Lessons learned on the progress of adoption of digital and model-based systems engineering into engineering enterprises

The SERC research on DE/MBSE adoption found many factors that must be addressed for organizations to achieve this transformation. Table 1 organizes the 12 most prominent factors in our research, organized across three categories: Organizational design, Organizational enablers/barriers, and Organizational change management. This research collected a set of detailed lessons learned around each from existing literature.

Organizational design	**Organizational Enablers/Barriers**	**Organizational Change Management**
Workforce knowledge / skills (SE domain, MBSE tools, digital strategies)	Leadership support / commitment	DE/MBSE methods / processes (maturity): MBSE terminology and libraries
Integration to support the digital implementation (tool infrastructure)	Training & categories of training	Change management process design (lessons learned, communicating success)
Demonstrated benefits/results Programs/projects using methods & processes	Resources for implementation (cost to use tools, willingness to invest)	People willing to use the DE/MBSE tools (a primary adoption measure)
People in model building roles	Tool Infrastructure: user experience with them and stakeholder buy-in	Greater use of DE/MBSE tools (overcoming resistance)

Organizational Enablers/Barriers

Leadership Support/Commitment:

1. "Successful implementation and adoption of MBSE is not a single, discrete event. Successful implementation requires a time-phased transformation in a complex System-of-Systems enterprise environment. As such, a coordinated vision across the entire enterprise is essential." 35
2. "Leadership sets direction, supports staff development, organizes for project and infrastructure development, support and sustainment (ask for artifacts, implement MBSE-based reviews, establish and reward milestones, measure progress)." 42
3. "Unity of Leadership is Essential. In the first infusions, management support for the effort must to be clear and consistent. Management must be willing to pay the startup costs and to give time for the effort to pay dividends. In addition, the engineering leadership must be reasonably unified in their willingness to work together to figure out how to do this." 4
4. "Executive Level Sponsorship. Although increased MBSE popularity has strengthened executive support, there are still conflicting MBSE adoption goals between short-term driven employees who care about low adoption cost, with others aiming at more adoption quality and long-term solutions." 13
5. "Failure to consider the broader engineering organizational needs, as well as those of the enterprise itself, results in lack of enterprise leadership support, including MBSE adoption decisions and choices that fail to operate within the overall engineering environment and fail to achieve their goals even within the systems engineering organization." 35

6. Organizations should be "aware of potential target programs and [have] just-in-time availability of mature tools, training, support, expertise, tailoring approaches, and troubleshooting prior to actually beginning the engineering. It also requires the encouragement of program leadership to recognize that the competitive environment likely requires changes to the development process for the sake of improved cost, schedule, and capability." 11

Training and Categories of Training:

7. "All engineers should get, at least, basic training in MBSE." 1
8. "New practitioners need training in the language methods and tools of MBSE. The training should also be adapted to different members of the project team. In particular, a small core modeling team may require more significant MBSE training, while the larger project team may only require sufficient training to understand the modeling artifacts. After the initial training, ongoing mentorship is essential to provide the support needed to help the team climb the learning curve." 19
9. "Everyone Needs Training, but to Different Levels... three groups need to receive training commensurate with their level of interaction with the models. Different levels of modeling familiarity are required, thus resulting in different levels of training... we have constructed a set of classes that addresses all three user-type groups. The classes are sequential, each one building on the one before it. We start with the basics: Architecting, AFT, MBSE and SysML familiarization for everyone. The second class is the advanced SysML and Tool-Specific training, for the engineers who will be working with the models (MagicDraw and AFT). Then finally the third class, really a continuing series of special topic sessions, is for those engineers who actually construct, maintain, and analyze the official project models." 4
10. "To master a modeling tool for UML and/or SysML, training and practice must provide some understanding of the definition of these model elements, how they relate, how to apply them efficiently in modeling tasks, but also what not to use of all available features. Even if only a subset of UML/SysML is used in the project, the users—and in particular the mentors—need to have understanding of the underlying meta-model and its implementation in the tool. The fact that SysML is based on UML, and that UML is in turn based on a "merge" of several other modeling notations/standards, makes the meta-model cumbersome and non-transparent." 2

User Experience with Tools and Stakeholder Buy-in:

11. "Provide expected SE products to accelerate adoption. Once the MBSE effort has proven that it can support existing processes with familiar products, these stakeholders may become more amenable to exploring more transformational approaches to improving processes and products, enabled by MBSE capabilities." 6
12. "Engage early and often - If… MBSE has resulted in the discovery of non-obvious issues and problems, the earlier empowered stakeholders are engaged, the earlier these issues can be addressed. Through the use of the model, the implications of a given decision or option can be quickly (relative to not using a model) analysed and then returned to the decision makers for resolution and further guidance if required. The early and regular engagement also militates against producing a perfect solution for the wrong question." 40
13. "Challenge: Tool Dependency and Integration. Companies need to pick a set of tools and train employees accordingly. Such a decision is not an easy task and there is no tool that satisfies all needs.

Moreover, integration between systems modeling tools and others, such as simulation or requirements, is still solved with specific solutions.” 13

14. “Peer Pressure Pays. The outside experts mentioned above could convey to our executive leadership their informed assessment of the state of the industry in a way that we practitioners could not. Their assessments are far more authoritative than ours could be, so that when they warn of JPL falling behind and becoming less competitive if it does not proactively engage with MBSE, the message is compelling and believable. In this way we have found that peer pressure pays in terms of building institutional support for MBSE. Likewise we have found peer pressure within JPL to be an effective driver of infusion. IMCE has organized several lab-wide opportunities for emerging MBSE-based efforts to showcase their work and share lessons learned. The obvious benefit of course has been to cross-fertilize and share learning across many efforts. The additional benefit is the spirit of healthy competition which has been fostered.” 5
15. “The models afforded by MBSE, specifically SysML, were shown to bridge the gap in communication between engineers and medical professionals. This suggests that the same benefit may be seen when working with professionals in other non-engineering domains. The ability to formally model aspects of the system, and display them simply enough for all stakeholders to understand, proved invaluable.” 38
16. “Expose the stakeholders to the model, but not in more detail than absolutely necessary - The model is a tool to enable design decisions to be made not an end in itself. Depending on the stakeholder group and the level of experience of the MBSE practitioners, the early and frequent engagement referred to above, may devolve into a discussion on the minutia of the model or the modelling process rather than being used as a forum to make decisions or discuss options and trades. Some stakeholder groups may, if allowed, become enamored of the model or the modelling process rather than focused on making the decisions the model was created for.” 16
17. “Challenge: Large Models Visualization. Different team members are involved in querying the model contents. Unfortunately, existing tools require additional training effort, and customizing the layout of model elements and diagrams is time consuming. Additional challenges appear in large models, where model navigation and understanding become highly complicated.” 13
18. “the process itself needs to be visible, with a clearly defined purpose and observable benefits of using supporting models – using models or diagrams to communicate complex use cases and system functionality is likely to be beneficial and improve communication of design information, but the process by which this is done must also be clear.” 22
19. “the tool must be used as a communication aid, as well as for storing and executing design information. It would require the development of a system model with the appropriate structure to communicate data between multiple domain-specific tools in order to execute and analyse the validity of the proposed system.” 22
20. “Benefit for project: The ability to embed recognizable graphical icons within the models to represent system elements allowed for the models to be intuitively understood without a great deal of additional explanation. This enhanced communication was perhaps the most outstanding benefit of employing a model-based approach to engineering a system.” 18
21. “Build models hierarchically and eschew "eye chart" diagrams. Each diagram should be built for a specific purpose, and only the information needed to communicate that purpose should be included in the diagram. Additional purposes can be served with additional diagrams or reports. Most of these large diagrams can—and should—be built hierarchically, in many smaller diagrams that each

