

DATA CERTIFICATION IN MODELING AND SIMULATION (M&S) VERIFICATION AND VALIDATION

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ABSTRACT

Verification, Validation and Accreditation/Certification (VV&A/C) have long been required steps in producing a Model & Simulation (M&S) that will satisfy the user. It has also been largely under-resourced, sidestepped or ignored because of time and cost constraints. One of the perceived difficulties in performing VV&A is the certification of the data used in M&S systems. Data collection often commences with little or no definition of "*what specific*" data needs to be collected or how this data will be used in the resulting software model. Interjecting verification and validation of data, and hence data certification, at appropriate points during software development, can occur with little impact on development schedules. To be sure, certification of data is not free, but it does not have to be difficult and it can be accomplished within reasonable resource constraints. More importantly, this certification is absolutely necessary to achieve a valid model that can then be accredited for its particular use. This paper will show when data verification, validation and certification should occur during system software development. Additionally, it will propose a redefinition of data certification that will limit data use based on the validation of the data and the model that will use the data.

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WHAT ARE DATA VERIFICATION, VALIDATION, AND CERTIFICATION?

This paper will walk through the definitions, procedures, and recommended changes to the Defense Modeling and Simulation Office (DMSO) Recommended Practices Guide (RPG) and current Data Verification, Validation, and Certification (VV&C) practices.

examples and possible improvements. It is useful during the discussions below to have an understanding of the generic M&S process with VV&A (see Figure 1).

'Today's Definitions

Confusion exists even in the definitions of Verification, Validation and Certification of Data. Listed first below is the overall definition of Data VV&C. Following that are some representative definitions of the components of VV&C (and their respective sources). It is important to recognize that although the definitions are similar in some respects, there is no single clear-cut definition in any of the components of VV&C. It is also important to recognize that VV&C must be considered from either the data producer or data user perspective.

Data Verification, Validation, & Certification (VV&C) (as defined in "DoD Modeling and Simulation (M&S) Master Plan 5000.59-P"). "The process of verifying the internal consistency and correctness of data, validating that it represents real world entities appropriate for its intended purpose or an expected range of purposes, and certifying it as having a specified level of quality or as being appropriate for a specified use, type of use, or range of uses. The process has two perspectives: producer and user process."

Data Verification:

Data Verification (as defined by "DoD M&S Data Administration Strategic Plan - Apr 96). "The assessment of data with the intent to ensure that they satisfy specified constraints and relationships, conform to specified data standards, and are transformed and formatted properly for their intended use. Data user verification performs this assessment using specifications derived from the intended use of data in a particular model for a particular purpose. Data producer verification performs this assessment using standards and specifications derived from

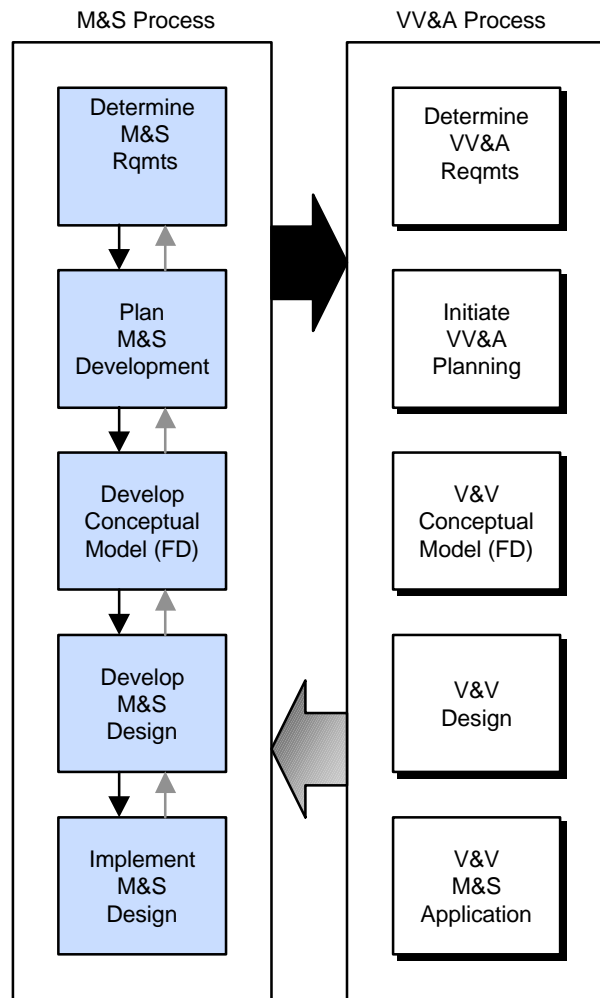


Figure 1. M&S Development with VV&A.

