Space 4.0 and the Evolution of the (Aero) Space Sector

The space industry is facing exciting times ahead, "a time when space is evolving from being the preserve of the governments of a few spacefaring nations to... diverse space actors around the world, including the emergence of private companies, participation with academia, industry and citizens, digitalisation and global interaction" (ESA, 2016). Dubbed Space 4.0, this confluence of emerging trends in launch vehicle capability, spacecraft miniaturization, demographic change, and internal as well as external technological development has heralded an era of rapid expansion, decentralization, entrepreneurial activity, and non-traditional partnerships. Successful Project Management (PM) in future space endeavours will require new approaches to address the seminal questions of PM (Cooke-Davies, 2002):

1. What factors are critical to project management success?
2. What factors are critical to success on an individual project?
3. What factors lead to consistently successful projects?

Our investigation focuses on four emerging topics related to PM and Space 4.0, namely:

1. Artificial Intelligence
2. Model Based Systems Engineering
3. Disruptive Technologies & Businesses
4. Demographic Trends & Inspiration

We seek to identify relevant trends, classify opportunities and risks, and offer recommendations for the future of PM in a space industry that is increasingly interconnected and dynamic.

00 - Research & Analysis Methodology

Befitting the spirit of Space 4.0, we incorporated many different sources of information during the course of our research, from traditional literature and web searches to in-depth interviews with subject matter experts. The following report offers our distillation of these varied perspectives on PM & Space 4.0 along with our own personal insights from experiences in the space sector and beyond. We have endeavoured in good faith to fairly represent the views of those interviewed while acknowledging that no textual format can truly convey the full context of the discussions held and lessons imparted. Each of the four subtopics is treated independently and recommendations are included within each section. Throughout this report, underlined text indicates that we have provided a clarifying definition in section **07 - Appendix.**

01 - Artificial Intelligence

Even though the application of Artificial Intelligence (AI) software to project management dates back as far as 1987, AI is only now really taking off. From software development to construction to logistics and finance, every company has projects that need planning, managing, and monitoring. But the PM tools we use are often complex, designed for specialists, and provide only rudimentary forecasting of potential problems. The key question then becomes: could AI-powered decision support systems and automation improve project success by reducing cost and schedule overruns, analyzing risks, preventing mistakes, and improving efficiency?

01.01 - Evolution of AI in PM

Over the years AI has become associated with different terms ranging from cognitive computing and machine learning to natural language processing. What they all have in common is the idea that machines could one day learn by themselves much like humans do, rather than merely following pre-specified instruction sequences or acting in accordance with a pre-programmed rule set (what is classically termed "automation") (Lahmann, 2018). To date, PM has focused on automation of tasks that are routinely carried out, requiring a certain degree of standardization. Then the first phase of prospect of AI evolution in PM will be followed by next key elements:

- *Integration & Automation:* streamlining and automation tasks through integration and process automation will enhance the quality of PM processes and reduce the effort and labour costs. It means that project managers will be focused on complex project activities, without pay attentions into the evident part of it.
- *Chatbot project assistants*: integration and automation with additional human-computer interaction will take over basic PM tasks and relieve project teams of repetitive tasks. In this case the project manager will be increasingly assisted by chat bots.
- *Machine learning-based PM*:Enabling predictive analytics and giving advice to the project manager based on what worked in past projects will give the increased visibility into the projects and enhance the quality of decision-making. Thus, Machine-Learning will give intelligent advice on project scheduling and tasks.
- *Autonomous PM*: creation of completely autonomous PM, which could combine the previous key elements will be possible within the next 10 - 20 years. Thereby it will enhance the quality of smaller, standardized projects and reduce the quantity of human/stakeholder interaction.

In view of foregoing, the AI will change the project delivery methods and, in general, the evolution of PM. But during this evolution it is important to remember that project managers will also stay relevant in the age of AI, if they focus on work that emphasises human skills. The summary of AI evolution in PM during next several years is presented in the Table 01-1 (see **07 - Appendix**).

01.02 - Infusing AI techniques into PM phases

Algorithms tell computers and other machines how to think and act intelligently and many tools and techniques, such as Knowledge Based Expert System (KBES), Artificial Neural Network (ANN), Genetic Algorithm (GA), Fuzzy Logic (FL) have been studied in order to achieve AI goals. These techniques can be and has been used in several applications in PM enabling better project performance. So, AI can make the life of project managers less (or maybe more) miserable. (Hamdy K., 2017). As an example these techniques can be implemented into

PM to achieve goals in design conception, project planning, cost estimation, as well as risk and performance management; for specific examples (see Table 01-2 from (Hamdy, 2017) in **07 - Appendix**).

