	7.83034655	0	6.73686553	7.33974697	8	**8**	**0.0%**
(156- 182)	5	0	0	1.47550841	1.4755084	9	**9**	**100.0%**
(157- 317)	8	2.29581959	0	1.47474226	1.47474346	8	**8**	**0.0%**
(161- 369)	11	0	0	1.47907797	1.47907814	8	**8**	**100.0%**
(164- 174)	5	0	0	1.47634994	1.4763499	8	**8**	**100.0%**
(164- 192)	5	0	0	1.47634985	1.47634993	16	**16**	**100.0%**
(165- 171)	5	0	0	1.33333333	1.33333333	6	**6**	**100.0%**
(165- 236)	11	0	0	1.33333333	1.33333333	8	**8**	**100.0%**
(166- 274)	8	0	0	1.47721849	1.47721832	8	**8**	**100.0%**
(167- 177)	5	1.73493715	0	6.22611495	1.90427048	8	**8**	**0.0%**
(167- 388)	12	0.55946113	0.7365648	1.60517898	4.00786899	13	**13**	**100.0%**
(171- 479)	14	0	0	1.05967692	1.05966423	5	**5**	**100.0%**
(171- 500)	14	2.76887637	1.57862946	2.24768937	1.05966176	16	**16**	**99.6%**
(172- 285)	8	15.8339774	0	7.43829173	1.56838391	8	**16**	**0.0%**
(173- 208)	5	0	0	1.47440342	1.474403	9	**9**	**100.0%**
(173- 223)	6	0	0	1.47440512	1.47440665	2	**2**	**100.0%**
(176- 356)	10	1.64754029	0	1.08790591	1.08788009	6	**6**	**0.0%**
(181- 194)	5	0	0	1.47673145	1.47673138	6	**6**	**100.0%**
(181- 207)	6	0	0	1.47673146	1.47673128	8	**8**	**100.0%**
(182- 186)	5	0	0	1.4755084	1.4755084	16	**38**	**100.0%**
(182- 219)	6	0	0	1.4755084	1.4755084	8	**23**	**100.0%**

PAIR	Index_t	Time to collision mean	std	Vel_ac1 mean	Vel_ac1 mean	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
(183- 428)	12	5.95208013	6.14728192	3.05106355	1.31736032	16	**16**	**56.8%**
(185- 191)	5	0	0	1.00528641	1.00528328	8	**8**	**100.0%**
(186- 219)	12	0	0	3.32698151	3.32690682	8	**8**	**100.0%**
(187- 191)	5	21.8117823	22.5271119	4.20041326	3.270915	16	**16**	**25.5%**
(189- 375)	14	0	0	1.06201539	1.06202234	7	**7**	**100.0%**
(189- 472)	14	0	0	1.06199178	1.06199751	8	**8**	**100.0%**
(190- 378)	10	2.07042159	2.00790749	1.47987527	1.47987705	24	**32**	**99.3%**
(192- 199)	6	0	0	1.47634995	1.47634991	2	**2**	**100.0%**
(193- 394)	11	5.35036401	4.41548339	2.70980386	1.17401616	49	**49**	**64.6%**
(194- 207)	6	0	0	1.47673119	1.47673136	8	**8**	**100.0%**
(194- 429)	12	6.80524607	3.81066766	4.31723758	1.47673145	16	**24**	**52.0%**
(194- 444)	13	0	0	1.47673098	1.47673143	6	**6**	**100.0%**
(195- 302)	9	0	0	1.4747992	1.47479847	21	**21**	**100.0%**
(197- 220)	6	1.56787341	3.30536738	2.17961997	2.43508227	10	**10**	**95.0%**
(197- 232)	7	0	0	1.08015512	1.08014196	8	**8**	**100.0%**
(199- 224)	6	0	0	1.47634992	1.4763498	8	**8**	**100.0%**
(203- 290)	13	34.8522788	0	2.67256989	6.7337344	5	**5**	**0.0%**
(204- 214)	6	5.07678432	0	7.46769036	7.09614215	8	**8**	**0.0%**
(207- 245)	7	0	0	1.47673154	1.47673124	7	**7**	**100.0%**
(211- 242)	7	0	0	1.04129174	1.04126981	8	**8**	**100.0%**
(211- 269)	7	0	0	1.04126787	1.04127019	8	**8**	**100.0%**
(212- 215)	6	0	0	1.06197474	1.06200995	8	**8**	**100.0%**
(212- 387)	12	0	0	1.06195531	1.06200959	8	**8**	**100.0%**
(212- 472)	14	0	0	1.06197347	1.33333333	3	**3**	**100.0%**
(217- 483)	14	0.36935378	0.38146694	1.47586945	1.47586992	16	**16**	**100.0%**
(219- 238)	7	0	0	1.4755084	1.47550841	8	**8**	**100.0%**
(220- 232)	7	0	0	1.08014922	1.08014168	9	**9**	**100.0%**
(225- 411)	12	0	0	1.02908652	1.02908667	8	**8**	**100.0%**
(229- 234)	7	0	0	1.47473586	1.47474441	8	**8**	**100.0%**
(230- 281)	12	45.354249		7.78187861	6.47649216	1	**1**	**0.0%**
(231- 236)	7	0	0	1.059653	1.05967383	8	**8**	**100.0%**
(233- 235)	7	0	0	1.47530997	1.47531338	12	**12**	**100.0%**
(234- 317)	9	1.80628413	0.4298756	1.47473815	1.47474325	15	**15**	**100.0%**
(234- 342)	10	0	0	1.47473896	1.47474167	8	**8**	**100.0%**
(234- 360)	10	0	0	1.47474471	1.47474621	16	**16**	**100.0%**
(234- 365)	10	0	0	1.47474154	1.47474264	9	**9**	**100.0%**
(236- 447)	12	0	0	1.05967088	1.05966066	8	**8**	**100.0%**

