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Comparison of Methodologies for Assessing Space Capacity and Ranking Orbital Region Risks

Andrea Muciaccia[a*], Camilla Colombo[a], Darren McKnight[b], Erin Dale[b], Alessandro Rossi[c], and Xiaoran Yan[c]

[a] *Department of Aerospace Science and Technology, Politecnico di Milano, Via Giuseppe La Masa 34, 20156, Milan, Italy, andrea.muciaccia@polimi.it, camilla.colombo@polimi.it*
[b] *LeoLabs, 4795 Meadow Wood Lane, Chantilly, VA 20120, USA, darren@leolabs.space, edale@leolabs.space*
[c] *IFAC-CNR, Via Madonna del Piano 10, 50019, Sesto Fiorentino, Italy,* a.rossi@ifac.cnr.it*, x.yan@ifac.cnr.it*

* Corresponding Author

Abstract

The sustainability of the space in Earth orbit is becoming an increasingly relevant topic within the scientific and operational communities. This is because the growing number of orbiting objects, whether active and manoeuvrable or uncontrollable from the ground, requires careful monitoring to prevent collision events and ensure continued reliable access to space in the future. Among the many studies conducted in this eld, various metrics have been developed in recent years to assess the impact of missions and the capacity of space, considering both the near future and longer timeframes. This capacity aspect is essential for determining how many objects can be launched and managed in orbit, which orbits are more congested than others and consequently setting limits on how many missions the space can handle. At the same time, these metrics also provide a means to evaluate the capacity consumption of individual missions or the entire population of orbiting objects and motivate best practices for space operations.

In this work, the Tracking the Health of the Environment and Missions In Space (THEMIS), the Criticality of Spacecraft Index (CSI), and the Risk Balance Model (RBM) approaches for evaluating the space capacity are compared and analysed to determine any potential alignment in their results and to investigate possible differences. This approach allows for the identification of the most influential parameters in capacity assessment and their relative importance. The work focuses on the low Earth orbit (LEO) region, dividing it in bins in altitude and considering the population of orbiting objects at a specific epoch with information on their size, mass, manoeuvrability, and location. The grid is not fixed in size; instead, varying altitude bin sizes are considered to assess their impact on capacity evaluation across different altitude shells. This analysis enables the classification of different regions based on their orbital risk, providing space operators and policy makers with valuable tools to evaluate the suitability of various orbital regions for missions.

Keywords: Space Debris, Space Sustainability, Space Capacity, Environmental Impact, Collision Hazard, Orbital Capacity

Acronyms/Abbreviations

ADR	Active Debris Removal
CSI	Criticality of Spacecraft Index
EOL	End-Of-Life
ESA	European Space Agency
LEO	Low Earth Orbit
LNT	Lethal Non-Trackable
MOID	Minimum Orbital Intersection Distance
PMD	Post Mission Disposal
RBA	Risk Abatement
RBM	Risk Balance Model
RBP	Risk Burden Posed
SDM	Space Debris Mitigation
THEMIS	Tracking the Health of the Environment and Missions In Space

1. Introduction

In recent years, space sustainability has become a topic addressed at a global scale. This is because the many new launches and the proliferation of space debris resulting from orbital fragmentations are leading to an increase in the number of orbiting objects [1][2] and hence a progressive congestion of certain regions of space. It has therefore become essential to understand how space activities can be developed in a way that is sustainable in the long term (that is, in the years to come).

For this purpose, over the years several indicators have been introduced to measure the impact that objects have on the space environment. Initially, these were defined to identify objects to be removed through Active Debris Removal (ADR) [3][4][5][6][7][8], as they pose a threat to the environment, especially in the event of fragmentation. Afterwards, they were also conceived as a tool for assessing the environmental impact of missions, to be used during mission design in order to ensure compliance with the principles of sustainable development of space activities. Many of these metrics, which can be distinguished into mission-based [9][10][11][12][13][14][15] and environment-based [3][16][17][18][19] categories, have been compared at the international level in an effort to reach global agreement and consensus. These analyses are still ongoing [20][21] and are attracting increasing interest and attention towards this sensitive issue. Later on, a further development emerged with the introduction of the concept of space carrying capacity; indeed, although it may appear infinite, the region of space around the Earth is a limited resource and, as such, must be carefully managed to ensure its availability for future use. The models currently under development can be divided into those that use indicators to assess the impact of missions as a basis for calculating space capacity [23][24][25][26][27][28][29][30], and those that directly estimate the number of objects that can be sustained in orbit [22].

