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Streamlined requirements management and matchmaking between space payloads and satellite bus enabled by Industry4.0 transformation and data intelligence

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Abstract

NewSpace comes along with complex topics such as digitization and Industry 4.0 which play a crucial role regarding emerging expectations of new clients. Requirements such as time-to-market and total cost of ownership are becoming more stringent, while at the same time demand for product and service quality is increasing. Furthermore, increased complexity of product lifecycle management makes a sustainable transformation of the space industry necessary.

Based on the project SLOTD4.0 funded by the German Federal Ministry for Economic Affairs and Energy and administrated by the German Aerospace Center (DLR) Space Administration, this paper addresses how platform economics with accurate knowledge management methods combined will be used to contribute to a more customer oriented and sustainable transformation towards meeting such expectations in the near future. Based on Industry 4.0 technologies and processes in combination with innovation strategies, a service architecture and different procedures are modelled to map the product life cycle phases of a modular satellite bus from ordering and acquisition to manufacturing and operation. By process optimization and closing of the gap between the business layer and the communication layer based on the reference architecture model Industry 4.0 (RAMI4.0), new potentials are uncovered and specified.

Moreover, business processes are presented plotting the phases of payload development and satellite production. Focus here is on the "Customer Journey". With modular end-to-end processes, development and production are accelerated, delivery times shortened, ordering procedures simplified and communication standardized. In addition, the processes themselves are also modularly structured and can therefore be added or changed over time. Based on broadly diversified results, a digital web platform has been set up adopting overlapping user needs. Such environment supports central administration of all user and mission relevant information, collects, and processes all technical specifications and requirements in an automated, simple, and standardized fashion. Specifically, the dedicated algorithm automatically determines the compatibility of payloads with characteristics of hosting satellite buses. The algorithm also identifies missing or incompatible properties for payload customers, and thereby generates feasibility awareness at an early stage on top.
Keywords: Digitization, Industry 4.0, Process automation, Requirements Management, Inventory Management

Acronyms/Abbreviations

CAD: Computer Aided Design
ERP: Enterprise Resource Planning
IAM: Identity and Access Management
iSSI: intelligent Space System Interface
iBOSS: intelligent Building Blocks for On-orbit Satellite Servicing and assembly
iBOSS GmbH: The iBOSS commercialization entity
KM: Knowledge Management
MAIT: Manufacturing, Assembly, Integration and Test
P/L: Payload
PLB: Payload-bay
RM: Requirements Management
S/B: Satellite bus
SLOTD4.0: Structure and lightweight construction optimized standard payload module and satellite bus connection for the transfer of technology demonstrations into Space and Industry 4.0 compliant processes
UI: User Interface
UX: User Experience

1. Introduction

The "Structure and lightweight construction optimized standard payload module and satellite bus connection for the transfer of technology demonstrations into Space and Industry 4.0 compliant processes", SLOTD 4.0 for short, is aiming for a new generation of small satellite system. While in conventional systems the payload and the satellite bus are built into a monolithic structure, in SLOTD4.0 they are integrated into distinct modules and connected by means of a multifunctional interface. The modular design of the satellite concept creates enormous flexibility throughout all project phases, from design, manufacturing, and integration to launch and operation of the system in orbit. Satellite bus, payload module as well as coupling interface can be standardized and thus create potential for significant cost reductions in manufacturing, assembly, integration, and testing (MAIT). In addition, a software-supported end-to-end service is applied which guides all involved stakeholders through the processes.

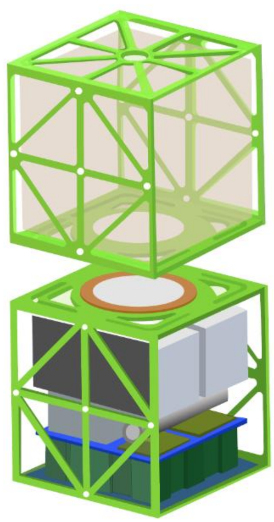

Fig. 1. Satellite architecture of SLOTD4.0 project with distinct modular satellite bus and payload bay

The System consists of two major space segment elements, depicted in Fig. 1: The Satellite bus (S/B) and the modular payload-bay (PLB). The universal S/B covers a wide range of payload (P/L) requirements and thus enables the implementation of a multitude of mission scenarios independent of the P/L to be carried. This will be achieved primarily through the use of in-orbit reconfigurable software, which will ultimately enable a software defined satellite. The PLB itself contains standardized mounting points as well as integrated sockets for power supply and data transfer to facilitate the integration of the P/L. Both space segment elements, S/B and PLB, are after separate integration finally connected via the international patented intelligent Space System Interface (iSSI) which is commercialized by iBOSS GmbH. The iSSI provides mechanical coupling as well as power and data transfer between S/B and PLB, see Fig. 2.