PAIR	Index_t	Time to collision mean	Time to collision std	Vel_ac1 mean	Vel_ac1 mean	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
(237- 238)	7	0	0	1.47550841	1.4755084	10	**10**	**100.0%**
(239- 481)	14	0	0	1.47625911	1.47625952	8	**8**	**100.0%**
(239- 488)	14	5.59050249	1.73807839	1.47625898	1.47625763	32	**32**	**79.1%**
(242- 269)	8	0	0	4.0864243	4.0868641	22	**30**	**100.0%**
(242- 284)	8	0	0	1.04126986	1.0412657	2	**2**	**100.0%**
(245- 264)	8	0	0	5.54455924	5.5445593	8	**16**	**100.0%**
(252- 258)	7	0	0	1.479078	1.47907852	8	**8**	**100.0%**
(256- 281)	8	0	0	1.4747052	1.47471124	5	**5**	**100.0%**
(259- 288)	8	0	0	1.47687569	1.47687537	16	**16**	**100.0%**
(259- 309)	8	0	0	1.47687499	1.47687555	8	**8**	**100.0%**
(262- 265)	8	0	0	1.33333333	1.33333333	8	**8**	**100.0%**
(263- 279)	8	0	0	1.47486026	1.47487523	12	**12**	**100.0%**
(263- 287)	8	0	0	1.47487243	1.47486009	4	**4**	**100.0%**
(263- 448)	13	0	0	1.4748616	1.4748683	16	**16**	**100.0%**
(263- 454)	12	2.93086335		1.47486894	1.47485882	1	**2**	**0.0%**
(265- 430)	13	4.70099781	0.29251879	2.02797175	7.42490295	9	**9**	**100.0%**
(266- 291)	9	0	0	1.33333333	1.33333333	8	**8**	**100.0%**
(267- 271)	8	2.58742575	3.74953614	2.08815872	2.35490931	21	**21**	**88.0%**
(267- 296)	8	0		1.4750228	1.47503085	1	**9**	**100.0%**
(269- 284)	8	0	0	1.04126216	1.04127878	8	**8**	**100.0%**
(271- 493)	14	2.08834437	0	1.47502061	1.47502795	5	**5**	**0.0%**
(279- 287)	8	0	0	1.47486473	1.47486095	12	**12**	**100.0%**
(282- 285)	8	0	0	1.4889473	1.4889467	16	**16**	**100.0%**
(283- 291)	9	0	0	1.01019235	1.01019372	8	**8**	**100.0%**
(288- 451)	13	3.74449804	0.9521723	1.47687535	1.47687138	45	**45**	**100.0%**
(288- 491)	13	9.39747425	0	1.476864	1.47687771	8	**8**	**0.0%**
(288- 519)	14	0	0	1.47687822	1.47687589	5	**5**	**100.0%**
(289- 460)	13	1.04244315	0.71277065	1.48431339	1.48431385	26	**26**	**100.0%**
(291- 455)	13	1.13048702		2.66819948	1.01019753	1	**9**	**0.0%**
(292- 313)	9	0	0	1.4755084	1.4755084	16	**16**	**100.0%**
(297- 327)	9	0	0	1.08920281	1.0892439	8	**8**	**100.0%**
(310- 409)	14	4.82823618	0	4.13200793	6.92076803	8	**8**	**0.0%**
(314- 442)	12	0	0	1.49061795	1.49061781	3	**3**	**100.0%**
(317- 342)	9	0	0	1.47475131	1.47474375	5	**28**	**100.0%**
(317- 350)	10	0	0	1.47473999	1.47474176	8	**8**	**100.0%**
(317- 360)	14	0	0	1.47474283	1.47474587	12	**12**	**100.0%**
(317- 365)	10	0	0	1.47474061	1.47474612	8	**8**	**100.0%**