Within this context, three models for assessing space capacity have been considered (all belonging to the set of indicators): Tracking the Health of the Environment and Missions In Space (THEMIS) [15][14], Criticality of Spacecraft Index (CSI) [8], and the Risk Balance Model (RBM) [3][27]. In the past, these models were initially compared to identify possible points of convergence and critical technical features [31], and subsequently also compared in terms of results by applying the methodologies to estimate the capacity consumed by a population of orbiting objects in different altitude slots in Low Earth Orbit (LEO) [32]. This is crucial, as different formulations can provide different perspectives, while comparing various models of the same concept (for example, the influence of debris flux on orbiting objects) can offer insights and highlight potential fundamental components for this type of formulations.

This work, instead, focuses on understanding how the models are influenced by the main parameters identified in previous studies, in order to assess the relevance of their variation or whether they are not sensitive. Each model, with possible improvements over previous studies, is therefore analysed to determine its level of sensitivity. This is essential both to understand how different formulations are influenced by the same parameter, and to identify which parameters most strongly affect the formulations, with the ultimate goal of improving individual formulations and, more broadly, the overall understanding of the space capacity concept.

2. Capacity models description

This section briefly introduces the three space capacity models, highlighting possible developments and improvements with respect to previous works. Indeed, as stated in the previous section, space capacity models are constantly evolving, responding and adjusting the formulation based on the results derived from simulations of individual models and comparisons with others.

2.1 THEMIS

At present, the THEMIS model has not undergone any changes compared to previous studies. Indeed, recent research has focused primarily on the applications of the capacity model rather than on modifications to the model itself, whose development and improvement are nonetheless ongoing and remain under investigation in parallel with these studies.

The model is based on the use of an indicator to assess the impact of individual missions. The indicator is calculated at each epoch of the mission [15][14]

$$I = p_c \cdot e_c + p_e \cdot e_e \tag{1}$$

with p_c and p_e the probability of collision and explosion, and e_c and e_e the severity of collision and explosion (i.e., the effects of the breakup in given orbital region), respectively. The evaluation is performed for the different phases of the mission to assess the total impact I_t as

$$I_t = \int_{t_0}^{t_{EOL}} I\,dt + \alpha \cdot \int_{t_{EOL}}^{t_{end}} I\,dt + (1-\alpha) \cdot \int_{t_{EOL}}^{t_f} I\,dt \tag{2}$$

where the first term of the Eq. 2 refers to the operational phase of the object, while the second and the third term refer to the Post Mission Disposal (PMD) phase where it is contemplated that the End-Of-Life (EOL) disposal may fail. The latter is taken into account through the PMD reliability α, ranging between 0 (fail) and 1 (fully reliable). Although not directly explicit, the formulation internally considers many factors such as

- The mass and the cross-sectional area of the spacecraft
- The evolution of the Keplerian orbital parameters along the mission
- The collision avoidance maneuver capabilities (and their efficacy)
- The type of PMD (e.g. reentry or graveyard orbits)

To evaluate the space capacity consumed by a population of orbiting objects, the results of the single missions are aggregated as [30]

$$\mathrm{C} = \sum I_{t_j} \qquad (3)$$

where I_{t_j} is the index of the j-th object considered in the set. In this view, the index can be currently seen as the share of the capacity of the specific mission under analysis. From this perspective, the index can be interpreted as the portion of capacity allocated to the specific mission under analysis.

