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Human and Robotic Exploration Data Base

Matthieu Melcot^a, Mounir Hafif^b,
Space Applications Services N.V, Belgium

^a Department of Control & Data Centres, Space Applications Services, Leuvensesteenweg 325, 1932 Sint-Stevens-Woluwe (Brussels Area), Belgium, matthieu.melcot@spaceapplications.com

^b Department of Control & Data Centres, Space Applications Services, Leuvensesteenweg 325, 1932 Sint-Stevens-Woluwe (Brussels Area), Belgium, mounir.hafif@spaceapplications.com

Abstract

The Human and Robotic Exploration Data Base (HRE-DB) is a web-based platform for mission planning. In the past, the ESA ISS science and operations planning teams used multiple disparate tools and practices, causing significant inefficiencies in collaboration. To improve interaction between mission planning stakeholders, ESA developed the HRE-DB as a collaborative platform.

The HRE-DB is a platform designed to standardize the data-flows between the different teams, and to provide a single-source-of-truth for the mission planning data. The HRE-DB aims at covering the entire life cycle of the experiments from the initial scientific proposals, to the planning, the execution, the reconciliation and the archiving. Hence fostering the collaboration between different groups of stakeholders.

A key objective of the HRE-DB tool is the capability to support the integration of the operations planning of the several space agencies participating in the ISS program. The ISS is a collaborative environment, where the agencies have to share resources (power, cooling, storage, crew time, data bandwidth, etc.) between the various system equipment and operations [1].

The HRE-DB application has been designed from the start as a distributed application. ‘Local tool’ versions of the application can be deployed in different agencies and partners to provide them the possibility to do internal mission planning. A ‘Central tool’ version of the application, deployed at one of the agencies or partners premises, has the capability to receive the planning’s submitted by the different ‘Local tools’ and to visualize the plans in a unified, consolidated GMT timeline.

This architecture allows the agencies and partners to own and store their data in their premises, while only exchanging a part of it to the ‘Central Tool’ for resource conflicts assessments. The Central Tool has also the ability to act as a hub to provide up-to-date data to the ‘Local tools’. For example, It can provide the latest updates on the flight plan.

The paper outlines the HRE-DB tool has been deployed at ESA since 2018 and the first deployment at NASA of the Central tool. It will report on the impact HRE-DB provided on the daily tasks and processes related to the operations planning of the ISS. The paper will also provide the current roadmap to apply these functionalities on additional platforms of the ESA human and robotic exploration such as the Parabolic Flights, the Lunar gateway and Mars missions.

Keywords: Mission, Planning, Collaboration, Database

Acronyms/Abbreviations

BI	Business Intelligence
COL-CC	Columbus Control Centre
COTS	Commercial off-the-shelf
CSA	Canadian Space Agency
ESA	European Space Agency

FAIR	Findability, Accessibility, Interoperability, and Reusability
FPIP	Flight Planning Integration Panel
GMT	Greenwich Mean Time
HRE	Human and Robotic Exploration
ISS	International Space Station
JAXA	Japan Aerospace Exploration Agency
NASA	National Aeronautics and Space Administration
NET	Not-earlier-than
NLT	Not-later-than
PIM	Payload Integration Manager
UI	User Interface
USOC	User Support and Operations Centre

1. Introduction

This paper presents the HRE-DB mission planning tool for operations on the International Space Station (ISS) and other platforms. It outlines the benefits for planners and how it facilitates collaboration in experiment and maintenance planning. The paper also highlights the challenges in adopting the tool and its future potential applications.

2. HRE-DB foundations

2.1. Single source of truth

In the context of mission planning, each ESA team has, over time, developed its own tooling and methodologies. Even inside a single team, one can find a variety of approaches developed by each individual. The same information is sometimes repeated and maintained over multiple supports by different persons and teams, most of the time in spreadsheets that are not synchronized [2].

This widespread heterogeneity of sources of information and data structures within ESA led the agency to think about a way to centralize the planning data into a single source of information, which in fine should become a single source of truth.,

Additionally, the design of software for planners standardizing the way how data are entered with validation mechanisms has been the starting point of the HRE-DB platform.

2.2. Collaborative environment

For many years, ESA has suffered from collaboration difficulties between different teams or individuals, due to the wide variety of practices, tools, and non-standardized processes. Many work interactions had and still happen through Word and Excel documents in email attachments. Some data are replicated over different ESA services, with variations in the data, missing or additional elements, or typos in the data. For instance, a recurrent issue is that each team owns a different version of the list of *organizations* or *participants* for *experiments* and *investigations*. If at a certain moment, the details of a participant need to be updated, or a new participant is to be added to the data, it may be the case for the spreadsheet of a team, but not for the one of another team. This lead to inconsistency between the different versions of the data owned by different teams and people.

The HRE-DB objective is to answer those issues by providing a centralized database, at the level of the agency or organization.

To achieve that goal, the HRE-DB is structured as a web-based application that uses a single database to store all the data related to the investigations and experiments.

In addition, the database schema is constrained in a way that incorrect or inconsistent data cannot be persisted. Furthermore, the application interface provides an extra layer of data validation, so that end-users data is checked in the UI, and hints are provided to the end user if the entry is incorrect.

2.3. Distributed architecture

From the beginning of the HRE-DB project, the architecture of the tool has been grounded upon the concept of an exchange of information between local agencies (ESA, CSA, JAXA...), and a central organization (NASA).

To elaborate this strategy, the HRE-DB tool has been structured around two different tools (see Fig. 1):

- A Central Tool: a version of the tool hosted in the central organization.
- A Local Tool: a version of the tool hosted in the agencies. Each agency has its own instance of the LocalTool installed in its infrastructure, hence the database and related data are within the realm of the agency.

Although both types of tools (Local and Central) are really similar in terms of UI, each of them provides specific capabilities.