PAIR	Index_t	Time to collision mean	Time to collision std	Vel_ac1 mean	Vel_ac1 mean	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
(317- 457)	13	0	0	1.47473946	1.47474368	14	**22**	**100.0%**
(317- 469)	13	2.99261222	0	1.47474481	1.4747426	6	**6**	**0.0%**
(317- 473)	14	0	0	1.47474275	1.47473996	15	**15**	**100.0%**
(317- 476)	14	0	0	1.47474629	1.47475086	3	**3**	**100.0%**
(317- 501)	14	0	0	1.47474264	1.47474792	8	**8**	**100.0%**
(318- 340)	10	0	0	1.47778445	1.47778627	8	**8**	**100.0%**
(327- 443)	13	63.4756251	2.569354	3.86352038	7.12075494	13	**13**	**0.0%**
(331- 440)	13	0	0	1.57367774	1.57367598	8	**8**	**100.0%**
(332- 382)	10	0	0	1.47611414	1.47611242	8	**8**	**100.0%**
(333- 504)	14	0	0	1.47485795	1.47487448	8	**8**	**100.0%**
(334- 338)	10	0	0	1.33333333	1.33333333	6	**6**	**100.0%**
(337- 353)	10	0	0	1.03160209	1.03153572	8	**8**	**100.0%**
(337- 373)	10	0	0	1.03157252	1.03159774	8	**8**	**100.0%**
(340- 362)	10	0	0	1.47778694	1.4777888	8	**8**	**100.0%**
(341- 351)	10	0	0	1.47721837	1.47721809	8	**8**	**100.0%**
(342- 350)	10	0	0	1.47473868	1.47473865	15	**15**	**100.0%**
(342- 360)	10	0	0	1.47474143	1.47474317	24	**40**	**100.0%**
(342- 365)	10	0	0	1.47474273	1.47474184	16	**29**	**100.0%**
(342- 457)	13	1.96863947	1.93888288	1.4747413	1.47474651	31	**31**	**99.5%**
(342- 469)	13	5.66670533	1.44801501	1.47474545	1.4747425	24	**32**	**82.1%**
(342- 473)	13	4.05702145	0	1.47474322	1.47474119	8	**15**	**0.0%**
(342- 476)	13	6.5115208	0	1.47473594	1.4747411	3	**11**	**0.0%**
(342- 501)	14	0	0	1.47473846	1.47474376	8	**8**	**100.0%**
(343- 352)	10	0	0	1.0119324	1.01193222	8	**8**	**100.0%**
(347- 421)	12	3.76825614	2.46219378	1.47487826	1.47488099	37	**37**	**90.5%**
(350- 360)	10	1.82371641	1.88352621	3.58883167	2.79683039	16	**16**	**99.7%**
(356- 445)	13	0	0	1.20341124	1.21784094	17	**17**	**100.0%**
(360- 365)	10	0	0	1.47474479	1.47474257	8	**15**	**100.0%**
(360- 376)	10	0	0	1.47475025	1.47473844	7	**10**	**100.0%**
(360- 457)	13	4.76104626	2.50142588	1.47474697	1.47474222	24	**24**	**81.5%**
(360- 469)	13	2.56164729	1.97367834	1.47474237	1.47474418	16	**16**	**98.8%**
(360- 473)	14	0	0	1.47473935	1.4747452	3	**3**	**100.0%**
(360- 476)	14	0	0	1.47474882	1.47474014	6	**6**	**100.0%**
(360- 492)	14	0	0	1.47473398	1.47474879	3	**3**	**100.0%**
(360- 501)	14	0	0	1.47474281	1.47474566	6	**6**	**100.0%**
(365- 376)	10	0	0	1.474738	1.47474486	8	**24**	**100.0%**
(365- 380)	11	0	0	1.47474438	1.47474479	8	**8**	**100.0%**

PAIR	Index_t	Time to collision mean	Time to collision std	Vel_ac1 mean	Vel_ac1 mean	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
(365- 457)	13	7.79479628	0	1.47473958	1.47474866	6	**6**	**0.0%**
(365- 476)	13	2.83254474	0	1.47473958	1.47474429	6	**6**	**0.0%**
(365- 492)	14	2.12833034	1.81516167	1.47474248	1.47474336	28	**28**	**99.6%**
(368- 372)	10	0	0	1.49503123	1.49503124	7	**7**	**100.0%**
(374- 376)	11	0	0	1.47474123	1.47474336	8	**8**	**100.0%**
(374- 380)	11	0	0	1.47474084	1.47473888	5	**5**	**100.0%**
(375- 387)	11	0	0	3.22749568	3.50298053	12	**12**	**100.0%**
(375- 395)	11	0	0	1.33333333	1.33333333	8	**8**	**100.0%**
(376- 380)	11	0	0	1.47475314	1.47474479	8	**8**	**100.0%**
(381- 385)	11	0	0	3.31491507	1.47586485	8	**8**	**100.0%**
(386- 390)	11	0	0	0.99774393	0.99774235	16	**16**	**100.0%**
(386- 398)	12	0	0	1.33333333	1.33333333	5	**5**	**100.0%**
(386- 427)	12	0	0	1.33333333	1.33333333	8	**8**	**100.0%**
(387- 395)	11	0	0	1.20566897	1.20566014	17	**25**	**100.0%**
(388- 432)	12	0		1.33333333	1.33333333	1	**1**	**100.0%**
(390- 398)	12	0	0	0.99774205	0.9977466	8	**8**	**100.0%**
(391- 425)	12	0	0	1.47460002	1.47460071	8	**8**	**100.0%**
(393- 416)	13	0	0	7.1324401	7.7341629	7	**7**	**100.0%**
(399- 401)	11	0	0	1.030385	1.03038829	7	**7**	**100.0%**
(410- 419)	12	0	0	1.47987721	1.47987837	16	**16**	**100.0%**
(413- 463)	13	0	0	1.47561719	1.47561596	8	**8**	**100.0%**
(416- 439)	12	0	0	1.47550841	1.47550841	5	**5**	**100.0%**
(416- 453)	13	0	0	1.47550841	1.47550843	8	**8**	**100.0%**
(419- 468)	13	0	0	1.47987637	1.47987923	8	**16**	**100.0%**
(428- 432)	13	0	0	1.01192969	1.01192501	10	**10**	**100.0%**
(430- 435)	12	0	0	0.99779861	0.99779839	2	**2**	**100.0%**
(433- 434)	13	0	0	1.47440615	1.47440392	8	**8**	**100.0%**
(433- 441)	13	0	0	1.47440719	1.47440615	6	**6**	**100.0%**
(434- 441)	13	0	0	1.4744062	1.47440572	5	**5**	**100.0%**
(434- 461)	13	0	0	1.47440615	1.47440543	8	**8**	**100.0%**
(437- 466)	13	0	0	1.47590197	1.47590269	3	**3**	**100.0%**
(438- 447)	13	0	0	1.05967453	1.05965787	8	**16**	**100.0%**
(439- 462)	14	0	0	1.4755084	1.4755084	4	**4**	**100.0%**
(439- 478)	14	0	0	1.47550839	1.4755084	8	**8**	**100.0%**
(442- 459)	14	0	0	1.49061847	1.49061846	8	**8**	**100.0%**
(442- 480)	14	0	0	7.69451399	7.60481294	8	**8**	**100.0%**
(442- 496)	14	0	0	1.49061807	1.49061822	7	**7**	**100.0%**