attempt to capture a small number of key concepts. Capturing too many layers of hierarchy in a single diagram makes it difficult to read and understand. A good rule of thumb was found to be to limit the scope of a diagram to what can be viewed on the computer screen without scrolling." 34

22. "Pilot programs can use available tools for early exploratory work. The principal value of the pilot effort is to provide valuable insight into the MBSE problem space, demonstrate the value of system modeling, architect the conceptual model, and serve as the launching point for the next iteration of the organization's evolution to an MBSE end state. The models themselves should not be seen as the principal objective of that effort. And the program should be willing to entertain changing tools if it is clear that the pilot toolset is not the most suitable solution for the longer-term effort." 6
23. "Keep the Focus on Engineering Products. Keeping focused on real engineering deliverables is important to avoid the pitfall of delivering a modeling solution everyone thinks is finished but which doesn't provide the required engineering answers. After all, the engineering deliverables are the whole point of the exercise. Our early attempts at "rolling up the mass" for the mass margin report showed this in stark relief: getting the numbers to add up, make sense, and be reliable turned out to require significantly more modeling and scripting than expected." 4
24. "Problems arose to a higher extent between system engineering and other specialty engineering disciplines. In spite of special training provided for, e.g., safety engineers, the feedback was that the models were very difficult to interpret. A conclusion is that model based projects should be prepared to provide "traditional style" information in the form of documents in order to, at some level, serve specific engineering disciplines when requested." 2
25. "It is not possible to make all stakeholders (of the model content) proficient in interpreting and navigating the model. Consequently, a way of extracting information from the model to traditional documents must be established so that stakeholders/colleagues can view and review model content as effective as with a traditional document approach, without extensive mentor support." 2

Resources for Implementation (Cost to Use Tools, Willingness to Invest):

26. "MBSE does imply heavy investment as well as a steep learning curve, especially in the initial phases, and is beyond the scope of a single project." 41
27. "MBSE adoption requires a substantial upfront investment, especially if it has not been considered before. This also includes determination of an effective investment strategy, accurate cost estimation and quantifying its return on investment." 13
28. Two approaches dominate MBSE adoption: off-cycle (in a sandbox environment) or on-cycle (directly on productive projects). The first approach is considered ideal, as not all companies have the required budget and time. The second approach is much more challenging and introduces additional costs for running projects. Choosing the wrong strategy can negatively impact the benefits of MBSE." 13
29. "… it is clear that the resource needed to align large teams to a coherent modelling methodology has been underestimated. Modelling opens up many new possibilities in terms of capturing design information and some stakeholders see the opportunity to revolutionise their engineering process. Here, the challenge is to communicate the cost associated with meeting ambitious objectives and the risk imposed by setting ambitious objectives that cannot be readily met by the current generation of SysML tools." 24

30. “For instance, companies with high available upfront investment might suffer from having the freedom that each department starts to define its own MBSE adoption solution. This brings later integration and model interchange issues.” 10
31. “Good tools are costly; time to implement MBSE before starting the project is costly; until it becomes mainstream or someone demonstrates value at no cost to them, many will resist.” 14
32. “The second challenge mentioned, the additional costs and efforts, requires an organizational proactive approach to put in place an overall infrastructure including training, toolset and MBSE support team. The costs mentioned in the challenge section have to be fully or partly supported by the overall organization rather than by the project itself. Training is already funded by the JSC Human Resource training department. Similarly, tool costs should be subsidized by the overall engineering organization in order to facilitate the insertion into a project and ensure standardization across projects.” 45
33. “Having enough skilled resources to support the MBSE efforts is critical to its successful adoption. Mentors should be made available to partner with the Systems Engineers in order to support the adoption of modeling practices and tools. Effort and budget is required to provide project mentors who can participate as part of the project team and be involved in the system design and integration.” 45

Organizational Change Management

DE/MBSE Terminology, Methods and Processes (Maturity):

34. “More time should be spent on properly defining how to best use existing methodologies, which therefore appear to cost much more time and resources than necessary. Time must be set aside to build up an MBSE-friendly infrastructure; otherwise MBSE practices will also be considered a burden, because they are not well defined.” 27
35. “Challenge: Method Definition and Extension. It is often necessary to customize an appropriate method according to a defined purpose and scope. It is a challenge to set up the required method, document it and facilitate it with modeling rules, guidelines, tool customizations and training materials. Further challenges arise when new method extensions are needed.” 13
36. “Apply engineering methodologies that support effective modeling of the architecture both horizontally and vertically. The modeling method must support the definition of end-to-end system threads, preserve decomposition, be executable, and provide the capability to associate requirements to the elements within the behavior model.” 9
37. “Tools are perceived as not really mature at least for SysML and language is found too complex so people prefer using MS Visio.” 14
38. “Tools and methodologies issues. projects also seem to create their own “style” in how ‘they’ decide to utilize MBSE on a project.” 14
39. “No common terminology for MBSE… There are no process models that integrate MBSE properly.” 44
40. "Do not use SysML for requirements handling only! since it was not meant to be used as such, it becomes a bit awkward and unhandy as compared to other tools, which are better suited to this kind of use." 32
41. “A well-defined MBSE method is essential. An MBSE method must be clearly defined to support the model development. The method should also provide guidance on how to organize the system model to ensure it can be navigated, managed, and controlled.” 42