01.03 - SWOT ANALYSIS

The advantages of AI have been presented in the context of PM, but threats and weaknesses are also present and should be accounted for. The summary of SWOT analysis is presented in the Table 01-3.

Internal origin (Attributes of the organization)	
STRENGTHS (+)	**WEAKNESSES (-)**
- Reduce costs and mistakes, time to treat project/clients requests - Facilitates routine operations - Analyze risks - Improves the analysis method - Keep projects on time and on budget	- No human creativity - Not able to balance the capabilities and emotions of diverse set of humans (empathy) and lead them toward success - Require special training for the team (online courses, corporate training) - Require continuous monitoring/adaptation - Additional research needed into ethical, legal, and social aspects
External origin (Attributes of the environment)	
OPPORTUNITIES (+)	**THREATS (-)**
- Integration with Apps not used in PM field (e.g., Even.com predictive budgeting tool) - Incorporate AI into PM portfolio as a way of facilitating predictive steering of complex transformation projects - Global cloud services	- Significant disruption to business models - Requires a large investment - Over-reliance on AI as a sole source of truth - Security, reliability and confidence in the AI system - Development of standards and platforms for testing

Table 01-3. SWOT analysis of AI in context of PM

01.04 - Conclusions & Summarized Recommendations

In summary, it can be said that project management covers many disciplines, only for some will AI be able to assist or take over. The main key of AI is to focus on ensuring that the strategy around it feeds into company larger business strategy, always taking into account the convergence of people, process and technology (Harvard business review, 2018). And project managers, who take the lead role in this strategy and project developments, will be assisted by

AI, but not replaced. It means that “cognification” of AI will lead to alteration of job roles, rather than their elimination. By respecting a good balance between the roles of AI and PM such strength points such as reducing of cost and mistakes, time management and keeping the projects on the budget will help to succeed in the project. In the same time, the AI implementation in the PM requires a company-wide transformation and large investments and specific knowledge of project managers.

As recommendation, it can be said that the company that wants to work with PM tools based on AI should be ready to invest in

- (the best) data scientists who have skills focused around machine learning to build your applications; solution architects who oversee enterprise implementation;
- systems engineers who ensure the appropriate infrastructure is in place to support those applications;
- and business advisers who understand specific factors within the data and the business value that will be derived from the application is the main thing your company must do.

Concerning the process of AI implementation the managers have to be sure that expectations/roles between developers and IT are be clearly defined and agreed upon. Make sure that users understand the expectations of working with output from the AI applications, and create a simple process for capturing input so the solution can be tailored for more accuracy and increased relevance to meet each business need. In this case the training/seminars conducting prior the implementation of AI will allow you to set proper expectations on what each team member should achieve.

Finally, AI technology implementation strategy is the simplest part because the main barriers often sit within people and processes. Therefore in order to maximize the ongoing innovation and value creation form AI deployments, the company must develop trusted, scalable and flexible data and analytics environment in the company (Harvard business review, 2018).

02 - Model Based Systems Engineering

Model Based System Engineering (MBSE) is rapidly becoming a day-to-day engineering practice which improves upon traditional document-based System Engineering (SE). MBSE provides a manageable and appreciable representation of a product throughout the process of specification, design, integration, operation, and validation. It is based on three main pillars which can be summarized as language, tool and methodology Figure 02-1 in **07 - Appendix** (Badache N. & Roques P., 2018). Multiple companies have adopted MBSE, ranging across a variety of industries, including space systems (23% of companies), aircraft (20%), defence (20%), automotive (7%), and other (30%) (Dvorak, 2013). Examples of companies are ESA, NASA, Northrop Grumman, Thales, Raytheon, CNES, and others; most of these companies also implement MBSE into their own Concurrent Engineering Center (CEC) tools.

02.01 - MBSE benefits for project management (PM)

MBSE presents many acknowledged benefits, which could be adopted for project planning, implementation and PM, including:

- **Consistency**: MBSE tools and languages express each design element using constructs with a single meaning and provide precise descriptions that can be evaluated for consistency, correctness, and completeness (London, 2012).
- **Traceability**: Models provide traceability to previous decisions, issues, requirements, or risks concerning to the project. Through these connections, system objectives can be traced to the system components that implement them (London, 2012).
- **Reuse**: MBSE allows for the creation of alternative views while reusing common elements. Portions of system models can be reused for alliterative design (London, 2012).
- **Information sharing**: MBSE helps interface between management models and more detailed engineering and technical models, including responsibilities definition as well as sharing between different organisations.
- **Knowledge capture**: Models serve as project memory, preventing information from being lost due to staff turnover (London, 2012).

