AIAG VDA and SAE J1739 DFMEA Methods, Similarities, Differences and Impact on the Auto Industry

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SUMMARY & CONCLUSIONS

The AIAG (Automotive Industry Action Group), VDA (Verband der Automobilindustrie) and SAE International (SAE) are the three most influential organizations in the worldwide automotive industry when it comes to the use of FMEAs.

The AIAG and VDA jointly issued the AIAG VDA FMEA Handbook [1] in June of 2019. The AIAG VDA FMEA Handbook replaced the AIAG 4th Edition FMEA Manual [2] published in 2008 and the VDA Product and Process FMEA Standard [3] published in June of 2012. In January of 2021, SAE published the SAE J1739TM-JAN2021 FMEA Standard [4] which is a revision of the SAE J1739 FMEA Standard published in January of 2009 [5].

When the AIAG VDA FMEA Handbook was issued, the expectation was that Ford, General Motors and FCA (now Stellantis) would require its use by identifying it as an IATF-16949:2016 Customer Specific Requirement. It has not happened.

This author believes there are multiple reasons why. Simply put, the AIAG VDA DFMEA methodology is ineffective in managing design risk, inefficient to use and cannot be effectively implemented with Excel for products that have more than one component. This is important since Excel is the most popular used tool used for implementing FMEAs. Although this paper is targeted towards the Design FMEA (DFMEA), there are also serious flaws in the AIAG VDA Handbook Process FMEA methodology.

Unfortunately, the committee that created the J1739TM-JAN2021 revision contained a significant number of representatives from the committee that developed the AIAG VDA FMEA Handbook. Although there are differences between the two documents, J1739TM-JAN2021 contains many of the core elements found in the AIAG VDA FMEA Handbook. These elements make the J1739TM-JAN2021 DFMEA method ineffective at managing design risk.

This paper will provide an overview of the fundamentals of both the AIAG VDA Handbook and J1739TM-JAN2021 DFMEA methodologies. The reader will learn why neither of the two methodologies support effective implementation of DFMEAs to manage design risk.

1 HISTORICAL ROLES OF AIAG, VDA AND SAE

Prior to the publication of the AIAG VDA FMEA Handbook, FMEA manuals published by the AIAG were considered to be the North American Automotive Industry FMEA standard. The AIAG published four different FMEA manuals. The first was published in 1993. The fourth edition was published in 2008.

The SAE began publishing the SAE J1739 FMEA Standard in July of 1994. The SAE J1739 FMEA Standard revisions were typically published within a year of a new version of the AIAG FMEA Manual. The SAE FMEA Standard and AIAG FMEA Manual were technical equivalents. The publication of the AIAG VDA FMEA Handbook changed everything.

The AIAG VDA FMEA Handbook was supposed to be a harmonization of the AIAG 4th Edition FMEA methodology and the FMEA methodology published in the VDA 2012 FMEA Standard. The VDA FMEA methodology was software based and required that a new methodology had to be one that the software could support. The existing VDA FMEA software could not support the AIAG 4th Edition FMEA methodology. The expected harmonization of the AIAG and VDA FMEA methods became an adoption of the VDA FMEA methodology.

The VDA software that drives the VDA FMEA methodology was jointly developed by Mercedes-Benz AG, BMW AG, Siemens AG and a small company owned by Peter Rosenbeck who created the original software on which the VDA FMEA methodology is based. Mr. Rosenbeck's had been hired by Siemens AG in 1988 to develop a failure diagnostic system with fault tree elements for a semi-conductor production process.

The original software was called "Object-FMEA". At the time, many people treated the FMEA like a fault tree so the conversion of Rosenbeck's Fault Tree software to FMEA software was a natural step. The original VDA FMEA software was called APIS IQ-FMEA 2.0 and was first distributed by Daimler-Benz Interservices (debis) in 1992. Daimler-Benz Interservices would distribute the software until 1996 when the first VDA FMEA manual was published.

When the first VDA FMEA manual was many complained that it looked like a users' manual for the APIS IQ-FMEA 2.0 software. In a paper titled "APIS-IQ Software" © 2008, Jürgen Eilers, Managing Director at APIS and one of the authors of 1996 VDA FMEA

manual, when discussing the VDA Workgroup 131 activities states "*Today's APIS IQ software was developed as part of a discussion accompanying the project.*"

2 AIAG VDA FMEA METHOD – DFMEA SELECTION

When using the AIAG VDA Handbook DFMEA method, individual DFMEAs are created for the product system, product subsystem(s) and product components. The system, subsystem(s) and component(s) are known as Elements. The Element of the product that the DFMEA is being performed on is called the Focus Element for the DFMEA.

