Pinta(OnWeb) setting sail for Martian moon Phobos – Establishing the Mission Planning System for the MMX Rover IDEFIX

Rainer Nibler[a*], Alexa Schöpf[a], Armin Wiebigke[a], Maria Th. Wörle[a], Jens Hartung[a], Daniel May[b], Henrik Muders[b], Christian Krause[b], Cedric Delmas[c]

[a] *Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Center), German Space Operations Center (GSOC), Weßling, Germany*
[b] *Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Center), Microgravity User Support Center (MUSC), Cologne, Germany*
[c] *CNES (Centre National d'Etudes Spatiales), Toulouse, France*
* *Corresponding Author: rainer.nibler@dlr.de*

Abstract

IDEFIX will be the first rover landing on the Martian moon Phobos, where it will be delivered as part of the JAXA mission MMX. As the Mission Planning tool for the preplanning and detailed planning of the rover operations, the recent-generation generic planning tool PintaOnWeb was chosen. This tool has been developed and is under ongoing further development at DLR's German Space Operations Center (GSOC). Like its predecessor Pinta, PintaOnWeb and its basic components, the Reactive Planning framework and the Plains library, are generally used within GSOC for Earth-orbiting missions and the planning and scheduling of ground-based assets as the core building blocks for semi- and fully-automated applications.

For the application of PintaOnWeb within the MMX IDEFIX mission, as for any other project, the know-how of the mission experts has to be combined with the know-how of the Mission Planning specialists to best implement the planning model and configure the components. This ensures smooth, reliable, safe and convenient manual daily operations by the rover specialists. The collaborative, interactive planning will then be performed outside GSOC by personnel from two agencies, CNES and DLR/MUSC, in Toulouse and Cologne, with interfaces to JAXA.

In this paper, the challenges of the IDEFIX MPS, the solutions we found and the benefits we can provide to this mission as well as other projects that are implemented in parallel, will be addressed. It will present the overall architecture and design and will also show the implementation of certain crucial features, such as the modelling of rover activities and resources, and data transfer flows. Additionally, insight into how a slim agile development approach was established and how this helps to meet the demands of all involved parties will be provided. The paper is also going to discuss how the tool, along with the development and support approach, will bring advantages for the upcoming phases of the mission, let it be the finalization of the pre-planning, cruise phase findings, perhaps large-scale short-term rearrangements after the agreements on landing site and date, and then the weekly and daily intense day & night operations for the rover on Phobos by the teams in Cologne and Toulouse.

Keywords: MMX, PintaOnWeb, Planning System, Rover mission, Sequence of Events, Interactive Planning

Acronyms/Abbreviations

CNES	-	Centre national d'études spatiales
DLR	-	Deutsches Zentrum für Luft- und Raumfahrt
ESA	-	European Space Agency
GSOC	-	German Space Operations Center
IDEFIX	-	Name of the MMX rover
JAXA	-	Japan Aerospace Exploration Agency
MMX	-	Martian Moons eXploration
MPS	-	Mission Planning System
MUSC	-	Microgravity User Support Center
NASA	-	National Aeronautics and Space Administration
OEF	-	Orbit Event File
Pinta	-	Program for interactive Timeline Analysis
Plains	-	Planning in Scala
PTC	-	Phobos Time Coordinated
RAX	-	Raman spectrometer
SoE	-	Sequence of Events

1. Introduction

The Martian Moons eXploration (MMX) mission (see **Fig. 1**) is currently being developed by the Japan Aerospace Exploration Agency (JAXA) in collaboration with several international partners, including NASA, the French space agency CNES, the European Space Agency (ESA), and the German Aerospace Center (DLR) [1, 2]. This mission is scheduled for launch in 2026 and represents a major step forward in our understanding of Mars and its natural satellites, as well as returning samples from Phobos back to Earth.

During this mission, the IDEFIX Rover (see **Fig. 3**) [3, 4] will be delivered to Phobos' surface (see **Fig. 2**). It was built by and is going to be operated in a joint collaboration of DLR and CNES in cooperation with JAXA. The operations of the on-Phobos phase of at least 100 days currently foreseen for 2028/2029 and the cruise phase to the Martian system starting in 2026 will be jointly and alternatingly executed by operations teams in Toulouse, at CNES, and Cologne, at DLR (MUSC) [6]. While one center is performing the execution of rover activities on the flight model, the other center will plan the upcoming execution period. On this one-week basis the centers will swap their roles as prime and secondary centers so that each control center is executing the activities it planned the week before.

Fig. 1: Illustration of the MMX Spacecraft. © JAXA

During its operational phase, the MMX rover has various constraints due to the harsh environment: The communication of the rover will be relayed via the mother spacecraft to Earth, which means that there will be no direct visibility from Earth to the rover during the rover mission. The IDEFIX operations are power critical and an important constraint is the available energy. Careful resource planning is an essential benchmark. Furthermore, the rover is equipped with two specialized WheelCams, which closely observe the interaction between the rover's wheels and the loose surface material. By analyzing the acquired data, scientists can better understand how Phobos' regolith behaves under mechanical stress, providing essential insights for optimizing MMX's landing strategy. The rover is equipped with two additional cameras, known as NavCams, which capture detailed 3D images of the terrain ahead. To gather even more science, IDEFIX will use an infrared radiometer called MiniRad, which continuously monitors temperature variations over a full day-night cycle. A second instrument, a Raman spectrometer known as RAX, will conduct spectral analysis of the regolith, allowing scientists to determine its mineralogical composition [3, 2].