Furthermore, MSBE provides benefits across the entire life cycle of a project, as presented on the Fig. 02-2 in **07 - Appendix** (Hause, 2013). Project managers are also able to track project status by continuously checking percentage completion of tasks (Bajaj, 2016) and MBSE supports management in PPBE (Planning, Programming, Budgeting & Execution Process) activities and decision making.

02.02 - MBSE maturity status and prospects

MBSE is still in an early stage of maturation according to International Council of Systems Engineers (INCOSE) data, presented in Fig. 02-3 (Chakraborty, 2016) (see **07 - Appendix**). INCOSE estimations predict that the capability and the usage of MBSE in both large and small scale production will greatly increase in the next 10-15 years, however the transition to model-based disciplines remains a challenge. The following changes are recommended to facilitate the SE transition to MBSE:

- Encourage widespread adoption of MBSE within organizations across industry sectors
- Improve practice of:
  - *Modeling languages:* Continue to improve in terms of expressiveness and function precision
  - *Methods:* Provide more adaptability to a diverse range of application domains
  - *Tools:* Integrate with other multi-disciplinary engineering models and tools
  - *PM Tools*: Define Project management models and tools
- Provide a workforce that is skilled in the application of MBSE

02.03 - MBSE interoperability issues

The full benefit of MBSE will only be realized with collaboration processes that are themselves supported by interoperable MBSE platforms, including modeling, simulation, and collaboration activities. We focus on the modeling interoperability activity of MBSE since it needs to be improved first. Current solutions for resolving the model exchange issue are reviewed by (Lu, 2018) and summarized as the following:

- *Linked data* - Models are described in Resource Description Framework (RDF) format and annotated using Uniform Resource Identifiers (URIs) to add semantic meaning.
- *Meta-model integration* - requires MBSE tools to exchange meta-models instead of full models. Exchanging complete information sets might be complicated and unnecessary; meta-models can yield a common template for exchanging MBSE models. These meta-models should be flexible and extensible.
- *Tool-based integration.* MBSE tools must provide Application Programming Interfaces (APIs) enabling data exchange and interfacing with other tools. These tools need to agree on a standard or protocol.

Currently, each tool and organization has its own proprietary model and language, thus, in the short term, we recommend using mediators between tools instead of creating a single standard that all tools should comply with. This hybrid solution can be achieved using linked-data, meta-model, and tool-based approaches. Eventually, when we have semantic MBSE models and standardized API, a globally harmonized dataset can be used within and across the various MBSE frameworks. Harmonizing global product data also enhances Data-Driven Design (D3) by enabling advanced learning algorithms to scan knowledge graphs. Thus, we can benefit from automatic feasibility detection at component, subsystem, and system levels.

02.04 - Conclusions & Summarized Recommendations

MBSE contains three main elements (i.e. the language, tool, and methodology) which need to be developed further in parallel to mature this methodology. .Above all, model execution is a critical element to apply MBSE, All MBSE tools enable element reuse, connect design elements, and provide an effective means of knowledge capture. But, MBSE is still at an early stage of maturity. This is the reason why MBSE interoperability, as well as the transformation from SE to MBSE, currently produces many issues, with expected resolution during the next 10-15 years. To succeed in the transformation to MBSE and the potential evolution towards Model-Based Project Management (MBPM), concrete recommendations include:

- Develop guidelines and training for implementation of MBSE initiatives
- Assist potential future users with implementation of MBSE (e.g. in smaller companies)
- Further stimulate the development of common standards for language, tools and methodology for easier implementation throughout the space sector (e.g. include them in ECSS or NASA PM Handbook)
- Define standards, tools and methodology specifically for MBPM. This can be defined in collaboration with e.g. the International Project Management Association (IPMA) for instance for:
  - Common Project planning, scheduling and resource allocation
  - Risk management and linking it to system design and task
  - Project Breakdown Structure linking to system design and project planning
  - PM views of the overall system model (e.g. quick overview of technical project status, current issues and budgets)

- Intensify collaboration with INCOSE and Object Management Group
- Support of a step-wise introduction of MBSE & MBPM into projects for smooth transition and paradigm shift (shadow-engineering as possible first step)
- Benefits need to be verified and communicated to improve acceptance of MBSE & MBPM

03 - Disruptive Technologies & Business Models

What are disruptive technologies? Will prominent space businesses have to cope with these new tides? And what changes are needed in order to survive the Space 4.0 era in terms of business strategies, supply chains, and PM? In this section, we analyze the impact and benefits of disruptive technologies on aerospace PM. Then, we discuss new business models that space businesses today should adopt as needed within a changing industry. Finally, we explore the supply chain sector in Space 4.0 and discuss how current suppliers can adapt to new trends.