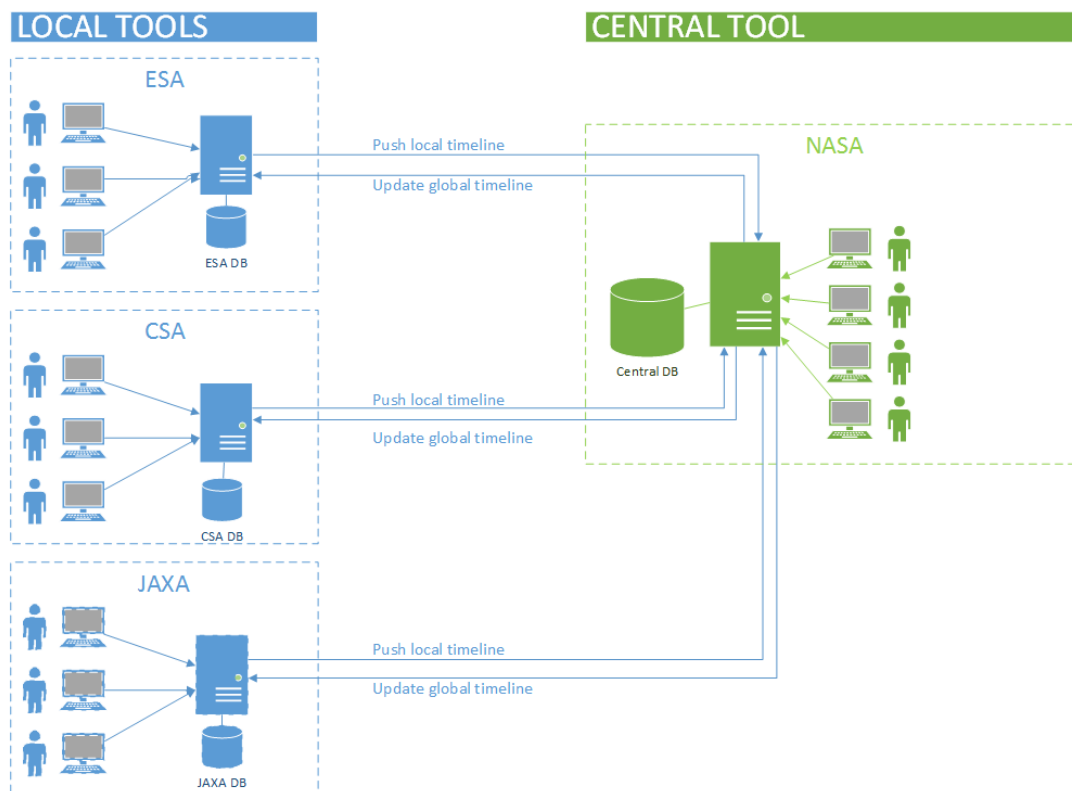


Fig. 1. Local tools and central tools

There are two streams of information between the Local and Central Tools:

A downstream from the Central Tool to the Local Tools:

The Central Tool owns the flight plan reference. For instance, in the case of ISS, the reference flight plan is the Flight Planning Integration Panel (FPIP) from NASA. This flight plan can be updated by an operator through the upload of a file containing future flights and potential changes on upcoming flights.

The Local Tool in turn has the capability to fetch this flight plan so that their GMT timeline that shows their own planning is in line with the most up-to-date flight plan.

Other information such as the “Crew Time Budget per Agency”, Mission and Platform definitions can be edited in the Central Tool, and then propagated to the Local Tools.

An upstream from the Local Tools to the Central Tool:

Each Agency Local Tool can at any time submit (with a push mechanism) the list of forecasted planning models to the Central Tool.

However should a planning model not be shared for confidentiality reasons, it can remain in the agency's Local Tool only.

2.4. Multiple platforms

The HRE-DB application is architected around the concept of a Platform (see Fig. 2).

A Platform represents the set of data related to a specific physical Platform on which experiments are carried out, such as:

- ISS
- Lunar Gateway
- Parabolic Airplanes
- ...

The application context is relative to the selected platform. Once a platform is selected, the application filters out the database content to display only data that pertain to that specific platform: For instance missions, experiments or investigations. The timelines like the GMT timeline are also filtered accordingly so that they only show the content of the selected platform.

Some features and fields are specific to certain platforms. For instance 'Increments' are only relevant in the frame of ISS. Those elements are therefore tailored so that they are displayed in the menus and pages only if they make sense for that selected platform.

The application also provides a way to select no platform in particular, hence the user can access the content of all the available platforms without filtering.

This list of platforms is extensible, making the application adaptable to upcoming platforms.

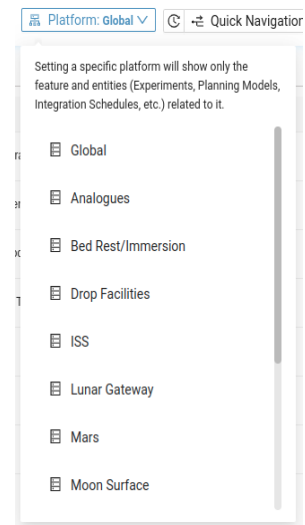


Fig. 2. Platform Selector

3. A mission planning tool

The HRE-DB has been designed to provide a way for mission planning teams to handle the lifecycle of the operations happening onboard ISS and other platforms (see Fig. 3).

Part of this lifecycle management is happening outside the realm of the HRE-DB. For instance, the execution is performed at the USOC, previously with a number of haddock tools [3][4]. However, one of the objectives of the tool is to provide the ability to collect the data produced at each step of the operation life-cycle.

The HRE-DB is capable to manage different types of operations from science experiments to facility maintenance.

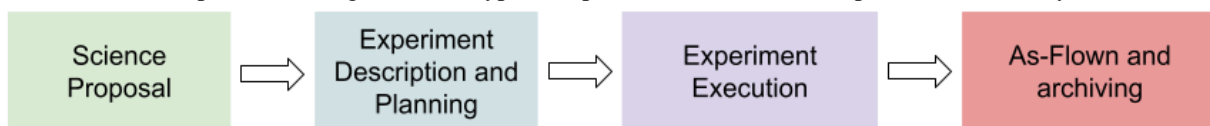


Fig. 3- Experiment planning life-cycle

The lifecycle of a science operation starts with a Science Proposal that is described on the dedicated HRE-DB page by the Research Scientists' team.

