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Prerequisites for an MBSE adoption support approach

Léa Kozak, Frédérique Mayer, Eric Bonjour, Jean-Pierre Micaëlli, Arnaud Riviere.

Abstract Design began its digital transition in the 1970s with CAD. *Model-Based Systems Engineering* (MBSE) would accelerate the process by profoundly modifying the structures and operations of design offices. The question therefore arises of describing what the adoption of a systemic innovation is such as MBSE and about deducing prescriptions. In this paper, we propose a state of the art on different approaches allowing the combination of the processes underlying its adoption. We will focus on what MBSE is for the Systems Engineering (SE) community; then on an approach centred on the organization's maturity to achieve MBSE activities; and finally, on the adoption of innovation, particularly from the point of view of usage. This paper will identify some scientific barriers that need to be overcome to provide a rigorous basis for an MBSE adoption support approach.

1 Introduction

In recent years, the airline industry has changed considerably, due to a sharp change in demand caused by the COVID crisis, but also to the emergence of new low-cost companies. These changes are forcing aircraft manufacturers to reduce their ramp-up time, costs and time-to-market of their products. At the same time, they must guarantee a high level of availability, safety, security and eco-efficiency of the aircraft, and maintain these technical performances throughout its long life cycle, i.e. over three decades. To respond to new market conditions while offering technically advanced aircraft, aircraft manufacturers are reviewing their processes, including those related to product design and associated research and development (R&D).

To improve their design performance, aircraft manufacturers intend to change their practice of Systems Engineering (SE). In the 1990s, this was based on the document; in the 2000s, on descriptive models and today, on executable models. Experience has shown that the "documentary" SE leads to the risk of having data that are disconnected from the project, and therefore a source of non-exact or false information. It also splits the designer's activity by making him/her distinguish between what concerns the modelling of the product and what concerns exchanges

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with third parties. Model-Based SE, or MBSE (*Model-Based Systems Engineering*), proposes a reference framework aimed at the integration, orchestration, interconnection, urbanisation, provision on a digital platform of executable, interactive models, improving the verification and validation of system specifications and architectures at the earliest possible stage, the collaborations among project players, or the reuse of knowledge and data from one project, business line, or stakeholder to the next. Consequently, knowing how to develop MBSE capabilities, to better (re)specify, (re)design, verify and validate complex, manufacturable and exploitable systems, all in a context of collaboration with multiple partners, becomes, for aircraft manufacturers, a strategic skill, source of a competitive advantage. Understood in this dimension, MBSE has a real systemic aspect. It is the basis on which to build the global organisation of design professions, design offices, projects, including R&D, and relations between the aircraft manufacturer and stakeholders. It is also likely to profoundly modify the practice and skills of designers (Boucher, Bonjour, and Grabot 2007), and even to give rise to certain roles, such as model architect. Finally, the MBSE is not an atom evolving in a vacuum: introduction of new modelling techniques, of more flexible ways of designing, for example by following the principles of *Design Thinking* or by using agile project management methods.

Although the promoters of the MBSE make many promises about the performance of this approach, it should be kept in mind that, like any large-scale innovation, there is nothing obvious or immediate about its adoption. Changing, at the same time, people's practices, their conceptualisations, tools, ways of coordinating, capitalising on knowledge, etc., is a source of tension and questioning (Quiguer 2013). Deploying the MBSE in a reasoned way requires clarification of: (1) its definition, which is still unclear; (2) the deployment processes initiated by managers; (3) the appropriation processes by operational designers (Magnani, Carbone, and Moatti 2019); and (4) its real gains in relation to the 'documentary' SE and to the models and modelling techniques that are embedded in current routines.

In this short paper, we will not be able to develop these four aspects. We will focus on how to encourage the adoption of MBSE by using the classic engineering notion of maturity. Adopting MBSE implies measuring (1) *ex ante*, the maturity of the organisation, business lines, individuals, etc., in terms of modelling; (2) during adoption, the gains obtained step by step, over the course of the projects instrumented by MBSE and (3) *ex post*, the maturity acquired in the field. Very rarely has a consultancy been able to complete the entire process of adopting the MBSE. To date, the MBSE is still relatively new. Therefore, in the absence of a

well-defined approach to the adoption of MBSE, we will present three basic building blocks in three separate areas. We will propose a state of the art on methods and tools that can help the adoption of innovations, on the evaluation of the maturity of the organisation in terms of transformation management, and we will review the approaches needed to adopt an innovation, such as MBSE. Our reflection will therefore be of a methodological nature. To do so, we will structure our discussion as follows. The first three sections will concern the state of the art on the digital transition in SE (Section II), on maturity models (Section III) and on the adoption of innovation (Section IV). In conclusion, we will propose a synthesis of these three states of the art concerning distinct and disjointed domains, to justify research avenues to rigorously build an approach to help the adoption of MBSE.