42. “By having the project team clearly identify their goals in adopting MBSE, one can better advise them on the method to follow. The method defines the concepts and rules to model the system. Using the method, the engineers can ensure that the models used to describe the structural and behavioral aspects of their systems are created accurately. The JSMT developed a meta-model, as a foundation to the modeling method, to capture the system architecture, hardware interfaces, and command and telemetry interfaces. The tools that extract data from the system models are used to generate multiple target products. This is aimed at providing added value to the project team.” 45
43. “Have the new MBSE processes well documented so you better understand what tool you will need.” 1
44. “The project team found that SysML-based MBSE practice provides a great level of flexibility, providing systems engineers with numerous options for facilitating and capturing systems engineering knowledge throughout the system lifecycle. However, this high-level of flexibility imposes the need to design the model structure carefully and select the most appropriate metamodel, SysML diagrams, and model elements to suit the project. This selection needs to be formalised and supported with model design rationale, in order to ensure consistent practices between team members, and across projects internal or external to an organization.” 16
45. “Models are Meant to be Abstractions. A common misconception of MBSE is that in order for the model to be useful it must describe everything, and describe it to a fine level of detail. This misconception needs to be corrected for an infusion to succeed, because otherwise resources will run out long before the job is complete. A key principle we have followed is to model only as far as we need to answer the question at hand. Assuming this is done on an infrastructure of common languages and tools, then the model can grow over time, as necessary, and each new model element will add synergistically to the body of work.” 4
46. “It is important to realize the necessity of different levels of abstraction, their relation and how to effectively use them.” 27
47. “One must be mindful when conducting the modelling task of the level of model fidelity needed, the purpose of the model, the questions that need to be answered, and not to model for the sake of modeling. Thus, the purposes of creating the model must be clearly defined upfront.” 15
48. “Establish a consistent approach towards the definition of equivalency relationships within the Model Based Engineering Environment. Specifically, a rigorous process must be in place to establish equivalency relationships, and to modify or remove equivalency relationships when associated artifacts change, undergo versioning, or are removed. Without a consistent process, equivalency relationships can become confused, corrupted, or lost, leading to unreliable traceability throughout the ASoT implementation.” 40
49. “For example, is it possible to have a single, unified model? If not, how should different heterogeneous models communicate? How should different disciplines and attendant models interact with each other? What measures need to be taken to assure common assumptions and consistent semantics across different models from the different disciplines? How should quality attributes be incorporated in system models and how can the models be analyzed in terms of the degree to which they satisfy the quality attributes? What is the best way to capture knowledge, decisions, decision rationale, and expertise of system engineers? Last, since a model is a shared, living representation of multiple domains of interest, how can a consistent “baseline” be established, and how should it be reviewed?” 30

50. “Defining different use cases for a use case diagram has allowed a cyclical requirements analysis. Thanks to this analysis it is possible to correctly translate the business requirements in system requirement.” 31
51. “Closely related is the lack of stopping criteria. Modeling easily becomes addictive. It is easy for an engineer to over-detail the parts he knows well and overlook what he less understands. It should be the opposite: hot spots of a system must be modeled with greater care.” 8
52. “An organization should create its own, domain specific cookbook when introducing MBSE. Domain independent recipes and practices can be collected in a commonly shared cookbook…which provides modeling patterns, recipes, guidelines, and best practices for the application of SysML.” 27
53. “It is also worth underlining the importance of adequate modeling guidelines clearly describing what information should be captured in UML/SysML and what should be captured using traditional methods. In the absence of such guidelines, users have a tendency to add information to the model just because the possibility exists, leading to information inconsistency and redundancy.” 2
54. “Not separating need and solution modeling is a major but common mistake. This actually is not a MBSE-specific problem, as customers and engineers are often too early diving into the solution, overlooking the problem space [12]. Adopting a new approach is an opportunity to change this wrong practice. Not separating need and solution blurs the reading grid of the model and increases the risk of delivering a system that actually does not fully satisfy the original operational needs.” 8
55. “Another major pitfall is keeping several engineering levels in the same model “for the sake of simplicity”. The architectural design of a system is not the same thing as the architectural design of each of its subsystems: Lifecycle are different, contributors are different, design drivers might be different, etc. Performing the design of a system and a subsystem in the same model is a major error that has led to significant refactoring work 2 or 3 times on … projects these last years.” 8
56. “Build in flexibility to adapt to future needs. Architects of the integrated set of system models should provide some flexibility in the structure of the models to allow them to grow to encompass new applications.” 34

Data/Model Accessibility and Libraries:

57. “There should be methods to capture, store, access, and share both artifacts and the central model.” 42
58. “The project team recommends creating an appropriate structure and defining where each type of textual component should be stored, since there are various locations available.” 16
59. “Ensure that the model is centralized and distributed. This does sound like a contradiction, but it is possible. Mostly it involves making MBSE a reality. A centralized repository for the information as opposed to a file-based system ensures that people are able to access the model as a whole rather than snippets. In addition, because of the pervasive nature of the model elements and the need for cross-references, much of the model is required for most operations. Keeping as much information in the model simplifies traceability considerably and helps ensure completeness, correctness, and consistency. It also provides a means for impact analysis.” 23
60. “In some cases, the technical debt that has accumulated in the models makes reuse of the model untenable, and significant refactoring of the models—if not complete reconstruction from first principles—may be the most effective approach to take in the long run.” 34
61. “Acquire required metadata for each digital artifact needed in order to support access control, search, approval, and recompete. Develop and adhere to a standard for the metadata collected. The

ASoT requirements call out collecting artifact expiration dates, country-of-origin, country-of-delivery, information criticality, non-functional requirements such as manufacturing constraints, and cost and scheduling metrics. The ASoT requirements also call out evidence to demonstrate the provenance of digital artifacts, such as the tools used to build or generate the artifact, the contract guidance used to produce the artifact, marking and licensing information (even from previous contracts), template models used to produce the artifact, and analysis results and certification results associated with specific versions of the artifact." 40