Once a Science Proposal is set up, and accepted, it can be converted into a Project. The Project is then broken down into one or several Investigations (see Fig. 4).

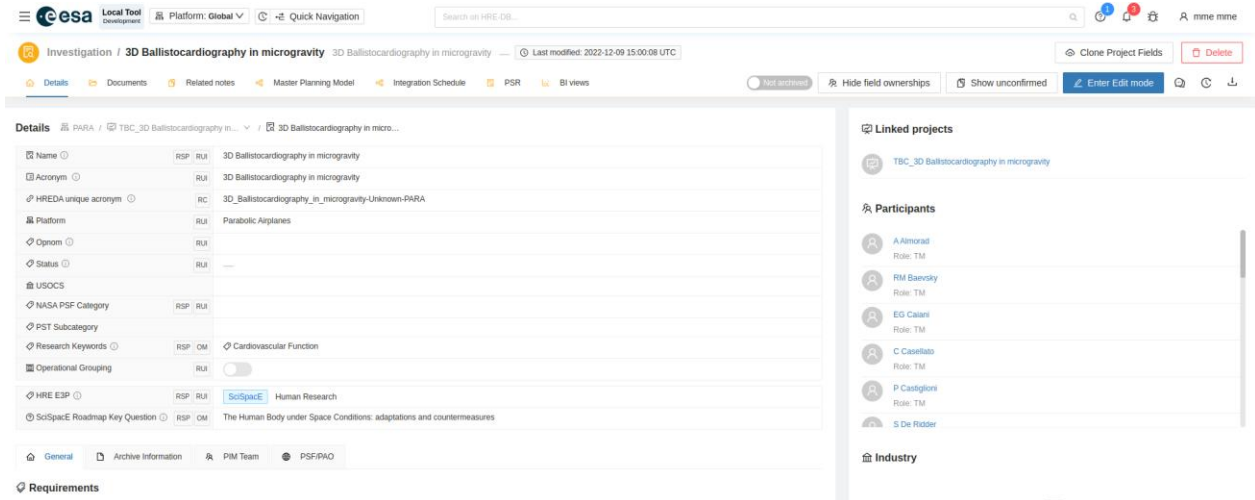


Fig. 4. - Investigation detail page

The Investigations in turn can be broken down into one or more Experiments.

An Experiment entity contains information about a science operation that will or has run in the ISS or another Platform. For instance, the Experiment page allows users to add the list of Participants to this Experiment, and the list of Industries and Organizations that are part of it. It also provides a large number of fields that help to fully describe an Experiment, for instance:

- List of Requirements
- Readiness Statements
- Science Description

The Experiment page also provides an overview of the key performance indicators (KPIs) (see Fig. 5) for the critical resources and constraints used and set by the experiment.

Crew time, up/down mass, and volumes are valuable resources in the utilization of platforms such as the ISS, so it is essential to monitor their usage and explore ways to optimize their consumption.

The KPI panel displays a summary of the primary and reserve crew time used in planned operation tasks, as well as the total up/down mass and volume. "

The constraints of the experiment are the connections between the vehicles and the elements that need to be uploaded or downloaded from/to the ISS or other platform. If a related flight is rescheduled, it will affect the experiment's plan. The application gives a comprehensive view of the flight dependencies and alerts the user if rescheduling a vehicle breaks the Planning Model.

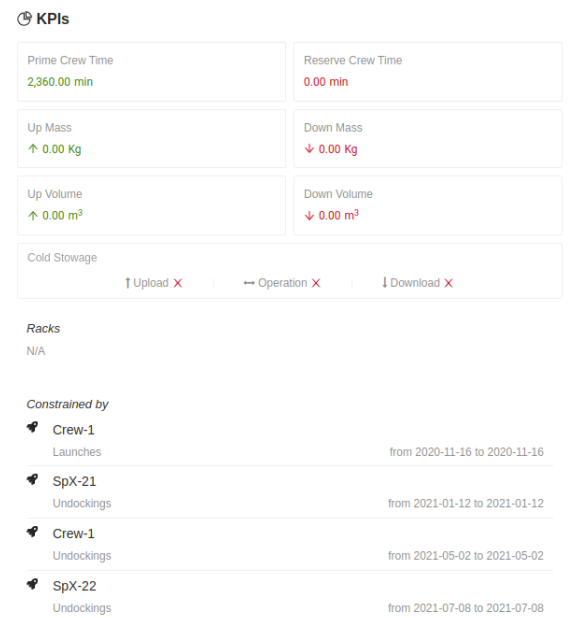


Fig. 5 . Experiment KPIs

3.1. Planning Models

Each Experiment entity comes with a Planning Model (see Fig. 6), which is a timeline representation of the tasks required to characterize and fulfill the Experiment.

The Planning Model starts as an empty timeline that can be filled with templates created by users in advance. .
 The Planning Model interface offers the user a list of task types such as ‘Pre-Flight’, ‘On-Orbit’, and/or ‘Post-Mission’
 tasks that can be drag-n-dropped onto the timeline.

Then once a task has been instantiated, the end-user can start to characterize it, using the side panel that offers the
 following tabs:

- Duration and crew time
- Metadata
- Equipment
- Racks and locations
- Documents

