Influencing IVHM Design

for

Sustainment Acumen

Background:

The utility of the IVHM and RCM design development process can be greatly enriched by initially adopting a more inclusive tactic that unlocks a robust “interdisciplinary diagnostic design data interchange segue” capable of creating and leveraging interdependent design data in a much grander scale. Traditionally, RCM-independently-derived design assessments brought attention to the importance of identifying component failures and their related impact on increasingly more complex designs. While the RCM process delves in quite a few additional equally important, yet discipline-independent directions, it has not been able to effectively *integrate* many other equally relevant diagnostic-related data sources. This more robust objective establishes sustainment value that is the product of a methodology that better leverages the investments already laid into the RCM Process and the interrelated design (including IVHM) development and sustainment activities.

Purpose:

The purpose of this paper is to explore the impact of those boundaries of traditional design development-independent approaches and to then to discuss specific areas that effectively add value by permeating such boundaries through the implementation of advanced design development-interdependent approaches. To this purpose, we'll be more specifically describing an approach that through an advanced Integrated Systems Diagnostics Design (ISDD) paradigm, providing a much more robust design "disciplinary-inclusive" approach. This highly interoperable approach collects, (re)organizes, (re)structures, corroborates, integrates, assesses, and cross-validates the relevant disciplinary-derived "design-independent" data (and companion assessment products) in the (ongoing) production of a "diagnostic design-interdependent" asset. We'll identify this asset as the "***eXpress*** Model" within the context of this paper, and thereby uncover a little of its vast potential from a higher level perspective.

Examining the FMECA:

In revisiting the FMECA assessment product, it has been traditionally considered to be the best analysis tool for assessing the effects of critical failures on a design or the fielded system. While the FMECA is an excellent tool for many reliability assessment applications, let's not bring it off its home turf and use it arbitrarily as a "Diagnostic Assessment or Diagnostic Implementation Tool" simply because we've misused it to circumvent diagnostics engineering in past efforts. While the FMECA is able to "identify" what "needs to be detected", it is unable to analytically specify "what can actually be detected" at the Integrated Systems' Level, as based upon the diagnostic integrity of the Integrated System.

Test & Fault Coverage Constraints not typically disclosed:

Fault Isolation assessment or implementation is not a core competency of the FMECA or any other Reliability assessment product. Due diligence in performing any Fault Isolation analysis must consider additional diagnostic design detail consisting of, but not limited to, (current design & prospective) Fault Group constituencies, (BIT) Test Coverage (i.e. including sensor coverage(s) per state-controlled dependencies) and any interrelated Test Coverage "Interference" constraining the effectiveness of interpreting status regarding any failure(s) detected or otherwise, presumed to be detected. Traditional FMECA's also become increasingly vague when employed to assess Fault Detection or Fault Isolation in the consideration of multiple failures diagnostic scenarios.

From a Fault Isolation perspective, the FMECA assessment product lacks the ability to comprehensively identify the impact of the critical failure(s) at the next level(s) as contained within the integrated systems' design. This is particularly apparent when any WRA(s) fail(s), or may appear to have failed, then any further association to the isolation of the failure(s) is not an effective utility expected of the FMECA at the integrated systems level. This is important consideration since the IVHM must be designed with diagnostic integrity of other subsystems fully in mind. This implies the IVHM must consider the interrelated impact and the integration of any included, but independently developed FMECA's – during design development, or at any time thereafter.

Often partnering design suppliers may use their own independent FMECA tools, if any, and in accordance with their respective independent design requirements. This is inevitable.

Furthermore, and since the FMECA's diagnostic implication disconnects are not typically readily apparent, traditional design approaches do not have a consistent and comprehensive method to automatically cross-validate heterogeneous FMECAs received from partnering subsystem design teams/activities within the development life-cycle of the integrated system. This is just the beginning of diagnostically undisclosed or "loose" areas that cause voids that, by happenstance, are ignored and skipped over in the traditional approach to designing the IVHM in the integrated systems' design development process.

Independent FMECAs & Declining Relevance:

It is of preparedness that the IVHM is able to benefit from the opportunity to be designed in such a manner that it is able to avoid the inevitability of FMECA data interoperability complications that are not managed seamlessly or effectively in traditional IVHM design development and integration endeavors.