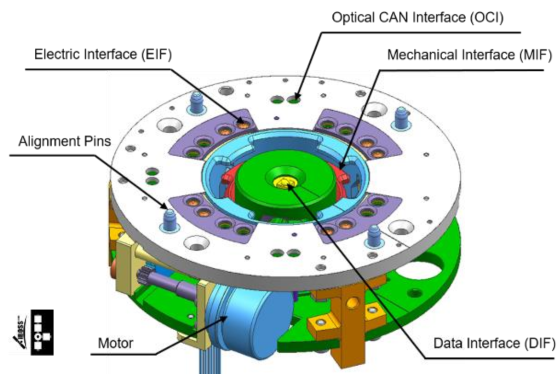

Fig. 2. Intelligent Space System Interface

2. Background

2.1 Terminologies of Industry 4.0

Industry 4.0 has the goal to create completely digitalized value-adding networks from simple value chains. Industry 4.0 is based on reference models. One of the reference models is the Industry 4.0 component. It describes that an Industry 4.0 product is composed of an Industry 4.0 component, which in turn consists of an asset and an associated administration shell. In the Industry 4.0 context, an asset describes a physical or logical object. Assets can be tangible and physical, intangible or in form of data and information. Assets can also be a composition of smaller assets [1]. The administration shell is the digital standardized representation of the asset to ensure interoperability between the applications that manage the manufacturing systems [2]. Recently, the term digital twin has become a synonym for the administration shell.

In addition, the product life cycle according to Industry 4.0 distinguishes between asset types and asset instances. Types describe the pure development world of (mainly) prototypes of a new sort of asset and instances describe the production world of an already developed asset.

2.2 Platform-based knowledge management

Knowledge Management (KM) has different definitions in different industries but the core meaning is similar. KM process is the managing of collective knowledge and resources within an organization for effective application [3]. Relevant organizational knowledge data is systematically and efficiently collected, developed, and shared for utilization [4]. Various information technologies such as intranets, internet and software agents can be tools for KM [3].

The software "Confluence" by Atlassian is a prominent KM platform. It provides a joint workspace for knowledge and collaboration. Members have the option to structure, organize and share their work to make necessary information visible and accessible for other team members [5].

2.3 Requirements management and enterprise resource planning tools

Requirements management (RM) and enterprise resource planning (ERP) tools are two prominent use cases of KM tools.

RM itself describes all operations regarding the preservation of the quality and value of requirements after their formulation until the end of a project. [6]. Requirements are necessary or restrictive properties of a system, which are imposed by the user and have to be factored in during the development [7]. According to the IEE 610-1990 requirements can be defined as “a condition or capability needed by the user to solve a problem or achieve an objective or a condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specifications or other formally imposed documents”. [8]. RM tools are used to specify and maintain said requirements. With RM tools, requirements can amongst other things, be versioned, edited, updated, and linked for traceability and easier access. Furthermore, remote access of requirements for e.g. project management for clients can be arranged. [9]

ERP tools are software tools used to plan, manage, and control resources of enterprises. ERP itself is an organizational concept for the direction of processes, which is incorrectly also used as a synonym for ERP IT systems and software. ERP systems support and optimize current processes and their development, including production processes, planning, finances, and inventory management [10]. Computer Aided Design (CAD) tools can also be incorporated into ERP, as they deliver significant information, such as machine settings and program data, for quality assurance and production processes planning [11].