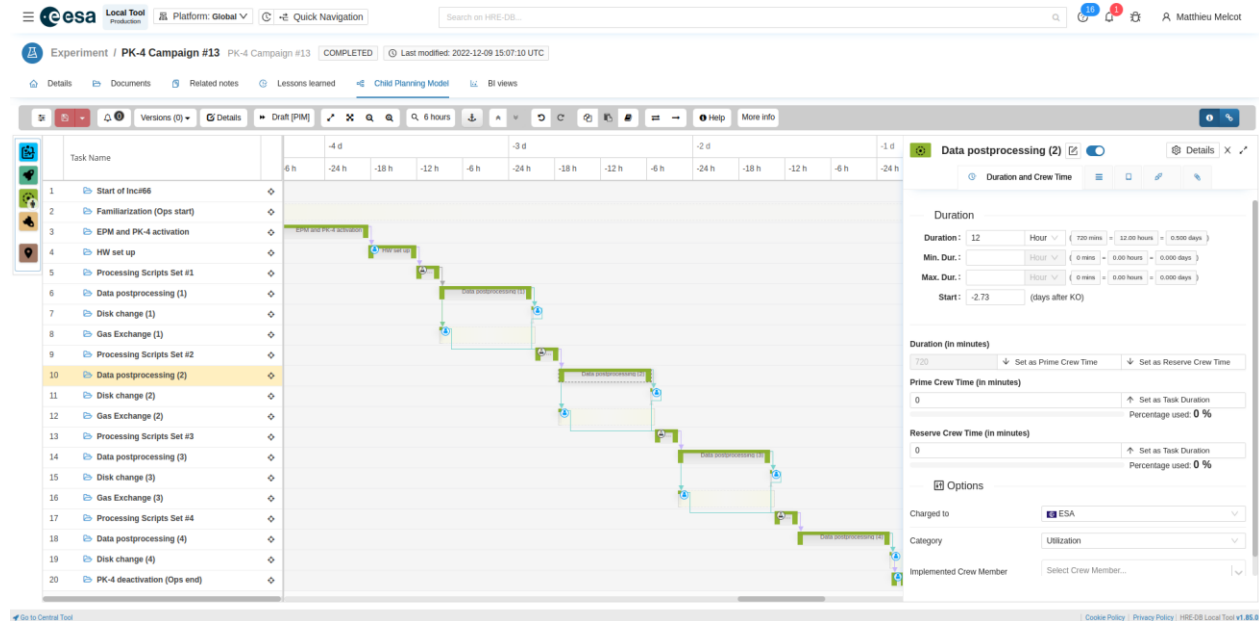


Fig. 6. Planning Model Editor

Once the tasks have been laid out on the timeline, the end-user starts to create temporal constraints (see Fig. 7) between the tasks, or between a task and an external event such as a vehicle flight, or the start of an increment in the case of ISS.

The constraints are configured with NET (Not-earlier-than), and NLT (Not-later-than) values.

If external constraints are set, the Planning Model that until now was defined only in a relative timeline is now able to be displayed in an absolute timeline, using calendar dates. This also opens the possibility to display it in a global GMT timeline together with other Planning Models, as will be described later in this paper.

Eventually, when the internal and external constraints have been set, the end-user has the possibility to request the re-organization of the timeline with respect to the constraints. When the re-organization is triggered, the system runs an optimization algorithm that tries to minimize the span of the Planning Model, without breaking the constraints.

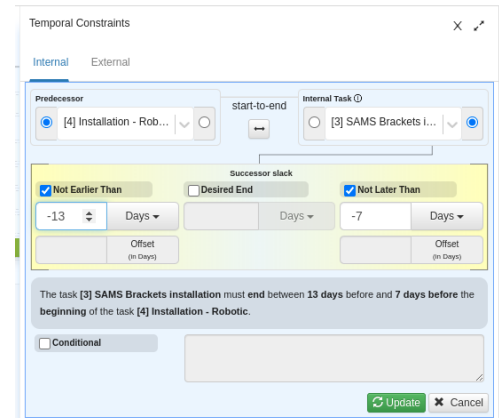


Fig. 7. Temporal Constraints configuration

3.2. Global GMT Timeline

One of the main benefits brought by the HRE-DB to the planners is the Global GMT timeline (see Fig. 8) which provide a comprehensive overview of all the operations and activities happening in a certain time frame.

The Global GMT Timeline provides five types of lanes:

- Increment

- Vehicles
- Agency Calendar
- Crew
- Planning Models (Experiments)

Each lane can display a list of scheduled blocks, and possible dependencies to other blocks.

In the Planning Model lane, the scheduled blocks are the tasks that are defined in the Experiment's Planning Model Editor (see previous section).

The Global GMT Timeline can be configured to display only certain types of information, using an advanced set of filters, for instance on the following attributes:

- Implemented Crew Members
- Implemented Vehicles
- Used racks and subsystems
- Planning Model state
- Planning Model tags

The list of active filters can then be saved as a profile and recalled at any time. This allows the different teams and domains to tailor a GMT Timeline visualization that fits their need. The timeline can then be exported as a pdf or an image, and integrated in a presentation.