PAIR	Index_t	Time to collision mean	Time to collision std	Vel_ac1 mean	Vel_ac1 mean	Coll. at *t*	Total Nº Collisions	Unavoid Prob (upd. Rt =1 s)
(446- 470)	14	0	0	1.47432829	1.47432674	8	**8**	**100.0%**
(447- 479)	13	0	0	1.33333333	1.33333333	8	**20**	**100.0%**
(448- 454)	13	0	0	1.4748627	1.47486586	8	**8**	**100.0%**
(448- 504)	14	0	0	1.47486663	1.47487728	8	**8**	**100.0%**
(453- 462)	13	0		1.47550839	1.47550841	1	**25**	**100.0%**
(453- 478)	13	0	0	1.47550839	1.47550838	8	**8**	**100.0%**
(457- 469)	14	0	0	2.80654267	2.80652599	11	**11**	**100.0%**
(457- 473)	14	0	0	1.47473779	1.47474594	8	**8**	**100.0%**
(457- 512)	14	0	0	1.47474422	1.47474783	3	**3**	**100.0%**
(462- 478)	14	0	0	1.4755084	1.4755084	8	**8**	**100.0%**
(469- 473)	14	0	0	2.66370597	2.6639016	15	**15**	**100.0%**
(469- 476)	14	0	0	1.47474396	1.47474867	8	**8**	**100.0%**
(469- 501)	14	0	0	1.47474465	1.47474265	6	**6**	**100.0%**
(471- 485)	14	0	0	1.48957326	1.48957291	5	**5**	**100.0%**
(471- 486)	14	0	0	1.48957293	1.48957267	8	**8**	**100.0%**
(473- 476)	14	0	0	1.47474459	1.47474094	8	**8**	**100.0%**
(473- 501)	14	0	0	1.47474199	1.47474296	3	**3**	**100.0%**
(476- 492)	14	3.50052289	0	7.32074263	4.11640531	8	**8**	**0.0%**
(478- 520)	14	0	0	1.47550841	1.47550839	5	**5**	**100.0%**
(480- 497)	14	0	0	1.49061805	1.4906179	8	**8**	**100.0%**
(481- 488)	14	11.6955049	7.63238002	7.2499562	7.66601342	19	**19**	**26.9%**
(485- 486)	14	0	0	1.48957259	1.48957239	8	**8**	**100.0%**
(496- 497)	14	0	0	1.49061806	1.49061757	8	**8**	**100.0%**

Table 14: Collision Pairs. Frankfurt Baseline Scenario

Additionally, it can be also seen that there are no collisions affecting stopped UAS (loitering or close to take off).

The following table summarises the probability of unavoidable collision, for each update rate and type and type of collision.

Probability of unavoidable collision	Update rate 1 sec	Update rate 3 sec	Update rate 5 sec
In flight UAS	**84.9%**	**86.9%**	**88.2%**
One stopped UAS	**-**	**-**	**0.0%**

Table 15: Probability of Unavoidable Collisions. Frankfurt Baseline Scenario

3.3 Navigation Accuracy Results

As explained, the traffic samples for the scenarios described in the previous section have been analysed with the Collision Risk Model for the Pre-Tactical Phase, considering two types of navigations receivers in all the flights: GPS L1 and SBAS (see section 2.2).

3.3.1 Madrid Reference Scenario

The results for the Madrid Reference scenario are shown below. GPS L1 and SBAS provide similar results in terms of collision risk, which present high peaks below TLS due as the trajectories have not been strategically deconflicted.