3. Space production assessed by Industry 4.0

In the following, an analysis is conducted to determine to what extent the space production deviates from the ideal of Industry 4.0. The Industry 4.0 Toolbox is a suitable instrument for analyzing and evaluating the Industry 4.0 competence of businesses. It is an instrument for competence analysis of both products and the production itself [12]. The toolbox shown in Fig. 3 consists of six application levels and five technological development stages [12]. The highest level of the development stages is the vision Industry 4.0. The as-is analysis is based on internal organizational experiences as well as results generated during a previous project called Space Factory 4.0 [13]. The analysis results in the following situation. Today, any kind of data is stored for documentation purposes only. Instead, it must be accessible in order to enable the evaluation of process planning and control. This issue creates the subsequent problem that production instances and machines are not communicating to each other. But for a streamlined production process, machines need direct access to the internet. Despite the fact, that cross-company data exchange is almost performed via outdated methods, such as email, company internal networking is almost based on standard data formats and rules for data exchange. As the production lifecycle within the space industry is spread across different organizations around the world, fully networked and integrated IT solutions between the suppliers and customers are crucial. In addition, human-machine interfaces within the production are still underdeveloped. A reasonable next step towards substantial enhancements would be the application of centralized or decentralized production monitoring and control systems. Given the fact that production in the space industry is generally based on small batches, it is alarming that even the efficiency evaluation of small batches results in a very poor score.

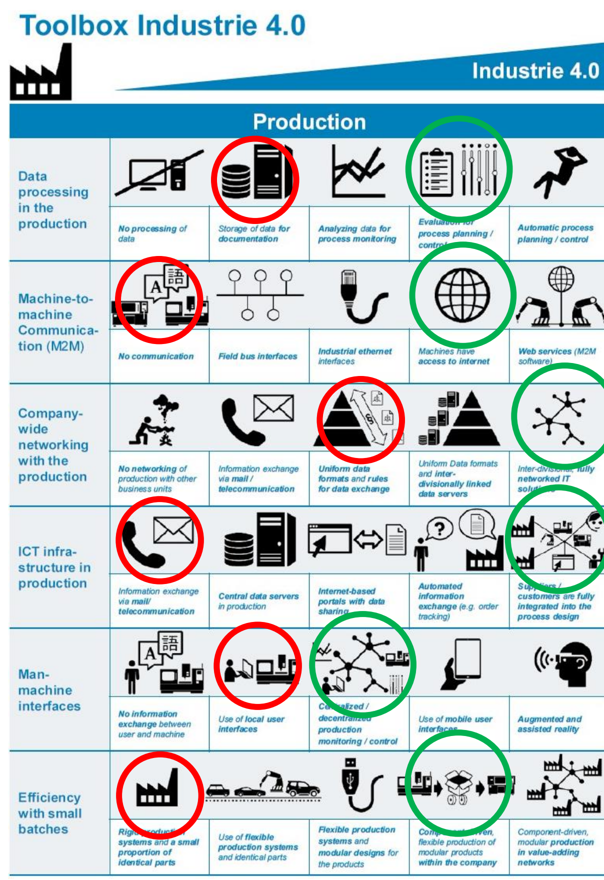

Fig. 3. Toolbox Industry 4.0 section production [12]

The production of most space companies is based on rigid production systems with only a small proportion of identical parts. Instead, a shift towards component-driven, flexible production of modular products within a company must be paramount. All this leads to a large deficit of the current satellite production methodology compared to the ideals of Industry 4.0 processes. Especially four areas are, from a knowledge management point of view, very critical and show high potential for improvement, see Fig. 4. These are the common but highly inefficiency small batches, poor ICT infrastructure, weak networking, and outdated data processing.

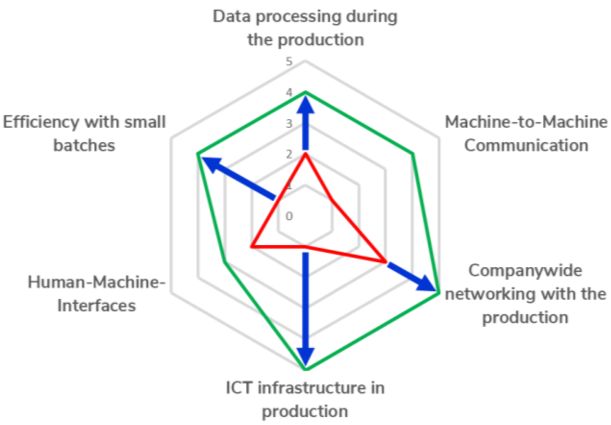

Fig. 4. Industry 4.0 competence profile of space production [13]

4. New streamlined production processes fitting Industry 4.0

In order to close the aforementioned gap between Industry 4.0 and the current state of space production new processes in combination with innovation strategies are developed. This new service architecture is modelled to map the product life cycle phases of a modular satellite bus from ordering and acquisition to manufacturing and operation.