Simply because any independently produced FMECA *appears* to be *"right"* as it *appears* to contain any relevant data or *appears* to meet the minimum independent FMECA design requirement(s), it is not necessarily serviceable to the level of expectation for continued implementation as originally believed. The degree of deficiency in the FMECA's *"rightful appearance"* will be, consequently discovered later at a less opportunistic time – particularly with respect to diverging from *"rightfully"* expected or affordable sustainment ideals.

If the traditional FMECAs are not integrated and cross-validated with interdependent interdisciplinary design assessment product artifacts, then the independently developed FMECA assessment product simply serves its own independent objectives. The systems' integrator typically receives "flavors" of FMECAs from partnering subsystem design teams/activities involved in the design development or sustainment life-cycles.

Can the FMECA be "*agile*" throughout "*entire*" Life-Cycle?

The systems' integrator must consider an "agile" path forward for the continued effective use of the FMECA assessment product, not in lieu of, but rather in addition to any current internal standard practice policies. This applies to any of its current integrated systems, any variant systems or subsystem design alternatives, or for a variety of new integrated systems in the future. "Data interoperability" is the start we need, but surely it is vastly different from "data integration", as the latter implies a much broader capability, as we'll discover in more depth later in this paper.

Uncovering the hidden diagnostic shortcomings of the IVHM

The IVHM design must be able to accommodate ("consume") independently provided FMECAs and flush out errors, omissions and inconsistencies before the effectiveness of the IVHM design can be determined. Since the traditional IVHM is not concerned with isolatable fault groups, but rather the designing of a response to any "sensed" or "*perceived* to be sensed" failure(s), it typically "reports" the error code(s) that triggered the sensing of the failure(s). The initial remediation events on-board may, in implementation, circumvent the identified "primary" failures in the FMECA "or" more accurately, the propagating of the primary failures from the experiencing of any critical or "undesired event" as identified in the companion Fault Tree Analysis, "FTA" assessment product.

But independent of the on-board "health managing" of any identified critical event(s), the "bridging" of the diagnostic conclusions to the off-board sustainment environment(s) are typically scant or ambiguous. This is due to the design practice whereby the traditional IVHM design does not consider the practice of Integrated Systems Diagnostic Design (ISDD) as a *design influence* characteristic. The standard practice should be to perform the "*design for sustainment*" objectives in concert with the IVHM design activity. Thus, allowing the on-board IVHM to provide, or "bridge" more enriched data (as retrieved from BIT failure(s), per operational state, etc.) to ensuing and evolving sustainment paradigms enabling the formulation of more relevant and accurate "diagnostic conclusions".

Sustainment Costs "***not avoided***" by IVHM Design:

The traditional IVHM's function may be effective on-board. However, its value is reduced through its limited diagnostic "knowledge" that can be extended from the BIT failure data derived from error codes (*"test results"*) to the off-board or second level maintenance environment. Since the typical on-board IVHM does not concern itself with Fault Group constituencies in order to perform its primary function, it forfeits the opportunity to impact the continuity in providing more comprehensive diagnostic information for the off-board sustainment activities. This lost opportunity to provide far more savvy "*diagnostic conclusions*" to the off-board sustainment paradigm typically results in the requirement for much costlier, higher skilled technicians or "Responsible Engineers". Additionally, even skilled RE's lack the opportunity to fully leverage the diagnostic utility of the failed BIT codes across the diagnostic inference model(s) as attained in any specific operational states.

The diagnostic effectiveness in the off-board sustainment paradigm shall remain as a function of, minimally:

- The diagnostic effectiveness of the on-board subsystems' diagnostic design integrity;
- The respective FMECAs of any included subsystems' designs;
- The IVHMs' ability to "interpret" the data as characterized in the various "integrated" FMECAs;
    - which may be a daunting endeavor when supplied with heterogeneous FMECAs not able to be continuously "cross-validated" with any other integrated systems' FMECA; or additionally, within the systems' evolving integration of the subsystem FMECA's;
- Any prior sustainment corrective actions previously performed.