3 EASIEST WAY TO UNDERSTAND AIAG VDA DFMEA

The easiest way to understand the AIAG VDA DFMEA method is to understand the VDA software on which it is based. The VDA software requires the creation of the product fault tree shown in Figure 1 below.

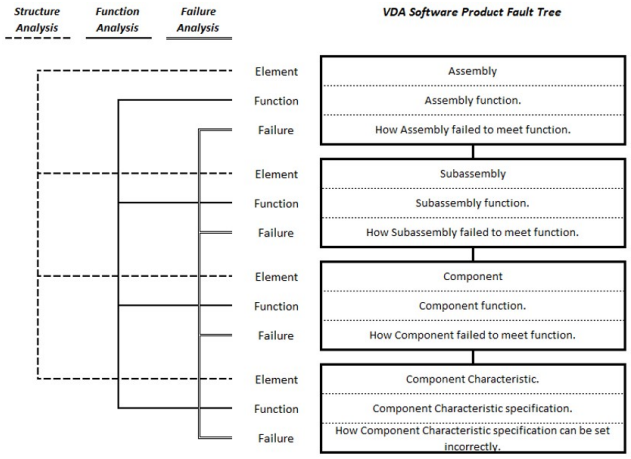

Figure 1: AIAG VDA Software Product Fault Tree

The creation of the "Structure Analysis" is the first step in creating the Product Fault Tree. The Structure Analysis is a graphical description of the Assembly, Subassembly, Components and Component Hardware Characteristic Specifications that make up the product including their linkages.

The second step in creation of the Product Fault Tree is to perform a "Function Analysis" and define the Functions for each of the Elements in the Product Fault Tree and the linkages between each of the Element Functions. The Functions for the Component Hardware Characteristics are their specifications.

The third step in creation of the Product Fault Tree is to perform a "Failure Analysis" and define the possible Failure Modes for each of the Element Functions in the Product Fault Tree and the linkages between each of the Element Failure Modes. The Failure Modes for the Component Hardware Characteristics are the ways the Characteristic Specification may be incorrect.

Figure 2 shows a completed section of a Product Fault Tree for a Seat Motor.

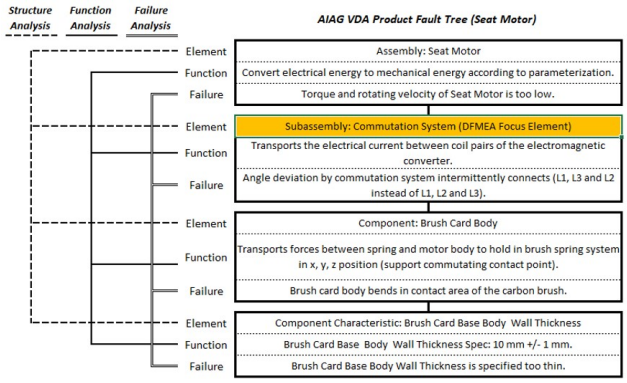

Figure 2: AIAG VDA Seat Motor Product Fault Tree

Once the Product Fault Tree is complete, the next step is to transfer the information into the DFMEA Form. The AIAG VDA FMEA Handbook offers two DFMEA Forms. This paper will use Form A (Figure 3). Form A is broken into steps. Step 1 is definition of the header. Figure 3 shows steps 2 through 4: Structure Analysis (Step 2), Function Analysis (Step 3) and Failure Analysis (Step 4).

AIAG/VDA Handbook DFMEA "Form A" (Steps 2-4)

Structure Analysis (Step 2)			Function Analysis (Step 3)			Failure Analysis (Step 4)		
1. Next Higher Level	2. Focus Element	3. Next Lower Level or Characteristic Type	1. Next Higher Level Function and Requirement	2. Focus Element Function and Requirement	3. Next Lower Level Function and Requirement or Characteristic	1. Failure Effects (FE) to the Next Higher Level Element and/or Vehicle End User	2. Failure Mode (FM) of the Focus Element	3. Failure Cause (FC) of Next Lower Element or Characteristic
Seat Motor	Commu-tation System	Brush Card Body	Convert electrical energy to mechanical energy according to parameter-ization.	Transports electrical current between coil pairs of the electro-magnetic converter.	Transports forces between spring and motor body to hold brush spring system in position.	Torque and rotating velocity of Seat Motor too low.	Angle deviation by commuta-tion system inter-mittently connects (L1, L3 and L2 instead of L1, L2 and L3).	Brush card body bends in contact area of the carbon brush.