The process consists of four major process sections, the lifecycle of the PLB & S/B, the lifecycle of the P/L itself, the section of Matchmaking and Virtual Assembly and the section of Mission Qualification and Post Matching Assembly, Integration and Testing (AIT). The lifecycles of the P/L and the PLB & S/B run simultaneously until the matchmaking process. In the process flowchart the PLB & S/B are considered as Industry 4.0 instance assets, elements which are taken from a collection catalogue and are already space qualified, compare Fig. 5.

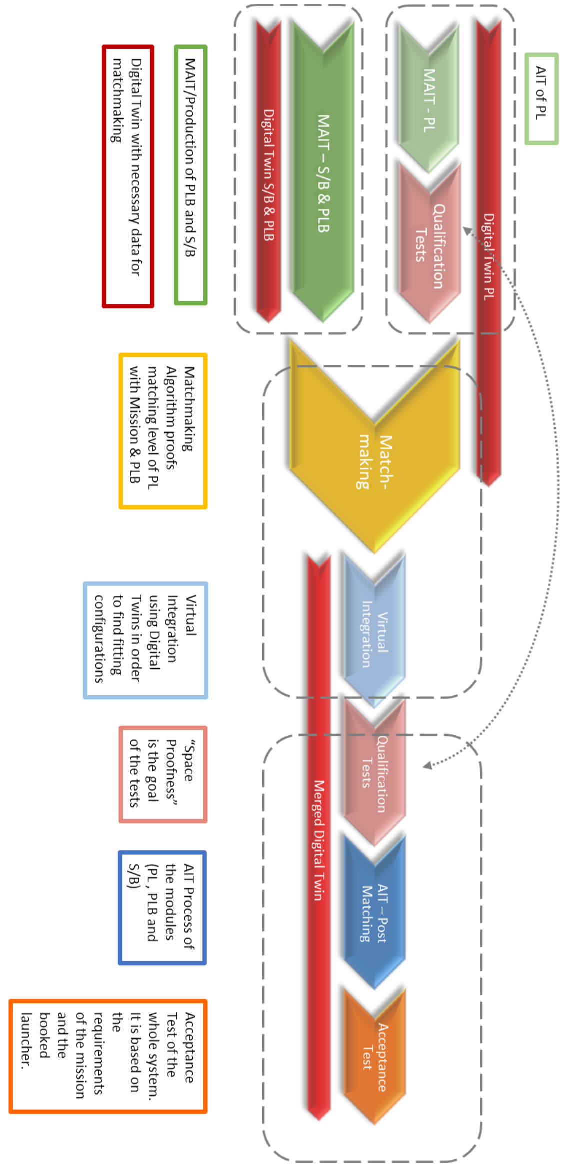

Fig. 5. Overall designed processes level 1

The lifecycle of PLB & S/B comprises the MAIT process. The P/L itself is considered as an Industry 4.0 type asset and needs to undergo a mission qualification and testing process after its MAIT process. If these tests cannot be performed at this step, they can be postponed but before the actual assembly of the P/L with the PLB within the AIT - post matching process. In case the testing is postponed, the P/L will provisionally be accepted and enters the matchmaking process with presumed data. In this step, the physical and other technical requirements of the client's P/L will be matched with a fitting PLB and with a requirement conform mission and S/B. The Digital Twins of the P/L as well as these of the PLB and S/B, which were created during their respective processes, are essential for the matching.