2.2 CSI

The CSI, Ξ, is a dimensionless quantity originally devised to quantify the risk posed by an abandoned object in LEO. Its formulation is fully described in [8], hence only the main features are recalled here. Given an object with mass M abandoned in space, we define:

$$\Xi = M/M_0\ A/A_0\ \rho/\rho_0\ L/L_0\ f(i) \qquad (4)$$

Where M is the mass of the object (obtained by any reliable source, such as, e.g., the ESA DISCOS database), A is the cross-sectional area of the object (obtained by the same source as for the mass), ρ is the spatial density associated with the orbital shell where the object is residing each year computed by evolving over several decades a reference scenario of the space debris environment (obtained by the MASTER population) with Space Debris Mitigation (SDM) 4.2 [35], L is the lifetime of the object at the altitude corresponding to the shell where the object is orbiting, computed through a fit to the lifetime profile of standard objects in LEO, $f(i)$ is a function of the orbital inclination i, reflecting the fact that the collision risk is maximum for high inclination orbits, while the terms M_0, A_0, ρ_0, and L_0 are normalising factors for the mass, the area, the spatial density and the lifetime, respectively.

In the most recent formulation of the CSI an additional term was included in the computation of Eq. (1) to better characterise the collision risk incurred by a spacecraft in a given region of space given the actual orbits of the nearby crossing objects. For each object in the considered population, the Minimum Orbital Intersection Distance (MOID) is now computed against all the other objects. The MOID gives the absolute minimum of the distance between the points lying on two Keplerian ellipses. Its computation allows to evaluate the risk of collision between two objects in crossing Keplerian orbits. We computed the critical points of the squared distance between the orbits of each object was computed by means of the algorithm described in [36][37]. Then the median of the MOID ($med(MOID)_i$) is computed for all the objects. Finally, the index computed for each object using Eq. (4) is multiplied by a normalised MOID term which is:

$$CR = min(med(MOID)) / (med(MOID)_i) \qquad (5)$$

where the term at the nominator is the minimum median MOID of all the objects in the population (hence, the normalisation limits the MOID term between 0 and 1). Hence, the final formulation for the CSI used in this work is given by:

$$\Xi_{MOID} = CR\ M/M_0\ A/A_0\ \rho/\rho_0\ L/L_0\ f(i) \qquad (6)$$

Building on this original formulation, the shell criticality was developed in [33]. This is based on the concept of fractional criticality. Dividing the LEO environment in M spherical shells of altitude thickness D, we can compute, using Kepler's equation, the fractional contribution of the altitude shell j to the criticality index of any object k in an eccentric orbit as:

$$\Xi_{k,j} = \Phi_{k,j}\ CR_k\ M_k\ A_k\ \rho_j\ L_k\ f_k \qquad (7)$$

where $\Phi_{k,j}$ is the fraction of orbital period that the object k spends inside the shell j. Thus, the overall criticality of an altitude shell can be computed because of the individual criticalities of all N relevant objects (including active satellites) transiting through it. I.e., the criticality of the *j-th* shell is given by the sum of the individual criticalities over all the k objects crossing the shell:

$$\Xi_j = \sum \Xi_{k,j} \qquad (8)$$

Finally, the overall criticality for the LEO environment can be estimated as the sum of the Ξj over all the M shells in which the LEO region was subdivided.

Recognising the fact that active spacecraft can manoeuvre avoiding collisions, in [34] a more complex formulation of the index was adopted by multiplying the CSI of any object by specific weights accounting for the manoeuvring capabilities, the mitigation/de-orbiting policy, the projected failure rates of each spacecraft, etc. In the present work, we assumed that all the active spacecraft, with mass larger than 50 kg, have collision avoidance capabilities and therefore we multiply the index computed by Eq. (4) by a factor equal to 0.2 (the multiplying factor is a model input). That is the weight of that specific spacecraft on the environment is “discounted” by 80 % due to its capability of avoiding collisions.