Figure 3: AIAG VDA DFMEA Form (Steps 2-4)

The first step in the transfer of data is to identify the Element of the Product that the DFMEA is being performed on. For this example, the Commutation System is the Focus Element.

The next step is to add the columns necessary to change the Product Fault Tree into a DFMEA. A "Severity (S) of FE" column is added to Step 4.

Two additional steps must be added to complete the DFMEA form. Step 5 is titled "DFMEA Risk Analysis" and includes columns for the Occurrence Rating, Design Prevention and Detection Controls and DFMEA AP. Step 6 is titled "Optimization" and is used to capture the planned/completed improvement actions and their results.

The additions can be seen in Figure 4.

AIAG/VDA Handbook DFMEA "Form A" (Steps 4-6)

Failure Analysis (Step 4)				DFMEA Rsk Analysis (Step 5)					(Step 6)
1. Failure Effects (FE) to the Next Higher Level Element and/or Vehicle End User	Severity (S) of FE	2. Failure Mode (FM) of the Focus Element	3. Failure Cause (FC) of Next Lower Element or Characteristic	Current Prevention Control (PC) of FC	Occurrence (O) of FC	Current Detection Controls (DC) of FC or FM	Detection (D) of FC/FM	DFMEA AP	Optimization Action Columns
Torque and rotating velocity of Seat Motor too low.	6	Angle deviation by commutation system intermittently connects (L1, L3 and L2 instead of L1, L2 and L3).	Brush card body bends in contact area of the carbon brush.	Simulation of Dynamic Forces on Brush Card (Test XYZ-1)	2	Sample Test: Measure Deformation Due To Brush Card Body Acceleration (Test ABC-1)	2	L	
Additional DFMEA Columns									

Figure 4: Additions to Transform Fault Tree to DFMEA

4 DETERMINING WHAT TO WORK ON IN THE DFMEA

Action Priority (AP) is used to determine the rows to work on in an AIAG VDA DFMEA. AP is determined by looking up the Severity (S), Occurrence (O) and Detection (D) ratings in an Action Priority Matrix to determine the AP value. There are three AP values: High (H), Medium (M) and Low (L). Figure 5 shows a few rows of the Action Priority Matrix used to determine AP.

Action Priority (AP)						
Effect	S	Prediction of Failure Cause Occurring	O	Ability to Detect	D	Action Priority (AP)
Product or Plant Effect Very High	9 to 10	Very High	8 to 10	Low - Very Low	7 to 10	H
		...	...	...	...	...
		Moderate	4 to 5	Very High	1	M
		...	...	...	...	...
		Low	2 to 3	High	2 to 4	L
		...	...	...	...	...

Figure 5: Action Priority (AP)

The AIAG VDA DFMEA method defines the Occurrence Rating as the "potential of the failure cause to occur". There is no reference to the probability of the Failure Mode occurring due to the cause. The Detection Rating is used to define the effectiveness of the Design Detection Controls.

5 SAE AND AIAG VDA DFMEA SIMILARITES

There are many similarities between the AIAG VDA and J1739TM-JAN2021 DFMEA methodologies. The J1739TM-JAN2021 DFMEA Method contains the following:

1. Individual System, Subsystem and/or Component DFMEAs are performed.
2. A Structure Tree or equivalent tool is suggested to define possible System, Subsystems and Components to perform DFMEAs on.
3. Similar definitions of Severity, Occurrence and Detection.
4. Action Priority (AP) method is used to determine what to work on.

6 SAE AND AIAG VDA DFMEA METHOD DIFFERENCES

Although the J1739TM-JAN2021 method uses a Structure Tree or equivalent, there is no performance of a Function Analysis or Failure Analysis. The Function Analysis is replaced by the Item-Function Matrix which is a listing of the System, Subsystem(s). Component(s), External Interfaces and Internal Interfaces as well as their Functions. The Item-Function Matrix (Figure 6) is created with the assistance of a block/boundary diagram whose creation is required by the J1739TM-JAN2021 methodology.