03.01 - Disruptive Technologies for PM in the Space Sector

The space sector is by nature risk averse. Hardware must be able to survive the rigorous space environment and in-orbit maintenance is seldom possible. Traditionally, the reputation risks and accountability factors present in large space projects have significantly limited adoption of new technologies. Unbound by these constraints of the traditional approach, Space 4.0 companies have embraced a wave of disruptive technologies which are driving the space industry to be more efficient and market oriented, leading to lowered costs, reduced lead time, and improved performance.

We divide disruptive technologies into two categories: technologies significantly driven by aerospace applications, e.g., reusable spacecraft, additive manufacturing (3D printing), in-situ resource utilization (ISRU), nanosatellites; and, technologies driven by other industries such as the Internet of Things (IoT), Blockchain, Cloud solutions, and video game devices.

- Disruptive technologies in the first category affect risk management in space projects as they are not yet backed by an extensive proof of usage and reliability. A more proactive risk management is necessary to assess and classify the potential benefits and risks compared to traditional technologies as well as to successfully mitigate any identified risks (Ganguly, Nilchiani, & Farr, 2017). However, effective PM usage of Commercial-Off-The-Shelf (COTS) components can make use of economies of scale to mass produce satellites cost effectively.
- Space 4.0 PM also needs to innovate in the second category of disruptive technologies:
    - The Waterfall Development Cycle is being replaced by rapid iteration and early development of minimal viable prototypes. Project funding needs to account for agile and iterative processes (e.g., Git, Scrum) as well as for continual upgrades throughout the mission lifecycle (Mittman, 2018 and Wolgast, 2018)
    - Blockchain can be used to verify project documents (Ulmer, 2018)
    - Cloud based solutions enhance concurrent development of a space project by reducing lead times, offering higher flexibility, facilitating documentation, and enabling geographically dispersed teams (PMI, 2018)

  - IoT contributes to the interconnection of development and testing equipment, reducing reporting effort and making production more agile through the digitization of logistics (Roma, Design 2 Produce, 2018)
  - Graphic Processing Unit (GPU) computing enables massively parallel simulations and rapid training of machine learning algorithms (Wolgast, 2018)
  - VR/AR systems can be used for spacecraft assembly, on-orbit maintenance, scientific team collaboration, and operations planning (Wolgast, 2018)

To incorporate the benefits of disruptive technologies and to collaborate with Space 4.0 industry, a common framework of standards, guidelines, common interfaces, and cybersecurity should to be established. For instance, ESA develops Electronic Data Sheets to represent data interfaces of electronic components for electronic data exchange among parties (Prochazka, 2017).

03.02 - Disruptive Business Models

The space market is no longer the sole domain of big players who produce, own, and operate satellites. Accelerated by affordable launch opportunities and the standardization linked to the CubeSat form factor, companies and startups offer commercial services driven by disruptive technologies and business models inspired by Internet entrepreneurs. For example, mega-constellation projects like OneWeb plan to deliver low cost, globally available internet services, relying on networks 100's of satellites (Henry, 2018). In short, Space 4.0 is defined by rapid innovation, lower costs, rideshares, commercially available parts, and agile development. To pursue market opportunities highlighted in Table 03-1, entrepreneurial ventures focus on developing products and services to align with changing customer demand, sometimes leading to rapid shifts in strategy or business model. Thus, partnering with startups necessarily entails higher near-term risk but potentially offers substantial long-term benefits (Alkalai, 2018).

Model	How it works	Example
Direct sales	Customer pays for specific service / product company has created (e.g., launch)	SpaceX, ULA, Blue Origin
	Built to client specification	Boeing, Lockheed Martin
	Subscription-based	Iridium, OneWeb
Data Provider	Customer pays for data collected by company	Spire, Planet, Google Maps
Marketplace	Company builds a platform where customers compare various options	Cubesatshop, spaceflight.com, NASA Tournament Lab

Table 03-1. Type of business models, how they operate, and example space companies.

