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Guidelines for Writing IVHM Requirements for Aerospace Systems

RATIONALE

The term Integrated Vehicle Health Management (IVHM) encompasses a set of capabilities that enable efficient sustainable operation and maintenance of components and subsystems within aerospace platforms. It is defined as “the unified capability of a system of systems to assess current or future state of member system health and integrate that picture of system health within a framework of resources and operational demand” [REF1]. Currently, there is little guidance addressing the development of IVHM system requirements. Current practitioners use knowledge developed exclusively through practical experience rather than following an established process. Systems with IVHM capability have unique challenges, which require a designer to look beyond their own field of expertise and consider the constraints and specifications of other interlinked systems. This Aerospace Recommended Practice provides working engineers and program managers overall guidance on all the elements of IVHM they need to consider when developing design requirements for a particular IVHM system.

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1. SCOPE

This Aerospace Recommended Practice (ARP) provides guidance on developing requirements for systems that include Integrated Vehicle Health Management (IVHM) capability [REF1], [REF18]. IVHM is increasingly being implemented on military and commercial aircraft. Some examples include the F-35 Joint Strike Fighter (JSF) [REF1] and the AH-64 Apache [REF3] in the military domain, and the B787 [REF4] and A350XWB [REF5] in the commercial domain. This document provides a systematic approach for developing requirements related to the IVHM capabilities of a vehicle system. This document is not intended to repeat general guidelines on good requirements writing [REF13], [REF20]. Instead, the focus is on the unique elements, which need to be considered for IVHM and the resulting specific guidelines that will help define better requirements and hence better systems. The multi-faceted nature of IVHM should include the process of requirements gathering. Therefore, this document presents some guidance on how to go about this task. The document also includes some case studies that illustrate, in a practical manner, what a good set of IVHM requirements might look like. These have been taken from real life examples, but have been generalized for the purpose of this ARP.

Section 3 of this ARP introduces the general requirements and considerations from the perspective of various stakeholders. This is followed by Section 4 describing the entire systems engineering process for IVHM systems showing how IVHM requirements are linked to other systems engineering elements, such as the verification and validation (V&V) process. Section 5 provides a detailed description of the requirements breakdown structure and writing process, including the taxonomy of a requirements document. Section 6 provides some examples of IVHM core (stakeholder) requirements for representative air vehicles, and Section 7 provides an application of the guidelines as an example.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

- [REF1] Ian K. Jennions, Integrated Vehicle Health Management: Perspectives on an Emerging Field, SAE International 2011.
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- [REF4] http://www.boeing.com/commercial/aeromagazine/articles/qtr_4_06/AERO_Q406_article4.pdf.
- [REF5] <http://www.airbus.com/aircraftfamilies/passengeraircraft/a350xwbfamily/technology-and-innovation/>.
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2.2 Acronyms and Abbreviations

ACMS	Aircraft Condition Monitoring System
BITE	Built-in Test Equipment
CBA	Cost Benefit Analysis
CBM	Condition Based Maintenance
CMS	Centralized Maintenance System
ConOps	Concept of Operation
COSSI	Commercial Operations and Support Savings Initiative
FMECA	Failure Mode, Effects and Criticality Analysis
FWS	Flight Warning System
HL	High Level
HM	Health Management
HUMS	Health and Usage Monitoring Systems
ICD	Integrated Control Document
INCOSE	International Council on Systems Engineering

IVHM	Integrated Vehicle Health Management
JAA	Joint Aviation Authorities
LGS	Landing Gear System
LL	Low Level
LGCU	Landing Gear Control Unit
LRU	Line Replaceable Unit
MEL	Minimum Equipment List
MRO	Maintenance, Repair, and Overhaul
OEM	Original Equipment Manufacturer
RMS	Reliability, Maintainability, and Supportability
SE	Systems Engineering
SRD	System Requirements Document
SSA	System Safety Analysis
UAV	Unmanned Aerial Vehicle
WRA	Weapons Replaceable Assembly

3. AN INTRODUCTION TO IVHM REQUIREMENTS

At the very highest level, IVHM delivers the sustainability needs of an aircraft. IVHM is comprised of a comprehensive set of hardware and software components either in the air and/or ground segment. Since IVHM capabilities refer first of all to a particular vehicle system, which is the source of current and future health state, operations and maintenance decisions of individual aircraft are embedded in the higher levels of fleet management. These constraints should be considered during the system design process.