It is important to note that although there is a column titled "Requirements" in the Item-Function Matrix that provides details about the Function, the Function and not the Requirements are used to drive the creation of Failure Modes in the DFMEA.

Item-Function Matrix					
Item/ Interface	Functions (for times considered higher risk based on preliminary risk assessment)	Requirements	Function Priority	External Interface Type	Internal Interface Type
Seat Motor	Convert electrical energy to mechanical energy according to parameterization.	1. Required motor torque defined in document #XYZ 2. Required motor speed range defined in document #XYZ.	H		

Figure 6: Item-Function Matrix

The J1739TM-JAN2021 DFMEA form shown in Figure 7 is very similar to the AIAG 4th Edition DFMEA form with the following exceptions.

DFMEA Technical Risk Analysis							
Item	Function(s)	Requirement(s)	Potential Failure Mode(s)	Potential Effect(s) of Failure	Potential Cause(s) of Failure	Current Design Controls - Prevention (P)	Current Design Controls - Detection (P)

Risk Assessment					Action Plan	Action Results
SEV (S)	OCC (O)	DET (D)	Risk Prioriti-zation	Potential Special Characteristic(s)	*Note: Multiple Column Details Not Shown*	*Note: Multiple Column Details Not Shown*

Figure 7: SAE J1739 JAN2021 DFMEA Form

The first difference is a repositioning of the Severity, Occurrence and Detection Rating columns. The second change is the replacement of the RPN column with the Risk Prioritization column which is used to capture the AP rating.

The final and most important change in the latest J1739TM-JAN2021 DFMEA form from the AIAG 4th

Edition DFMEA form is the replacement of the Class column with the Potential Special Characteristic(s) column. J1739TM-JAN2021 says the following about special characteristics:

"A special product (design) characteristic is a feature of a product that requires special care because incorrect nominal values/tolerances and corresponding manufacturing/assembly variation may have significant influence on product safety, performance, fit, and service life. The purpose of selecting special product characteristic is to communicate the risk to manufacturing, assembly, and/or other interfacing design disciplines."

7 DFMEA FUNDAMENTAL OVERVIEW

Designs are comprised of hardware specifications and/or software code. Designs fail to meet design requirements because their hardware specifications and/or software code are improperly specified**.** The Design FMEA is a risk assessment of the adequacy of the hardware specifications and/or software code in defining a product that will meet the design requirements. It assumes that manufacturing will build the product to the specifications.

There are seven key elements found in all DFMEAs that are effective at managing risk. They can be seen in Figure 8.

Item/ Requirements	Potential Failure Mode (FM)	Potential Effect(s) of Failure (FE)	Sev	Class	Potential Cause(s) of Failure (FC)	Occ	Design Prevention Controls	Design Detection Controls	Det	RPN	Recommended Actions
Design Requirements	Failure To Meet Design Requirement	Description of Harm Due To FM	7	YS	Improperly Defined Spec/Code	4	Method of Determining FM Probability Due To FC	Method of Determining FM Probability Due To FC	3	84	Design Changes To Prevent Objectionable Incident

Key Risk Management Element Legend

Objectionable Incident Definition	Harm Description With Severity Rating	Residual Risk	Root Cause of Objectionable Incident	Design Risk Controls	Probability of Incident Due To Cause	Risk Reduction Action Tracking

Figure 8: Key Elements of DFMEA for Managing Risk

The first two columns of the Design FMEA are used to define the possible objectionable incidents. The "Item/Requirements" column contains the design requirements. The "Potential Failure Mode" column contains the "objectionable incident" or how the design can fail to meet the design requirement. The design requirements place in the Requirements column must contain sufficient detail to be verified using the Design Controls.

The third and fourth columns of the Design FMEA are used to define the harm. The "Potential Effects of Failure" column is used to capture the harm that can occur when the design fails to meet the design requirement. The "Sev" or "Severity" column is used to define a numerical rating for the severity of the harm. When a design fails to meet a design requirement, multiple types of harm with different levels of severities can occur. It can be difficult to identify the probabilities of all the types of harm that can occur when a design fails to meet a design requirement. Consequently, the Design FMEA uses the worst-case effect to determine the severity of the harm and the probability of the Potential Failure Mode or "objectionable incident" as the probability of exposure to the harm. Although this can lead to overstating the risk for a failure mode it will never lead to understating it.