Any degradation in the IVHM's ability to effectively enable the reporting of comprehensive diagnostic conclusions will result in second level diagnostic uncertainty that will cause the off-board (second level) corrective actions to be broader, more intrusive, and less diagnostically conclusive. This lack of conclusive diagnostic information is one of the leading causes of <u>false removals, false systems' aborts, NFF's, RTOK's, CND's</u> and myriad of incomplete or inappropriate maintenance actions being performed (intrusively) on complex integrated systems. The key enablers to improving the IVHM and subsystems' diagnostic performance as contained within the fielded integrated systems, can be discovered in the more effective leveraging of the integrated systems diagnostic design capability and methodology.

Traditional and rigid IVHM design approaches that lack the ability to equally effectively corroborate and cross-validated design interdisciplinary assessment products (and relevant data artifacts contained therein) will continue the ongoing burdening of costs emanating from any of those sustainment maladies described above. But more importantly, will compel the IVHM design to be placed in undetermined re-work or update cycles. This is an unfortunate product from institutionalizing a specific "end-to-end" approach that discerns itself from a more forgiving, "agile" approach that is able to seamlessly "integrate" any new (or proposed) design in an assessment-corroborative interdisciplinary manner.

In traditional and rigid, end-to-end, IVHM design approaches, sustainment activities will also exacerbate a growing divergence of the IVHM's diagnostic effectiveness as maintained systems forever change the failure characteristics within the fielded asset. Unless the IVHM's diagnostic design can absorb these failure disparities in a seamless and scalable manner, any ongoing attempts to sustain the initial IVHM design cannot avoid the causing of the same lessons to be relearned, recycled and reworked repetitively at undeterminable costs.

Furthermore, since the IVHM design knowledge is captured within the ***eXpress*** System(s) model, the ability to effectively resume or update the IVHM will be greatly eased while costs and risks of reliance on seeking vacated or displaced expertise is marginalized. Knowledge captured is "IP asset" gained.

For the reasons briefly described above, Systems' Integrator's expertise with the ***eXpress*** diagnostic modeling paradigm provides an unmatched opportunity to resolve these challenges, while progressing forward to solving a host of more aggressive sustainment objectives by leveraging the Integrated Systems Diagnostics Design. The most effective path forward commences by the establishing this highly advanced diagnostic design capturing and modeling environment as early in the design development life-cycle as possible.

Transitioning towards a proactive, interdisciplinary-effort-leveraging IVHM design approach:

The "interdisciplinary-inclusive" participation structure within the ***eXpress*** diagnostic modeling paradigm forms the foundation for an effective transition that collectively services the seamless and on-going enrichment of the design development *and* sustainment life-cycles.

This highly interoperable, ISDD modeling environment allows the diagnostic capability for any design(s) to be represented within either a functional and/or a failure effect-based model. As such, this "function or failure representation hybrid" advanced capability establishes the capturing of the design's functional or failure effect propagation interdependencies. The integrated functional and failure-effect-based diagnostic design representation(s) facilitates the (re)use of any hierarchical set(s) of models. One of the *initial* benefits from early capturing of design(s) in this modeling paradigm is the enabling of an "agile" (seamlessly updateable) "*diagnostic assessment to diagnostic implementation*" asset. As such, it can be applied on any, independent or integrated diagnostic design model(s) throughout the diagnostic design development life-cycle(s).

The ***eXpress*** "Integrated System" model(s) describes the interdependent structure and functionality and any interrelated diagnostic characteristics of the subsystems contained within the diagnostics design of the "fielded product" – also used synonymously herein to describe the "Integrated System(s)".

Therefore, this ***eXpress*** Integrated System(s) diagnostic design represents not only the systems' "functions to failure mode" relationships, but includes an ability to assess the diagnostic effectiveness that considers any mixture of *groupings of tests* that reflect the respective purpose and intended scope of each *test set*. This approach is particularly enlightening as it facilitates a robust capability to assess and influence the integrated diagnostic effectiveness for any specific or broadly general areas within the IVHM design from an interdisciplinary diagnostic design perspective. Of course, any "test set" can be modified, updated, edited or combined with any other "test set" as the design or the sustainment philosophy or technology may evolve.