2.3 RBM

The RBM was motivated primarily by a need to assess the need for space sustainability efforts such as active debris removal. As a result, the fragment population is not considered in its modelling approach. It is recognised that if constellation resiliency and efficient operations (e.g., minimising the number of risk reduction manoeuvres) are a concern then the inclusion of fragments, as is done for the other two models analysed in this paper, is indeed appropriate.

In the model, the orbital capacity is evaluated as a function of the Risk Burden Posed (RBP) and Risk Abatement (RBA) of a set of objects for a given altitude.

The evaluation is performed as

$$OC = \sum [RBP \cdot (10 - RBA) \cdot AA] \tag{9}$$

where RBP (intact object) is the product of the mass of each object multiplied by its area, and AA is the altitude adjustment (objects persists at higher altitudes).

For the original model

- RBP (catalogued fragments and Lethal Non-Trackable (LNT)) are not covered since collisions by them create relatively fewer objects compared to two intact objects.
- RBA (intact derelict) = 0, means no risk is abated
- RBA (operational payload, OPL) = f(manoeuvrability, PC to manoeuvre, and PC abatement goal) = 2.15 x {MAN x 0.33}x2.15 x {1 – ([6 +$\log_{10}${RMM/PC}]^2/10)}x2.15 x {1 – ([7 +$\log_{10}${AbPC}]^2/10)}

The risk balance model was updated to account for the local spatial density and reduce the persistence effect. These were both motivated by discussions with the other two capacity models covered in this paper. However, these changes did not change the distribution of peak debris-generating potential levels in LEO.

In addition, an examination of using different bin sizes (i.e., go from 10 km to 50 km resolution) was investigated. It was found that this change softened the peak effect from the bin at 850 km and would have moved it to second place on the list of regions of concern if we had used the larger bin size.

A minor adjustment to the default manoeuvrability metric was introduced which accounted for the three means to assess manoeuvrability: from Space-Track.org, open-source analysis, or machine learning of actual orbital behaviour. If any of these methods suggested the ability to manoeuvre, a default rating of 2 (out of 5) is applied. This aspect has become even more important as numerous new constellations have begun deployment to a wide range of altitudes and within the next five years will create significant overlap between different constellations.

3. Methodology

3.1 Comparison of formulation ingredients

The starting point of the comparative work involved examining the three models to identify similarities and begin defining potential key features for space capacity models [31]. This was carried out by analysing their different formulations, the underlying components, and the perspectives shaped by their intended purposes, followed by listing the main parameters and assumptions. The results showed that the ability of active satellites to perform avoidance manoeuvres is a key factor in reducing the persistent collision risk of long-lived derelicts in high orbits. In addition, all models rely on mass and hard body radius data but differ in evaluating the impact of the debris flux: THEMIS includes small untrackable debris, CSI uses a fixed collision velocity, while THEMIS and RBM variable values. Some approaches also identify specific objects for active debris removal (CSI, RBM). Despite these differences, all models are designed to provide information and highlight dangerous and congested areas.

3.2 Comparison of space consumed capacity results

The second step was to compare the models with a common operational case scenario [32], namely the calculation of the capacity consumed by a population of orbiting objects in LEO. Particular attention was given to the impact at different altitude levels (625 km, 775 km, 850 km, 975 km, 1450 km, considering different altitude bin sizes (10 km and 50 km), on capacity assessments and to the effect of including or excluding operational (i.e., active) satellites from the analysis. All three models relied on a standardised LEO space object population, defined as all non-decayed, intact objects (comprising operational payloads, non-operational payloads, and rocket bodies) with an apogee below 2500 km, as listed in the LeoLabs public catalogue as of January 31, 2025. Across all cases, the three models consistently distinguished between the lower-risk regions (625 km and 1450 km) and the higher-risk regions (775, 850, and 975 km), generally identifying 850 km as the most critical. While the models showed strong overall alignment, further investigation of variations in the normalised index is required.

An updated version, considering the modified formulations is presented in the following tables. Table 1 shows the results considering non-operational objects and 10 km bin, while Table 2 shows the results considering non-operational objects only and 50 km bin.

Table 1. Orbit shells ranking according to the consumed capacity level - 10 km bin with non-operational objects.