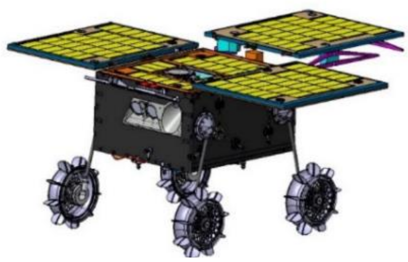

Fig. 3: Illustration of the IDEFIX Rover. © JAXA

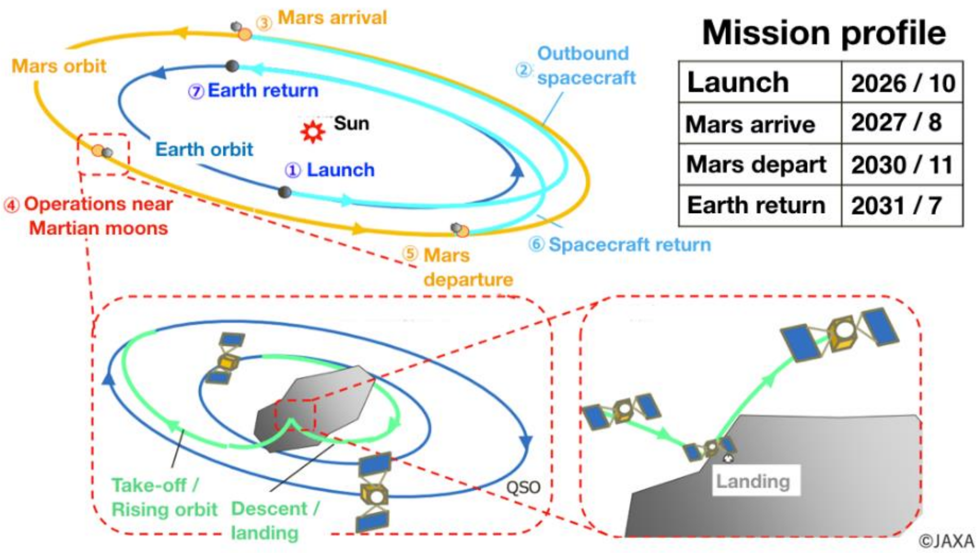

Fig. 2: MMX mission profile elaborating the launch (1), the phase of the outbound spacecraft (2), arrival on Mars (3), operations near the Martian moons (4), Martian departure (5), return of the spacecraft (6) and return to Earth (7) as well as important, preliminary dates. © JAXA

To manage and plan these crucial factors and instruments, the planning tool PintaOnWeb will provide the main Mission Planning System (MPS) for the Rover during its preparational, cruise and operational phase.

PintaOnWeb already provides a huge variety of configuration capabilities [5], such as the modelling of activities and constraints, and well-defined interfaces for project-specific extensions, like specialized import and export tasks.

However, the planning and executing of rover operations provides certain special requirements for operators and systems. Additionally, the generic PintaOnWeb is still under agile development and continuously gaining more capabilities. For instance, at the time of the implementation kick-off for the IDEFIX MPS, PintaOnWeb still lacked several commodities useful for the interactive, collaborative, but also concurrent planning needed for this type of mission and its manual planning workflows.

This paper will present the overall architecture and design of the IDEFIX MPS and will also show the implementation of certain crucial features, such as the modelling of rover activities and resources, and data transfer flows. Additionally, insight into the applied slim agile development approach will be given, which helps to meet the demands of all involved parties. The paper will also discuss how the tool, along with the development and support approach, will bring advantages for the upcoming phases of the mission, let it be the finalization of the pre-planning, cruise phase findings, perhaps large-scale short-term rearrangements after the agreements on landing site and date, and then the weekly and daily intense day & night operations for the rover on Phobos by the teams in Cologne and Toulouse.

2. MMX Mission Planning System

The MMX mission requires a robust planning system to manage its complex operations efficiently. Given the mission's ambitious goals - including interplanetary travel, rover maneuvers, surface exploration, and sample return [1] - precise coordination and adaptability are essential.

Rover operations will be managed by two control centers, each alternating between execution and planning roles. While one center oversees the execution of rover activities on the flight model, the other will prepare plans for the upcoming execution period. This rotation occurs on a weekly basis, ensuring that each center carries out the activities it previously planned [6].

PintaOnWeb will serve as the primary planning tool for IDEFIX operations and is therefore one of the core components of the MMX mission (see **Fig. 4**).

Both control centers will use the same instance of PintaOnWeb simultaneously, ensuring they work with an identical activity timeline. Any timeline adjustments made by the prime center during real-time rover operations will be immediately visible to the secondary center, enabling seamless coordination for the following week's planning.

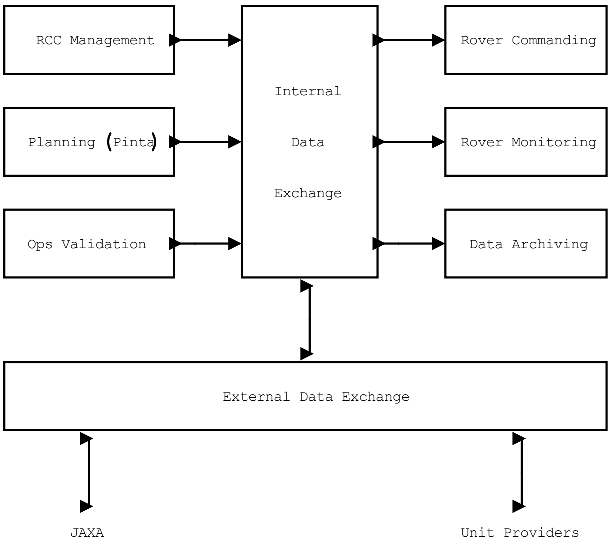

Fig. 4: The main components of the MMX mission, with PintaOnWeb as the mission planning system.