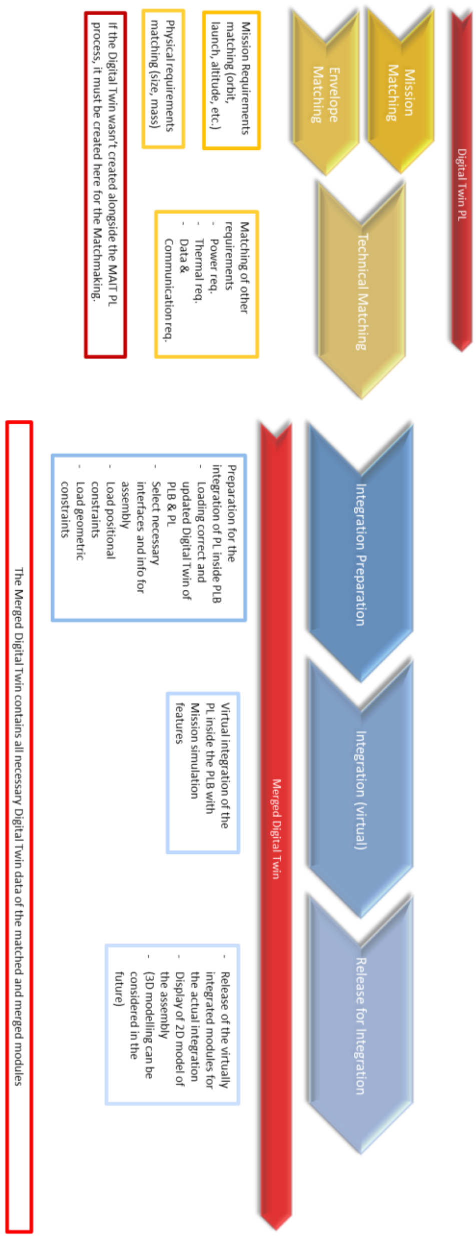

Fig. 6. Level 2 designed processes Matchmaking and Virtual Integration

After a successful match, the Virtual Integration process follows, see Fig. 6. The matched pair of PL and PLB will be virtually integrated using the previously created Digital Twins.

Initially, the required data for the integration phase is derived and is collated until a fitting configuration is found. Later, the modules are virtually integrated and finally released for the actual integration. The created Merged Digital Twin is accompanying these processes. A visual output of the merged modules can be realized as 2D or 3D models.

As previously mentioned, if the qualification of the P/L has not been performed already within the P/L process chain, they need to be completed at this stage before continuing to the AIT - Post Matching phase. Hence, module qualification of the P/L regarding mission-relevant requirements are checked to ultimately achieve "Space Clearance". With the P/L and the PLB having been released and matched, the AIT - Post Matching process is initiated. In this final step, first the client's PL is fully integrated into the PLB and the complete system comprising PL and PLB is tested. The fulfilment of the final test, the Functional Test, allows the merge between the PLB and S/B as well as the subsequent initiation of the final integrated acceptance tests based on the booked launch vehicle and desired mission profile.

5. Process optimization via customer journey

The P/L owning party is often interrelated with the engineering team of the involved satellite manufacturer, launch provider and other elaborate service provider. The entire process is linked to the investment of a significant amount of unpaid effort into requirements gathering and analysis. The concepts and applications presented have the main goal to enable customer-centric procedures. To allow this, highly standardized and modularized workflows are essential. An End-2-End Service enables a fast and economic access to space for a wide range of different P/L types.

Imagine the following scenario: Each customer has an individual virtual environment where he can specify, plan, manage and communicate all P/L and mission related information and specifications. The above described matchmaking process allows an in-situ match and requirements gap analysis in order to allow a suitable match. Via the in section 4 mentioned Digital Twins, all involved parties have a continuous and uninterrupted information availability. The high-quality availability of all-time information enabled by the Digital Twin, allows on-site contract, regulatory, and registration procedures. The customer and all involved parties are continuously informed about every status of the AIT phase, launch preparation phase, as well as the launch phase itself