	625 km	**775 km**	**850 km**	**975 km**	**1450 km**
THEMIS	2	4	5	3	1
CSI (MOID)	1(2)	3	5	4	2 (1)
RBM	1	3	5	4	2

*In red results from previous work

Table 2. Orbit shells ranking according to the consumed capacity level - 50 km bin with non-operational objects.

	625 km	**775 km**	**850 km**	**975 km**	**1450 km**
THEMIS	2	4	5	3	1
CSI (MOID)	1(2)	4	5	3	2 (1)
RBM	1	3	5	4	2

*In red results from previous work

What emerges from the results is that only the CSI formulation led to changes in the outcomes, showing that the other modifications did not affect the results previously obtained. However, the results remain comparable, since the region of highest risk continues to be at 850 km, while the two lowest-risk regions are at 625 km and 1450 km.

3.3 Comparison of the influence of the main ingredients

The final step, presented in this work, involved once again a critical analysis of the models; this was carried out both by examining the results obtained and by considering more broadly the evolution of space activities.

On the one hand, an effort has been made to investigate the outcomes of previous simulations, also taking into account the type and amount of data required for the calculations; on the other hand, an attempt has been made to assess whether the formulations are consistent with the current evolution of space technologies and, more broadly, with the growing scale of space-related activities. The massive deployment of large constellations, the revision of guidelines (e.g. re-entry time), as well as improvements in certain technologies, have introduced changes that must be reflected in space capacity models.

In the following section, the main results are organised by broad topics, bringing together several smaller key findings.

4. Key findings

4.1 Background population

The evolution of high-LEO (i.e., altitude above 700 km) must be scrutinised very carefully due to the persistence of the debris left in orbit and the clear requirement for active removal of payloads at the end of life. This is a key aspect, as the background population has been included as a parameter since the very definition in the THEMIS and CSI models, and has more recently also been introduced into the RBM. The analyses revealed that the introduction of this dependency did not produce any changes in the ranking predicted by the RBM compared to the analyses carried out in 9. On the other hand, a potential change in the background population could lead to a significant variation in the results of the THEMIS and CSI indicators. For the former, this is because the background population is used as a reference to calculate the probability of collision with the object whose impact is being assessed; thus, by altering the number and position of the background objects, the flux of potential colliding objects would be affected, thereby influencing the object's impact on the environment (a higher or lower collision probability may result in a greater or lesser impact). Similarly, the CSI also relies on spatial density as a proxy for collision probability and would therefore be affected by any potential change in it. It is therefore essential to continuously monitor and update the catalogues containing the distribution of all orbiting objects, from operational satellites to debris, so as to use the most accurate possible background population. Any discrepancies could in fact affect the results of some formulations, potentially leading to a different ranking of orbital slots.

This, of course, is not only related to the presence of debris generated by fragmentations, but also to inactive objects that remain in orbit, especially in recent years with the launch of a large number of satellites. Two major constellations in high-LEO have shown good reliability and responsible operational practices. For example, Iridium has had only five satellites abandoned in LEO out of over 181 satellites deployed (2.8% failure rate) and OneWeb only two satellites out of 685 deployed (0.03% failure rate). However, the Thousand Sails (i.e., Qianfan) constellation has had at least six (but possibly more than 10) out of 90 deployed resulting in at least a 6.6% failure rate. Guowang has fared much better with only one out of the first ~90 satellites deployed (i.e., ~1% failure). However, out of a combined 16 launches for Guowang and Qianfan there have been 10 rocket bodies abandoned around 800 km altitude (one of which has had a major fragmentation event). The Thousand Sails constellation is slated to have nearly 1,300 satellites deployed to ~1,100 km altitude over the next five years. If this rate of payload failure, rocket body abandonment, and rocket body explosion were to persist the growth of orbital debris at these already cluttered altitudes around 800 km would be significant and would greatly affect capacity assessments in these regions.