2 The MBSE, emblem of the digital transition of design offices

The digital transition of design offices, trades or projects is an old story, which started in the 1960s and led to remarkable achievements, including CAD-CAM software, digital simulation, etc. SE, developed by engineers for engineers since the same decade, could not ignore the basic trend of digitisation of design activities. Since the beginning of the decade 2000, we can observe an acceleration of the digitisation of all professional or leisure activities, individual or collective, etc., so that SE experts must specify how this translates into design offices, trades, design projects, etc. The MBSE is one expression of this concern.

The scope of the digital transition in design offices

Although it is relatively new, some authors have already pointed out that MBSE may provide benefits among its early adopters (Friedenthal, Moore, and Steiner 2015). MBSE would be nothing more than a continuation of the digitisation of design initiated with CAD; it would not change anything in the habits of designers or the routines of design offices. As for the cost of adopting MBSE, it would concern the purchase of the required licences and equipment, as well as the training of their users. This view of MBSE deployment as the purchase of new digital resources is far too restrictive. Other authors emphasise that MBSE profoundly changes organisational practices and structures (Chami et al. 2018). The analogy with earlier stages of the digitisation of design offices would be misleading. In fact, the deployment, the adoption of MBSE would not be so easy (Cloutier 2019; Chami et al. 2018). MBSE is not a 'simple' digital tool; it has a conceptual scope (the product and the design process are rethought), methodological (the procedures to be followed are transformed) (Henderson and Salado 2021) and systemic (the whole

organisation is affected) (Chami et al. 2018). Adopting it would imply at least a double adoption: at the process level (with a method) and at the method level (with tasks instrumented by specific tools) (Henderson and Salado 2021). However, in the literature, these two levels are not dealt with properly (Henderson and Salado 2021).

Better understanding the MBSE: existing tools

The difficulty of implementing MBSE has led to a need for a deeper understanding of what it is and what conditions need to be in place to enable its adoption. As a result, several communities of practice have developed frameworks that can assist managers in the transition to MBSE (McDermott et al. 2020).

"*The INCOSE Capability Maturity Matrix*" is intended to be a useful consensus-based tool for identifying and assessing the capabilities needed for MBSE adoption (Hale and Hoheb 2020). This matrix is the result of community work involving several administrations and companies. It is built around 8 domains, describes maturity into 5 stages and identifies 42 modelling capabilities. With this table, it is possible to identify the level of maturity of the organisation concerned and the desirable level. However, this matrix does not give the way to progress between the maturity stages, nor the effort needed to achieve it, nor the resources to allocate.

Atlas Helix model is also concerned with SE, but more at the level of its implementation in the project (Hutchison et al. 2018). Based on the work of Sheard (1996), Helix distinguishes three categories. The first is about the system under development; the second is about the process and organisation of the SE; the third is about the team developing the system. Each category has roles with well-defined tasks.

In addition to a modelling maturity measurement matrix, INCOSE, in association with the Systems Engineering Research Center (SERC) and the National Defense Industrial Association (NDIA), conducted a broad survey of the SE community in 2020. The aim of the survey was to (1) measure the overall maturity of the SE digital transformation to be able to report on the real benefits of MBSE, (2) identify the main barriers and enablers to its adoption in the engineering community, and (3) identify the changes affecting the operational activity of systems engineers. This investigation was supported by a systematic review of the literature, particularly in three areas considered important: SE as such, engineering design and space systems engineering. As a result of this extensive research, 48 benefits of MBSE were identified (McDermott et al. 2020): "some of the most common benefits relate to improved communication and information sharing, increased traceability, improved

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consistency, improved complexity management, reduced costs, reduced time, improved knowledge transfer, reduced errors, increased productivity and improved knowledge management". However, the experts from INCOSE, SERC and NDIA point out that MBSE is mainly supposed to satisfy five key performance requirements, namely: quality, velocity and agility, transferability, but also usability or acceptability. These last two requirements are interesting because they do not concern the organisation, but the individuals that make up the organisation. Unfortunately, this survey shows that it is mainly quality and agility that attract the attention of those deploying MBSE. These would be the easiest requirements to verify and measure (accuracy rates or design times), but they restrict the scope of the value that MBSE adoption potentially brings.