Gently, Integrated Systems Diagnostics Design is a robust approach that enables design teams to continue design development efforts as usual, by facilitating an interoperable data capture environment. In this manner, the same methods, tools and approaches in the creation of the initial design data artifacts can be continued to be performed by design teams as usual. At the same time, the design data will be (re)used and imported into this new ***eXpress*** model paradigm, on an iterative basis as the design develops. This process enrichment enables the opportunity to observe exhaustive diagnostic design interrelationships that are not otherwise apparent or thereby unable to be proactively managed. Essentially, this process is similar to establishing a sort of "Diagnostic CAT Scan" of the design's inherent diagnostic integrity. As the design matures, the diagnostic design matures right in step during the design development life-cycle. The diagnostic design behaves as the "heartbeat" producing a “living” diagnostic knowledgebase characterizing the evolving nature of the diagnostic design. This will remain as an “Intellectual Property” asset that will exist throughout the sustainment life-cycle. Ultimately, we’re going to be able to leverage this “diagnostic design IP” for many purposes – advanced diagnostic assessments, operational health management support simulations and run-time implementations.

In concert and transparent to the design process, ISDD opens a brand new segue to working as a much more collaborative, integrated design team. There is a distinct difference between diagnostic data “sharing” and data “integration”. Diagnostic data “integration” is only attained when the interrelated design teams are able to cross-validate their respective interdisciplinary design assessment products (and any related data artifacts contained therein) with, and amongst any other interdisciplinary design assessment products.

The “designing for the sustainment life-cycle” can be timely when performed in the “design development life-cycle”, which is not a strength of traditional IVHM design methodologies. The ***eXpress*** modeling paradigm unlocks the opportunity to encounter previously unidentified diagnostic “chads” (assumptions) and anomalies in the design process. Better yet, this inherent capability enables the realization of these cost drivers early in the design development life-cycle. This is during the precious time that enables the avoidance of unnecessarily increasing sustainment costs burdened by the belated learning of lessons caused by traditional design data “sharing” errors, omissions, inconsistencies, etc. These and many other untapped design development and sustainment benefits are natural byproducts of the ***eXpress*** “designing for sustainment” agility.

As opposed to data “integration”, prevailing data “sharing” activities as is ubiquitous in traditional design approaches, evade valuable data quality discovery opportunities by resorting to the use of independent and adjunct multidisciplinary design assessment products or approaches. When data is truly “integrated”, any interrelated diagnostic design assessment products ought to not only be expected to assess the integrated systems capability, but also be able to be a “turn-key” output assessment product derived “from” the agile, integrated systems’ interdisciplinary design data “knowledgebase”.

Traditional IVHM design approaches that lack the ability to equally effectively corroborate and cross-validated design interdisciplinary assessment products (and relevant data artifacts contained therein) will continue to the ongoing burdening of costs emanating from any of those sustainment maladies described above. But more importantly, will compel the IVHM design to be placed in undetermined re-work or update cycles. This is an unfortunate product from institutionalizing a specific “end-to-end” approach that discerns itself from a more forgiving, “agile” approach that is able to seamlessly “integrate” any new (or proposed) design in an assessment-corroborative interdisciplinary manner.

In traditionally rigid, end-to-end, IVHM design approaches, sustainment activities will also create a growing divergence from the initial IVHM design’s diagnostic (or sustainment) effectiveness, causing lessons to be relearned, recycled and reworked repetitively at undeterminable costs.

Furthermore, since the IVHM design knowledge is captured within the ***eXpress*** System(s) model, the ability to effectively resume or update the IVHM will be greatly eased while costs and risks of reliance on seeking vacated or displaced expertise is marginalized. Knowledge captured is “IP asset” gained.

The ***eXpress*** diagnostic modeling environment is essential for determining the diagnostic designs’ ability to “Uniquely Isolate” any failures (loss of function). This capability enables the assessment to determine if the design is able to isolate between the sensor and any of the functions contained on the object that is being sensed.

More specifically, this design development life-cycle assessment capability identifies if any (on-board, BIT reported, for example) functional failure is able to be discerned between the loss of any other specific “unique” function (contained within the same failure space), as based upon the ability for the sensors to sense between those functions (at any particular operational state) and given the diagnostic integrity of the sensor(s) at the time of the interrogation. This is a critical capability since this is where False Alarms and False System Aborts (FSA) are rapidly introduced. In lieu of writing about countless examples to substantiate this critical point, it would be much simpler to review the design's impact on these sort of metrics in an interactive operational support simulation-based environment.