IVHM supports cost, safety, and performance benefits of a vehicle. Each health management (HM) function must “buy” its way onto the platform. In other words, IVHM capabilities will only be implemented if it contributes to those requirements as justified by a previously carried out cost-benefit analysis. Of course, there are exceptions for mandatory requirements such as safety-related ones for reaching airworthiness credit. Refer to AIR6275 [REF6] for a comprehensive discussion of conducting cost benefit analysis (CBA) for an IVHM system.

The major assumption in this document is that HM systems are being developed concurrently with the aircraft systems they will support. In the recent past, many systems have been retrofitted into the vehicle to solve a particular monitoring or maintenance issue. While there is a place for such systems, the vast majority of IVHM systems will be included in the vehicle design of the future. Therefore, IVHM functionality will be a top-level objective. This requires consideration of requirements allocation that explores the reality that not all IVHM requirements reside in a single subsystem bucket and may need to be allocated appropriately. Many times IVHM requirements are decomposed and allocated to various subsystems on the vehicle, in addition to the IVHM system. In other words, everyone has a role to play in fulfilling a high-level IVHM requirement.

The implementation of the specific IVHM objectives for a given vehicle is best described as a process, which (in most cases) will be carried out by a multidisciplinary team. In many projects, the IVHM team will be independent of the vehicle design team from a line organization standpoint, however, they will need to work in close coordination with other parts of the integrated product team (IPT) because the design process will be iterative. These teams will include the mechanical and electrical component IPTs, the controls and the reliability, maintainability, and supportability (RMS) teams, as well as safety assessment teams.

IVHM requirements are derived from stakeholder priorities driven by their business outcomes or use-cases. In commercial aviation, the investment in IVHM is largely driven by economic factors. IVHM should maximize the operational availability of the vehicle as well as minimize maintenance costs. In military aviation, the rationale for IVHM requirements has another accent. The emphasis is on mission availability and performance whereas cost takes a lower ranking.

The intention of IVHM is the reduction of direct maintenance cost (DMC) and the improved performance of a system. On a higher level, this might involve the vehicle, potentially involving dedicated sensors, hardware, and software. The IVHM design team will need to balance any projected savings or benefits with increases to the air vehicle direct cost and weight, to ensure an overall reduction in lifecycle cost. A cost benefit analysis should be conducted for each IVHM system, with benefits being direct and indirect. The benefit may not be immediate and may take some significant time after aircraft fleet introduction to be realized. Justification for an indirect benefit may be based on cost avoidance, such as a reduction in unscheduled maintenance. A direct benefit exists when the IVHM system is credited with replacing a scheduled maintenance event. The safety and performance enhancement also need substantiation. The architecture that realizes the IVHM functionality will likely be unique to each vehicle implementation, depending on the physical system to which IVHM is applied. Dedicated IVHM resources such as sensors and processing are often added only when required and justified. In almost all cases, however, there are top-level hardware, software, memory, and display resources that are needed to support the provision of an IVHM function, both on and off the air vehicle. For example, the accelerometers and processing needed for mechanical diagnostics are unlikely to be supported by standard air vehicle hardware resources. The signal generation and processing required to support structural health monitoring (SHM) is another example of where dedicated sensors and processing resources are likely to be required. In addition, there is a strong need for modularity and flexibility of the initial version of the IVHM system (e.g., through configurability of reports or recordings) for those cases that can only be identified after field experience with the vehicle. The implementation must wisely take these considerations into account.