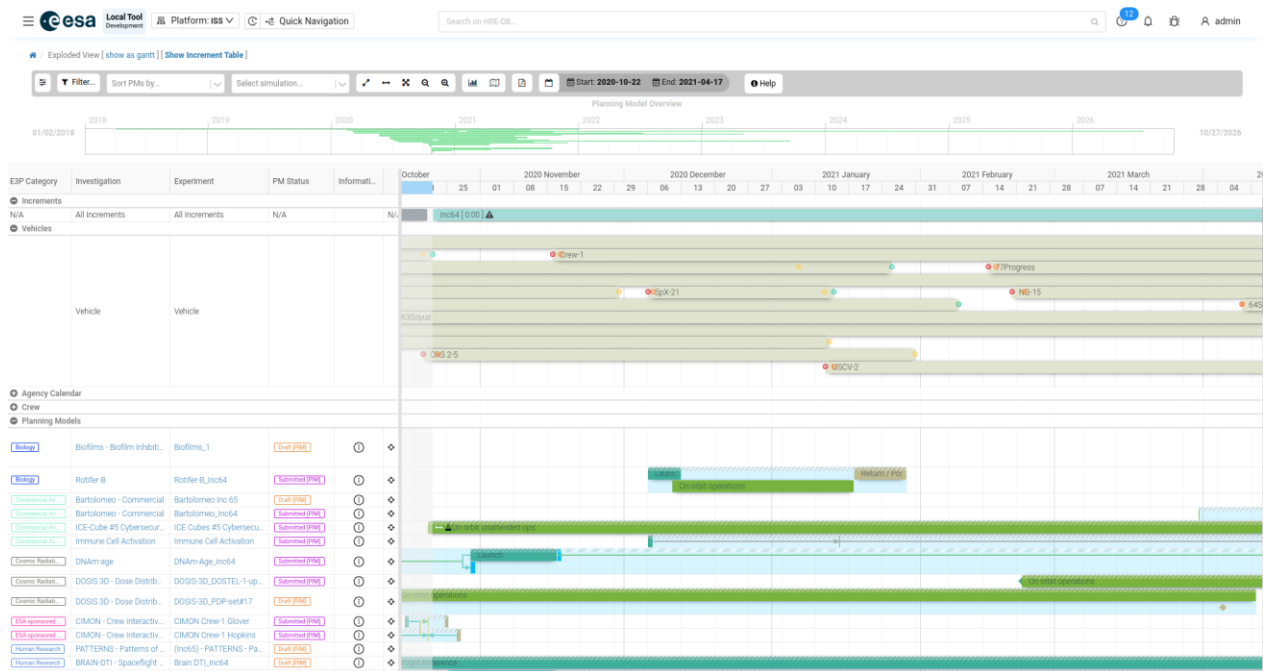


Fig. 8. Global GMT Timeline

In addition to the scheduling information, the Global GMT Timeline also provides several visual hints so that end-users can have a glimpse of a complete overview of the situation in a certain timeframe. Icons displayed on the blocks give information about the block type and configuration. Different types of hatching also provide a clue on the different phases of an experiment scheduling: pre-flight, on-orbit, and post-flight. Hovering the blocks displays a tooltip that provides detailed information about e.g. the crew member executing the task, the vehicle used for this task (for upload/download tasks), the task sponsor, etc.

3.2.1. Resource conflict panel

The Global GMT Timeline provides a Resource conflict panel (see Fig. 9) which displays the usage and the potential conflicts between shared resources, for instance, racks or sub-systems. When a conflict is detected, it is highlighted in red. One can then hover the mouse on the related blocks to visualize which tasks are creating the conflict and perform necessary corrections on the planning.

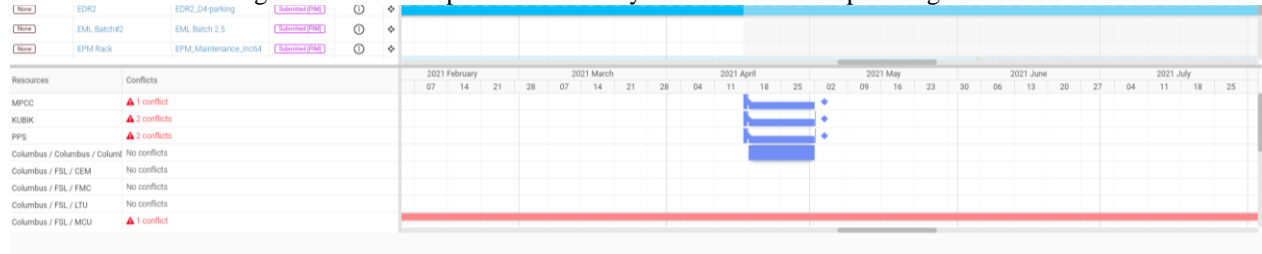


Fig. 9. Conflict panel

3.2.2. Tabular view of the Global GMT Timeline

The Global GMT Timeline can also be visualized in a tabular format (see Fig. 10). In this view, each experiment is displayed as a row.

This tabular view provides a way to get a synthetic overview of what happens in a specific window, but also to edit certain properties of the experiments that occur in that window, such as tags, documentation, and requirement tracking. The view provides also the users with the ability to edit the crew time as planned, or executed so that the reconciliation process can be facilitated.

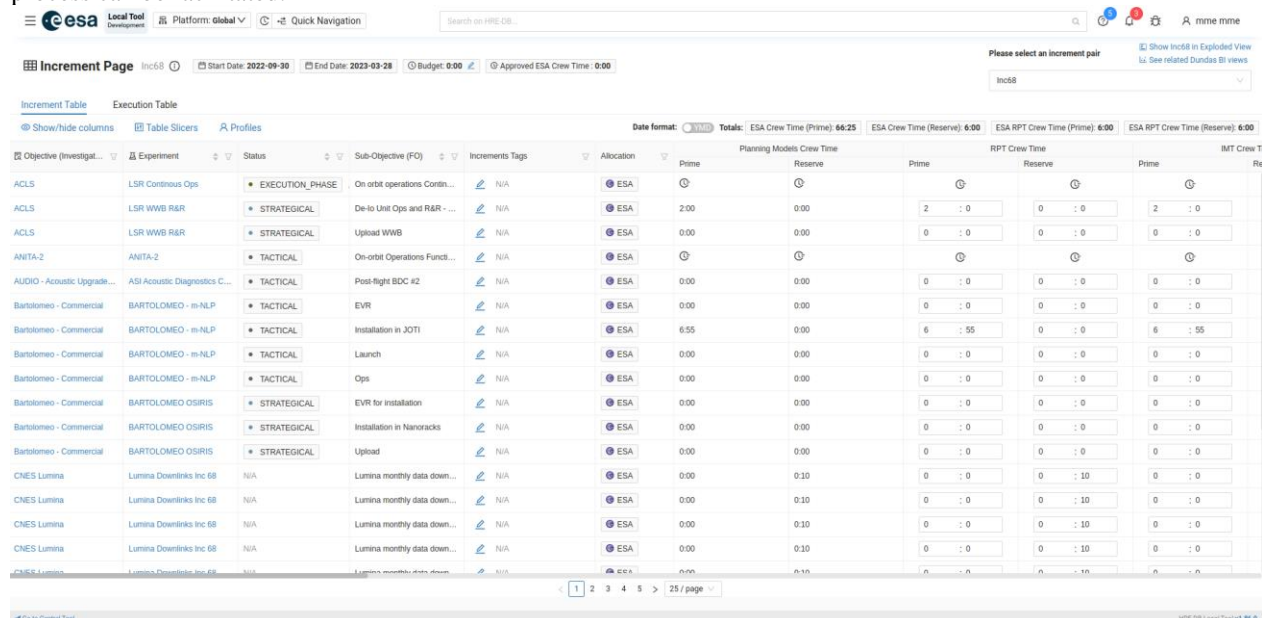


Fig. 10. Increment Table

In addition to the Increment Table, an Execution Table gather the results of the execution of the experiment tasks in the ISS or other platform. In the case of the ISS, the execution information is downloaded as Col-CC (Columbus Control Centre) package and then mapped against the planning data.