62. "It is easy to fall into the trap of putting semantics into diagrams: the semantics must be instead fully defined by the model behind in order to create more artifacts from the same source in an automated way: this requires an expensive initial effort which pays back many more times later on." 27
63. "Models Evolve. The model needed in concept formulation is very different than the model needed in detailed design, or in operations. Models need to evolve and grow, and sometimes shrink. This should be the focus of model reuse along the project lifecycle. It also helps to answer the people who will suggest that building a detailed model of the last flown mission will help you formulate the next. It all goes back the principle of modeling for a purpose, and not more. While the models may change, these changes can be evolutionary and cumulative as long as they are connected by a common set of ontologies and methodologies." 4
64. "the more the analysis can be separated from the model, the more reusable it will be. For our mass analysis we have achieved a high degree of separation of the model from the analysis, and as a result we are able to run exactly the same mass analysis script on all three of our mission option models. The corollary to this is "keep the model aligned with the concept rather than with the analysis". We initially found ourselves adopting modeling patterns which made the analysis scripts easier (drifting back into the Excel mindset). But we soon discovered that in order to further expand and refine these analyses, we would be forced to model in more and more non-intuitive ways. Therefore we discovered, and adopted, the principle that the model should be kept intuitive and aligned with the concept. We are convinced that the extra work required to make the analysis tools work is well worth it in the long run." 4
65. "What constitutes a complete set of models is a fundamental gap that is beyond the purview of MBSE. Also, the specification of model uses and how to use models is an overarching concern for model-based approaches." 30
66. "Focus on the underlying data, not just diagrams. While diagrams are the most visible products of a model, a well-architected model can provide many more insights through queries and automated report generation than the hand-assembled diagrams can by themselves, and additional views can be generated from that model through automated model transformations." 34
67. "At the commencement of every project, it is essential to establish a package structure to enable model elements storage, data accessibility and control, model management, and data exchange." 15
68. "But if the first mission element took longer than expected to analyze … the second and third ones showed the power of developing reusable methods: they each took a fraction of the time of the first. For the first mission element… both model capture and analysis were performed in the SysML model and the mass report took approximately two work-months to complete. The subsequent two concepts we modeled … each took about one half work-month each. And, a subsequent change of … design was accomplished in a fraction of that time. So, our advice is to first focus on description, and then implement analyses. A large part of the benefit accrues as soon as people start using the

descriptive models, and this gives time and support to allow the more difficult work of analysis to be done.” 4

69. “Separate the Model from the Analysis. … Two troublesome characteristics worth mentioning in this context are: as it is commonly used, the model and the analysis are inextricably intertwined; and by the nature of the tool, the model is forced into a form which facilitates the analysis. It is clear that the more a model can be a self-contained, internally self-consistent, and an intuitive description of the concept, the more informative it will be. Moreover, the more the analysis can be separated from the model, the more reusable it will be… The corollary to this is “keep the model aligned with the concept rather than with the analysis”. We initially found ourselves adopting modeling patterns which made the analysis scripts easier (drifting back into the Excel mindset). But we soon discovered that in order to further expand and refine these analyses, we would be forced to model in more and more non-intuitive ways. Therefore, we discovered, and adopted, the principle that the model should be kept intuitive and aligned with the concept. We are convinced that the extra work required to make the analysis tools work is well worth it in the long run.” 4

70. “Challenge: Modularity and Reusability. Many organizations still follow an opportunistic and isolated reuse approach, where a set of data is copied and pasted from one context to another. Unfortunately, this still happens even with system models and results in losing the “source of truth” as soon as the copied source or pasted target is changed.” 13

71. “Provide Versioning, Variants, and Backups. If possible this should be done on a whole model basis. Again, this ensures that impact and traceability can be assessed against the whole model. If done on a section by section basis, it becomes more likely that version skew will take place.” 23

72. “Model configuration management is different. Configuration management of these descriptive models is a little different than for typical analytical models. The reason for this is that these descriptive models share some features with analytical models (software) and some features with program documentation (static documents). Like software, these models are contained in electronic files. Like program documentation, these models are intended to describe the system primarily for human understanding across multiple perspectives, and therefore need to reflect the system more precisely than typical analytical models, which only need to capture the essential abstracted characteristics of the system as it pertains to that analysis perspective. However, some of the unique properties of these models may add complexity to the configuration management process. For example, software configuration management typically relies on textual comparisons of software source code and checksum calculations performed on binary files. In contrast, system models are neither textual nor linear in nature, so model comparison will be much more complex. For example, moving a graphical model element within a diagram constitutes a change to the model file, but may or may not represent either a syntactic or semantic change. Because of these unique characteristics, configuration management processes for models will need to incorporate and improve upon the appropriate features from both software configuration management and document configuration management practices.” 6

73. “Another part of the MBSE infusion approach that has been successfully implemented … is the creation of a library of reusable models. By providing exemplary reference models, a project can jump start the model development. During SysML model development, for various projects, models that has the potential for re-use were collected for future projects. [we] designed a preliminary library structure for re-usability. As a result, some common representation and re-usable elements

have been established that are shared with new projects to leverage at project initiation. A library of reusable SysML elements is essential to assisting beginners and expert modelers in adopting MBSE.” 45

74. “Acquire the data rights for each digital artifact … Consider technical data, computer software, and computer software documentation data rights and communicate the DoD’s desired rights in the solicitation for each procurement based on the TD and CS strategy according to Defense Federal Acquisition Regulations Supplement (DFARS) 207.106 in the Acquisition Planning Phase of the procurement. The Statement of Work and CDRL should identify negotiated data rights for each digital artifact to be delivered… Communicate data rights and distribution marking policy for all types of digital artifacts that the ASoT will manage. Communicate the granularity with which markings are to be applied within diverse types of artifacts. For example, policy might call for data rights markings applied at the level of blocks in a SysML model.” 40
75. “Communicate the approved representations for each type of digital artifact. Adopt and adhere to a set of approved representations (languages, formats) to facilitate interoperability between different ASoTs and to simplify the recompete of any digital artifact. During our demonstrations we found that contemporary tools can manage and relate different data representations, but to configure and maintain these tools requires engineering effort.” 40
76. “Communicate the security policies that will enforce authorized access to digital artifacts stored in the ASoT. Stakeholders contributing digital artifacts to the ASoT should understand how the ASoT will protect those artifacts. The ASoT requirements call for security policies addressing, for example, information sensitivity, contractual rights, and organizational role.” 40
77. “MBSE needs to incorporate artifacts/objects that are maintained outside the MBSE database. For example, detailed design drawings, which are created using specialized tools, are generally maintained in a configuration-controlled external database. Accessing these drawings from within the model, while maintaining consistency of the model with these drawings inevitably leads to parallel systems that need to be individually maintained while remaining mutually consistent.” 30

Change Management Process Design:

78. “A successful MBSE adoption effort must address enterprise level challenges, such as: Identification of organizational changes and new skills training required for all constituent organizations within the enterprise needed in a digital environment over the full lifecycle of systems.” 35
79. “An organization or project team should not make the transition to MBSE in an ad-hoc manner, but should employ concepts of organizational change in support of continuous improvement. These concepts include clearly identifying the issues to be addressed by MBSE, engaging stakeholders, developing and executing a plan for improvement or transition, and monitoring the results.” 19
80. “Efficiency requires reengineering the business process, rather than just building the legacy process into the model.” 26
81. “The adoption of MBSE is not isolated to the System Engineering department. It affects the entire set of engineering disciplines and overall business enterprise.” 35
82. “The most challenges related to MBSE adoption are noticed to be based on the human and technological factors. It starts with the awareness and change resistance on both executive and engineering levels within an organization. It goes over having the right MBSE resources to define the purpose, scope and method. Additionally, these challenges need to be addressed from the early phases and directly depends on the executive sponsorship and available upfront investment.” 10