An RMS assessment often leads to a system safety analysis (SSA) for the vehicle, including failure modes and effects analysis and functional hazard analysis. In this context, IVHM can be utilized as one of the methods to mitigate the impact of failures on system operations. Involvement of IVHM at this stage of the system assessment will result in a set of IVHM requirements that directly contributes to reducing the vehicle operational interruption rate.

The development of IVHM includes both processes and a technical system. One of the critical ingredients for writing good requirements is to make sure that all stakeholders have been identified; in contrast to classical design activities, stakeholders for IVHM requirements are numerous and multifaceted. A more detailed description of this is given in the next section.

4. THE SYSTEMS ENGINEERING PROCESS AS IT APPLIES TO IVHM

The intent of this document is to provide guidance on how to integrate the IVHM requirements development with the system's overall technical development process. Therefore, the recommended key concepts and steps are enumerated at the system level and details, specific to IVHM design and development, are provided for each of these system level steps. For more references to systems engineering (SE) process, please refer to [REF8], [REF9], and [REF10].

Various government agencies and commercial organizations describe different life cycle stages from a variety of stakeholders' viewpoints. Although these stages differ in detail or terminology, they all follow a similar process that includes systems engineering steps at their core. The high level SE process (lower part of as described by the International Council on Systems Engineering organization, INCOSE) is juxtaposed with the ISO generic lifecycle (upper part of Figure 1).

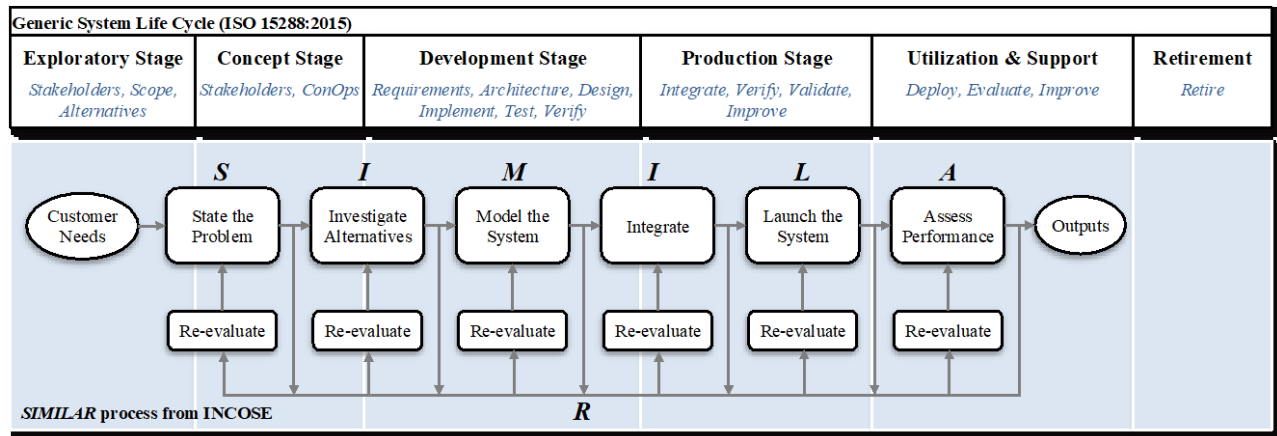


**Figure 1 - A generic approach to systems engineering process
(adapted from INCOSE and ISO)**

The detailed systems engineering process is well represented by the classic V-diagram as depicted in Figure 2. This shows the various tasks that need to be carried out during the development of a system. These tasks map directly onto the development and production stages in the system lifecycle. This document uses these stages as the basis for discussing the requirements development process. First, the SE process is described in the IVHM context (this section) and then, in the following section, recommended guidelines for writing IVHM requirements are provided. Since this document focuses on product requirements, the following sections will mainly cover the INCOSE/SIMILAR process flow until the utilization and support stage.