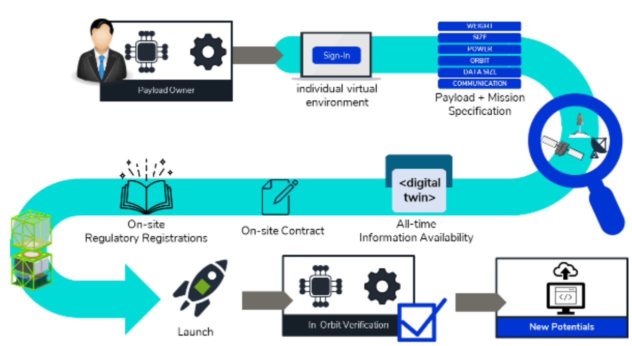

Fig. 7. Customer journey at SLOTD4.0

The digital infrastructure enhanced by the functionalities of the Digital Twin allow an improved and central execution and evaluation of the mission itself. A continuous and unbroken digital availability of knowledge within this process will unleash new potentials after the end of life of a prospective mission. These can be software tests or any other in-orbit-demonstration activity.

6. Digital platform for requirements and inventory management for space missions

Space missions are typically very complex projects that require close cooperation between different organizations. The involved stakeholders must exchange a significant amount of information during different phases of the project. This often leads to a loss of information or the distribution of inappropriate information. Examples from previous missions show that such circumstances can lead to severe delays and/or even catastrophic consequences. The use of adequate software tools helps to tackle these challenges, to optimize processes, and to counteract the risks. Such digital tools are widely used RM and ERP tools as described in Section 2.3. However, with Industry 4.0 and the ever-growing need for efficiency improvements with an ever-increasing need for adaptation, the gap between individual customer requirements and existing company resources as well as the associated need for improved KM is becoming increasingly significant.

The use of digital platforms is becoming unavoidable and contributes to closing this gap with suitable functionalities. Available mission resources of different carrier systems are manifested and made digitally accessible. P/L owners and further involved stakeholders will get a dedicated access to a portal, which enables the adequate exchange of information and requirements. The entire data and information exchange take place completely via this digital portal, and the risk of information loss between the actors involved is minimized by creating a central information channel and a high degree of transparency.

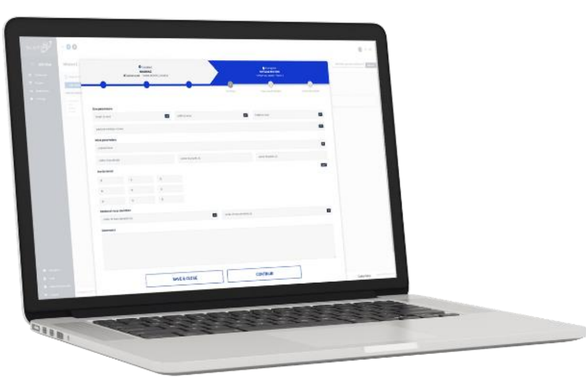

Fig. 8. Visualization of the SLOTD4.0 RM tool

Fig. 9. Visualization of the SLOTD4.0 ERP tool

With the support of such a platform, KM is raised to a new level. As mentioned in section 2.2, KM is the process of systematically developing, collecting, and distributing relevant information and data between the parties involved. The development of requirements and information is the responsibility of the respective parties depending on their point of view. For example, the payload owner, alone or together with other parties involved, is responsible for developing and defining the requirements for his mission and payload objectives. The entire information and data are collected on the platform either after or during the process of information generation. Dedicated platform views and access levels make the storage of information intuitive. This simplifies handling and avoids time-consuming training for the utilization of the software itself. Thus, user interface (UI) and user experience (UX) are highly relevant topics that must be considered and implemented with high quality when realizing the platform.

Once information and data have been stored digitally, the distribution of data is simplified. However, this activity requires loads of manual work and corresponding contractual conditions, as not all information may be shared with all stakeholders. To optimize the information exchange procedure and to eliminate the risk of human error, the platform automates this process. Through an extensive identity and access management (IAM) system, access rights can be assigned to the respective stakeholders right at project kick-off based on predefined roles (identity). During the project, access rights can be extended or reduced at any time if required. Thus, contractually defined limitations can be met in a traceable manner, as access to certain information can be denied.

In addition to the IAM system, the matchmaking algorithm is a core functionality of the platform. While the IAM system handles the distribution rights, the matchmaking system automates the distribution of the information itself. If the system detects a match between mission and payload requirements and carrier availability, information and data is automatically forwarded to authorized parties. In addition, information and data which are classified by the system as being relevant for a specific party are also forwarded automatically. If such information and data are classified as sensitive, the IAM system ensures an appropriate approval process.