Adopting MBSE: an initial list of failure and success factors

The adoption of MBSE faces some obstacles. These may be a lack of perceived value and support for its deployment, but also the availability of skills or some kind of cultural and general resistance to change (Cloutier 2019). This type of classic analysis underestimates the systemic scope of MBSE, the profound changes that its adoption induces in terms of organisational structure, processes, business lines, operational activities, methods, modelling techniques, digital tools, etc. The immediate adoption of MBSE is a myth and its deployment is inherently fraught with challenges, not all of which are being faced (Chami et al. 2018; Albers and Zingel 2013).

Without claiming to be exhaustive, which is illusory given the relative novelty of MBSE, the literature already proposes certain success factors for its adoption. Authors tend to multiply good practices. We propose to group them by major themes. To adopt the MBSE, it would be appropriate to think in terms of:

1. upfront and core investment. Deploying MBSE requires a substantial initial investment, particularly in training practitioners. However, project budgets are tight and do not devote enough resources to learning about a new and sometimes confusing process innovation (relating to ways of performing activities). Building good practice in MBSE also involves experimentation, testing and potential failure. Collaboration in a 'multi-centre modelling' effort and the transfer of experience through mentoring generally facilitate the adoption of innovation (Parrott and GRC 2016);

2. organisational. Professionals who have experienced the transition to MBSE report that barriers to its adoption are often found in the overall organisation,

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organisational culture, alignment of tactics (in this case, MBSE deployment) with strategy, networks of influence and coalitions within the organisation (MBSE promoters and supporters vs. opponents or neutrals), and management support (McDermott et al. 2020);

3. numerical. MacDermott et al, (2020) highlight the importance of IT infrastructure, dedicated software, support for its use, data management, to successfully adopt MBSE;

4. experiential. MacDermott et al, (2020) emphasise how the commitment of the operational designer, their skills in modelling, their ability to mobilise the right resources, promote the adoption of MBSE. Unfortunately, current work focuses on the technical details of MBSE and not enough on identifying and understanding what it is, experientially, by those who need to take it on (Chami et al. 2018).

By way of an initial summary, the MBSE is part of a long-standing movement towards the digitalisation of design offices. Its adoption is a work in progress: we do not have the necessary hindsight to properly identify the factors facilitating or preventing it. However, it is recognised that adopting MBSE requires a systemic innovation because it has a multidimensional character requiring a global view for the management of the transition. As such, it poses many organisational, managerial, technical, methodological, and experiential challenges for its potential users. Our brief review of the literature allows us to state, with our current knowledge on the subject, that there is no methodology for adopting the MBSE that is operational, empirically validated and customisable. It must therefore be constructed. To do this, two blocks, currently outside the strict domain of MBSE, must be considered: the first concerns the maturity of an organisation, which provides an organisational and managerial view of its adoption (Section III); the second relates to the user's experience, i.e. the cognitive, practical and experiential aspects of its use (Section IV).

3 Maturity assessment: an anchor point

Preliminary definitions

In the specific case of the adoption of MBSE, the term maturity occurs at several levels, from the individual to the overall organisation, and at several points in time, before, during and after appropriation of this innovation.

Without carrying out an in-depth linguistic analysis, we can see the semantic proximity between the word maturity and those of evolution, change, transformation, innovation, etc. For our purposes, we will distinguish them carefully. Thus, innovation will be understood as an event, i.e. the intentional introduction of a well-defined novelty into an existing context, capable of initiating a transformation of someone or something. Accompanying this transformation will require change management (Autissier et al. 2019). The MBSE will thus be the innovation studied; design practices will be profoundly transformed by it and change management will consist of implementing support to make its deployment effective in the aircraft manufacturer's design offices and stakeholders. The adoption of MBSE will be the horizon of the congruent processes listed in the previous sentence. Maturity will be the criterion to be assessed before, during or after adoption. Maturity, understood in this sense, is unambiguously a concept of performance management, here of design or by extension: of R&D.