To adapt to the changing Space 4.0 market, new PM practices are needed to:

- *Address complexity as a function of interfaces* - PM may benefit from a shift from top-down integration approaches to a more flexible framework of developing missions based on standardized interfaces between subsystems (Pierre & Kirasich, 2018)

- *Seed a broad spectrum of technology start-ups (entrepreneurial / pre-revenue)* - while commercial companies and venture capitalists can acquire equity in start-ups, space agencies could provide small levels of funding on the basis of technology return (Alkalai, 2018)
- *Investigate data providers as supplemental sources of scientific information* - commercial providers are unlikely to carry the right instruments for future scientific investigations, but they could provide supplemental data with higher temporal and spatial coverage. Dedicated missions from space agencies would not be competing with commercial providers, but rather the two sources of data would be complementary (Alkalai, 2018)
- *Incorporate decentralization at various scales* - new platforms (Git, Slack, Blockchain) enable distribution of effort and communication with low barriers to use, enabling teams to collaborate with less need for traditional hierarchies (Mittman 2018, Ulmer 2018). Crowd-sourcing and the "gig economy" can be incorporated through public competitions and companies matching freelance workers to specific short-term needs (Buquo et al., 2018)

03.03 - Supply chain and supplier certification in Space 4.0

Long-established space companies are based on low volume, high cost, and high reliability systems. To achieve target quality standards, space agencies and prime integrators establish tight requirements for their suppliers, entailing extensive documentation, certification, and quality controls. Traditional suppliers that want to enter in the Space 4.0 market need to adapt their production line to solutions with lower costs, higher volumes, and shorter lead times (Olofsson & Orstadius, 2018). On the other hand, new Space 4.0 companies are intrinsically based on mass production and a "good-enough" quality approach:

- *Supply Chain for Small Satellites* - companies like Planet and Spire, while trying to build robust small spacecraft, sacrifice some reliability for lower costs. They rely heavily on COTS to build very large constellations with a spacecraft lifetime of 2-3 years; mission assurance is met via redundancy of spacecraft. Moreover, spacecraft designs can be quickly updated before the next launch so that future failures are prevented. Embracing COTS for CubeSats, NASA has created the SmallSat Parts On Orbit Now (NASA, 2018) database to help spacecraft developers to understand the usage, type, and source of a wide spectrum of nanosatellites components.
- *Supply Chain for Launchers* - SpaceX, seen by many as an ambassador for the Space 4.0 paradigm shift, implements a unique approach for the development and procurement of their rocket parts. Eighty percent of its Falcon 9 launcher value is produced in-house, giving greater control over the supply chain; COTS parts are not used unless at least two providers of the same part exist in the marketplace.
- *Space Logistics and Sustainable Supply Chains* - reusable launch vehicles encourage work and travel in space; however, we need to supply humans in space with food, fuel, oxygen, and spare parts. In the long run, we will need to harvest materials from in-situ sources as well, making outer space an integral part of the supply chain. There are many organizations that embrace this concept, for example, MIT's Interplanetary Supply Chain Management and Logistics Architectures (IPSCM&LA) and Planetary Resources.

03.04 - Conclusions & Summary Recommendations

Disruptive technologies encourage innovation, fast-paced development, low cost, and more customizable space projects. Successful PM in Space 4.0 will place greater emphasis on decentralized cooperation, standardization of essential interfaces, and leveraging developments coming from outside the traditional aerospace field. Moreover, Space 4.0 will be market-driven with companies aiming to achieve a "good-enough" quality at a reasonable price. COTS parts developed for commercial companies can be leveraged, but there remains a clear need to monitor their on-orbit performance. Finally, there are no well-founded PM studies with project metrics or lessons learned for the application of disruptive technologies for space missions. Many institutions have not yet made valuable information publicly available.

It is therefore recommended to:

- Further promote standardization within the industry as is happening for the Cubesat sector.
- Continue and improve the monitorization and documentation of the in-orbit performance of COTS parts.
- Perform an evaluation study of successes and failures in disruptive technologies and approaches. Moreover, a space-sector conference for exchanging the experiences and lessons learned is highly desirable.
- Take full advantage of cloud solutions for sharing data/services among stakeholders and incorporate decentralization at various scales.
- Seed a broad spectrum of technology start-ups (entrepreneurial / pre-revenue companies).
- Investigate data providers as supplemental sources of scientific information.
- Address complexity as a function of interfaces. In particular, develop missions based on standardized interfaces between sub-systems, and, whenever possible, adopt a more flat organizational structure instead of a top-down authority.

04 - Demographic Trends & Inspiration

While the phrase "rocket science" is synonymous with difficult challenges and high technology, various sectors have outpaced the space sector as the most "technologically advanced" domain, particularly robotics, information technology, and the Internet of Things. At the same time, many companies and agencies struggle to attract young professionals and retain top talent in the space industry, hindering efforts to adapt to Space 4.0 (Aviation Week, 2017 and Tellier, 2017). Recruitment and retention efforts are hampered by the perception that the space sector is inherently slow-moving and that success is limited to existing players. On the other hand, natural excitement for space exploration, the existence of engaging technical challenges and the potential to create major impacts on the world all present opportunities. Above all, the importance of new workforce technologies and business processes should not be overlooked when seeking to attract and retain the top talent for Space 4.0.