2.1. *PintaOnWeb*

PintaOnWeb [5] is a web-based interactive planning and visualization tool designed for seamless accessibility. This is made possible through a modern, service-oriented web application architecture, eliminating the need for installation or manual updates. Unlike its predecessor, Pinta – a locally installed Windows application – PintaOnWeb provides a more flexible and user-friendly experience by running entirely within a web browser. The predecessor Pinta [7], with the built-in SoE-Editor capabilities [8], has a rich history spanning nearly two decades, having supported various spacecraft missions operated by the German Space Operations Center (GSOC) [9]**.** Pinta is an acronym for **"**Program for INteractive Timeline Analysis**"**, reflecting its core function in mission planning and timeline management and lending its name from "La Pinta**"**, the fastest of the three ships used by Christopher Columbus on his first voyage across the Atlantic. The successor, PintaOnWeb, represents the next logical evolutionary step for the mission planning system of the future.

Since computationally intensive calculations are performed on the server, PintaOnWeb can be accessed from any device without impacting user performance. This cloud-based approach ensures a seamless experience, allowing users to focus on planning tasks without the need for powerful local hardware. PintaOnWeb enables multiple users to work within the same planning system simultaneously, fostering real-time collaboration. Users can adjust the planning state in real time, such as rescheduling activities and updating activity parameters, and these changes are visible nearly instantly to all other users of the system. Unlike locally stored states that require manual export and import of files for sharing, this system ensures that all participants have immediate access to the most up-to-date planning data. This streamlined workflow allows for faster feedback and more efficient coordination among team members and across teams.

To maintain security and control, PintaOnWeb incorporates user authentication and mission-specific access rights. Depending on their role, users can be granted different levels of access, such as read-only permissions or full editing capabilities.

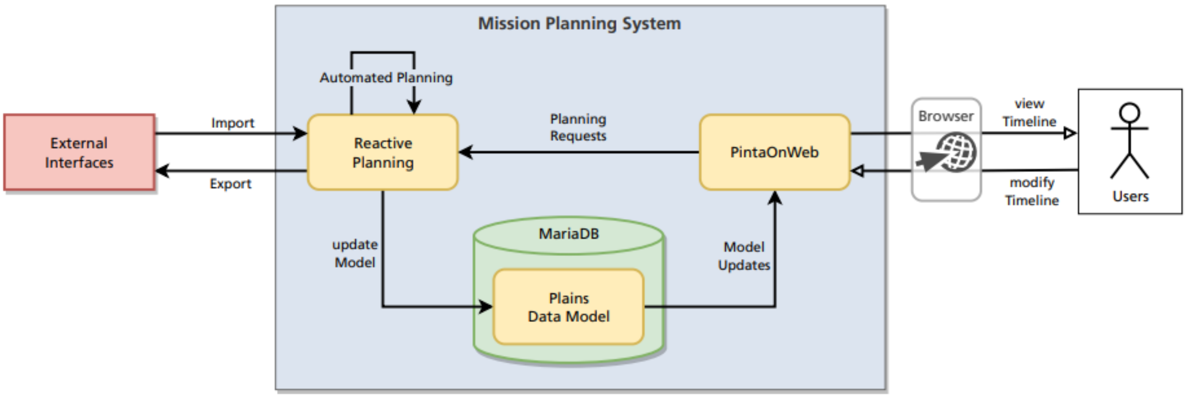

Fig. 5: A mission planning system based on PintaOnWeb, Reactive Planning and Plains

PintaOnWeb is not a standalone planning system but rather an interface built on top of a Reactive Planning system and a Plains planning model [10, 11]. The Plains model serves as the foundation, storing all planning data and offering essential functionalities such as conflict detection. Meanwhile, the Reactive Planning system manages the automated import and export of planning data and executes automated planning tasks and algorithms (see **Fig. 5**).

Any modifications made by users through the PintaOnWeb interface are processed within the Reactive Planning system, ensuring that all changes are integrated seamlessly and maintaining a consistent planning state at all times. The Plains model allows the definition of various constraints for activities and resources, which are then checked for every change of the planning state. This way, users of PintaOnWeb can immediately see if any of their changes violate any mission constraints, and can plan accordingly.

PintaOnWeb also features a batch mode, in which a user can make multiple changes and inspect their effects in private, without yet sending them to the Reactive Planning system. Only when the user then explicitly submits these changes, they are integrated into the live planning system and distributed to all other users.

2.2. MMX-specific Extensions

A core principle of PintaOnWeb is maximizing the reusability of generic functionality to minimize the effort required to establish a new planning system for a specific mission [5]. At the same time, the architecture allows for the integration of custom components to meet mission-specific requirements. The overarching goal is to implement the majority of features in a generic and reusable manner within the core PintaOnWeb software, ensuring that mission-specific extensions are only needed for unique use cases. The following sub-chapter will describe in more detail the MMX-specific configurations and extensions that were necessary to provide a mission planning system for MMX.

2.3. Configuration of the Planning Model

In a Plains planning model, activities can have one or more parent relationships with other activities, forming a hierarchical, tree-like structure. Resources, on the other hand, do not have any parent-child relations. In PintaOnWeb, this core structure of the planning model is presented as a model tree (see **Fig. 6**) for intuitive inspection, similar to a file system's directory structure. For the IDEFIX MPS, all relevant activities of the rover and spacecraft have to be inserted into the planning model, and their relations defined in such a way that the resulting model tree is logically structured and easy to understand. The IDEFIX MPS is required to plan not only the operational on-Phobos phase of the rover itself, but also the cruise phase. To battle this, the model tree (see **Fig. 6**) was divided into four parent activities: *Import*, *MMX*, *RolBox* and *Rover*. *Import*

Fig. 6: The IDEFIX Rover Planning Model Tree

includes activities imported from files, e.g. an OEF file, which are needed to plan according to sun phases or to plan possible down link opportunities. *MMX*, *RolBox* and *Rover* include their specific children activities: E.g. a ground link between the MMX spacecraft and a ground station is only depended on the spacecraft and not directly on the rover, therefore it is a children activity of *MMX*. *RolBox* children activities are needed to transfer data from the rover to the MMX spacecraft. The *Rover* activity then again consists of several children activities, including activities only scheduled during the cruise phase or activities only scheduled during its operational phase.