The Joint Countermine Operations System (JCOS) program will be used for illustrative

the producer's mission statement or the requirements of a specific data user or community.” (DTWG VV&C Task Group - Nov 95).

Data Verification (as defined by “DOD INSTRUCTION 5000.61, DoD Modeling and Simulation (M&S) Verification, Validation, and Accreditation (VV&A)”). “Data verification is the use of techniques and procedures to ensure that data meets constraints defined by data standards and business rules derived from process and data modeling.”

Data Verification (as defined in “DoD Modeling and Simulation (M&S) Master Plan 5000.59-P”). “Data producer verification is the use of techniques and procedures to ensure that data meets constraints defined by data standards and business rules derived from process and data modeling. Data user verification is the use of techniques and procedures to ensure that data meets user specified constraints defined by data standards and business rules derived from process and data modeling, and that data are transformed and formatted properly.”

Data Validation:

Data Validation (as defined in “DoD M&S Data Administration Strategic Plan - Apr 96”). “The assessment of data for their intended use by evaluating the methods by which data values have been derived and comparing those values against independently-acquired values that are either known or best-estimates. Data user validation performs this assessment with the intent to ensure that data are appropriate for use in a particular model for a particular purpose. Data producer validation performs this assessment with the intent to ensure that data satisfy stated validity criteria and assumptions, derived from the producer's mission statement or the requirements of a specific data user or community.” (DTWG VV&C Task Group - Nov 95).

Data Validation (as defined in “DOD INSTRUCTION 5000.61, DoD Modeling and Simulation (M&S) Verification, Validation, and Accreditation (VV&A)”). “The documented assessment of data by subject area experts and its comparison to known values.”

Data Validation (as defined in “DoD Modeling and Simulation (M&S) Master Plan 5000.59-P”). “The documented assessment of data by subject area

experts and its comparison to known values. Data user validation is that documented assessment of data as appropriate for use in an intended model. Data producer validation is that documented assessment within stated criteria and assumptions.”

Data Certification:

Data Certification (as defined in “DoD Modeling and Simulation (M&S) Master Plan 5000.59-P”). The determination that data have been verified and validated. Data user certification is the determination by the application sponsor or designated agent that data have been verified and validated as appropriate for the specific M&S usage. Data producer certification is the determination by the data producer that data have been verified and validated against documented standards or criteria.

Data Certification (as defined in “DOD INSTRUCTION 5000.61, DoD Modeling and Simulation (M&S) Verification, Validation, and Accreditation (VV&A)”). “The determination that data have been verified and validated.”

How Is Data VV&C Performed Today?

Verification

Although not well defined, much of the verification of data today is "provided" by the data producer. That is, the producer of the data usually provides data that addresses specific items, such as: “who” produced the data; “when” the data was produced; rudimentary information on “how” the data was produced; and identifies the authority that "certified" the data. The data producer may also act as a "data user surrogate" and perform some V&V services as to the usability of the data given the model/algorithm/intended use.

The DMSO VV&A Recommended Practices Guide (RPG) calls for a parallel VV&C data certification process in conjunction with the M&S VV&A accreditation process. Additionally, data certification can be viewed from both the perspective of the data producer or the data user. This paper will be focus on the data user (specifically, the model and/or simulation that will use the data). It should be noted that the terms “data user” and “software developer” will be used synonymously. However, the term "user" by itself will refer to the actual end user of the finished simulation system..

Data verification means that the data produced conforms to the specification and this is usually a function of the data producer.