Maturity, key performance criteria in change management

A process is usually defined as a set of tasks (or practices, routines) and work rules (Sánchez Garzón 2019) with the aim of fulfilling a mission. For the ISO 9001:1992 standard, the process is reproducible in whole or in part. It can be represented using dedicated models, for example a flowchart or BPMN (2006) and thus codify the organisation's routines. Finally, there are several performances of the process. We can ask about its quality, its reactivity, its effectiveness, its efficiency, its cost, etc. These performances are operational: they concern the usual course of the process, not its transformation. To grasp it, maturity is therefore required.

In the literature, there are three types of maturity models, descriptive (measurement of current maturity), comparative (comparative maturity, including with respect to a benchmark) or prescriptive (recommendations for plans to raise maturity). We can refine this typology by considering two types of maturity frameworks: (1) linear frameworks, in which the stages of all the processes of the organisation are reached one after the other, in accordance with a pre-established order, as in the CMMI (1999) or the PMMI (Sánchez Garzón 2019); we will not describe these models further because the pre-established order does not make sense for a transformation that requires constant adjustment to the context and the environment; (2) non-linear frameworks, in which the stages to be reached differ according to the processes and can be reached by following a personalised path according to needs. In linear frameworks, it is important for the organisation to have processes that conform to a

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benchmark established by a comprehensive review of good practice. In non-linear frameworks, it is the relevance of the path followed by the organisation that matters.

4 Adoption of innovation

Organisational capacity approach

A priori, the adoption of innovation is a process following a non-linear path. It depends on the context in which the innovation to be adopted is present; it transforms practices, in this case design practices, in a way that is difficult to detail *ex ante*; it necessarily integrates many fields, technical, organisational, managerial, cognitive, transactional, etc., and actors, hence the need for specific change management. Depending on the types of products to be developed, the professions, the projects, etc., the design or even R&D processes do not all need to be at the same level to have the necessary maturity for the proper functioning of the project, the design office, the network linking the aircraft manufacturer and the stakeholders, etc. Finally, in the specific case of adoption, the descriptive models remain incomplete because they shift the problem towards an explanation of the use and not towards the prediction which makes it possible to account for the weight of the context (Terrade et al. 2009). This is a very important characteristic for adoption because it is the first step in the process that we will see in the next part. It is therefore risky to derive from these existing descriptive models prescriptive models that are at the same time rigorously formulated (Sánchez Garzón 2019), empirically valid, consensual and relatively easy to use.

However, there are three interesting models for building original descriptive models:

1. Interesting work considers maturity as a capability revealed by certain types of events. The researchers of the ESSEC Chair of Change propose a questionnaire with 40 items classified under four headings: the challenges of change, the resources of change, the change projects and the ecosystem of change. (Autissier et al. 2019) According to the results obtained, they classify the maturity of the organisation into three types strongly inspired by Mechanics: "organisation in inertia", "organisation in unblocking" and "organisation in movement". Following this typology, we can distinguish a linear maturity, in the first type, with an organisation that is constantly improving; an event-driven maturity, linked to an innovation or any event that unblocks an organisation that was previously in a deadlock, and an organisation that is capable of

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transforming itself, for example by questioning its business model. While the ESSEC grid is useful for an audit of the capacity to change at a strategic level, it does not address design processes and does not indicate how, depending on the type, to drive change.

2. "The Potential Innovation Index (IIP) (Boly et al. 2014) goes further in this respect. The IIP proposes a diagnosis of the capacity to innovate by referring to six types of good practice linked to strategy, project management, HR, knowledge, projects and creativity, which are divided into 18 activities (Boly et al. 2014). The IIP allows the company to be identified as passive, reactive, preactive and proactive.

It is necessary, but not sufficient, to look at the adoption of innovation from an organisational perspective alone. There can only be successful adoption if the innovation is inserted into the reality of its user and assimilated by a community of users (Arbelaez Garces, Rakotondranaivo, and Bonjour 2016). It is therefore necessary to consider adoption from a user-centred point of view, which implies a more refined approach to this phenomenon.