The definition of activities provides maximal flexibility: With the possibility to define parameters, dependencies and algorithms, basically all activities can be implemented according to the mission's requirements. For IDEFIX, high-level activities were defined that consist of several low-level activities in a specific order. The user now only needs to schedule the high-level activity of interest (e.g. *LocoForwardDriving*) and all corresponding low-level activities will be scheduled automatically. Some activities may also be depending on parameters such as temperature values for which the power consumption then differs (e.g. *MiniRadSHWarmUp*). By defining parameters in combination with custom algorithms, the user now only needs to enter pre-defined temperature values and the power consumption and its resources get updated accordingly.

2.4. Configuration of the Workspace

A key feature of PintaOnWeb is its intuitive graphical representation (see **Fig. 7**) of planning information, making complex data easily understandable [5]. The platform supports timeline plots, which visualize scheduled activities, and resource plots, which track resource availability and usage over time.

To enhance usability, PintaOnWeb allows the definition of a list of customizable plot configurations as a workspace. A default workspace with all important mission information is configured, but users are also free to configure the plot to create their own workspaces. These workspaces can be shared among multiple users, enabling different perspectives on the planning system based on specific use cases. This flexibility ensures that teams can tailor their views to focus on the most relevant aspects of mission planning.

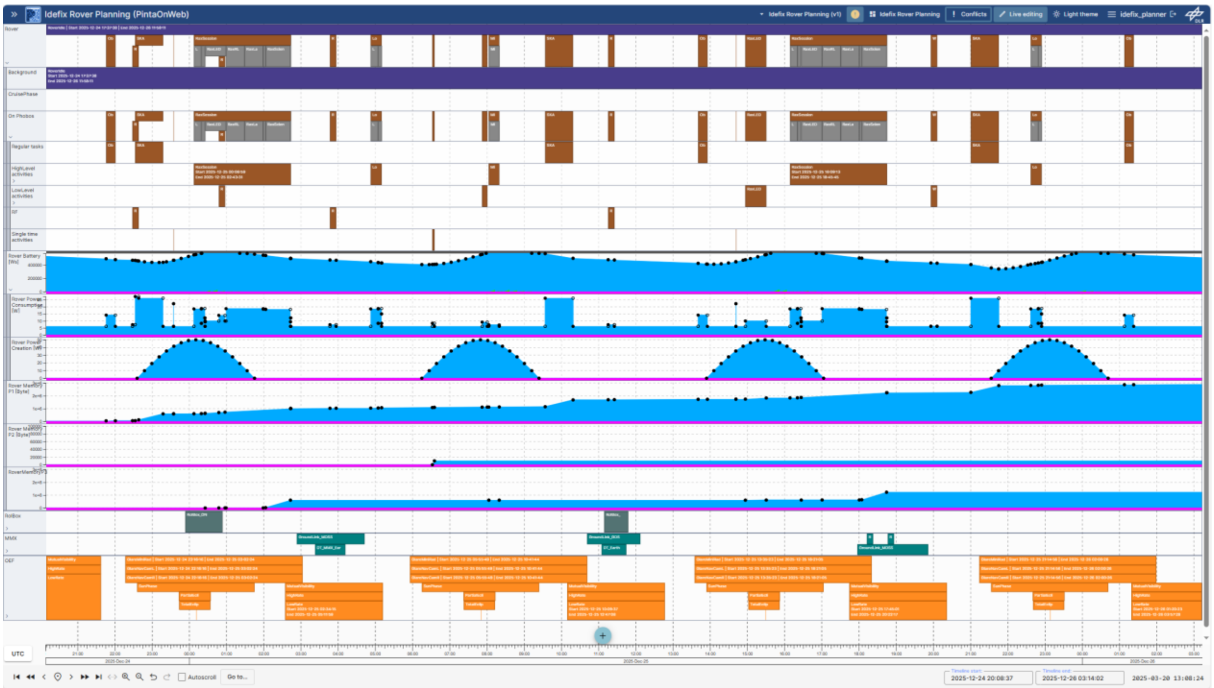

Fig. 7: The PintaOnWeb workspace for the IDEFIX Rover Planning.

The by default provided workspace for the IDEFIX Rover (see **Fig. 7**) is currently made up of four main plots (*Rover*, *RolBox*, *MMX* and *OEF*), similar to the structure of the model tree, which again consist of a variety of subplots that contain and display all planned (or in case of an OEF, imported) timeline entries. Additionally, *Rover*, *RolBox* and *MMX* also include subplots for the mission critical resources: Rover battery, and all their respective memories. As soon as activities are scheduled or as soon as an OEF is imported, the corresponding timeline entries appear in the plot and give a structured and clean overview. In critical phases, for example if the battery power is lower than a defined threshold, affected activities will appear in red and a conflict is created. This way, the operators see exactly where and when problems are expected and can solve them quickly. Specific activities can also be dependent on other activities (e.g. a data transfer from *Rover* to *RolBox* requires an active *RolBox*): If one or more of these dependencies is violated, a conflict is shown.

2.5. Phobos Time

When the rover is on Phobos, time is defined based on Phobos' rotation. While UTC or other Earth-based time scales remain relevant for mission operations, the primary time scale for the rover mission planning is determined by the Sun’s motion in Phobos’ sky. To accommodate this, a specialized time scale, similar to Local Mean Solar Time (LMST) used for Mars rovers, is required. This system is called Phobos Time Coordinated (PTC).

Phobos is tidally locked to Mars, meaning it always presents the same face to the planet, much like the Earth’s Moon does with Earth. As a result, its rotation period matches its orbital period, both approximately 0.319 days. However, due to the ellipticity of Phobos' orbit, its rotation is not perfectly uniform in speed and direction, exhibiting variations known as “librations.” Additionally, since Phobos is gradually spiralling inward towards Mars, its spin rate slowly increases over time.