Metric	GPS L1	SBAS
Number of cells with Collision Risk hotspots (risk > TLS)	6112	6335
Total number of Risk cells	122681	128630
Average Collision Risk	4.852E-08	5.644E-08
Average Instantaneous Collision Risk	8.088E-05	1.534E-04
Median Instantaneous Collision Risk	1.195E-08	1.298E-08

Table 16: Comparison of the results from the Collision Risk model. Madrid Reference Scenario

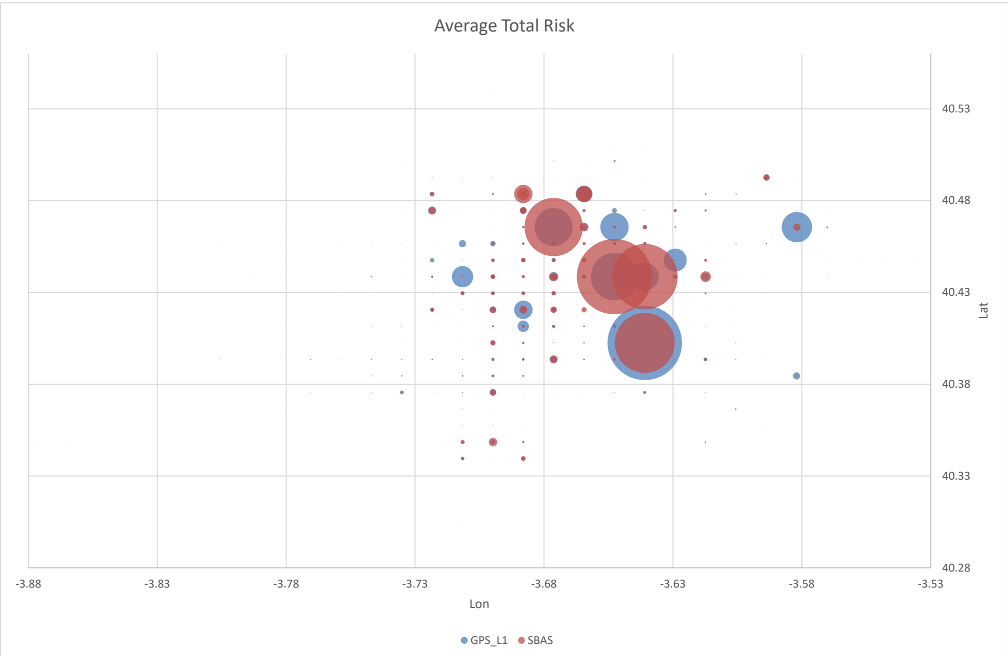


Figure 5: Collision Risk per cell GPS L1 vs SBAS. Madrid Reference Scenario

3.3.2 Madrid Speed Control Zones Scenario

The results for the Madrid SCZ scenario are shown below. GPS L1 and SBAS provide similar results in terms of collision risk, which present high peaks below TLS due as the trajectories have not been strategically deconflicted. The collision risk is reduced compared to the Reference Scenario.

Metric	GPS L1	SBAS
Number of cells with Collision Risk hotspots (risk > TLS)	5127	4940
Total number of Risk cells	123947	120175
Average Collision Risk	7.618E-08	6.032E-08
Average Instantaneous Collision Risk	5.491E-05	5.106E-05
Median Instantaneous Collision Risk	7.985E-09	9.565E-09

Table 17: Comparison of the results from the Collision Risk model. Madrid Speed Control Zones Scenario