In addition to this, the launch of a large number of satellites in specific regions of space was also one of the drivers for improving the THEMIS model. In fact, the introduction of large constellations raised issues in the term describing the severity/effects of a potential fragmentation [38]. This led to a revision of the formulation, aligning it to better account for this type of mission architecture [14].

4.2 Bin size and physical properties

Another point of discussion concerned the bin size, required to define some reference regions for which the level of consumed capacity is calculated (as defined in Section 3.2). This, in fact, influences the region of space under consideration, as it determines the number of objects included or excluded; this can play a crucial role in potential fluctuations in the consumed capacity results across the different bins. Indeed, as already mentioned, space activities are evolving, and over time there may be changes in the regions of space that are used and exploited depending on the purpose. The apparent migration of major constellations to lower altitudes may be a reflection of the people with the most knowledge and experience in space operations avoiding the higher altitudes in LEO to minimise the persistence of both their own hardware and debris that might affect their operations. However, for constellations operating at higher altitudes with checkout altitudes much lower would require members of these constellations to transit a large portion of LEO. This transit would create a potential short-term space traffic coordination challenge that would require collaboration between constellation operators to minimise inter-constellation collision risk. In addition, the next five years will introduce the likelihood of major constellations having an overlap of operational altitudes. Specifically, the altitude shells of Guowang and Starlink V2 are slated for overlap at potentially ~520 km and ~550 km. This occurrence, if it happens, will stress the concept of orbital capacity at these altitudes without significant cooperation such as sharing propagated ephemeris, manoeuvre plans, and criteria for execution of risk reduction manoeuvres.

In light of this, it is essential to understand the influence of bin size in the calculation of risk regions, also by defining different bin sizes, since the same variation in altitude corresponds to different volumes of space, with a larger volume being considered at higher altitudes compared to lower ones. From the analyses carried out, some dependencies of the models on the consumed capacity results have emerged.

Starting from the CSI, despite the results being identical for the 10 and 50 km shells, a closer analysis showed a dependence on the shell size definition of the examined space. In particular, the underlying object density adopted (ρ, ρ_0 in Eq. (4)) exhibits marked discontinuities at the boundaries of the considered shells. A different subdivision of the altitude shells for the assumed background density could result in a change in the ranking between the 850 km and 975 km shells.

For THEMIS, similarly, the bin size influences the number of objects included in the analysis. Since the consumed capacity is assessed as the aggregation of the impact of individual missions, removing objects would mean excluding part of the capacity share considered. On the one hand, this could involve the removal of massive objects, whose fragmentation effects might be significant, while on the other hand, it could lead to the loss of objects with a high collision probability due to the background population; in peculiar cases, both effects could be found in the same object.

Finally, for the RBM the mass of each object is distributed uniformly across the orbital range, mitigating fluctuations in mass density. As a result, the choice of bin size (10 km versus 50 km) produces only minor variations.

As a general comment, while the generation of fragments varies linearly with the mass involved in any event the persistence of debris varies exponentially with altitude, this sensitivity is marked in capacity analyses. This is highlighted by the major differentiation between just 200 km difference from 650 km to 850 km in all the models: going from one of the least (currently) worrisome regions to the most worrisome region in LEO.

Considering the results of the analysis, it would be essential to carry out a detailed analysis based on a tailored selection of bin sizes, bearing in mind the possibility of variable bin size for the different altitudes considered. For the larger bin size (i.e., 50 km), where the bins tart and end may have an effect that might need to be studied. For example, around the 850 km cluster altitude a 50 km bin of 825 km to 875 km would undoubtedly be different from a bin going from 850 to 900 km.

4.3 Operational vs non operational

The last investigations concern the distinction between operational objects (able in some cases of performing avoidance manoeuvres) and uncontrollable ones, and the impact of their inclusion or exclusion in the set under analysis. The ability to perform manoeuvres clearly provides an advantage, as it reduces the risk of a potential fragmentation due to an in-orbit collision. For this reason, all three models have incorporated a parameter to account for this feature. The modelling is carried out in different ways, leading to a different relative weighting of the objects across the models.