83. “The human factor plays a central role, particularly if key players have different levels of MBSE knowledge and adequate time for training is not granted. Consequently, change is not always accepted, compared to existing approaches, it creates strong resistance due to the lack of expertise to deliver the required artifacts.” 13
84. “Grow capabilities slowly (through a roadmap) to more advanced capabilities.” 36
85. “Bring everyone to adoption (i.e., avoid creating castes).” 1
86. “Operational users get lost in their objectives, face difficulties with the tooling. Damages are there already when help is sought, typically leading to blaming the method and workbench.” 8
87. “The adoption of MBSE and the development and implementation of the digital engineering environment requires systems engineering methods and rigor. If not applied to the definition of requirements, development of the CONOPS, analysis of organizational impacts, and security concerns and the planning of development and integration, the resulting implementation of tools and the information technology infrastructure will likely fall well short of the strategic needs of the business and the functional and performance requirements.” 35
88. “Standardization of language across domains is necessary to aid in communication between teams.” 22
89. “To alleviate the perception of increased risks, targeted presentations are created and directed to new and potential users that explain the benefits of using MBSE, highlights the available models and tools, and presents successful project experiences. These presentations need to clearly emphasize the value proposition of MBSE and provide evidence on how the project can benefit by adopting MBSE.” 45
90. “More time should be spent on properly defining how to best use existing methodologies, which therefore appear to cost much more time and resources than necessary. Time must be set aside to build up an MBSE-friendly infrastructure; otherwise MBSE practices will also be considered a burden, because they are not well defined.” 27
91. “Pilot projects can be used to validate the MBSE approach. A pilot project should be well planned with clear objectives, deliverables, milestones, and sufficient resources to achieve the objectives. In addition, team continuity with effective leadership and stakeholder participation are essential.” 19
92. “As a consequence of not adapting how projects were planned and executed, the MBSE initiative often became an isolated effort, not part of the generic planning process, leading to unclear goals and objectives. Successful implementation is a management issue, and requires managers have the relevant understanding/competence. However, this necessary education/training is often not taking place on all levels.” 26
93. “There is resistance to enforced consistency. Smart people like to do things their own way, which makes collaboration and knowledge transfer more difficult.” 26
94. “Tooling inertia describes phenomena of the current in-house tooling environment that made our participants refrain from adopting MBSE. Tooling inertia includes resistance against learning new tools as well as potential incompatibilities of MBSE tools with current tools, and resistance to integrating new tools.” 44
95. “Inertia cannot be easily offset without a change agent or a technology champion. Understanding where to champion the efforts and at what level of the project, is important to successful adoption of MBSE.” 45

Organizational Design

Workforce (domain) Knowledge/Skills:

96. “There is a learning curve associated with reprogramming engineers. It can be more difficult to learn a new way of doing a familiar task than to learn it fresh.” 26
97. “Another major inhibiting factor is the availability of skilled practitioners; not just to actually execute MBSE-based projects, but the advocacy and energy of our most talented modelers is now spent in projects (a good thing) without much time left over to educate management or practitioners in other parts of the adoption curve than early adopters (not such a good thing).” 14
98. “The final lesson learned is the addition of new team members to the trade study. As the trade study matures and goes through cycles , team members come and go. One of the biggest challenges for the team is bringing new team members up to speed on the Trade Study itself. Background knowledge ... is critical. Since the Trade Study continues moving forward, bringing any new person into the team would require them to come up to speed on all existing [knowledge], the trade study work done so far, as well as keeping up with current trade study work being done. ... The Trade Study team has found an incredible value of MBSE and this modeling methodology when bringing new team members up to speed rapidly. Tradition SE practices would have a new team member reading thousands of pages of documentation on each of the network processes and systems. Using MBSE and our specific model, new members are able to go to one source for all information they would need to come up to speed on the study as the existing network diagrams have all been created already. At the same time as the new team member is parsing through previous cycle diagrams to learn the working of each network and what the integrated solution might be, the team member can also browse models which are currently being created so the transition from keeping up to speed on the study, to producing for the study, can be as smooth and painless as possible. This has enabled our team to bring in new members and quickly get them up to production capability for the team, which in turn allows the team to shift off veteran members to further work in any one of the specific cycle programs.” 3
99. “In the early formulation phase in which we find ourselves there is a curious duality. On the one hand, the key work in early formulation centers around conceptual thinking. The spacecraft we propose are mere sketches, and a critical function of models is to describe the design space generously, in which the concept can evolve and take shape. On the other hand, we must always show that our concepts are feasible, and one of the ways we do this is build and analyze a ‘point design’ which we analyze for technical resources, performance, and cost. The models that we build to address these two disparate viewpoints must of necessity be partly conceptual and partly realizational. This should not mislead one into thinking that the space between them must be entirely filled in: it has proven very workable to have some parts of our model be treated as strictly conceptual, and other parts be treated as realizational (e.g., for the mass margin analysis).” 4
100. “Models Evolve. The model needed in concept formulation is very different than the model needed in detailed design, or in operations. Models need to evolve and grow, and sometimes shrink. This should be the focus of model reuse along the project lifecycle. It also helps to answer the people who will suggest that building a detailed model of the last flown mission will help you formulate the next. It all goes back the principle of modeling for a purpose, and not more. While the models may change, these changes can be evolutionary and cumulative as long as they are connected by a common set of ontologies and methodologies.” 4

101. “Models need to be architected and peer-reviewed. The conceptual model and the organization of models into modules can significantly impact their usability, consistency, and maintainability. It is important to have experienced architects familiar with both the problem space and the capabilities of the tools to lead that effort.” 34

Workforce Tool Knowledge/Skills:

102. “the first infusions will not have the benefit of an engineering pool with ubiquitous modeling skills…we found that the best way to get started on the right path was simply to hire as many of the existing cadre of skilled MBSE practitioners as we could afford.” 4
103. “Get Outside Expertise. From the very beginning, visionary managers … brought in world-class outside expertise to teach, advise, and guide our adoption of MBSE. These experts imbued our efforts with a maturity and credibility which would otherwise have been achieved through expensive trial and error. In addition, because some of these experts have also been in positions of executive leadership, they were also extremely helpful in helping executive leadership … understand the value proposition for MBSE. So outside expertise has proven invaluable both for the quality of the infusion itself, as well as the institutional support for the infusion.” 5
104. “Team Organization Matters... The pattern we have found that works well is a three-tiered one involving a small set of core modelers within a larger set of modeling-savvy systems engineers, within a larger set of all project personnel. While we have found that descriptive modeling can be done by almost anyone with the basic training, the additional rigor and consistency needed for quantitative analysis requires us to designate a smaller team of people who are modeling experts and who can apply best practice to the official configuration managed project models. Presently we have a core modeling team of a half dozen or so, within a larger team of 20 or so engineers. The experienced systems engineers provided guidance to keep the modeling focused on providing useful information, as well as mentoring of the core modelers who tended to be more junior. Frequent (daily) interactions were crucial to getting useful products: we were pathfinding so we had to stay very closely in touch. As important as it is to have a core modeling team, it is just as important to avoid fencing them off from the rest of the project. If the models are to be useful to the project, the project must understand and interact with the modeling team regularly, and likewise the modelers must be engaged in the larger engineering effort. Modelers who are also capable systems engineers will naturally employ their modeling skills to deliver engineering products in a model based way.” 4
105. “Given the modeling and analysis tools now available, an MBSE methodology is essential — otherwise every student invents their own, and this lesson carries over into the practice of MBSE as well.” 37
106. “There is a need for a team of expert modelers that can be provided by the organization to any project. In the past it was identified as a critical core function to develop and maintain a cadre of users for applications such as CAD and Finite Element Analysis since an individual project could not afford the time to train project members on the proper use of these detailed modeling tools. MBSE should be treated in the same manner. The time to train a MBSE modeler and to become proficient at the tool is beyond the ability of any single project. Another problem is that the MBSE modeler on one project may not continue with MBSE after that particular project. The time invested to train that modeler is lost when the project is completed. By having a team of MBSE modelers matrixed into all projects, the skills can continue to improve on each new project.” 45

107. “Models are Meant to be Abstractions. A common misconception of MBSE is that in order for the model to be useful it must describe everything, and describe it to a fine level of detail. This misconception needs to be corrected for an infusion to succeed, because otherwise resources will run out long before the job is complete. A key principle we have followed is to model only as far as we need to answer the question at hand. Assuming this is done on an infrastructure of common languages and tools, then the model can grow over time, as necessary, and each new model element will add synergistically to the body of work.” 4
108. “Prefer methodological knowledge over domain knowledge - While it would be optimal to have practitioners with a sound understanding of both MBSE methodology and the domain being analysed, this will not be achievable in all instances. If this is the case, it is recommended that an experienced MBSE practitioner be preferred to a domain expert. To extend Logan’s (2011) observation on MBSE enforcing good SE: expert application of MBSE on a group of domain experts will elicit a better product than a less than expert application of Systems Engineering on the same domain savvy personnel.” 17
109. “No matter how much UML/SysML and tool training is performed, there is a critical period in any project where engineers are getting frustrated in their attempts to apply the MBSE techniques. This is partly due to the gap in complexity between the comparably simple examples used in training and the size and complexity of the product under development… experienced mentors were engaged to assist developers to overcome such frustration and to ensure that modeling guidelines were applied by the individual developers. The mentors also had the responsibility to verify and approve implementation of tool/method “add-ons,” such as report generator implementation, document templates, and modeling guidelines. By experience, at least two members in the project team need to have experience in development with the use of object-oriented methods, the modeling tool, and large-scale models. Having two experienced persons reasoning about how to plan the modeling approach and how to partition the model, brings stability and safety to the proposed and adapted method. Initially, in a project, it seems desirable to have one experienced mentor for every 5–7 developers... Naturally, mentor support can be decreased as developers gain proficiency. With less mentor support, the risk increases for a diverging model and/or insufficient stringency or quality in the model/system.” 2
110. “Skill in modeling comes mainly from practical work and the learning curve to become highly productive seems to be 3–6 months, depending on modeling focus, engineering back-ground, and ambition. A wide range of learning curves was observed; one engineer with a good background in object-oriented methods became highly productive in 1 month. Hence, pilot projects for MBSE introduction should be allowed to have longer calendar time allotted, until the first increment of system analysis and design has been completed. For following increments the calendar time can be “paid back” through increased efficiency gained by the MBSE approach. With this initial investment in the “core development” phase, …we believe that there is a great potential for cost and time savings in the following phases.” 2

Integration to Support the Digital Implementation (Tool Infrastructure):

111. “The MBSE implementation itself is a system of interest (SOI) and requires the same systems engineering technical processes and any other SIO for successful design and development. As one SOI within the larger digital engineering system-of-systems, the MBSE SOI will most likely be integrated into an existing network of engineering tools, networks and data repositories.” 35

112. “Operational engineers have spent too much time installing and configuring the engineering workbench, which has impacts on their operational milestones.” 8
113. “Communicate the approved tools that the DoD will require stakeholders to use. Communicate these selections in the solicitation and/or Statement of Work. The ASoT requirements call out the need for a registry of approved modeling and analysis tools and the need to store the model analysis results in a systematic way that supports examination by subject matter experts.” 40
114. “The model building tools allow the import of data from different sources; this accelerates the building of the model. One of the objectives is to leverage existing artifacts that stakeholders have built to accelerate the development of models. Creating a tool, … to generate elements and diagrams from an Excel spreadsheet was the beginning of the toolset development. Modelers utilized this tool to build models directly from existing spreadsheet artifacts they have collected.” 45
115. “Tools to validate the generated models and products were developed to check for adherence to the recommended modeling method. For example, before the SysML Builder plug-in builds the model, it checks the accuracy of the data for import. As more stakeholders were exposed to the modeling method and tools, they requested additional capabilities to extract an increasing number of system design artifacts. Expanding the tool suite and generated products makes MBSE useful to a broader audience and increases the stakeholder involvement.” 45
116. “To build these MBSE tool suites in house, it was necessary that [we] develop a set of processes to guide the specification, development and deployment of the tool suites, and a unique set of SE skills within the cadre of engineers who execute these processes.” 20
117. “Tool selection should be driven by needs. Stakeholder concerns and needs for the models should be solicited first, then the desired outcomes for the project, as these should be the ultimate drivers for the project. The questions that the models are intended to answer to achieve these outcomes should be identified, followed by the products that the model set needs to contain or produce to answer these questions. Then, the methodology to be followed to develop those products through the sequential application of system modeling concepts should be fleshed out to the point where the needs of the modeling language and the tools are made explicit. This process provides a traceable framework for identifying tool needs based on the stakeholders’ needs for the integrated set of models.” 6
118. “Security classification issues complicate model management. While one of the strengths of the MBSE approach is that the model can be queried and transformed to construct a near-infinite variety of customized views, some of these views may result in classified associations of information. This may pose a significant challenge for security review of models.” 6
119. “13. Tools and modeling languages evolve very quickly. These modeling tools and modeling languages are evolving quickly, so any tool assessment, no matter how disciplined the decision process, will also become out of date quickly. The model architects will need to keep up to date with the latest developments in the modeling tools, explore the new features and capabilities being added with each new release, and understand what old bugs or deprecated modeling constructs have been eliminated. Establishing a reusable tool and language selection criteria provides a repeatable method for assessment.” 6
120. “Communicate the interfaces approved for access to other stakeholder ASoTs, such as OSLC. Our tool survey revealed that of the two common approaches for tool integration (either build a custom interface or build to a common standard), building to a common standard is more scalable and better supports future capabilities.” 40