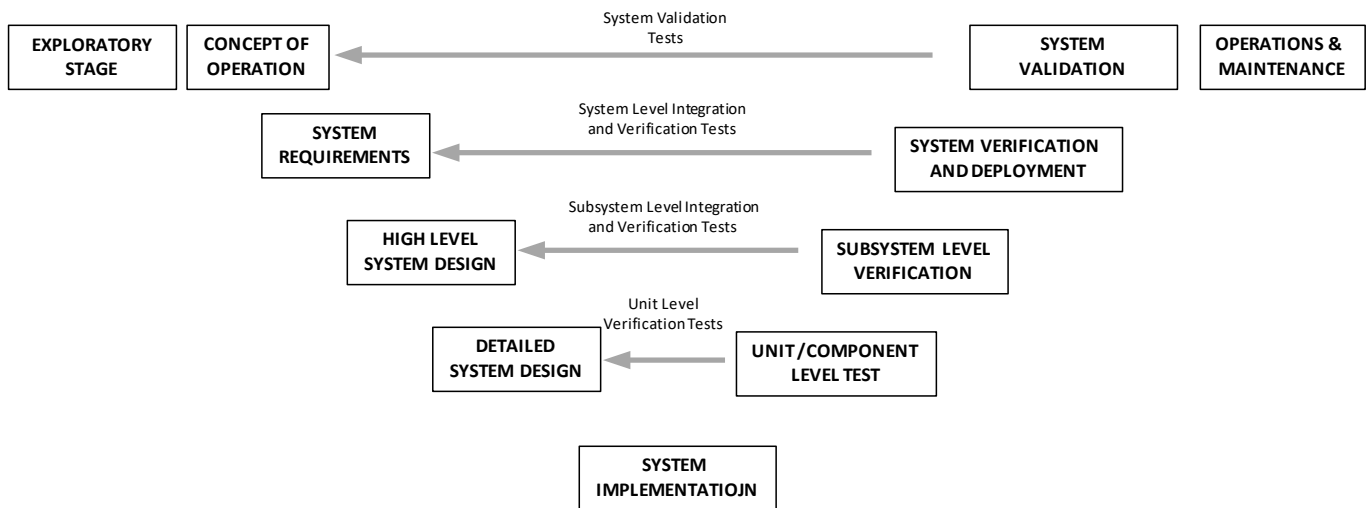


Figure 2 - Generic V-diagram depicting key systems engineering steps

This ARP uses the systems engineering process for identifying those steps where each time in the process a certain degree of IVHM definition should be provided, the scope of IVHM cannot be limited to a single system. Under that understanding, the definition of IVHM requirements can be considered as a transverse activity across all systems.

4.1 Exploratory and Concept Stage

The exploratory and concept of operation stage involves obtaining a clear understanding and justification of the customer's needs and system's constraints. This stage includes identifying user needs, exploring various concepts that meet those needs, and selecting a concept solution that can be developed and tested. Some key steps are:

- a. Identify stakeholders and needs for IVHM
- b. Define the scope of IVHM functions
- c. Develop the concept of operations (ConOps) and use cases for IVHM
- d. Identify various interfaces between components of the IVHM system and the vehicle for which IVHM is being developed
- e. Data inventory
- f. Upfront coordination between stakeholders and various subsystems
- g. Future initiatives

Each of these steps is now considered in turn.

4.1.1 Identify Stakeholders and Needs for IVHM

The key to the development of good requirements is to identify the stakeholders early and document their needs. IVHM involves a broad set of stakeholders, including line maintenance, maintenance management, owner, operator, customer, OEM, and regulatory authorities, to name a few, which can be categorized from a requirements perspective in the following manner:

- Maintenance personnel and management; e.g., line, overhaul, MRO
- Operating crew
- Fleet manager; e.g., mission commander
- Owner; e.g., airline/lease company/United States Air Force
- Regulatory authorities; e.g., airworthiness, certification
- General public
- Health monitoring system integrator; e.g., third party IVHM provider
- Original equipment manufacturer; e.g., OEM's internal integrated engineering teams developing the product