The ISDD process, through the ***eXpress*** diagnostic modeling environment, is able to output an ***eXpress*** diagnostic design data file that is directly importable to a fully integrated sustainment simulation companion tool, or "STAGE". The captured diagnostic design data used to produce assessments (FD/FI, FMECA's and many other required assessment products) is used directly in STAGE to seed time-based sustainment metrics. From the STAGE simulation, such stochastic values as calculated for FA, FSA, MTBCF, MTBSA, MTBUM, RUL and well over 200 additional (and ground-breaking) sustainment-related graphs are produced. "STAGE" provides a pallet for the assessing of virtually an unlimited assortment of operational support and Health Management simulation calculations. With respect to the IVHM or any design, the STAGE simulation is able to simulate the occurrence of failures of components (and based upon their respective diagnostic design impact) in accordance with their assigned failure rates over a selected sustainment horizon ("lifetime"). In this manner, the designs' inherent diagnostic architecture becomes exposed.

An additional capability of the STAGE operational support simulation is that the calculations consider the impact of maintenance activities. In this manner, the results computed by STAGE reflect the value or costs associated with any proposed sustainment philosophy. When the diagnostic design is augmented with any selection of sustainment "mixtures" of preventative and corrective maintenance, STAGE will consider these parameters when producing the selected simulation graphs. These graph(s) produced from the STAGE simulation show the strengths and weaknesses of the integrated systems' diagnostic design in a broad range of critical assessment graphs along with any selected interrelated costing or performance-related graphs. All of the STAGE graphs can be immediately exported to MS PowerPoint while the data contained in the graphs can be, likewise exported to MS Excel, which facilitates ease of data sharing. This is just another immediately available design & support assessment collaboration option requiring no additional data input.

As mentioned earlier in this paper, any capturing of the diagnostics design within the ***eXpress*** modeling paradigm, the designs' functional and/or failure effect propagation interrelationships are able to be captured in a single representation. Due to this unique ***eXpress*** diagnostic design capturing paradigm, the same "***eXpress*** diagnostic model" can be used for evaluations of a design's diagnostic capability in ground-breaking and unmatched perspectives and detail. The ***eXpress*** models can also behave as "building blocks" that can be immediately used in the creation of hierarchical FMECAs, FTAs, prediction of diagnostic performance, and generation of assessment-to-actual runtime diagnostics. Supporting these capabilities, the ***eXpress*** modeling paradigm includes the generation of a wide variety diagnostic-output(s), XML compatible run-time diagnostic file outputs, and implementation(s) targeting evolving sustainment technologies.

While forcing continued traceability to the diagnostic designs' maturation in both the development and the sustainment life-cycles, ***eXpress*** models may be initiated during any phase of the design development process, but offers increased value and opportunity when instituted as early as possible in the design development life-cycle. Accordingly, the ***eXpress*** models can be used or modified as needed, to perform iterative and "current" assessments of the diagnostic capability of the (integrated) systems' diagnostics design, thereby providing useful design feedback to FMECA analysis within the RCM Process to better substantiate any advance diagnostic implementation in the sustainment paradigm, including CBM+.

Combining Talent: *eXpress* and IVHM Design

In conjunction with the advanced ***eXpress*** Diagnostic Modeling capability, the host embedded on-board IVHM application is able to provide an efficient framework for organizing salient knowledge acquired from the subsystem or selected system(s) under analysis. The diagnostic reasoning activities are ultimately capable of achieving consistency with the diagnostically-optimized IVHM capability from the process of being vetted in the ***eXpress*** diagnostic modeling paradigm. In this manner, any BIT failures (and “Diagnostic Conclusions based thereon) retrieved by the on-board IVHM application are able to be “bridged” to the off-board sustainment paradigm.

Contemporaneously, and while the IVHM performs its function on-board the vehicle, any BIT data retrieved in the off-board sustainment environment can be diagnostically interpreted in a more comprehensive and diagnostically-conclusive manner. This is the result of influencing the diagnostic designing of the on-board IVHM to, and, for the “bridging” of the diagnostic designs’ BIT data to more effectively commence the off-board second level sustainment activities.

The difficulty in creating an IVHM diagnostic system lies in designing of a diagnostically-savvy knowledgebase for the physical system because of inevitable tradeoffs between complexity and completeness. Of course, this must begin by first establishing of the “diagnostic integrity baseline” of the “*Health Management Reasoning*” and its role as an integral component of the broader, more inclusive, on-board IVHM architecture. “Cost-benefit” tradeoffs are effectively attained within the ***eXpress*** modeling paradigm, given a collaborative and cooperative working environment with equally shared vision and objectives.