Usage approach

The innovation adopted transforms usage (Bobillier Chaumon, Dubois, and Retour 2006). Before reaching this state, some authors propose a three-stage sequence, all centred on the user, namely acceptability, acceptance and appropriation. As the user experiences the novelty, he or she would move from one phase to another in what is often understood as a continuum. It is during this phase that the user defines, based on his representations, his intention to use the innovation. Acceptance is anchored in the first practices of the innovation, in its first manipulations. The novelty is put to the test in a situation and from this experiential test, the user judges whether this first one is effective or not. Appropriation, the last phase of the continuum, is cognitive. That it is based on different cognitive processes by which the user readapts his or her usage patterns with regard to the novelty in an activity that makes sense to him or her. (Nadal, Sas, and Doherty 2019) Once these patterns have stabilised, the innovation is adopted and gradually becomes commonplace.

Authors have developed what acceptability and acceptance are based on the rational behaviour of the user, who is supposed to be able to weigh up the usefulness and usability of the innovation. In the UTAUT model (Unified theory of acceptance and use of technology), Venkatesh and Thong (2012, 2022) extend this analysis by combining factors that are (1) objective, i.e. the specifics of the innovation; (2)

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subjective, such as emotions, habits; and (3) environmental. (Venkatesh 2022) It is the interplay of all these variables that would explain why a given innovation is recognised as acceptable and then accepted. The UTAUT model focuses only on product innovations (Acosta Salgado, Bonjour, and Rakotondranaivo 2020), is tinged with behaviourism and therefore leaves out the social or cognitive factors explored in depth by another approach which recognises use as a form of activity.

The use-as-activity approach reveals important aspects of innovation adoption. This adoption must be analysed both from :

1. a view centred on the technique, as with the TRL and generally any 'technocentric' approach, and a view centred on the individual as a potential user, as advocated by the 'anthropocentric' approach (Rabardel 2014) or even an organisational approach when it comes to a systemic innovation such as the MBSE;
2. a view centred on instrumentation, i.e. on the producer of the innovation who drives adoption, and a view centred on instrumentalisation, i.e. on its user, who drives the process;
3. a view centred on the individual user, as indicated above, but also a view focused on the collectives playing inhibiting or facilitating roles (Leplat 1994). Collectives manifest themselves in the concrete forms of an ideology or an option, sometimes volatile, shared by its members regarding innovation, communities of practice, mutual aid networks, networks of influence promoting the said innovation, etc;
4. a naturalised view of adoption, as a process that goes without saying, and a managerial view, emphasising the need to manage it within the framework of a change management strategy (Boly et al. 2014), using different levers, including training (Chahir 2021), experimentation, feedback, etc., but carried out in context (Autissier et al. 2019), i.e. following the principles of the non-linear models presented in section II.

5 Conclusion and the future work

This state of the art has provided the basic building blocks for developing an approach to assist in the adoption of MBSE, particularly in the specific context of the aeronautical sector. To date, there is no ready-to-use approach. Our brief review of the literature shows that adoption is still an undefined process. It requires a certain congruence between innovation, transformation and change management. The latter

needs measurement tools, the most interesting of which, to date, and as far as the field of design or engineering is concerned, is the maturity of techniques and processes. However, the existing maturity models focus rather on the operational performance of organisational processes and little on the organisation's capacity to adopt the innovation or the sequence of acceptability, acceptance and appropriation of the innovation revealed by analyses of its use.

Our brief review of the literature has shown that an MBSE adoption process must be multidimensional. It involves technical, organisational and individual aspects. It must also be non-linear. The maturity required to adopt the MBSE or acquired following its appropriation is a path in a marked out space, in which an organisation or a user follows certain trajectories or overcomes blockages that can be clearly identified; it does not consist of following a predefined sequence as is the case with the CMMI. Finally, activity theory (Engeström and Sannino 2010), some aspects of which we have sketched out in dealing with the analysis of innovation use, provides a framework for merging the dimensions identified and thinking about the tensions inherent in any adoption of innovation. In the case of the MBSE, it is a question of thinking about the tensions between the deployment of a systemic innovation, therefore heavy, and the agility required of digital projects today; between the appropriation (specialisation) of the trade by an actor and the need for interoperability for collaboration within the organisation; between abstraction and the need to have models that are appropriate in use (therefore specific); between the virtues of the model in terms of knowledge sharing and the problems of transaction costs and intellectual property that it poses. We have no doubt that this topic will be the subject of hot discussions among SE professionals.

In our future work we will further define the specificities of MBSE and of the adoption of the MBSE in the aeronautical context to confront the different dimensions. We will create a conceptual model to highlight the dependencies between them.

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