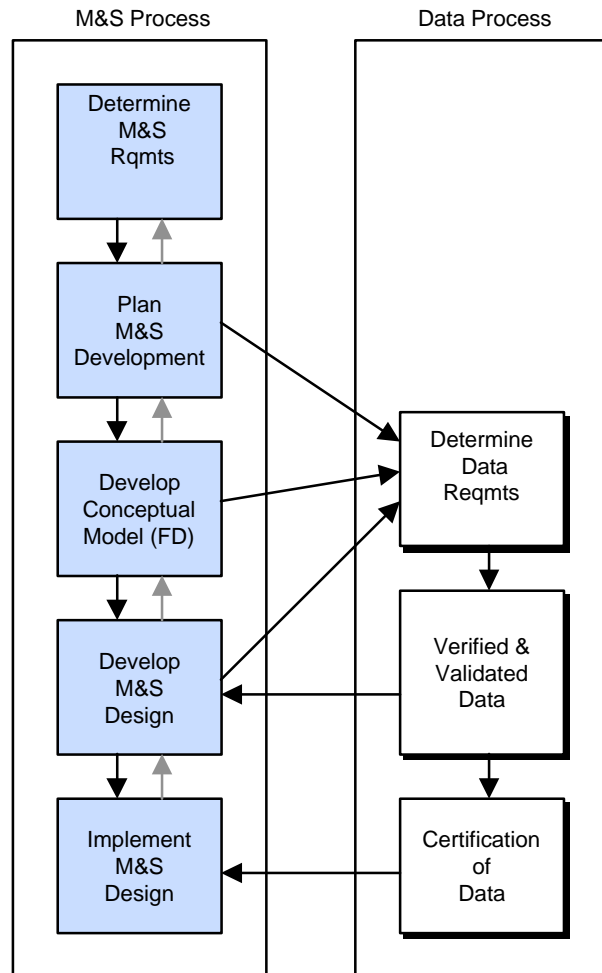


Figure 2. M&S Development Process with Data VV&C

The JCOS Example

JCOS uses A/B tables to determine probabilistic outcomes of interactions between ships and mines, and Mine Countermeasure (MCM) systems and mines. A sample simplified table is shown below (see Figure 3). This mine detonation data is generated by the Total Mine Simulation System (TMSS), a United Kingdom one-on-one engagement simulation developed in response to the Falklands war. This data is used in the U.S. Navy NWP-27-1, "Mine Countermeasures Operations" document. This link from the accepted TMSS model to a naval warfare publication provides the pedigree and authoritativeness of the data.

MINE TYPE	VEHICLE GUISE	MINE SENS	OCEAN ENV
XXX	SHIP X	MOST	GOOD

SPD	DEP	AW	B	F	BD
10	20	254.0	.85	185.0	.1
15	20	200.0	.78	150.0	.1

Figure 3. Unclassified Example of A/B Table used in JCOS ModSAF Code. Table wrapped to fit column width.

An explanation of the table in above follows:

MINE TYPE: Self-explanatory - However, it is important to recognize that the first column shows the interaction "point of view." Specifically, this determines what happens with the mine as the ship approaches, versus what happens with the ship as it approaches the mine.

VEHICLE GUISE: The specific ship that is approaching the mine.

MINE SENS: Mine Sensitivity, considered either most or least.

OCEAN ENV: Ocean Environmental Conditions, considered either poor or nominal (good).

SPD: Speed of the approaching ship (in knots)

DEP: Depth of the mine (in meters)

AW: Actuation width (in meters) - the path width within which the system (the ship in this case) will interact with the mine.

B: Characteristic actuating probability. The average probability of the mine detonating once the ship is within the actuation width.

F: Dangerous Front (in meters) - the path width in which there is a likelihood a platform (the ship in this case) will be damaged by the mine's detonation.

BD: Damage Probability - the probability that the system (the ship in this case) will be damaged if it comes within "dangerous front" distance from the mine.

The authoritative data produced by TMSS and then used in the JCOS MODSAF code is

considered certified by the producer and, therefore, verified for use by the data user. The data producer "produced" the A/B tables for the JCOS code based on the users' "intended use."

Validation and Certification

According to the DMSO RPG, data validation should demonstrate that the produced data represents the "real world." The data user should perform this data validation function. However, currently many data producers are asked to complete this phase. This is the case in JCOS because the data is produced from TMSS; which is an accepted data production simulation and is used for real world planning for mine countermeasure operations. Thus it is accepted as authoritative, real world data acceptable for the intended use of the JCOS simulation.