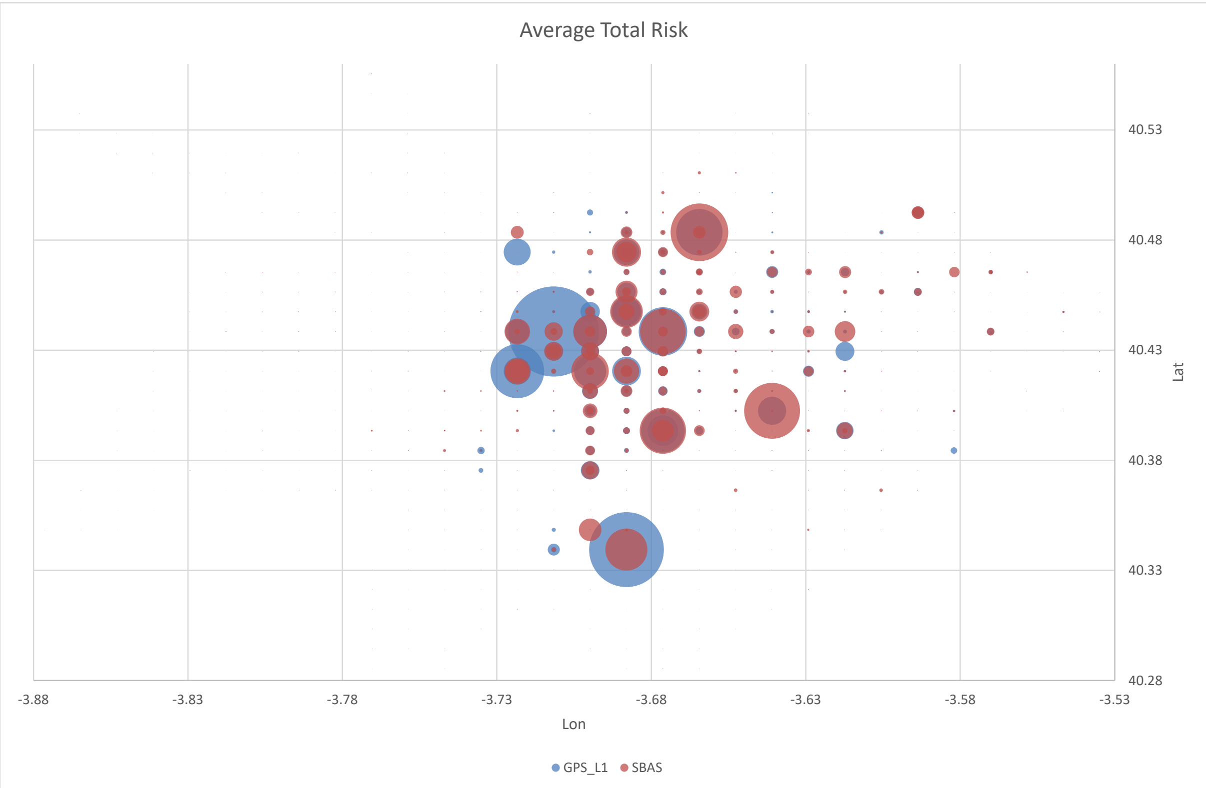


Figure 6: Collision Risk per cell GPS L1 vs SBAS. Madrid Speed Control Zones Scenario

3.3.3 Madrid Layers Scenario

The results for the Madrid Layers scenario are shown below. GPS L1 and SBAS provide similar results in terms of collision risk, which present high peaks below TLS due as the trajectories have not been strategically deconflicted. The collision risk is significantly reduced compared to the Reference Scenario. SBAS results are also slightly better than for GPS L1

Metric	GPS L1	SBAS
Number of cells with Collision Risk hotspots (risk > TLS)	3175	3050
Total number of Risk cells	120254	120242
Average Collision Risk	7.235E-08	1.357E-07
Average Instantaneous Collision Risk	4.444E-05	8.785E-05
Median Instantaneous Collision Risk	1.186E-08	1.185E-08

Table 18: Comparison of the results from the Collision Risk model. Madrid Layers Scenario