04.01 - Engagement and Inspiration via Crowdsourcing

Institutional programs like NASA's Center of Excellence for Collaborative Innovation (CoECI) offer access to curated communities of expertise by issuing challenges to solve difficult and focused problems (Buquo et al., 2018). In addition to their high-impact, low-cost track record of technical success, these public challenges elicit responses from people of all disciplines and backgrounds (approximately 70% of all challenge solutions come from outside the technical domain of the issuer). When feasible, PM practices should incorporate these crowd-sourced initiatives, especially as they open opportunities to work with, train, and potentially hire highly capable people with little prior space experience.

04.02 - Infusion of Best Practices from Other Industries

PM should observe and adapt technologies from other industries and not reinvent solutions that already exist. For example, Virtual Reality/Augmented Reality technologies are currently being widely implemented in the videogame industry and also in medicine and construction projects to improve the visualisation and perception of the planned end product and thus improving the end result. Applying such cutting-edge technologies from outside aerospace to challenging projects within the space sector would increase “space” appeal, for example to computer scientists and others interested in information technology (Wolgast, 2018). Likewise, modern PM processes make aerospace companies more attractive to a younger generation, e.g., going paperless and remote work. Environments like Git and Slack encourage agile development, flattened hierarchies, and the sense of a “digital commons” where all contributions are encouraged and recognized (Mittman, 2018). Additionally, many tech companies actively encourage employees to spend a percentage of their time on “non-project” work experimenting with new processes and technologies, even when the pay-off might be uncertain or in the indefinite future.

04.03 - Mentoring and Peer-Networking

Cultures of mentoring and life-long learning are a key aspect of successful PM, especially in the rapidly changing Space 4.0 environment. Experienced staff can give guidance and motivation to young professionals while sharing best practices and important context for institutional processes. In turn, early career professionals are often more attuned to the newest advancements and are enthusiastic to experiment with evolving technology. Accordingly, PM should promote cross-generational partnering within projects to capitalize on the relative strengths and experiences of different age cohorts. Likewise, strong peer support networks, for example the New Researcher Support Group at JPL, help with employee retention by fostering a sense of community, promoting collaboration, and providing access to informal institutional knowledge. In addition to improved outcomes on existing programs, these approaches help prepare motivated teams of young professionals, ensure demographic stability within the industry, and generate new project concepts that lead to future space mission development.

04.02 - Conclusions & Summary Recommendations

In order to manage the industry shift to Space 4.0 and improve project efficiency, companies and organizations within the space sector should focus on:

- Engagement and Inspiration via Crowdsourcing
- Infusion of Best Practices from Other Industries
- Mentoring and Peer-Networking

Incorporating certain practices may require adaptation to meet the realities of the space sector, including cultural (or even legal) restrictions within companies and space agencies as well as differences in project goals, structures, budgets, and time constraints. However, the proposed policies contribute to a culture of openness, innovation, and enjoyment; adopting these practices within PM would change the image of traditional space companies/organizations and help them be seen as attractive, forward-thinking career opportunities for young professionals.

05 - Concluding Remarks

Space 4.0 is globe-spanning phenomenon, represented on every continent and composed of organizations scaling from the largest governmental agencies and most venerable companies to the newest start-ups and most intimate university research laboratories. As such, we find it difficult to adequately summarize all the trends and opportunities for the future of project management. However, throughout our investigation we have identified a few cross-cutting themes, summarized as follows:

- The importance of the human factor within project management, even as artificially intelligent assistants and model-based approaches increase in capability
- The importance of interfaces between systems and organizations, particularly in terms of addressing risk via standardization and interoperability
- The need to capitalize on trends, technologies, and processes coming from outside the traditional aerospace sector
- The opportunities for greater efficiency, innovation, and job satisfaction afforded by decentralized technologies and work practices

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07 - Appendices

07.01 - Key Definitions

Application Programming Interfaces (API) - is a set of subroutine definitions, communication protocols, and tools for building software. In general terms, it is a set of clearly defined methods of communication between various components (Wikipedia definition).

Artificial Intelligence - is the ability of a computer (or a machine) to perform certain tasks thought to require intelligence including: logical deduction and inference, learning and adaptation, ability to make decisions based on past experience, insufficient information, conflicting information, ability to understand spoken/natural language (Hamdy K., 2017).