121. “Consider … Tools that support standardized, interoperable data representations and interfaces provide flexibility and enable the credible threat of recompete.” 40
122. “Invest in open standards. To meet engineering objectives an organization may need to use multiple tool environments. For example, an organization might use MagicDraw for a modeling environment, IBM DOORS for requirements management, and IBM Rational Change Management for change management. Any significant engineering effort generates a vast amount of data, with data overlapping in representation and storage. An ASoT should integrate accumulated data so that query operations can traverse data relationships.” 40
123. “Automated Web-Based Model Reports are Critical. One of the issues faced by adopters of MBSE is that the default vendor offerings require a consumer or reviewer of model information to use the vendor tool. Because the tools have a significant learning curve, this can present an insurmountable hurdle to acceptance among non-modelers (i.e., management, sponsors and review board members). As luck would have it, a separate team … had already invested in and developed a solution.” 5

Demonstrated Benefits/Results:

124. “In contrast, the discipline specific Subject Matter Experts (SME) generally are not very interested in the MBSE approach since system integration is not their primary responsibility. The benefits to the individual discipline are often overshadowed by their direct responsibility. To win over the SMEs, there needs to be some concrete added value provided to them. By demonstrating some of the tools described below, the SMEs can be convinced to give MBSE a try. For instance, producing documents, and requirements compliance matrices from the information captured in the models, and showing the ability to produce the reports that project management and design engineers utilize during the design process can demonstrate how MBSE based approach can assist the SMEs in their daily activities. Demonstrating the capability to support the communication between all the project stakeholders is also important to obtain acceptance of the MBSE approach. Showing evidence of successful projects that have benefited over time can help the project justify the additional costs.” 45
125. “the project team members need to be convinced that the extra effort required to develop the models provides some direct benefits. Generating products such as a parts list, connectivity information, telemetry and command data, requirements and traceability from the model is a considerable help for the project team. SMEs and other stakeholders can also benefit from these products.” 45
126. “Resolving disconnects is a key benefit of MBSE. These disconnects linger unnoticed because the document-centric approach for knowledge management results in many information stovepipes that may only intersect due to serendipitous circumstances. However, building models based on the available data sources was found to be very useful in exposing the disconnects, driving stakeholders to recognize the disconnects and beginning the process of resolving them. The state of consistency of the program’s technical baseline will determine how much time is spent resolving these issues. If the MBSE effort is being tracked against schedule milestones, it is important to realize that this time spent is more a benefit of MBSE than a cost of MBSE. MBSE found the latent problems—it did not create them.” 34
127. “First Description, Then Analysis. Another common misconception is that models are not really useful until they can be subjected to quantitative analysis. This is simply not the case. Capture and

description are powerful and far-reaching first steps. Just describing something in a formal modeling language like SysML immediately improves communications and understanding. The benefits of this would be difficult to overstate." 4

128. "Change impact assessments. Changes to the conceptual design continually occurred during early supplier engagements. The Operations Concept Definition (OCD) and Maintenance Concept Definition (MCD), System, Subsystem requirements and interface requirements were analysed by various SMEs and refined. The inherent traceability of the MBSE approach significantly assisted these impact assessments with a near end-to-end visibility from project business requirements to functions and interfaces to system and subsystem requirements. This has enabled trade-offs to be made against the user's operational requirements and commercial off-the-shelf (COTS) products offered by suppliers, with the intent to minimise customisation in products." 39
129. "Using Enhanced Functional Flow Block Diagrams (EFFBD) for scenario modelling were found to be novel to the … system acquirer, supplier and user, and considerable time was spent on advocating the benefits of using this method. The best EFFBD scenario review results came from preparing the reviewers with a simple flow block diagram example, explaining the purpose of the information captured in them, and keeping the review session numbers low (1 –3 people). Following a few sessions, majority of the reviewers were able to utilise the diagrams to create a shared understanding of socio-technical interactions between multiple operational and technical stakeholders." 39
130. "sharing the model with all stakeholders and making it the reference. Once a model is recognized as the reference, it is used as a source for other engineering activities and its existence becomes therefore less likely to be challenged. Evangelization, coaching and MBSE commitment from the management are necessary to reach this goal." 8
131. "Best practice: Using diagram automatic generation when possible instead of manually maintaining diagrams." 8
132. Demonstrated "ability to link system elements and components to the requirements and provide end-to-end traceability from the final system architecture, back to the original customer goals." 18
133. "A model-based architecture [is a] valuable communication device, especially for stakeholders who desire system information to be conveyed quickly and efficiently." 18
134. "…some short time benefits can be easily obtained. For instance, communication between cross-functional teams, single source of information, traceability between requirements and system artifacts etc. Project planning need take this into account and commit sufficient resources in advance avoiding budget over-runs later." 41

Programs/Projects Using Methods and Processes:

135. "A crucial basis for MBSE adoption is to define a clear purpose and scope (the why and what). Ideally, it must be precisely described before beginning the deployment. However, this is a challenge in real world applications, where modeling can be used in so many ways." 13
136. "For new programs the challenge is to gain adoption early during the program definition phase. Short time-to-market leaves little time for learning MBSE once the program begins, yet there may be little demand to learn an MBSE approach prior to having a targeted program for application." 11
137. "Well-defined modeling objectives and scope are critical to MBSE success. The application of MBSE to a particular project should have a well-defined purpose, objectives, and scope, and the scope should be consistent with the planned resources and schedule." 19