The Phobos Time Coordinated (PTC) is defined as a mean time scale, disregarding all oscillatory variations in the relevant variables. It assumes a constant rotation of Phobos, a uniform motion of Mars around the Sun, and no orbital movement of Phobos around Mars. The reference point for Phobos Day 0 at 00:00:00 PTC is defined as E0, while the standard duration of a solar day on Phobos is denoted as Tp. Given an epoch E, the PTC is calculated as:

$$\boldsymbol{PTC = (E - E_0) \times \frac{86400}{T_p}}$$

PTC represents the mean local solar time at Phobos’ theoretical prime meridian. To determine the mean local solar time at other locations on Phobos, a system similar to Earth's time zones in UTC is used, expressed as “PTC + X.” For a landing site with a geodetic longitude λ (ranging from 0° to 360° eastward), the time zone offset is defined as:

$$X = \lambda * \frac{24}{360}$$

In PintaOnWeb, users can choose from several configured time scales from a dropdown menu within the time axis (see **Fig. 8**), which are then applied to the time axis visualization as well as all visible dialogs in the whole timeline view. For the MMX mission, available time scales include UTC and TAI, which are important for commanding, preparation, and coordinated mission planning, as well as PTC, which is adjusted to the rover’s longitude.

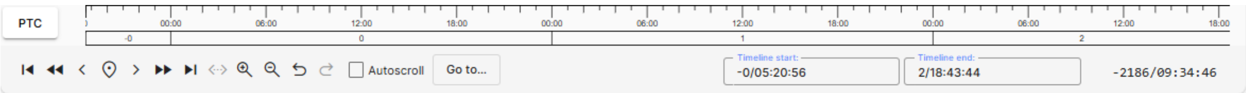

Fig. 8: Time axis of PintaOnWeb displaying the PTC

2.6. Power Modelling of the Rover

Managing battery power is critical to the mission. The battery must always maintain enough charge to ensure the rover’s survival while also enabling efficient mission planning to maximize scientific output. Therefore, detailed energy consumption monitoring is essential.

To estimate available power throughout the mission, the power consumption of each activity is predefined. Regular updates, incorporating housekeeping data on activity energy use and the solar panels' charging curve, help maintain an accurate assessment of the remaining power at all times.

During a sun phase, the rover's power generation by the solar panels $\boldsymbol{P(t)}$ for $\boldsymbol{0 \le t \le t_{max}}$ is approximated by a sinusoidal function, where $\boldsymbol{p_{max}}$ represents the maximum power output at Phobos noon, and $\boldsymbol{t_{max}}$ denotes the duration of the sun phase:

$$\boldsymbol{P(t) = p_{max} * \sin}(\pi * \frac{t}{\boldsymbol{t_{max}}})$$

The rover’s battery fill level $\boldsymbol{E(t)}$ is then given by integrating $\boldsymbol{P(t)}$ over the time parameter t:

$$\boldsymbol{E(t) = p_{max}} * \left(\boldsymbol{1 - \cos}\left(\pi * \frac{t}{\boldsymbol{t_{max}}}\right)\right) * \frac{\boldsymbol{t_{max}}}{\pi}$$

Manually managing solar array power generation, activity power consumption, and the limited battery capacity can be quite complex. However, we have defined all power characteristics inside our Plains model, which then calculates the power state at any given time and can integrate changes from rescheduled activities nearly instantly. Whenever the user modifies the timeline in PintaOnWeb, the system immediately updates and provides real-time feedback on any energy violations (see **Fig. 9**).

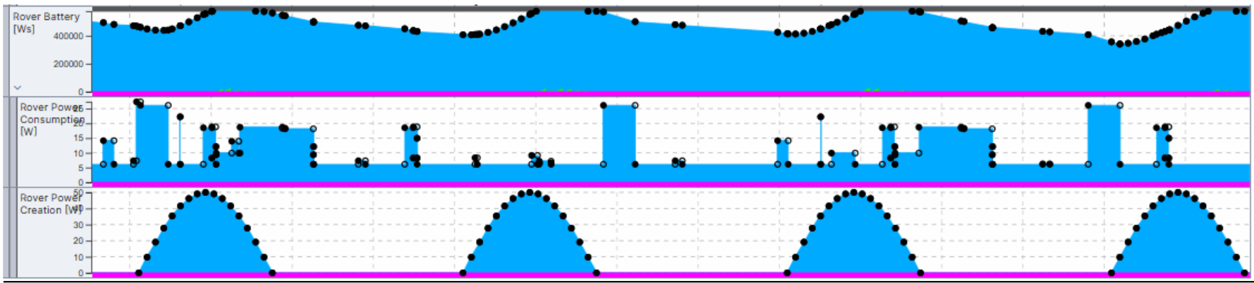

Fig. 9: Resource plots within PintaOnWeb displaying the Rover Battery [Ws], the Rover Power Consumption [W] and the Rover Power Creation [W]

2.7. Data Modelling from the Rover back to Earth

Most Earth observation missions (e.g. EnMAP [12]) have one partition/memory that needs to be downlinked during a ground station contact. For the MMX mission and the IDEFIX rover, up to four partitions need to be taken into consideration, as well as different transfer rates and dependencies:

The rover itself has three memories *P1*, *P2* and *P3* (see **Fig. 10 a)**, **b)**), which are filled with data produced by the rover. Additionally, the rover produces real-time housekeeping (HK) data for which there is no specific memory reserved. Therefore, this data is only transferred to the RolBox when there is an active link between rover and RolBox. The RolBox has four memories *P0*, *P1*, *P2* and *P3* (see **Fig. 10 c)**, **d)**) which are filled with data from their respective rover counterparts.