3.3. Assets and capabilities modelling

Assets and capabilities are resources that are shared among various experiments of a certain platform. As described in previous sections, the utilization of the resources for a specific experiment can be defined in the Planning Model Editor, and conflicts can be monitored in the Global GMT Timeline once the planning model has been timelined through a constraint e.g. a vehicle flight.

The assets and capabilities of a platform can vary over time. That's why there is a need for users to edit the repository of assets and capabilities so that new elements can be added, and existing ones can be modified to match the current context in the platform.

The HRE-DB provides several editors to manage the list of modules, racks, subsystems, equipment, and hardware which are on board the ISS, or any of the other platform which is selected.

The properties of these elements such as their weight, mass, positions in the platform, or part number can be set with great detail. Those attributes can then be used in reports generated from the database.

3.4. Integration Schedule

In addition to the Planning Model edition, the application also provides another type of planning called Integration Schedule (see Fig. 11). This planning reflects the necessary administrative and development steps that need to be carried out before an experiment is executed in the target platform.

Document preparation, progress meetings, and development activities can be tracked into a single gantt chart, and constraints can be set between the tasks.

At any time, the Integration Schedule can be imported or exported from/to Microsoft Project.

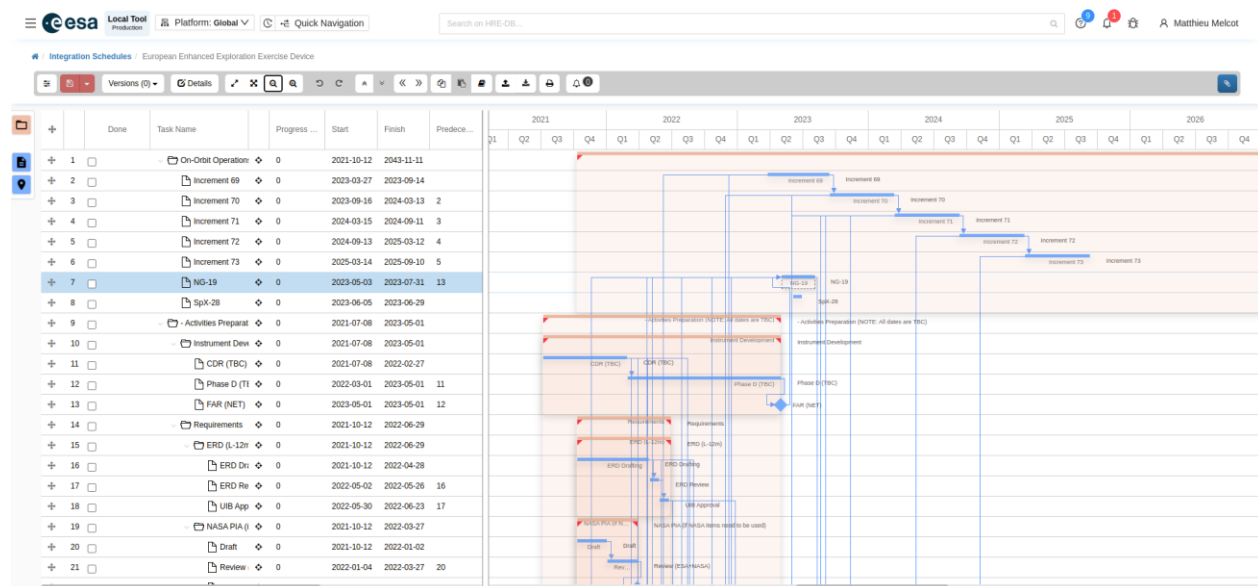


Fig. 11. Integration Schedule

4. Users collaboration

In addition to the data inconsistency issues met by ESA teams and described in the previous section, processes between the different ESA teams are not always standardized, which makes team interactions sometimes chaotic.

One of the main objectives of the HRE-DB is to emphasize end-users' collaboration and provide a consistent way of exchanging information.

4.1. A tailored interface

The application provides a tailored interface that filters the information presented in the menus and the homepage to a specific group of users.

When an end-user opens the application for the first time, he is invited to choose from which team is part (see Fig. 12).

This setting is persisted so that the application will continue to display only the necessary information to that specific user upon future visits.

The homepage displays a list of widgets that are relevant to the team setting selected by the end user. The homepage and widgets' goal is to provide a synthetic view of the data that is relevant to the logged-in user, and quick access to more detailed data.

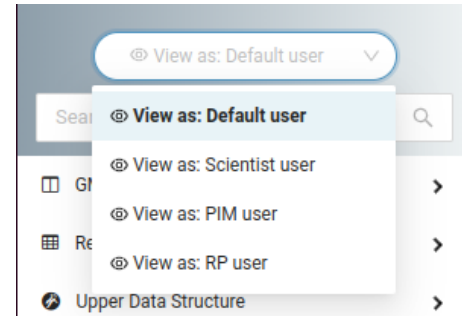


Fig. 12.

For instance Payload, Increment Manager (PIM) staff will see on their homepage (see Fig. 13) among other things the following widgets:

- A feed showing when the staff has been assigned as a PIM to new experiments.
- A list showing the list of Projects, Investigations, and Experiments on which this user is a participant
- A list of other Projects, Investigations, and Experiments that the user wants to follow

The homepage is designed to be extended or adapted to upcoming needs. New widgets can be added, providing a better overview of the data in the context of a specific team.