Each stakeholder may have his or her own unique interests to the IVHM capability under development. For example, the vehicle operator, who is often also the owner, is looking for fuel savings, increasing availability in the fleet, reducing turn times in the shops, and lowering maintenance cost. The maintainer (both line and shop) is looking for parts availability, highest throughput, and reducing no-fault-found (NFF) incidences, parts inventory, and maintenance cost, etc. If the maintainer has a long-term service agreement (LTSA) with the customer, its needs are very different than if they only had a time and material (T&M) contract with the operator or owner. The OEM and the ultimate end user also have stakes in recommending IVHM capability. All these considerations should be addressed from an integrated standpoint in order to avoid and separate treatment of stakeholder needs and therefore significantly different designs for IVHM. While this document focuses on new vehicle solutions, retrofit solutions will have their own unique set of requirements of cost, weight, compatibility, and the need to obtain supplemental certification. The highest desires of the stakeholders should be translated by the IVHM design analyst into high-level (HL) requirements. Once analyzed, these requirements should be translated to more detailed low-level (LL) requirements that are more specific and hence easier to verify.

Specifically, the activities in this step should try to answer the following questions:

- Who are the users of the IVHM capabilities of the system?
- How are the different IVHM stakeholder requirements addressed, such as: the level of automation, use of engineering analysis, what decisions/actions will the system generate in what kinds of man-machine interfaces, and what is the scope of the system?
- Given multiple stakeholders, an important question arises regarding work share. In an IVHM system, there will be IP and data issues that must be resolved. Who makes money from providing a service, what data is propriety, who holds the rights to what services, etc. Questions such as these must be answered to avoid conflicts later.

4.1.2 Defining Scope of the IVHM Functions

Defining the scope for IVHM functions is key to satisfying all relevant stakeholder requirements, setting expectations, narrowing down ideas, focusing on prioritized fault modes, and bounding the development effort. Complex designs consist of multiple subsystems comprising numerous components that can each develop fault modes that cannot be feasibly or practically tackled by IVHM. Therefore, the focus should be placed on those that are more critical from the overall system's point of view, while remaining within the overall scope statement. Specifically, this step is about correctly defining the enterprise vision: how do different organizations integrate together to provide IVHM, and what is the cost/data sharing strategy?

A scope statement should include the following information:

- **Justification (WHY):** Justification deals with answering some high-level questions, such as:

- What is the intent of the system being considered?
- What is its main purpose (priorities between cost and performance, without affecting safety)?

Note that much of the rationale for the IVHM capability will be derived from vehicle system requirements, from which, through a rigorous CBA, the justification for IVHM functions will be derived.

- **Objectives (HOW):** Objectives identify and track top-level vehicle requirements or system requirements as drivers for IVHM capability.

Define the IVHM functions; specifically, the IVHM outputs and/or the IVHM actions. These outputs can be a set of implemented actions based on prognostic estimates (autonomous functions), proposed alternatives, prognostic outlook, or just the current state estimate.

- How will the IVHM output be used?
- How will IVHM affect, and/or be affected by, other related system development activities?

- **Product Scope (WHAT):** The features and functions of the products, services, and/or results the project will produce.

- What is the scope of the capability being considered?
- Will the real-time on-board system be capable of adaptation to, or an enhancement to, the supply chain for maintenance or logistics?
- In addition to the reliability of the system and its components, what level of criticality is required? Will the capability be mission, safety, or flight critical? How will the criticality impact specific and general vehicle system requirements? Additionally, how will criticality affect IVHM itself such as design assurance level, process rigor required, architecture impacts such as dual string IVHM, etc.?

- What is needed - diagnostics, prognostics, decision support, or decision-making, etc.?

An increasingly significant element of requirement development is security. Security considerations include information sensitivity, data rights and proprietary information, and the requirements and procedures of classification.