Systems’ Integrators have the option to leverage the captured ***eXpress*** diagnostic design models in the generation of “***eXpress*** output FMECAs”, capable of cross-validating the data contained therein with the designs’ Fault Tree Analysis (“FTA”), and visa-versa. This ability to “toggle” from, or back to, the ***eXpress*** FMECA and the ***eXpress*** FTA, which is essentially, the diagnostic designs’ “turn-key” automated, "top-down" view of the FMECA. The *initial* top-down representation of the ***eXpress*** FTA, can be referred to as the "Inverse FMECA", meaning that it provides an architectural platform to instantly account for the inclusion and propagation of all Primary Failures contained in our targeted FMECA and their interrelated combining failure effects, as they propagate to the top level of the design or system.

The ***eXpress*** FTA is another assessment product output of the ***eXpress*** modeling paradigm, which is traceable to the diagnostics design of the (evolving) integrated system. The ***eXpress*** modeling paradigm is able to (re)use existing data or mimic earlier created FTA output representations from FTA’s created in a separate tool, method, or by a third party supplier, which are traditionally created in a manner that is separate and adjunct to the designs’ diagnostic designs’ architecture. Traditionally, FTAs have not been concerned with the integrated systems diagnostics design architecture, which is an ongoing costly weakness of that traditional approach. Some of the costs will be expressed and/or implied within this paper and some of those ongoing costs become more painfully apparent when the burden is shouldered by those without “a dog in the fight”.

The natural path forward is for the Systems’ Integrator is to produce the FTAs for or within their company-required tools or methods. But since the Systems’ Integrator is a “systems integrator”, it will be also need to remain open to receiving FTAs produced by other suppliers in other methods and tools – and there’s a likelihood that some those major subsystem suppliers may have produced, or intend to produce ***eXpress*** models. In this regard, the ***eXpress*** modeling environment allows for Systems’ Integrators to have it both ways.

Regardless if the traditionally produced FTAs were generated internally by the Systems’ Integrator, by any external third party, or may otherwise exclude costly design updates into existing FTAs, the establishing of the ***eXpress*** FTA provides an innovative alternative to such traditionally-rigid FTAs. The ***eXpress*** FTA gracefully extends the utility and ease of (re)producing and maintaining an evolving, uniform “integrated systems” ***eXpress***

FTA. This enables the ***eXpress*** FTA to seamlessly and continuously reflect design updates or the occurrences of maintenance activities throughout the sustainment life-cycle.

Maintenance activities forever change the ensuing failure characteristics of the integrated system. To this point, a stern position of FTA "agility" is itself, a risk avoidance measure.

This ***eXpress*** FTA allows for the immediate top-down visualization of the design level effects of the primary failures contained in the selected level of analysis as identified in the companion FMECA design(s). Meaning, if the FMECA is targeting the FTA to include the component or box level failures as primary failures, then the level of the FTA analysis can support either alternative, or as limited by the level of FMECA data available.

The ***eXpress*** FTA enables the interactive inclusion of "and" gates and polling "or" ("K of N") gates, external events and a host of other symbols typically used to represent more complex interdependent failure events. A host of other fundamental capabilities are also characterized within the ***eXpress*** FTA to maintain a sense of familiarity with more experienced folks delving in this aspect of the Reliability Engineering discipline. Some of those typical visual hallmarks include the "probability of occurrence" or "Q" calculation for any "cut set" contained within the ***eXpress*** FMECA, and thereby inference, the integrated ***eXpress*** FTA.

Where the separations begin to occur when describing the diagnostically-influenced FTA from the adjunct traditional FTAs, is that the ***eXpress*** FTA is cross-validated with the FMECA *and* the diagnostic capability of the design interrelated therewith, which opens the headroom for enriched "diagnostically-savvy" FMECAs and FTAs. This is a discriminating capability because, not only are all of these assessment products capable of being updated instantly, consistently and comprehensively, but so is "true-to-form" with respect to the companion (evolving) diagnostic implementation(s).