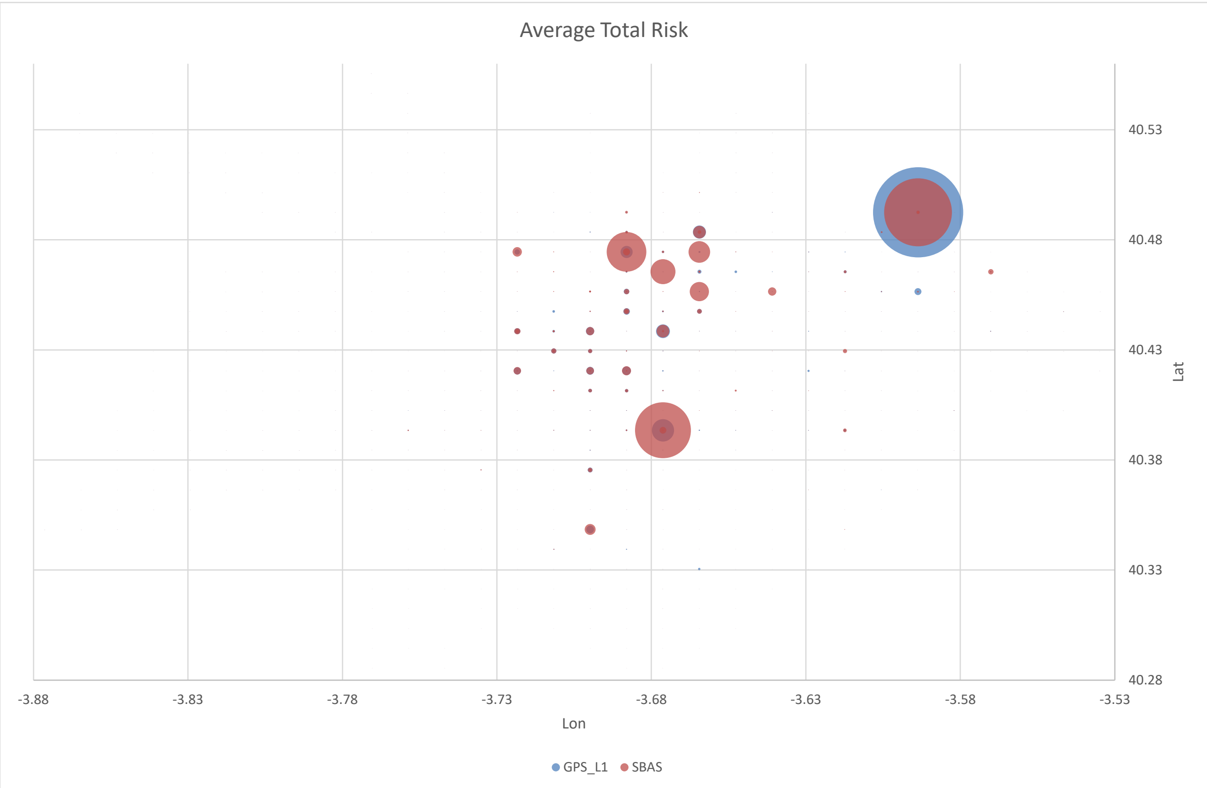


Figure 7: Collision Risk per cell GPS L1 vs SBAS. Madrid Layers Scenario

3.3.4 Madrid Routes Scenario

The results for the Madrid Routes scenario are shown below. SBAS provides better results than GPS L1 in terms of collision risk, which present high peaks below TLS due as the trajectories have not been strategically deconflicted. The collision risk is significantly increased compared to the Reference Scenario.

Metric	GPS L1	SBAS
Number of cells with Collision Risk hotspots (risk > TLS)	10513	10283
Total number of Risk cells	136913	132939
Average Collision Risk	5.096E-08	2.718E-08
Average Instantaneous Collision Risk	1.236E-04	9.218E-05
Median Instantaneous Collision Risk	1.090E-08	1.099E-08

Table 19: Comparison of the results from the Collision Risk model. Madrid Routes Scenario

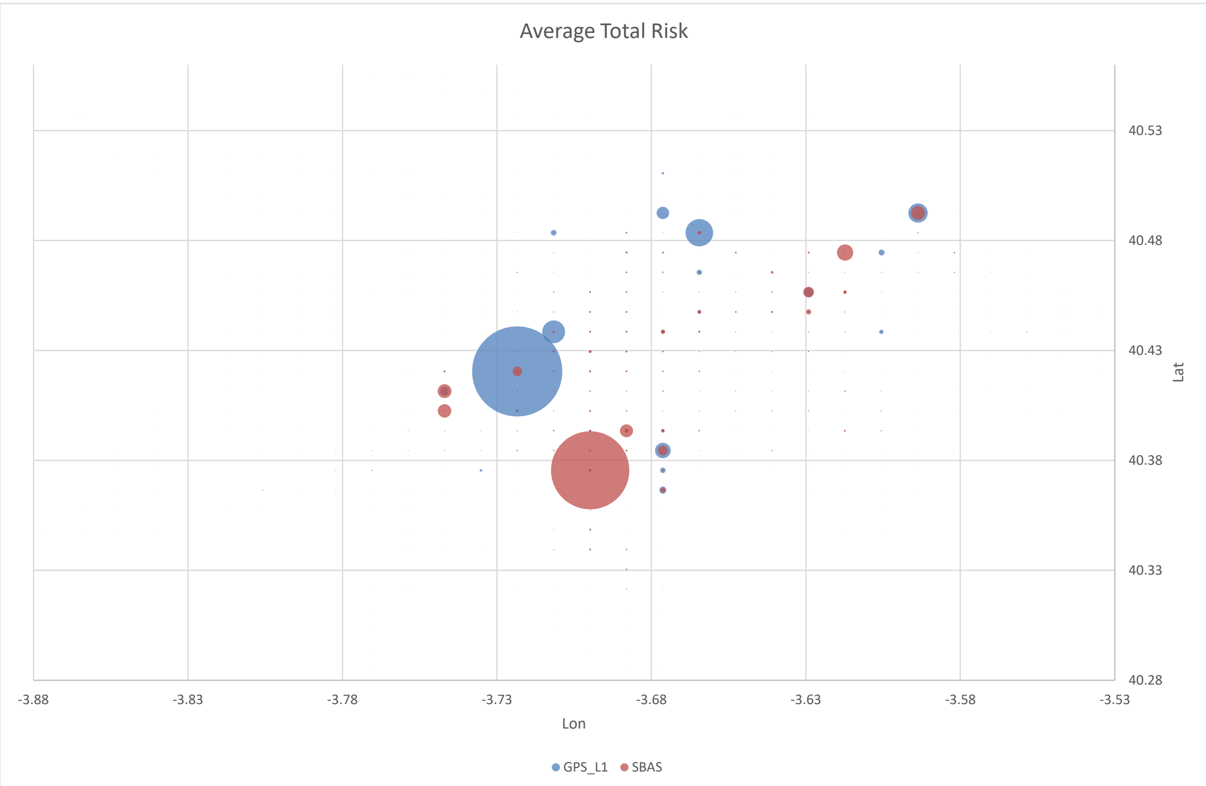


Figure 8: Collision Risk per cell GPS L1 vs SBAS. Madrid Routes Scenario

3.3.5 Frankfurt Baseline Scenario

The results for the Frankfurt Baseline scenario are shown below. GPS L1 and SBAS provide similar results in terms of collision risk, which present high peaks below TLS due as the trajectories have not been strategically deconflicted.