- **Product Acceptance Criteria:** The process and those criteria for accepting completed products, services, or results should be established. Acceptance criteria can be defined in terms of product specifications validated by certain tests, demonstrations, and/or documented reports. For an IVHM enabled system, such criteria may be specified in terms of false positives, false negatives, timeliness, prediction horizon, or similar types of metric as discussed in ARP5783 [REF15]. At this stage, a general idea of such criteria must be put forward, which will help in identifying the end use case and customer outcomes.
- **Constraints:** Constraints document various technical and non-technical restrictions that limit the scope of IVHM development or that limit the access to algorithms, data, and required resources. Some typical development constraints include time and budget limits. In aerospace applications, these constraints may also include limits on weight, volume, computational power, communication delay, communication protocols, data, and physical access to system, etc. These constraints have a direct influence on IVHM system capability and scope. All such constraints must be identified and enumerated in the scope document. In general, constraints identification will try to answer the following questions:
 - How does accessibility influence the requirement development process?
 - What other systems and data access will have to be considered?
 - Will there be single or multiple users with read/write access and the necessity to establish publish/subscribe protocols?
 - How often and for how long will access be required to be available?
- **Assumptions:** Assumptions document all reasonable expectations, beliefs, or approximations used when accurate information is not available a priori. Generally, assumptions may result from two situations:
 - IVHM development is carried out as a separate activity. The IVHM development will be based on an understanding of how the vehicle system would operate nominally and under various faults that are candidates for health monitoring. All assumptions should be listed that describe the model of the vehicle system as seen by IVHM, such as interactions, availability of data, noise levels, communications, operational conditions (for functions active during operation), hardware capabilities, assurance of software and hardware integrity, etc. The designer will be responsible for the system transmitting those parameters where an external application can perform health monitoring and in getting evidence to the operator. For this case, the IVHM development team might not be identical with the system design team.
 - Design and development are interlaced with IVHM objectives. In this case, the design team is accountable for the fulfillment of stakeholder requirements and IVHM V&V (verification and validation) is part of the system development plan. The example in Section 7 is focused on that case.

The other major source of assumptions is the uncertainty of future operating conditions, changes in vehicle system and/or system ConOps, changes in intended use of IVHM output, etc. Assumptions that deal with such uncertainties should be identified and documented.

4.1.3 Concept of Operations and Use Case Documents for IVHM

A ConOps is a document that describes the characteristics of a system from the user's point of view. This document describes the quantitative and qualitative system characteristics to all the stakeholders. It is recommended that this document includes use cases to describe the interactions between the user and the system to achieve the stakeholder goals.

The ConOps document is well understood in the military domain [REF11] and systems engineers have started to employ it in general systems engineering processes as well. Many modeling-language frameworks, such as Systems Modeling Language (SysML) or Unified Modeling Language (UML), start with a ConOps, as well. However, the concept of “use cases” often forms a much stronger basis for developing requirements. Both concepts are defined below.

The ConOps development begins as a thought exercise where the utility of novel ideas is explored through various scenarios in which a system would operate and benefit from the new concepts. The level of detail in the scenarios should be just enough to allow need statements to be derived. The ConOps document can be iteratively revised as more insights are gained through the development phase. The ConOps document is a means to communicate the understanding of the needs to the stakeholders. An overall system ConOps document is expected to include a module specific to IVHM, which will describe the functions of the IVHM capability in situations with/without fault conditions in the vehicle system. The ConOps document should describe both normal and abnormal operations of the vehicle.

The use case development also results from thought experiments; however, they are somewhat more detailed than the ConOps document. Use cases describe, in specific detail, how the capability is going to be used by the users. The key to developing a useful use case is to identify the users, or actors, and their actions on the vehicle system. Use cases should describe the nominal operating case as well as the abnormal (or alternate) operating cases.