Knowledge Based Expert System (KBES) - use knowledge, facts, and reasoning techniques to solve problems normally requiring the abilities of human experts.

Artificial Neural Network (ANN) - computing systems inspired by biological neural networks constituting animal brains. Such systems "learn" to perform tasks by considering examples, generally without being programmed with any task-specific rules.

Genetic Algorithm (GA) - a metaheuristic inspired by the process of natural selection. Genetic algorithms are used to generate solutions to optimization and search problems via bio-inspired operators such as mutation, crossover, and selection.

Fuzzy Logic (FL) - a method of reasoning that resembles human cognition. FL imitates human decision making by incorporating intermediate possibilities between the extreme values YES and NO.

Blockchain - is a growing list of records, called *blocks*, which are linked using cryptography. Each block contains a cryptographic hash of the previous block, a timestamp, and transaction data (generally represented as a merkle tree root hash). Blockchain allows transparent transactions tracking. (Wikipedia definition)

Disruption - "*Disruption* describes a process whereby a smaller company with fewer resources is able to successfully challenge established incumbent businesses. *[...]* When mainstream customers start adopting the entrants' offerings in volume, disruption has occurred" (Christensen, Raynor, & McDonald, 2015). This new company targets overlooked segments and delivers a more-suitable, advantageous and cheaper solution. Though a new disruptive technology might not be a technological breakthrough, but it succeeds in changing the market. Some momentous disruptive technologies being applied or developed in space sector are in domains of materials, manufacturing, accessible and affordable space, as well as information technology. These new trends tremendously change the space project from development upto the management level.

Model Based Systems Engineering - is a systems engineering methodology that focuses on creating and exploiting domain models as the primary means of information exchange between engineers, rather than on document-based information exchange.

Project Management - is the practice of initiating, planning, executing, controlling, and closing the work of a team to achieve specific goals and meet specific success criteria at the specified time.

Systems Engineering - is an interdisciplinary field of engineering and engineering management that focuses on how to design and manage complex systems over their life cycles.

07.02 - Tables from Citations

Table 01-1: Summary of anticipated evolution of AI in PM (Lahmann et al., 2018)

	Integration & Automation	Chatbots assistants	Machine learning-based project management (PM)	Autonomous PM
Key element	Streamlining and automating tasks through integration and process automation	Integration and automation with additional human-computer interaction, mainly based on speech/text recognition	Enabling predictive analytics and giving advice to the project manager based on what worked in past projects	Combining the previous phases, autonomous PM leads to little-to-no human interaction in PM
Outlook	Sophisticated PM tools will enhance the quality of PM processes and reduce the effort and labour costs Project managers can focus on complex project activities and its value	Chatbot assistants will take over basic PM tasks, relieve project teams of repetitive tasks and provide more interactive automation capabilities The classic project manager leading a PMO will be increasingly replaced by project assistants	Predictive project analytics will give project managers increased visibility into the project's future and enhance the quality of decision-making Machine learning-powered PM will give intelligent advice on project scheduling and tasks	Implementation of autonomous PM for smaller. standardized projects involving relatively little human/stakeholder interaction Purely autonomous project managers seem unlikely within the next 10 to 20 years, since certain skills ex. creativity will remain the human domain
Where we expect AI to support project management skills?				
Technical PM	YES	YES	YES	YES
Strategic& business management	NO	NO	(YES)	(YES)
Leadership	NO	NO	NO	(YES)

Table 01-2. AI algorithms into PM tasks (Hamdy, 2017)

	Project planning	Cost estimation	Risk management	Performance management
KBES	Provide estimates of the duration and resource requirements for project activities based on expert knowledge	Estimate the suitable markup to increase the possibility of winning tenders	Estimate the probability of occurrence for project risks allowing a more accurate quantitative approach to risk analysis	Assess claims and provide expert decisions based on the claim conditions
ANN	Automate the sequencing of project activities based on functional requirements	Predict the possible cost overruns based on the selected contractor, the competence of the project manager, the project size and the type of contract used	Combined with Monte Carlo simulation to mimic the human procedure of risk evaluation and adaptation	Predict the performance of future projects based on the project parameters such as the project manager's competence, the contractor's ability and the contracting method used
GA	Optimize the schedule of construction project activities in order to minimize the total cost with resource constraints	Get accurate forecast of project cost from past data	Supports simulation of risk factors	Analyze past projects and resources to produce an optimal performance management
FL	Determine project priorities in the portfolio management process	Optimize the cost-time trade-offs in construction projects	Assess risks in construction projects to model probability distributions	Improve project management efficiency in construction projects