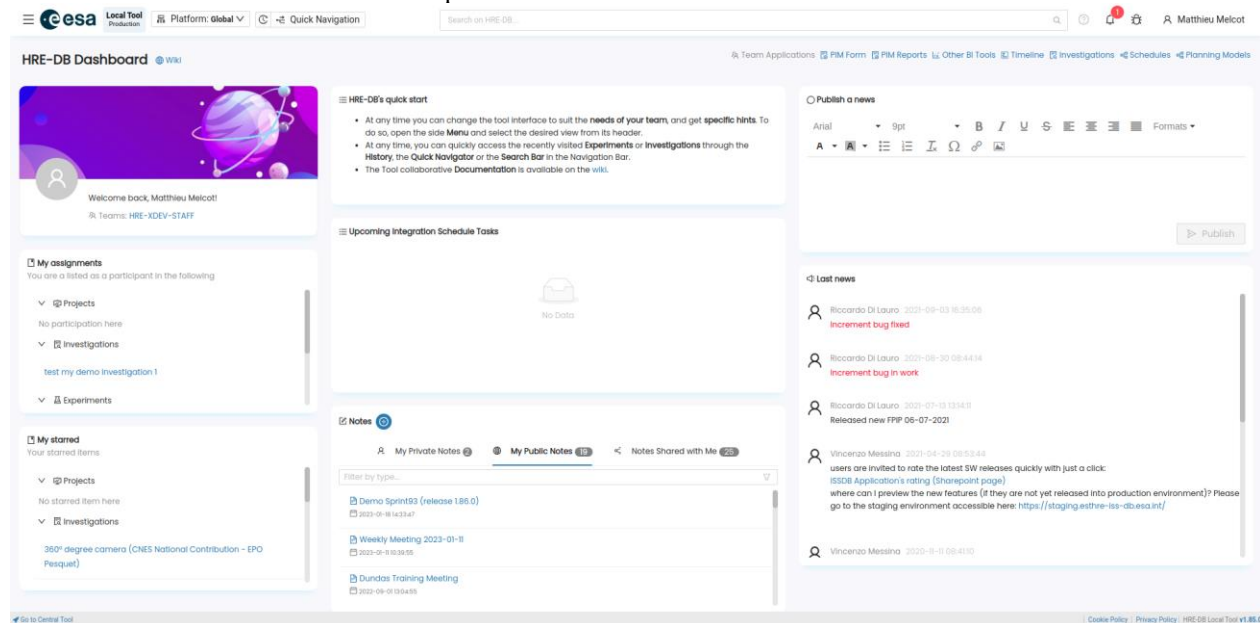


Fig. 13. HRE-DB Homepage

4.2. Smart search

One of the challenges of a database is to provide an easy way to browse the data.

The FAIR (Findability, Accessibility, Interoperability, and Reusability) data principle emphasizes the need for the data to be Findable.

The HRE-DB provides a smart search box (see Fig. 14) that allows the users to browse the database in an extensive way. The smart search feature matches the typed text with the fields of the entities in the database.

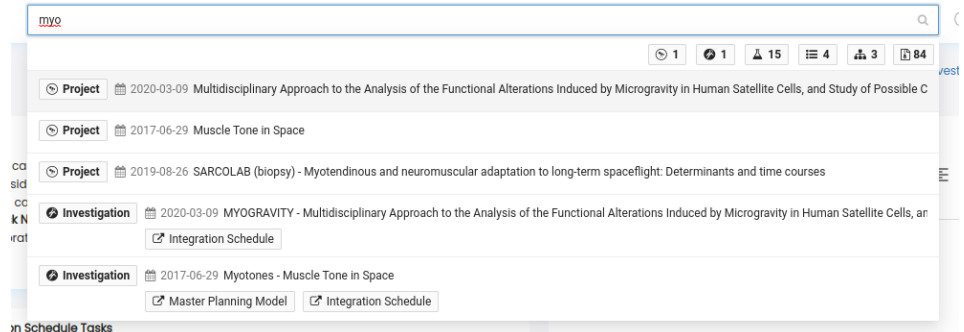


Fig. 14. Smart search box

The search box also provides a set of toggles to refine the search to specific elements of the database. Clicking on a link opens a new tab that displays the targeted resource, maintaining the current context of the user in the first tab.

4.3. Notifications

One of the side effects of the collaborative feature of the HRE-DB is that users may need to be informed that something changed in the database. To address this need, the application proposes an embedded notification system. Notifications are raised upon data changes and shown to specific roles and teams according to the needs (see Fig. 15).

For instance, the following events can among others send notifications:

- The global flight plan has been updated.
- The planning of an experiment has been impacted by the update of a vehicle flight date.
- The fields of an experiment have been updated.

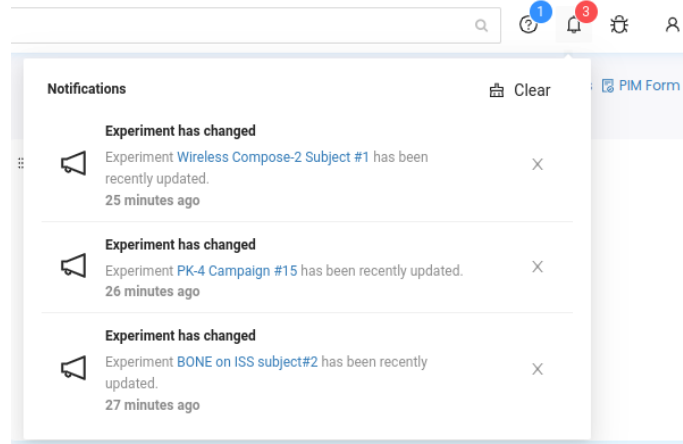


Fig. 15. Notification panel

The notifications are accessible to the users on the homepage header, and links to the related entities help to quickly visit the affected pages.

4.4. Archiving

The lifecycle of an Experiment is completed with the archiving process. At any time, an experiment can be set as 'archived', so that all its data is frozen. Archived data stay however searchable. The browsable repository of archived experiments provides a knowledge base for future planning so that planners can check out the properties of past activities with respect to upcoming ones and adjust their planning accordingly.

4.5. Document Management

Planning of missions and science relies heavily on documentation, for instance, payload engineering documentation. The HRE-DB application comes with an integrated document management system backed by MinIO COTS.

MinIO is an industry-standard object store optimized for high performance, with high scalability and availability.