For example, the ConOps document might state that “The vehicle will be able to take off in normal and abnormal environmental conditions. The vehicle will also be able to take off if a single engine fails during takeoff.” The use cases associated with this ConOps might be far more detailed and would describe exactly what normal conditions are. Use cases will describe a set of abnormal conditions, including temperature, altitude, rain and ice, and head and cross wind parameters. All possible faults that can occur during take-off that need to be designed for would also be specified. Because the general concepts are similar, both are used interchangeably in the course of this document. The key is to make sure the set of requirements that result from these thought experiments are correct and complete.

The ConOps/use case document for systems equipped with IVHM should be divided into two main parts:

- a. **Pre-Interaction State:** The first part of the system ConOps/use case document describes a typical nominal system operational scenario. Since no health concerns are present for the system, the IVHM capability is expected to continue monitoring the vehicle system and not interfere with the nominal vehicle system functions. The IVHM output should be indicative of a healthy vehicle system without any false positives, resulting in unnecessary concerns and/or actions.
- b. **Interaction and Post-Interaction States:** The second part of ConOps/use case document should describe the IVHM function when the vehicle system experiences a fault or abnormal condition. The IVHM output, the corresponding set of actions, its interactions with the vehicle system, and expected consequences should be described at a generalized level. If the IVHM response were expected to be similar for all possible fault modes, a single scenario description would be sufficient. Otherwise, the ConOps/use case document should include a description for each category of contingencies. Furthermore, scenarios such as where the IVHM function may be expected to adapt/evolve during the vehicle's life cycle, or where IVHM response is different in different modes of operation, should be included. The various different life cycle stages to be considered could be system development, integration, test and verification, operations, training, maintenance, upgrades, etc. However, the most important stage that needs description is health management operations, to include applicable maintenance actions. Furthermore, the ConOps/use case document should include scenarios from all key stakeholders to ensure all IVHM users are satisfied and that any conflicts can be solved with respect to the previously agreed baseline.

The ConOps/use case document module relevant to IVHM should try to answer the following questions:

- Who are the IVHM stakeholders? What are their perspectives?
- How would these stakeholders use the IVHM output in their decision-making and corresponding actions?
- What are vehicle system operational modes (both nominal and off nominal) under which the IVHM capability will operate?
- What are the IVHM normal (and abnormal) operational modes and how do they affect system safety?
- How would the IVHM capability function in the presence of an anomaly (system degradation, fault, unanticipated operational mode, etc.)?
- How is the IVHM capability expected to interact with the vehicle system (i.e., inflow and outflow of information)?
- Will the IVHM capability control hazards, and/or maintain safety, and/or protect assets?



Ultimately, the ConOps/use case documents are used to derive system requirements and validation requirements. When considering intent and scope, the details of the ConOps are a significant element and affect much of the preparation for requirements development. Therefore, the more details that are added in the ConOps/use case document, the more coverage of requirements can be achieved. All assumptions should be clearly stated. If during the development stage any assumption is found to be incorrect, then the ConOps/use case document needs to evolve and corresponding requirements should be re-assessed for modification as necessary.

4.1.4 Identify Interfaces for the IVHM Capability

This step defines and documents various interactions that would take place in an IVHM equipped system. Interactions include interfaces between the vehicle system and the various elements of the IVHM capability, such as sensors, communications, control system, displays, etc. Furthermore, the interfaces between various modules within the IVHM capability needs to be identified. Some typical interfaces of this type could be data interfaces between software modules, between data acquisition and state estimations algorithms, and between state estimation and decision/planning modules. It must be noted that the actual definition of interfaces takes place later during design, but the location of these interfaces should be identified early.