In briefly highlighting an advanced capability that becomes part and parcel within the ***eXpress*** FTA assessment product, is the ability to discern which percentages of the condition (calculation) leading to the undesirable event are able to be "uniquely isolated" in that specific "branch" or "cut set" representing the occurrence of that undesired event. This enables uniquely valuable "inside" information that, from an integrated systems design development or sustainment perspective, is able to determine the portion, if any, of the undesired event is able to be detected or isolated as determined within the constraints of the test coverage of the BIT for and by, any particular operational state, for example. The ***eXpress*** FTA also enables the inclusion of "Prognostic Events" to be fully integrated and included in the calculation of the probability of occurrence of undesired events, given prognostics.

As a result, the companion ***eXpress*** FTA baseline architecture is automatically generated once the integrated systems and the FMECAs are fully captured in the ***eXpress*** models. This is performed early in the design development life-cycle, which will greatly enrich and support the IVHM design development paradigm. By capturing all interrelationships and interdependencies subsystems' functional and failure effect propagation, ***eXpress*** (and its companion ISDD tool suite) influence the IVHM design the opportunity to take advantage of robust and agile diagnostic alternatives that are not technologically or cost-effectively possible for traditional IVHM designs.

The most obvious sustainment value begins with the ***eXpress*** Diagnostic Models as they are also (re)used to support the production or maintenance environment(s). In this implantation, the captured diagnostic design will instantly improve the accuracy and effectiveness of maintenance tasks via any compatible technology or Portable Maintenance Device (PMD).

But additionally, the importing the ***eXpress*** diagnostic models into its companion Run-Time Guided Troubleshooting Application adds another level of advanced diagnostic continuity and capability.

This Guided Troubleshooting Application can be hosted or accessed via a fully-featured API. This provides the maintainer with the ease of access to any preferred GUI without losing the benefit of the ***eXpress*** diagnostic design knowledgebase. This flexibility is greatly enhanced while the guided troubleshooting performance on the PMD is largely improved.

Since traditional on-board IVHM implementations have lacked the need or ability to determine any knowledge of “fault isolation groups” from the retrieval of triggered on-board BIT failure codes, the “bridging” of the diagnostic conclusions able to be gained from the on-board assessment(s) are essentially not existent. Again this is a typical (costly) shortcoming of traditional on-board to off-board sustainment approaches.

This shortcoming goes typically undisclosed or ignored when the opportunity to redirect or open up the solution options is not a timely or favorable endeavor. Accordingly, the ending sustainment capability suffers unnecessarily from such traditional IVHM development practices.

That said however, and when the off-board diagnostic sustainment paradigm is able to derive diagnostic conclusions, due to its inclusion in the design development of the IVHM and any related BIT codes, it will enable the off-board diagnostic solution to “bridge” the sustainment implementation(s). This integrated and “bridged” sustainment implementation will allow for more intelligent back-end diagnostic implementations to be instantly serviceable. Going forward, it’s easily adaptable to technology evolution. This evades the inevitability of on-board IVHM from being a mostly rigid and costly implementation to update for bridging to off-board diagnostic paradigms in the future. Going further and as failure resolution is gained from the off-board guided troubleshooting paradigm, the history of these resolutions is captured in any robust or commercially available database tool structure.

As the maintainer steps through the off-board guided troubleshooting experience in this *“BIT to Guided Troubleshooting*” demonstration, any prior failure resolutions are able to be accessed contemporaneously with the UUT design knowledge. This is another unique quality that allows the maintainer to be guided by empirical knowledge (past diagnostic resolution given current diagnostic status), but also provides the design knowledge to the maintainer. In this regard, the maintainer isn’t going to be surprised by First Failures (cons of case-based reasoning) and the maintainer can leverage past experience (pro of case-based reasoning). But going forward, this new off-board paradigm will also enable the inclusion of prior or existing fault resolution data from legacy systems. This enables its use to benefit from being included early in deciding sustainment alternatives and also facilitates a gateway to add new value to existing legacy paradigms where sustainment costs have already exceeded their welcome.

Systems’ Integrator has the opportunity to greatly enrich and define its sustainment capability and value for the future. We shared some of the highlights of a truly unified and integrated systems diagnostics design paradigm. To this purpose, the sustainment capability should always be considered an equal priority in the “designing for influencing sustainment” in the “designing development” life-cycle – but in a much more cross-disciplinary-boundary environment.

Alternatively and boldly, Systems’ Integrator ought to lead the way in “Defining the Future”.

Topic Notes

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