RolBox memory *P0* is filled with the real-time housekeeping data produced by the rover. The transfer rate for *P1* data is calculated by subtracting the real-time HK transmission rate from the overall available data rate. Data is transferred from rover memory *P1* to RolBox memory P1 until rover memory *P1* is empty.

The transfer rate for *P2* data is calculated by again taking the overall available data rate and subtracting the real-time HK rate, as well as the data production rate with which new data for rover memory *P1* may be produced. This is done, so that rover memory *P1* stays empty, even during the transmission of *P2* data.

The transfer rate for *P3* data is calculated by the same principle. However, also the data production rate with which new data for rover memory *P2* is produced needs to be subtracted.

If there is still transfer time available, all rover partitions will be continuously transferred, so that they stay empty.

With the same principles, data from all four RolBox memories is transferred to one MMX memory. The data transfer rate is calculated similarly for all four partitions, however, for *P1*, *P2* and *P3* the data production rate for RolBox memory *P0* needs to be subtracted additionally, since the RolBox has a distinct memory for *P0* (see **Fig. 10 c)**, **d)**).

Finally, data from the MMX memory is transferred to Earth (see **Fig. 10 e)**, **f)**) with a specific data rate until the MMX memory is empty.

To initiate this data transfer, certain activities need to be scheduled and their dependencies need to be considered: For data transfer from rover to RolBox, the activity “RF_TX_Rover” needs to be scheduled, which needs a planned “RolBox_On” activity. To initiate the data transfer from RolBox to MMX, “RolBox_On” needs to be scheduled. For the final transfer of data from MMX to Earth, “DT_MMX_Earth” needs to be planned as well as an active ground link to a ground station is required.

With the developed IDEFIX MPS, this model and its related dependencies are covered by an integrated, custom algorithm and the rover operators will only need to schedule the data transfer activities for rover, RolBox and MMX, and data will be transferred accordingly between all affected resources. In case of not satisfied dependencies, conflicts will be displayed and can be resolved accordingly.

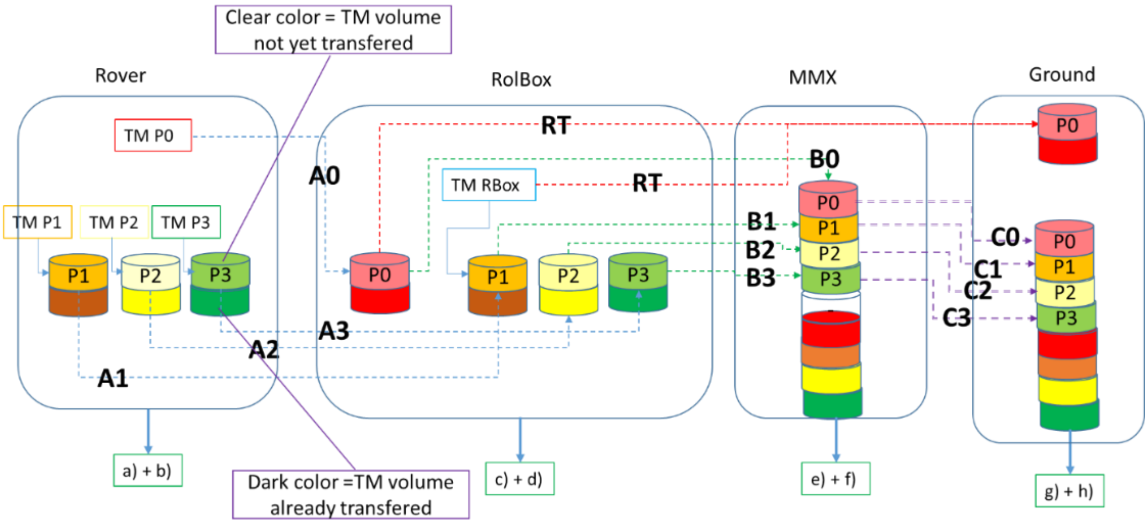

Fig. 10: Overview of the principles for the modelling of the data transfer from rover to Earth. a) and b) visualize the rover partitions, c) and d) the RolBox partitions, e) and f) the one MMX memory and g) and h) visualize how the data is collected on Earth. Image credits: CNES

2.8. Importer and Exporter

The underlying Reactive Planning Framework provides a generic data import mechanism through file ingestion, requiring only configuration rather than extensive custom development [11]. Additionally, a message-based interface supports seamless integration within service-oriented architectures, enabling both data collection from external services and on-demand export of planning information.

The Rover MPS requires the possibility to import OEF files and JAXA SoEs. The custom algorithms behind the importers extract the data from the files and create timeline entries (see last plot in **Fig. 7** for an example of imported OEF events).

Additionally, the Framework already contains a generic data export mechanism, that only requires configuration and mission specific adaptions. For the IDEFIX Rover, the export of a SoE as a *.csv* file is required.

One key advantage of this approach is its high reusability—importers as well as exporters can be efficiently reused across multiple missions with only minor modifications, significantly reducing development effort and enhancing interoperability between different mission planning systems.