138. “Indisputably the most important of all best practices is to set clear modeling objectives right from the beginning of the project: identification of inputs and outputs of the model. Ideally, these objectives would be captured in a model management plan, also containing the modeling guidelines.” 8
139. “A third lesson learned is the division of modeling between two geographical diverse teams. … Each team has a lead modeler which has some background in MBSE, and thus, their own ideas of how models should be constructed and how information should be represented. This is a problem since one of the main goals of this modeling work is to link information from the software diagrams to the operational process flows, and vice versa. If two teams are not on the same page, as far as modeling methodology, this could present a problem when it comes time for integration/linking… the modeling team has gone through several iterations of methodology discussion before finally settling into a final methodology. Even with everyone seemingly on the same page, the team still finds it important to meet on a regular basis to reevaluate the modeling standards for the trade study and discuss any issues occurring or that we might see on the horizon.” 3
140. “By providing a graphical, navigable model template with standard notation for architectures and behaviour, development time can be reduced and the benefits of more complex modelling features can be extracted over the course of multiple projects. Best practices can be built into the model template structure.” 22
141. “Replace the "vicious cycle" with the "virtuous cycle" (If a model isn’t being used, it won’t get the resources or attention needed to keep it current and relevant. However, if a model isn’t current and relevant, it won’t be used) (virtuous cycle, in which the models are so highly valued and frequently used that the enterprise is compelled to commit the resources to maintain them, which allows them to retain and expand upon that value, and continue to increase in value).” 34
142. “Just Do It. We’ve found that the best way to figure out how to apply MBSE is to do it for real: make the commitment to adopt MBSE as the way to produce (at least some subset of) the project products, and then figure out how to accomplish this. This is in contrast to the suggestion sometimes made by skeptics, that a “safer” or “more gradual” approach would be to conduct a “shadow” or “parallel” pilot that allows side-by-side comparison of benefits and drawbacks, including cost.” 4
143. “Dashboarding. Dashboards were created for the digital systems model (DSM) to measure the level of coverage and were an effective way of communicating progress and areas of improvement to senior management. Model data in the DSM enabled these representations.” 39
144. “Best practice: Documenting the model. Not only should each model element be correctly and textually described, the global model should be given a reading grid providing external readers a logical path to browse the model.” 8
145. “Maintain the project schedule and ensure it is “trackable”. A project schedule that is trackable is one where the project schedule tasks and deliverables correspond to what people are actually doing on the project. This may sound obvious, but I have been unpleasantly surprised by too many project schedules to assume that this is always the case. Regular and short-term deliverables are essential to letting you know when you are falling behind. Finally, contingency planning needs to be done to investigate what to do when things go wrong.” 23
146. “Acquire the digital artifacts the DoD needs to approve and recompete the fielded system. “Knowing what you know” was a recurring theme in our discussions with stakeholders; data does no good if you cannot find it or do not have the rights to use it. Digital artifacts that the DoD requires to

recompete the system should exist within an ASoT that is under the DoD's control. Mark the digital artifacts approved for integration, and associate with each digital artifact the evidence that justifies that approval. Track the system throughout its lifecycle to identify the as-approved, as-built, as-maintained, and as-destroyed versions of the system. Acquire models to represent legacy components." 40

147. "CM Can Start Modestly. In thinking about the needs of a Configuration Management (CM) system for our models, we found that the Initial exploration in the IMCE Concept of Operations was helpful. Initially setting up the model to support collaboration, we focused on: structuring modules and packages with collaboration in mind; and we emphasized single owner packages in topically-defined modules. Model access permissions were set loosely for the time being. Lightweight versioning was found to be sufficient: Teamwork was used to track changes to model elements; DocWeb reports captured snapshot of full model and resource reports; reviewed and baselined versions are tagged as such in DocWeb. Quality Control is developing as needed: scripts are now doing some rudimentary model validation; a hand calculation is used before report release as final correctness check." 4
148. "Exploit "network effects" to accelerate adoption (the more a model is used, the more data it contains and integrates, the more valuable it is)." 34
149. "Model the "T" to explore both breadth and depth. Modeling needs and issues driven by the breadth of model scope were found to differ significantly from those driven by depth of modeling detail. Exploring both of these dimensions of modeling early in the model life cycle was found to mitigate the risk that poor decisions made early in the model's life are allowed to propagate far and wide as the model grows." 34
150. "Alongside with model progress monitoring, it is crucial to organize regular model reviews involving not only model contributors but also domain experts. The model cannot be considered as the reference if all stakeholders are not involved." 8
151. "Iterative Design Approach -Through regular stakeholder meetings to confirm the results of the operational and functional analysis, divergent (and at times conflicting) stakeholder expectations were able to be managed. Presenting previous decisions and the resultant analytical consequences enabled convergence to be achieved when describing the physical domain. A strength of using a model based, vice a paper based, approach enabled a relatively fast turnaround on the effect of decisions made by the key stakeholder group." 17

People in Model-Building Roles:

152. "Success here can be traced to the following factors: A clear objective with modeling from the start of the project creating a clear sieve for identifying information within scope of the model. Strict adherence to a tested pre-defined methodology. One single experienced user who took command of methodology definition (considering the constraints imposed by the tools used) and further refinement of the document generator." 24
153. "To counter the pitfall of capturing several engineering levels in the same model, use models as a means to perform co-engineering. In the case of a transition from a system to a subsystem for example, subsystem stakeholders have to be involved in any decision related to their subsystem and must validate that the high-level view the system stakeholders have is accurate, relevant and feasible." 8

154. “Seek the "killer apps" (specifically identified high impact applications of the methodology that can motivate each stakeholder to make the leap from skeptic to advocate).” 6
155. “We let the discovery of the need drive the solution. There was ‘top down’ innovation but not in the traditional sense of pre-ordained specifications: it consisted mainly of constant guidance during the modeling process to keep the effort focused on satisfying the end objectives.”: 4
156. “Real Examples are Powerful. Trying to describe to stakeholders and potential collaborators what MBSE looks and feels like has proven to be rather difficult and not very effective. We have found that many people ‘get it’ for the first time only when they see an actual example.” 4
157. “Always take extreme care when showing diagrams to persons not introduced to SysML! Systems Engineers are nowadays used to MS Visio diagrams in which an exact and precise meaning is not associated with each type of arrows and blocks, and in which the purpose of the diagram is supporting a paragraph, or a document. This leads to misunderstandings, confusion and misinterpretations of the SysML diagrams. When a modeller presents a diagram to other engineers, he or she needs to make sure, before even explaining the diagram itself, that the others understood: the purpose of the diagram (e.g. showing architecture and not functions), what each type of element represents (e.g. physical block), and the meaning of each link (e.g. composition).” 32

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