Although data is often considered "verified" and "validated" at this point, it still has not been used in the M&S by the data user. Data certification should determine if the data is suitable for a "specific" use. Some M&S developers request data from producers having stated the data's intended use. The producers then provide data to meet that "intended use" and consider the data "certified." This "verification" by the data producer and subsequent "validation" by the data producer and/or user is then assumed to be tantamount to "certification." Other programs often use "results testing" of the implementation to complete the "certification" of the data. If subsequent test results are "successful," the data is automatically deemed to be "certified."

JCOS considers the A/B table data produced by TMSS to be "valid." After JCOS ModSAF implementation, the resulting simulation is "tested" to see if the results of interactions support the data provided by TMSS. Essentially, the simulation is being tested to ensure that the implemented "valid" A/B Table data is not somehow "distorted" and yielding different results from those expected. However, if the simulation results match the information provided in the A/B tables, the resulting simulation is often considered "valid" and, subsequently, the data is considered to be "certified."

HOW CAN IT BE IMPROVED?

Data Verification

Meta Data (Where did it come from? How was it produced?)

Part of the problem in "data VV&C" arises from misunderstanding the difference between the "data producer VV&C" and the "M&S data VV&A." Although the data provided may be authoritative and reliable from the data producer's point of view, it has not been integrated into the "new" environment of the model (and/or simulation) that will be using the data. Verification by the data user requires the data producer to establish the data's pedigree and authoritativeness by providing "meta data" for the "produced" data. This meta data should include how the data was produced, what variables were present during its production, and the definition/format of data elements.

JCOS A/B tables can easily provide this "meta data" because the TMSS system is documented and has a set number of defined input variables that control the generation of the resultant tables. Additionally the produced data elements are well defined.

Conceptual Model Development

The idea of "conceptual models" is not inherently new, but the formalizing of the process of conceptual model development and the subsequent V&V of conceptual models IS relatively new. Functional Descriptions (FD – formerly and incorrectly called a conceptual model), the conceptual description of the real world object that is to be simulated, are the basis for software design. Functional Descriptions are implementation independent but simulation dependent descriptions of real world objects or tasks. "Specific" data is often collected after FDs and/or requirements specification are completed. However, sample data for algorithm development and/or "real world" data availability should be part of the FD. This is not normally the case today, and, therefore, there has been little to no effort to directly link data to the FD.

FD verification can be defined as, "Did I build the thing right?" Is the data contained in the FD "authoritative" (real world) and of the correct "resolution" to support the intended use? Determining what data is "available" and

“authoritative” is part of the verification process of data and should be accomplished as part of the FD verification. Items that should be verified include:

- Is the data authoritative, real world?
- How does the FD use data?
- Does the produced data support the resolution of the FD(s)?

The first bullet is a relatively simple matter of tracing the "pedigree of the data". The second is more involved but is integral to the development of the FD. The last bullet is critical to the success of the software developer. If the data doesn't support (or doesn't exist to support) the FD resolution, then the first point of departure in deciding what to change (resolution of FD or "translate" data) is made. The verification of the FD is the developers first attempt to ensure that the produced data included in the FD and FD resolution support each other.

Although FD often contains performance data, this data is not meant to be used by software development personnel to design and develop code, but to simply serve as a foundation for subsequent knowledge engineering (KE) tasks. The first version of a conceptual model should provide just enough information to perform KE activities. At this point in the development of an FD, a software model design describing the specific physical system has not been developed by domain design personnel. This lack of a software design makes it almost impossible to produce an FD that will contain all the data/information that may ultimately be required to model the physical system or mission task.

Feedback from the KE and software development processes should ensure that the conceptual model is modified to include information and data that is required to support software design/implementation. If this “feedback” approach is not taken, an inordinate amount of time could be spent describing a system in the initial conceptual model that probably will not provide all the pertinent information and data that is required to model the system.

For example, the JCOS FDs did not contain any links to or discussions of the A/B Tables generated by TMSS. Therefore, there was no verification performed to determine if the FDs supported the A/B Table data. Once the A/B Tables were determined to be the appropriate

interaction data, this information should have been fed back through the FD process for validation.

Data Validation and Certification

The Functional Description

The FD's V&V must be documented. According to the RPG, this documentation "explains why (or why not) the assumptions, algorithms, modeling concepts, anticipated data availability, and architecture of the FD are expected to provide an acceptable representation of the subject modeled for intended application of the model or simulation." Additionally, interactions with other models or simulations must be taken into account. This is true for the FDs, as well as being true for the data that supports the FD and further software design. It is important to remember that data validation from a user's point of view requires that the data be "appropriate for use in an intended model". This data validation must be done at the FD stage for all the same reasons that M&S validation of a FD is done.