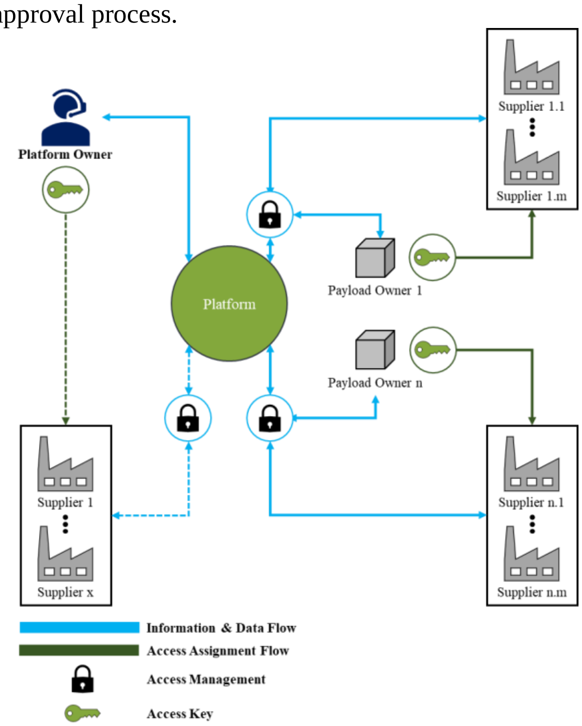

Fig. 10. Information and access management on the digital platform

Therefore, in the age of Industry 4.0, a digital platform for requirements and inventory management is an important tool that complements the advantages of RM and ERP tools with additional functionalities and can close the gap between individual customer requirements and existing company resources as well as optimize the entire KM process.

7. Conclusion

The realization of a space mission is dependent on the collaboration between multiple organizations, divisions, and people split in different phases. At the very early phases of a mission, the payload owner undergoes a long-lasting process to specify all mission-, payload-, and administration-related requirements. As you can see in Fig.11, the impact on the total life cycle costs is during the requirements phase at highest. This means that the total costs for development, production, and operation can be significantly influenced by an appropriate requirements management. With the beginning of the MAIT phase, changes become almost impossible or very expensive.

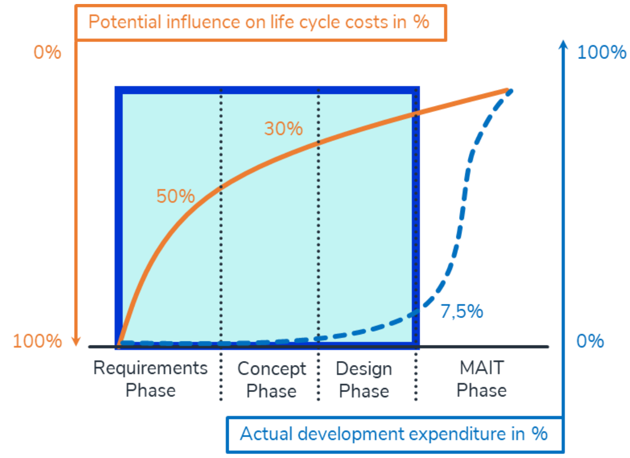

Fig. 11. Cost-influence diagram space projects [14]

As analyzed before, the industry is currently utilizing different incoherent tools and communication channels. This inconsistency complicates the already complex requirements management and matchmaking process between the payload, the satellite bus, and the underlying mission. This creates further uncertainties for payload owners. This untransparent process causes the loss of requirement and mission awareness and leads to further misjudgments and delays. This could explain the absence of non-space companies within the space industry.

Information availability and transparency in the early phases of a space mission are crucial as they open the possibility of significant influences on the final result. Digital knowledge management leads to streamlined insights. Important information of a space mission can be made available and transparent already in the early phases empowered by digital and central data management. Only this enables a timely impact. The early availability of critical information enables significant influence on the final results at the right time. The defined digital processes to specify spacecraft resource availability and to gather payload requirements enable collaborative matchmaking and the merge between requirements management and enterprise resource planning. The agility and flexibility shown can unleash completely new potentials for business cases not available before.

Acknowledgements

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