3. Design and Development Approach

As already stated, an agile design and development approach was chosen for the MMX Rover MPS project. Starting with the capabilities of the generic tool suite of GSOC with PintaOnWeb, Reactive Planning and Plains on the one hand, and the knowledge of the to be modelled activities, resources, and interfaces, and of what is generally of importance to best support rover operations workflows at the two control centers at MUSC and CNES on the other hand, an iterative process was set up:

The rover experts, that also will make operational use of the planning tool later on, have compiled a “living” document with a detailed description of the planning model needed from their perspective, e.g. with details on variable and non-variable parameters of rover activities, and on how the variable ones are to be calculated, on the resource behavior during certain activities and conditions, on how the Phobos time is calculated, etc. While implementing this content in the code configuration of PintaOnWeb/Plains, the mission planning experts questioned these details to get a better understanding while giving feedback on the nomenclature, giving advice on how some things could best or better be modelled to ensure having the correct effect of automated constraint evaluation, to ensure visibility of conflicts, to allow for simple interactions during the planning process, etc. First versions of the “look-and-feel” of the tool and planning model implementation were discussed together, operational use cases were explained by one party, potential PintaOnWeb workflows or modelling options by the other, and thus are getting solved in collaboration while, alongside, the written documentation is constantly “improved”, too. PintaOnWeb itself, still under further development, got direct input on wishes, explanation needs, and application preferences of an additional, almost-external user group. Furthermore, for instance, the access-right configuration and a remote deployment process at

MUSC were already established, while details on the interface items' content were and are still in clarification by us with MUSC with the international partners of the MMX mission. Many more examples can be named. This process still continues, while there is now a first version of the planning tool available to the users, not expecting that it already fulfils all final requirements and still requiring many details to be implemented, but ready to allow the usage in the current preparation phases first pre-planning activities, to be black-box-tested and once again checked against the specification by them, and, which is most important, for the later operators to get a feeling about it, to train, to learn along with using it and, to give instant feedback to the developers on potential improvements.

The same will apply as soon as the overall project implementation has enough proceeded that the CNES operations team and rover experts can also start to get involved in using the tool. Equally to the DLR MUSC operations team and rover experts, they will have new questions and concerns and improvement ideas, which probably will lead to further refinements. Additionally, the multi-user, multi-national interactive, (pre-)operational use of the MMX rover MPS, and thus PintaOnWeb, will give valuable input for the further development of the user interface and its backend functionality during the next year(s), until the operational phases of IDEFIX.

Furthermore, the support of the GSOC development team will not end with the delivery of the final version of the tool suite to be used for the final trainings and then the first operational days, but will also be available during the operational phase in the form of a User Help Desk and 3rd level support. From "regular" satellite missions operated "in-house" at GSOC, we are used to quickly provide advice and explanations on our Mission Planning software components usage, re-configuration possibilities, etc., collaborating in the discussion of workarounds, up to implementing modifications, e.g. of the algorithms on short notice. This same support will be given to the IDEFIX operations teams, if needed for some reason, e.g. due to unexpected behavior of the rover or local conditions differing from the assumptions made beforehand.

4. Conclusions and Outlook

On the abstract level, the modelling of activities, resources, variables, constraints, and interactive planning of timelines for rover operations is very similar to setting up a planning system for a "regular" Earth orbiting satellite mission and its payloads. Thanks to the very abstract approach of the generic GSOC tool suite for defining a mission planning model, it was a logic decision to rely on that tool suite as a baseline and therefore benefiting from all the functionality already covered therein.

As it was outlined by the paper at hand, however, there were and are some differences to consider in this kind of mission, with non-standardized interfaces, prioritized data downlink mechanisms, the relatively small operations window regarding access times. A particular challenge is the very limited overall operations time windows in which the maximum output of this special mission has to be achieved by all contributors, in combination with the multi-national mission setup. Thus, the provision of PintaOnWeb is accompanied by the provision of the Mission Planning developers' expertise for developing mission-specific configuration and extensions. To achieve these without wasting too much time in document iterations in a more classical approach, a light-weight agile approach is followed, with the goal of reducing the risk of misunderstandings between the planning experts and the mission experts, that would harm and/or overcomplicate the planning operations.

Even though still a list of details is to be implemented, already the development phase until now and the first roll-outs prove that the MMX rover MPS as well as the chosen process fulfill the expectations. As more user experience will be gathered in the first training sessions of the tool with the rover experts, further wishes and adaptations can be integrated into the system.

Our Mission Planning development team definitely is proud to let Pinta, resp. its successor version PintaOnWeb, now even sail outside the Earth's gravitational field, and contribute to a Martian moon rover MPS. At the same time, this mission also brought and probably still will bring innovations, robustness and extended configuration capabilities to our generic tool suite for the more Earth-bound missions. This includes multi-user scenarios and further work on improving the user learning curves for the frontend user interfaces, especially for application by non-MPS-expert, and non-GSOC users. Other, partly interactive, Mission Planning systems that are currently under development in our department (e.g. those for SeRANIS [13], CAPTn-1, COMPASSO, CubeISL, Grace-C, and H2Sat), will directly or indirectly benefit from the enhancements that have already been implemented in the generic components. Vice versa, the IDEFIX MPS will equally benefit from the further evolution of PintaOnWeb.

Coming back to the MMX rover mission in general, we hope that the work presented in the paper at hand laid the ground for a successful further progress in setting up the IDEFIX operations environment, and successful finalization in the next years as intended. Our mission planning system, among so many other building blocks of the overall mission, should facilitate a successful operational lifetime of IDEFIX in the cruise and on-Phobos phases, and delighted operators, both in Toulouse and Cologne.

References

[1] Martian Moons eXploration – Mission Flow: https://www.mmx.jaxa.jp/en/mission/

[2] Kuramoto, K. (2021) *Overview and Science of MMX*. In: 15th Europlanet Science Congress 2021, held virtually, 13-24 September 2021. Online at https://www.epsc2021.eu/, id. EPSC2021-878

[3] Ulamec, S., Michel, P., Grott, M., Böttger, U., Hübers, H.-W., Murdoch, N., Vernazza, P., Özgür, K., Knollenberg, J., Willner, K., Grebenstein, M., Mary, S., Chazalnoel, P., Biele, J., Krause, C., Ho, T.-M., Lange, C., Grundmann, J. T., Sasaki, K., Maibaum, M., Küchemann, O., Reill, J., Chalon, M., Barthelmes, S., Lichtenheldt, R., Krenn, R., Smisek, M., Bertrand, J., Moussi, A., Delmas, C., Tardivel, S., Arrat, D., IJpelaan, F., Melac, L., Lorda, L., Remetean, E., Lange, M., Mierheim, O., Reershemius, S., Usui, T., Matsuoko, M., Nakamura, T., Wada, K., Miyamoto, H., Kuramoto, K., LeMaitre, J., Mas, G., Delpech, M., Celine, L., Rafflegeau, A., Boirad, H., Schmisser, R., Virmontois, C., Cenac-Morthe, C., Besson, A., Rull, F. (2019) *A rover for the JAXA MMX Mission to Phobos.* In: 70th International Astronautical Congress, IAC 2019, IAC-19. International Astronautical Federation. IAC 2019, 2019-10-19 - 2019-10-25, Washington D. C. USA.