07.03 - Figures from Citations

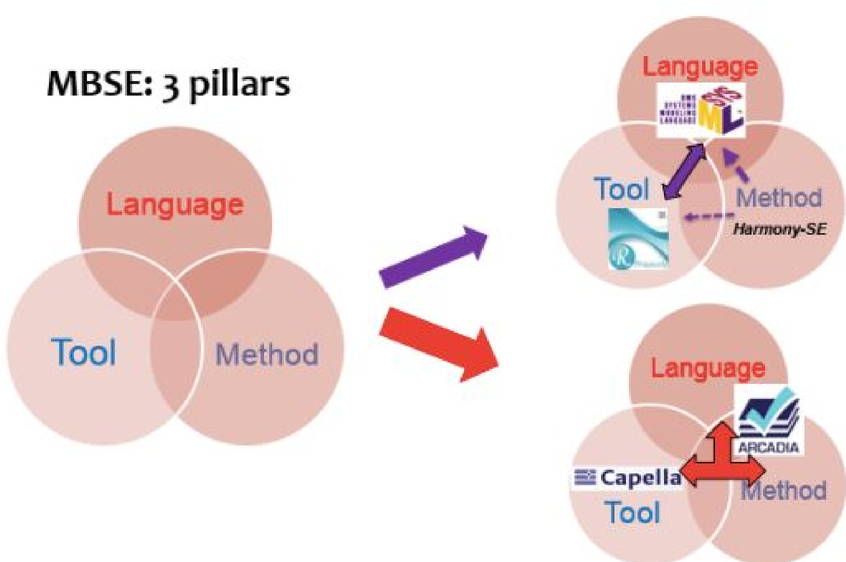

Figure 02-1. MBSE 3 pillars implementation (Badache N. & Roques P., 2018)

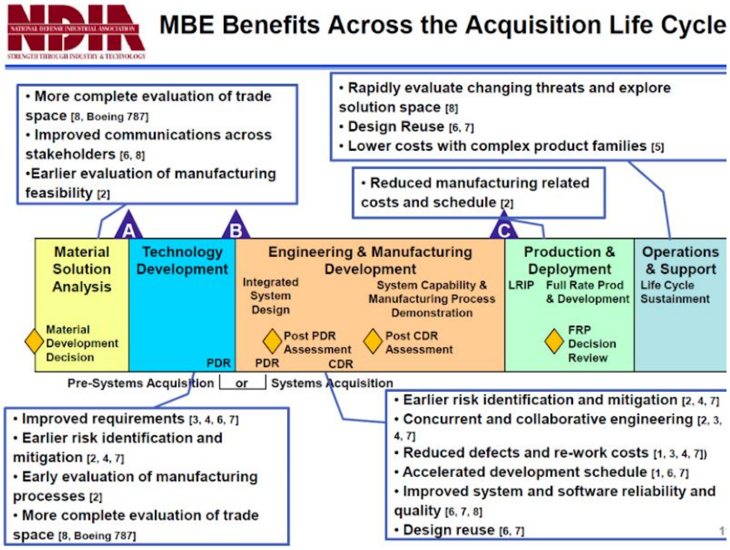

Figure 02-2. MBSE benefits across the acquisition life cycle (Hause, 2013)

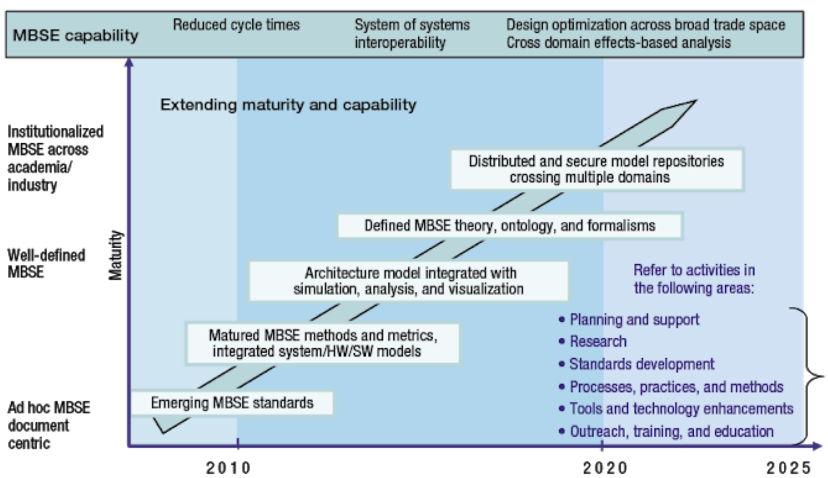

Figure 02-3. MBSE Maturity Road Map, INCOSE IW (Chakraborty, 2016)