A specific instance of the document manager is attached to each type of entity in the application. Hence documents can be specifically attached to e.g. Experiment, Investigation, or app-wide.

Each document can have multiple versions, and a set of related metadata attached to it.

The documents can be previewed directly in the application.

4.6. Notes system

The HRE-DB application provides an advanced notes system. Any user can write and share notes between different groups. Notes can also be attached to database elements such as experiments or investigations.

5. BI connection

The clean and organized structure of the HRE-DB database makes it easy to interface with a Business Intelligence (BI) application.

In operations, the HRE-DB application is interfaced with the Dundas BI software (see fig. 16). However, any other type of BI software, such as Tableau or Microsoft BI can be interfaced with the HRE-DB.

The BI application provides a UI for developers and end-users to develop dashboards and reports on the HRE-DB data. The dashboards and reports fetch the data in real-time from the HRE-DB database or use cron warehousing which is useful when the amount of data needed to feed the dashboards is significant and that it needs to be cached. Different types of visualization can be used to render the data.

In the BI environment, developers build a library of datacubes on top of the HRE-DB data. These datacubes transform the original data into 'data views' which can in turn be used to feed dashboards and reports.

The dashboards and reports building can be delegated to non-developers such as team staff. This activity requires no advanced programming skills and is mainly a configuration job.

Once dashboards have been built they can be combined into higher-level dashboards that aggregate multiple views, and that can be parametrized with dropdown.

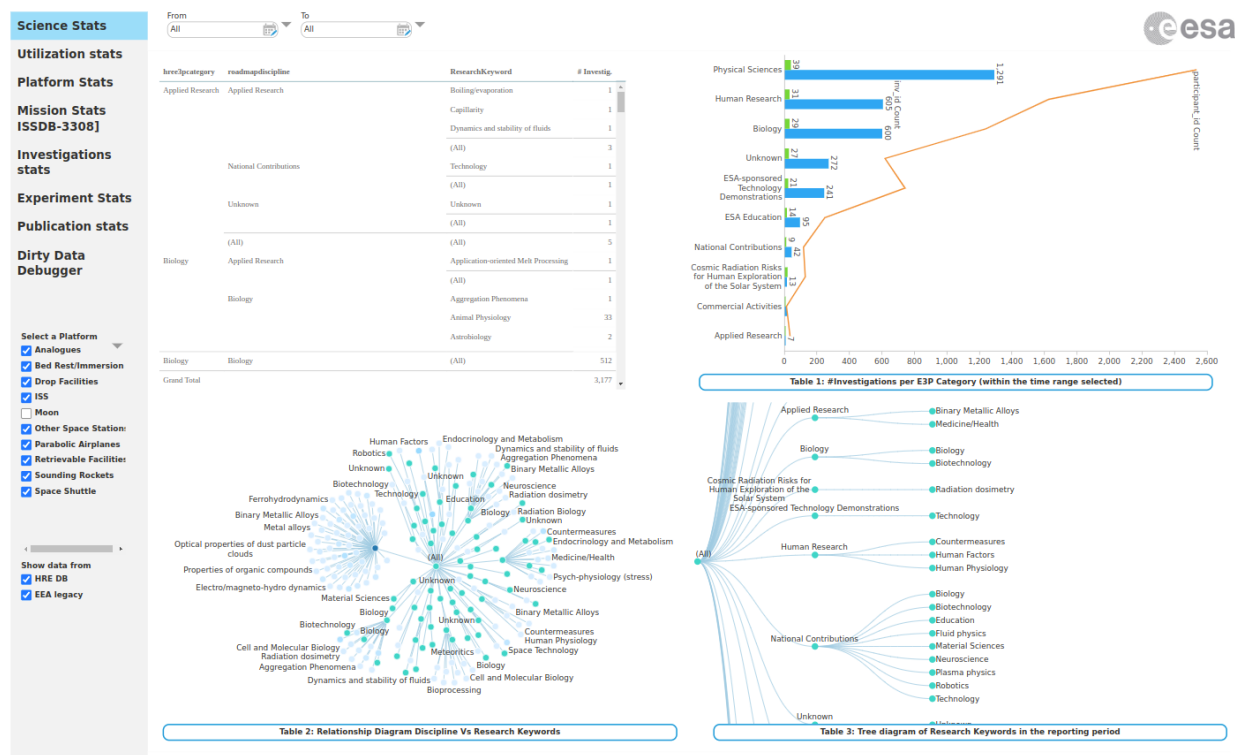


Fig. 16. HRE-DB BI dashboard

6. Results and Discussion

The HRE-DB application is currently in use at ESA, primarily by the Payload Integration team. However, it is still a work in progress and has yet to be widely adopted as the primary information hub and reference tool within the organization..

The development and implementation of the HRE-DB application have posed several organizational challenges.

One of the main challenges is determining how software can streamline internal processes when multiple practices and processes have been in place for many years. This requires close collaboration between the organization and the development team, as the organization must clarify its processes and communicate them effectively to the development team, who can then recommend the best solutions. While Agile and Scrum methodologies are useful in developing such software, it is crucial for the organization to establish a clear list of requirements and internal data flows early on in the process.

Another challenge arises from the fact that the database is frequently edited by multiple people, which raises questions about the reliability of the information. This is partially addressed with groups and permissions, and through traceability of changes. However, it is important to establish strict workflows and processes from the start to prevent incorrect data from entering the tool.

7. Conclusion and Future Work

The HRE-DB application allows fine-grain planning of activities and a global overview on a centralized GMT timeline. Furthermore, the distributed architecture benefits consortium of agencies or companies who want to share data but also keep private data in their own infrastructure.

Initially tailored for the ISS, the HRE-DB application design has evolved to become a tool to manage missions operated on any type of platform, such as Analogues, Drop Facilities and the Lunar Gateway. It is also customizable to enter the new era of commercial activities in space, in the ISS such as the ICE Cubes service [5], or for future commercial Space Stations[6]. For new space missions, the output of the HRE-DB planners will be delivered to the flight operations teams by interfacing with mission control systems such as Yamcs [7]. This will enable operators to access planned activities directly from the flight operations consoles.

Acknowledgments

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