As a practical case, in the investigated population and considering the 10 km bins, excluding active objects would reduce the count of objects from an initial 147 (at 775 km) and 144 (at 975 km) to 80 and 141, respectively. This can influence the final consumed capacity value. By contrast, in the 50 km scenario, this trend is mitigated because more objects (especially inactive ones) are included in the bin.

Some discrepancies were identified in the THEMIS model, which does not rank the 850 km bin as the highest when a 10 km bin size is considered. This difference may arise from the model's approach to weighting operational versus non-operational objects, resulting in a distinct evaluation of each mission's impact compared with the other models; indeed, this model was developed to have and indicator useful during the mission design phase with the capability of assessing the impact considering some useful mission parameters (in this case, the collision avoidance manoeuvres capability and efficacy). Moreover, due to this modelling, the number of active objects included in the set may change the capacity consumed in the specified slot.

Regarding the RBM, the results indicate that the capacity estimations are relatively insensitive to the inclusion of operational satellites in the population, thus highlighting a greater weight associated with derelict objects. This is because operational satellites are given a manoeuvrability score taken into account in the algorithm, so active, manoeuvrable satellites exhibiting best practices minimise the added risk posed to a shell because of their mitigation techniques. In addition, during the analyses it was noted that the RBM heavily weights the mass present in an orbital shell over the probability of collision. This implies that very massive objects have a higher weight in terms of consumed capacity compared to less massive ones and even compared to less massive objects located in regions with a higher background flux.

For the CSI, due to the lower weighting assigned to operational payloads, no distinction emerges between the case including operational satellites and the one excluding them. However, no manoeuvring capability for all objects in the results would results in a ranking swap between the 775 km and 975 km shells, driven by the significant change in the number of considered objects.

5. Conclusions

The concept of orbital capacity requires a balanced understanding and application of satellite operator behaviour, triggers for fragment generation events, and derelict hardware abandonment rates. Further, the altitude at which these features are considered drastically affect the level of concern as persistence of objects' increases exponentially by altitude. The advent of deployment of large constellations complicates the orbital capacity evaluation situation as it magnifies space safety and space sustainability challenges through the rapid fielding of hundreds to thousands of satellites into a variety of altitudes throughout LEO in a short period of time. This means that orbital capacity models must be able to adapt to evolving technologies and mission types launched into orbit, so that appropriate regulations can be introduced to ensure the sustainable development of space activities.

In recent years, there has been a growing number of models developed not only to identify hazardous objects to be removed through ADR, but also to assess the impact of missions on the space environment, as well as to quantify space capacity (especially in LEO) and its current level of utilisation. This is a positive development, as it shows that the topic is highly relevant and must be addressed broadly and at an international level in order to achieve the greatest resonance and consensus. However, it is also important to compare the various models in order to identify possible improvements, but above all to enhance the understanding of this topic, which is still in its early stages of development.

This has been the objective of the analyses and comparison of the three models THEMIS, CSI, and RBM. The starting point was to compare the models in order to understand their differences and the most important elements that resulted to be common across the different formulations, assessing their relevance. The analysis then moved from theory to practice by examining a case study to observe the behaviour of the models when applied to real scenarios; in this way, it was possible to identify points of overlap, areas of agreement, and potential discrepancies among the models, thereby enabling further investigations both at the level of individual models and with respect to the key elements that should be shared across all formulations. Finally, with this work the perspective shifted back to theory to examine how the parameters identified during the research tend to influence the individual models and their outcomes. What emerged is that some formulations are more sensitive to certain reference parameters (e.g., bin size, background population influence, etc.), but less to others. This is also due to different perspectives and modelling approaches applied to certain elements, such as the debris flux used in the assessment of collision capacity. This sensitivity may stem from intrinsic aspects of the model, but also from the level of complexity of the model itself, which clearly plays a fundamental role when making comparisons.

This comparison does not end with the present work; future studies will be carried out to analyse further perspectives of these models and their possible modifications, also coming from the feedback from these analyses.

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