Data is validated when the FD is validated in the "normal" M&S VV&A process (see Figure 1). FDs are a "consumer" of data verified by a data producer. Ultimately, when the FD is validated, the data contained in the FD is itself, validated.

The RPG states that, "Conceptual model verification and validation should occur before further M&S development to avoid the potential pitfall of inaccurately representing the system and not meeting the proposed requirements. Errors caught at this early stage of development are easier and less expensive to fix."

JCOS did not perform formal validation of the data with the FD but had to answer many of the questions that FD validation would have done at the implementation stage. These questions include: Is the resolution of the FDs sufficient for the data in the A/B Tables (and visa versa)?; Are the interactions described in the FDs such that the A/B Table data can be used? For example, in Figure 1, BD is damage probability. Is the damage model in the JCOS simulation capable of handling this probability? In its current form? Speed in the A/B Table is measured in 5-knot increments. Does the kinematics model of the ship in the JCOS simulation use only 5-knot increments? Does it have more (1 knot increments) or less (10 knot increments)

resolution? If the kinematics model is in 1-knot increments, what happens when the ship is approaching the mine at 13 knots? It could be argued that the software developer asked the data producer for A/B tables in 5-knot increments knowing the resolution of the ship kinematics. Or he may have known he was going to write an algorithm to interpolate between the listed table speeds. How are these trade-offs documented? How does the user of the JCOS simulation know what he is getting? Documenting this information in the FD gives the user and software developer the assumptions/limitations of the "produced" data.

Additionally, results were not being achieved as expected given an A/B table implementation. Detonations happened only at the Closest Point of Approach (CPA) not before or after. Depending on the intended use, is the valid? Documentation of this phenomena during validation will let the user determine the validity of this representation. The additional effect of this implementation that would have to be considered is the damage that would incur given a CPA detonation. Most likely this would be the yield the worst case damage for every mine detonation. Although certainly not "real world", perhaps valid, perhaps not valid – the intended use would yield the validity of this simulation implementation.

Software

Software validation asks many of the same questions with regards to data. Is the implementation model of the same resolution as the FD? If so, data validation should be simple. If not, does the data need to be "translated" for use by the implementation model? If so, how is the data translated? If this is the case, we now have a "new" producer of data that probably has additional VV&C requirements. However, if rigorous conceptual model validation is completed, there is a high degree of confidence that the software implementation of data will be acceptable. The RPG lists numerous ways to perform validation of software. However, it is interesting to note that none of the validation methods separate the "data" from the "algorithm" while performing validation activities.

JCOS Implementation Models used the A/B Table data and are currently being tested for validity. Many questions had to be answered about the resolution of the data and the resolution of the software models to determine the best

implementation scheme. Although this path may work, the confidence the program manager and programmers have in the implementation can be drastically improved with a VV&A plan that includes data VV&C from the start.

Data & Limitations

Verification should first form a list of data use assumptions/limitations

Functional Descriptions should contain an assumptions/limitations section that clearly describes the assumptions and limitations of the process descriptions, inputs and outputs, and provided data contained within the FD.

Pedigree - The user and the software designer need to know how the data was produced. Is that data "authoritative?" What was the resolution of the models (or "real- world" entities) that produced the data? What were the assumptions and limitations on the processes that produced the data? This is the first step in capturing the important "meta data" of the produced data that is going to be introduced into the M&S under development. It will be captured in the assumptions/limitations section of the FD. It provides a level of confidence to the user and necessary design requirements to the software designer.

In JCOS most, if not all, of the pedigree information was provided to the software designers. Although this process is necessary, the elimination of feedback to the FD and FD validation introduces risk and a lower level of confidence. Additionally, the data not validated breaks the chain of traceability required for software validation and ultimately M&S accreditation.

Functional Description - How is the M&S going to be used? Is there a resolution problem between the FD and the data? Are there supporting interactions? These are questions the conceptual modeler should be asking when including data in the FD. The software designer will also ask these questions and will provide direction to the FD for specific software design supporting data. This feedback "look" ensures data inclusion in the FD and subsequent validation.