[4] Delmas, C., Krause, C., Arrat, D., Baroukh, J., Biele, J., Boutet, M., Brunner, C., Buse, F., Deutschmann, B., Doumas, N., Dupont, C., Endres, S., Fayard, S., Granena, D., Grebenstein M., Gregoire, M., Größel, R., Grott, M., IJpelaan, F., Holderried, R., Jansen, S., Kayal, K., Lagabarre, S., Larque, T., May, D., Michel, P., Muders, H., Murdoch, N., Ottavani, M., Rousseau, F., Smisek, M., Schröder, S., Tardivel, S., Ulamec, S., de Vera, J.-P., Vernazza, P., Wasner, P., Wörle, M.T., Yoshikawa, K. (2025) *MMX-Rover: A small Rover for big firsts.* In: 18th International Conference on Space Operations. SpaceOps 2025 - 18th International Conference on Space Operations, 2025-05-26 - 2025-05-30, Montréal, Canada.

[5] Wiebigke, A., Krenss, J., Hartung, J., Wiesner, S., Nibler, R., Fürbacher, A. (2023) *PintaOnWeb - The Front End of GSOC's Next Generation Mission Planning Systems.* 17th International Conference on Space Operations (SpaceOps 2023), 2023-03-06 - 2023-03-10, Dubai, UAE.

[6] Krause, C., Delmas, C., Arrat, D., Baroukh, J. Biele, J., Boutet, M., Brunner, C., Buse, F., Deutschmann, B., Doumas, N., Dupont, C., Endres, S., Fayard, S., Granena, S., Grebenstein, M., Gregoire, M., Größel, R., Grott, M., IJpelaan, F., Holderried, R., Jansen, S., Kayal, K., Lagabarre, S., Larque, T., Mary, S., May, D., Michel, P., Muders, H., Murdoch, N., Ottavani, M., Rousseau, F., Smisek, M., Schröder, S., Tardivel, S., Thiesse, H., Ulamec, S., de Vera, J.-P., Vernazza, P., Wasner, P., Wörle, M.T., Yoshikawa, K.. *MMX Rover Operations – Concept and Current Planning.* In: 18th International Conference on Space Operations. SpaceOps 2025 - 18th International Conference on Space Operations, 2025-05-26 - 2025-05-30, Montréal, Canada.

[7] Nibler, R., Hartung, J.H., Krenss, J., Fürbacher, A., Mrowka, F., Brogl, S. (2022) *PINTA—One Tool to Plan Them All.* In: "Space Operations: Beyond Boundaries to Human Endeavours", Springer Aerospace Technology (SAT). Seiten 345-379. doi: 10.1007/978-3-030-94628-9_16. ISBN 978-3-030-94627-2. ISSN 1869-1730.

[8] Hartung, J., Nibler, R., Peat, C., Spörl, A., Wörle, M.T., Lenzen, C. (2016) *GSOC SoE-Editor 2.0 - A Generic Sequence of Events Tool.* In: 14th International Conference on Space Operations. SpaceOps 2016 - 14th International Conference on Space Operations, 2016-05-16 - 2016-05-20, Daejeon, Republic of Korea. doi: 10.2514/6.2016-2568.

[9] Portfolio Mission Planning Services: https://www.dlr.de/en/rb/research-operation/portfolio/dlr_rb_portfolio_missionplanningservices.pdf

[10] Lenzen, C., Wörle, M. T., Prüfer, S., Wickler, M., Fürbacher, A. (2023) *GSOCs Planning Library: History, Generic Features and Lessons Learnt*. In: Proceedings of the 13th International Workshop on Planning and Scheduling for Space (IWPSS), Seiten 54-62. International Workshop on Planning & Scheduling for Space (IWPSS 2023), 2023-07-07 - 2023-07-08, Prague, Czech Republic.

[11] Wörle, M.T., Lenzen, C., Göttfert, T., Spörl, A., Grishechkin, B., Mrowka, F., Wickler, M. (2014) *The Incremental Planning System – GSOC's Next Generation Mission Planning Framework.* In: "Space Operations: Innovations, Inventions, and Discoveries", pp. 285-307. Progress in Aeronautics and Astronautics, Vol. 249. AIAA 2015. ISBN 978-1-62410-198-4. doi: 10.2514/5.9781624101991.0285.0308.

[12] Fruth, T., Lenzen, C., Gross, E., Mrowka, F. (2018) *The EnMAP Mission Planning System.* In: 15th International Conference on Space Operations, SpaceOps 2018. 15th International Conference on Space Operations (SpaceOps 2018), 2018-05-28 - 2018-06-01, Marseille, France. doi: 10.2514/6.2018-2525. ISBN 978-162410562-3.

[13] Porcelli, F., Schwarz, R., Cossavella, F., Lino, M., Wörle, M. T., Polzin, H., Förstner, R., Knopp, A. (2025) *Design, Architecture, and Management of Operations in SeRANIS, a Multifunctional Small Satellite Mission.* In: 18th International Conference on Space Operations. SpaceOps 2025 - 18th International Conference on Space Operations, 2025-05-26 - 2025-05-30, Montréal, Canada.