Metric	GPS L1	SBAS
Number of cells with Collision Risk hotspots (risk > TLS)	1276	1233
Total number of Risk cells	39671	34391
Average Collision Risk	5.251E-07	4.629E-07
Average Instantaneous Collision Risk	1.040E-04	1.124E-04
Median Instantaneous Collision Risk	4.510E-08	5.522E-08

Table 20: Comparison of the results from the Collision Risk model. Frankfurt Baseline Scenario

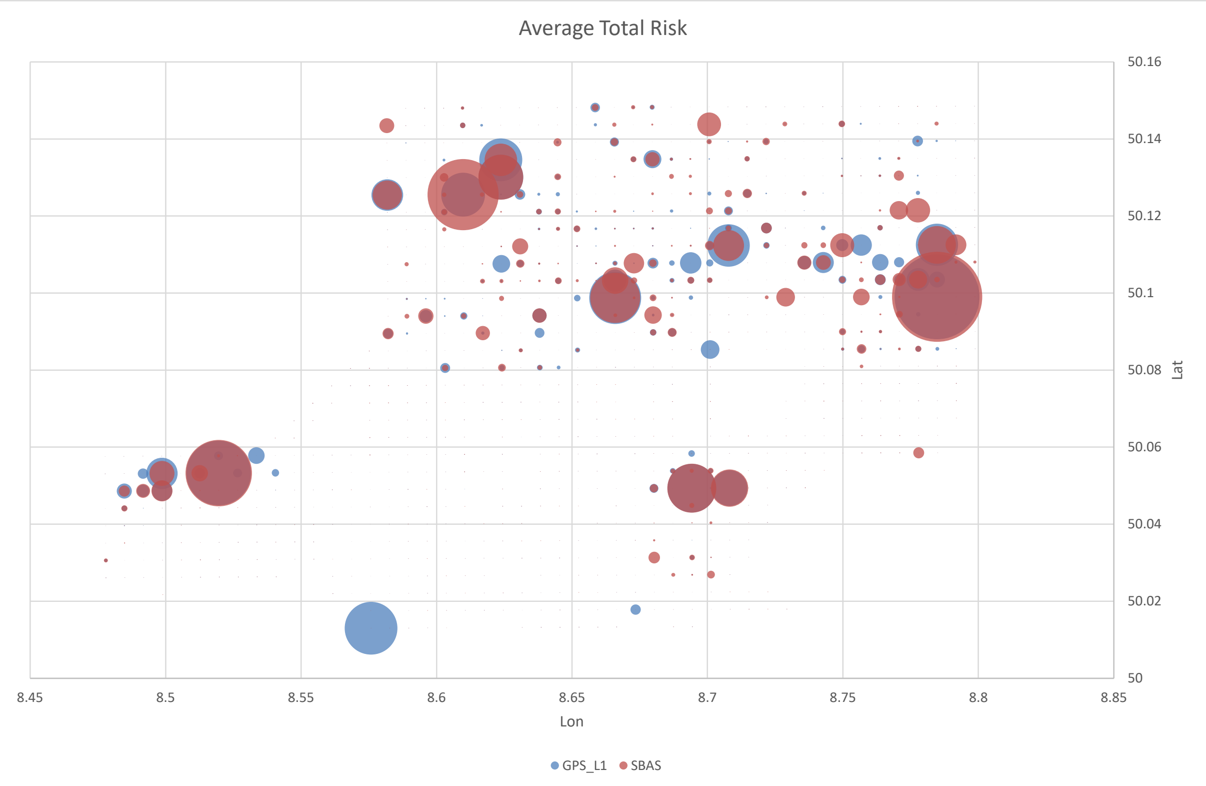


Figure 9: Collision Risk per cell GPS L1 vs SBAS. Frankfurt Baseline Scenario

4. Conclusions

This document analyses the CNS performance requirements identified in DACUS D4.2 [1], by means of the Collision Risk model for the Strategic Phase, and evaluates their applicability in the Pre-tactical phase.

The assessment of applicability to the Pre-tactical Phase of the CNS Performance Requirements identified with the Collision Risk Model for the Strategic Phase has been developed analysing the effects on different traffic scenarios of the impact of the variations in Communications Update Rate and Navigation Accuracy.

In terms of Communications Update Rate, the evaluation of the results for the different scenarios considered shows that a 1 second update rate largely increases the capacity to avoid potential UAS collisions by means of Tactical Deconfliction Service, compared to 3 or 5 seconds update rates. It also shows that the implementation of DCB measures in the pre-tactical phase, reduces the likelihood of collision, except for the Organisation per Routes, but, even in this case, the percentage of unavoidable collisions is lower compared to a non-deconflicted scenario.

Additionally, the results from the Frankfurt Baseline scenario indicate that when the traffic load is beyond the airspace capacity, the capacity to prevent collisions by means of a Tactical Deconfliction service becomes negligible.

The size of the conflict detection volume limits the benefit observed of using GNSS receivers with better navigation accuracy. As the size of the volume is determined by many factors including reaction time, which itself is limited by communications latency, it can be concluded that the likelihood of collision does not depend significantly on the navigation accuracy,, except for structured airspaces such as layers and, above all routes organisation, where the effects of navigation accuracy on the collision risk are much more relevant. However, as explained in DACUS D3.3 [7] and D4.4 [1], the navigation accuracy would impact on the required conflict detection margin and, therefore, on the false alarm rate.

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