Interfaces relevant to the IVHM capability should try to answer the following questions:

- What interfaces are encompassed by the scope of IVHM?
- How do on-board and off-board systems pass data to each other, link to sustainment and finance databases, or other logistic and supply chain data collection systems?
- Can the IVHM functions access data from busses supporting core system functions?
- Are system related sensing and operational environment data available to the IVHM capability?
- What are the compatibility considerations regarding data exchange?
- Are there existing legacy systems?
- Is the IVHM capability/functionality updateable and can contemplated future systems be accommodated?
- What standards have to be met and what means and methods will be used to link to other data systems?
- Which subsystems or components will the IVHM monitor?
- Will the IVHM capability be a part of a control loop?
- Who will be the users of the IVHM output and how will this output be made available to them (displays, alarms, databases, etc.)?

One of the key interface consideration emerges from the fact whether IVHM is granted merely a read-only interface, i.e., vehicle systems send data to IVHM but IVHM does not send data or commands to them. In such cases, requirements on IVHM system are simpler. However, if IVHM can send data or commands to other systems, one must ensure IVHM is at the proper criticality level to do so and that receiving systems are architected to properly protect themselves against receipt of IVHM commands at the wrong time or bad commands. When considering interfaces, the IVHM interface should improve access to data through a common, universal format, which is scalable and enables multi-disciplinary users to analyze data to discover valuable information. Examples of interfaces include on-board systems, off-board systems, maintenance systems, planning systems, data warehouse, logistics, finance systems, OEMs, acquisition, HR (human resources), research environments, and other services. Documentation of interfaces should be done via interface control documents/specifications, architecture drawings, data flow diagrams, sequence diagrams, data mapping diagrams, and example data.

4.1.5 Data Inventory

Data relevant to IVHM are generally available from multiple sources within and outside of the vehicle system. The IVHM developer should explore all of these sources to assess what data has the potential to provide useful information. Vehicle health management data comes, in general, from on-board and off-board sources; reference data is also essential. Sources of data include:

- **On-Board Data Sources:** Operational data, e.g., flight phase, status, or other discrete signals; parametric data, e.g., air speed, angle of attack, timing; and fault data, e.g., fault and maintenance codes, built-in test codes.
- **Off-Board Data Sources:** Maintenance data, e.g., maintenance actions, pilot or crew reports, part installation and removal information; test stand data, e.g., test stand test limit reference data, test summary reports; and unstructured data, e.g., bore scope or other hand-held inspection device data.
- **Reference Data:** System and subsystem organizational structure, e.g., work unit code, engineering units (knots, psi, degrees Fahrenheit), on-board and off-board data recorder configurations, hardware and software versions, calibration/correction/conversion other metadata info and a data dictionary including domain-specific semantic information.

4.1.6 Upfront Coordination

The development of IVHM requirements is a collaborative process. Consequently, many organizations and information sources must be prepared to participate in requirements generation.

- **Resource Availability:** The supporting resources for the program should be taken into account and vetted through the responsible organization and all support functions as well. Resources include, in some cases, facilities, finances, and equipment. Additional considerations may come from support elements and include computation and data resources.
- **Schedule:** As health management is often a multi-disciplinary enterprise, it also tends to be multi-organizational as well. As a result, independent scheduling and tasking needs coordination and an upfront understanding of program resources.
- **Coordination:** The primary element of coordination is frequent and unambiguous communications. In addition, contributing elements are a clear statement of work and schedules, well-understood and mutually agreeable contract terms and conditions, well-understood roles and responsibilities, working sessions and technical interchanges, collaborative tools, information exchange processes, and a common technical and systems domain knowledge.

4.1.7 Future Initiatives

In some cases, requirements are developed to address upcoming standards or regulations. Any development should be aware of the future and allow for changes that may come from internal or external sources. The changes may be technical or regulatory, but a firm understanding of their potential impact is essential for generating viable requirements.

4.2 Development and Production Stage

A formal SE process starts during the development stage, where all requirements and activities are systematically documented and thorough review cycles are implemented as decision gates. The ConOps developed during the exploratory stage should be used to derive requirements for the overall system. The requirements should then be flowed down to lower levels for specific individual subsystems and components, as shown in Figure 3. Each step of this V diagram is now discussed, from systems requirements down to implementation and up the right hand side to operations and maintenance.