As one example, in the case of JCOS, the conceptual modeler might ask what are the

environmental conditions used in generating the A/B table? Are they the same (or same resolution) as the FD defining the environment?

Certified Data Use Has Limitations

Validated Data - As stated earlier, data is validated with the conceptual model. However, it is explicitly tied to that conceptual model (which is validated for an intended use). This by design puts a limitation on the data as presented to the software designer. A perhaps overly simplified way of expressing this limitation is: Model (or algorithm) + Data = Simulation (or Model). The data by itself has little use, the model by itself is incomplete. The meta data/pedigree helps define how the data was produced and therefore the resolution requirements of the models that will use the data.

In JCOS this information was not formally gathered or validated through the complete VV&A process. It was provided at the software design/implementation phase of development and as such carries a higher degree of risk.

Validated Model - A validated FD includes on first pass meta data and sample data (or pointers to producer of data). After the Preliminary Design phase and Detailed Design phase (as data requirements are refined with final determination of algorithms) exact data is added to the FD and a "re-validation" occurs which serves to "certify" the selected data. Again meta-data and use restrictions accompany data and conceptual model. This leads to the determination that, from a user's perspective, there is not a separate VV&C process for data certification. Data validation ("certification") comes when it is included with the conceptual model and traced through the high level design, detailed design, software verification and software validation. Therefore, there is only VV&A of an Model or Simulation and the "data certification" becomes an integral part of the VV&A process.

CONCLUSION

Steps to Data Certification (Validation)

From a data user's perspective (a developer of conceptual models and M&S), Data Certification is "part and parcel" of the VV&A process. The M&S developer's VV&A plan should include procedures to handle producer "certified" data with

meta data (data verification) as part of the FD validation (data validation), software verification, and software validation (data certification) (see Figure 4). The DMSO sponsored VV&C Tiger Team has over the past year also come to the determination that, from the Data User's perspective, VV&A of the resulting M&S and VV&C of the requisite data are not separate and parallel processes but are indeed a single integrated process.

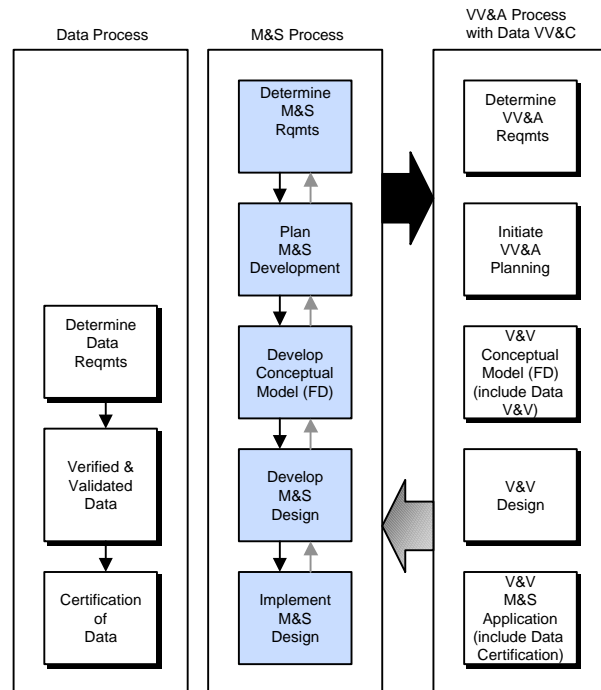


Figure 4. M&S Development with Data VV&C as part of M&S VV&A.

Limitations to Data Certification

Limitations of the data must be brought forward with the data as it is combined in the FD. Pedigree, resolution, and interaction limitations should be well documented in the FD both for user validation and software design considerations.

Proposed Definition of Data Certification for Data Users

Again from the data user's perspective, data VV&C is performed with the "normal" verification, validation, and accreditation steps. Data Certification adds sub-steps to the already defined VV&A steps that are performed in conjunction with M&S VV&A. I would propose the following definitions for data users Data VV&C:

Data Verification. Data user verification is performed during M&S verification and is an assessment that the data producer's data is certified and formatted properly for their intended use.

Data Validation. Data user validation is performed as part of M&S Functional Description validation and is an assessment to ensure that data is appropriate for use in a specific model for a specific purpose.

Data Certification. Data user certification is performed as part of M&S software validation and is the determination by the application sponsor or designated agent that data has been verified and validated as appropriate for the specific M&S usage.