A design can fail to meet a design requirement due to multiple mistakes in defining hardware specifications and/or software code. In a Design FMEA, the possible mistakes that can lead to the design not meeting a design requirement are placed in the "Potential Cause(s) of Failure" Column. A numerical rating equivalent to the probability of the design failure to meet the design requirement (Failure Mode) occurring due to the hardware specification or software code mistake listed in the Failure Cause column is placed in the "Occ" or Occurrence Rating Column. Known as Risk Controls, the Design Prevention and Detection Controls are used to determine the "Occ" rating. To be effective, the Occurrence rating must objective to determine the level of Residual Risk in the design.

The Severity (Sev) and Occurrence (Occ) ratings for each row of the Design FMEA are looked up in the Risk Matrix to determine the residual risk for the row (See Figure 9).

10		YC	YC	YC	YC	YC	YC	YC	YC	YC
9		YC	YC	YC	YC	YC	YC	YC	YC	YC
8				YS	YS	YS	YS	YS	YS	YS
7				YS	YS	YS	YS	YS	YS	YS
6				YS	YS	YS	YS	YS	YS	YS
5				YS	YS	YS	YS	YS	YS	YS
4				YS	YS	YS	YS	YS	YS	YS
3				YS	YS	YS	YS	YS	YS	YS
2				YS	YS	YS	YS	YS	YS	YS
1				YS	YS	YS	YS	YS	YS	YS
Sev/ Occ	1	2	3	4	5	6	7	8	9	10

Figure 9: Risk Matrix (Auto Industry DFMEA)

Boxes with symbols represent unacceptable levels of residual risk. Boxes without symbols indicate acceptable levels of residual risk.

A symbol means that work must be done to improve the hardware specification or software code identified in the Potential Causes of Failure Column. The modifications that will be tried and the tracking of their success are placed in the "Risk Reduction Tracking" area of the Design FMEA which is comprised of multiple columns.

A matrix assessing whether the AIAG VDA and J1739TM-JAN2021 DFMEA methods contain the necessary elements to effectively manage design risk is shown in Figure 10.

Key DFMEA Risk Management Element	AIAG VDA DFMEA Method Performance	SAE J1739 DFMEA Method Performance
Objectionable Incident Definition	1. Only "Function" related design requirements. 2. Insufficient Function detail to support Design Verification.	1. Only "Function" related design requirements. 2. Insufficient Function detail to support Design Verification.
Harm Description With Severity Rating	Adequate	Adequate
Root Cause Definition	1. Not provided for Assembly and Subassembly level DFMEAs.	1. Not provided for Assembly and Subassembly level DFMEAs.
Risk Control Definition	Adequate	Adequate
Probability of Incident Due To Cause	1. Probability of cause provided. 2. Probability of FM causing incident provided provided for Assembly and Subassembly level DFMEAs.	1. Probability of cause provided. 2. Probability of FM causing incident provided provided for Assembly and Subassembly level DFMEAs.
Residual Risk	1. Action Priority (AP) which is used to indicate Residual Risk includes detection component.	1. Action Priority (AP) which is used to indicate Residual Risk includes detection component.
Risk Reduction Action Tracking	Adequate	Adequate

Figure 10: AIAG VDA/SAE DFMEA Method Assessment

The matrix shows that both methodologies fail to contain four of the key elements required for effective DFMEAs.

The first area of failure is Objectionable Incident Definition. Both methodologies concentrate on Functional Design rather than overall Product Design that includes many other design requirements other than those that are function related. There are many instances where customers return properly functioning product because they do not like the way the product looks for feels. Supporters of the two methodologies will argue that a "Requirements" column exists to capture these kinds of detail, but the "Requirements" entries are not used to drive the Failure Modes which drive the failure causes that must be addressed.

The two methods often also require design engineers to specify Design Requirements at component levels that are not required for the design process and the engineers do not know at a level that is verifiable. Figure 10 shows examples of this.

Seat Motor DFMEA Entries Created Using AIAG VDA and SAE DFMEA Method

DFMEA	Function	Failure Mode	Failure Effects	Failure Cause	Non-Verifiable
Seat Motor	Convert electrical energy to mechanical energy according to parameterization.	Torque and rotating velocity of Seat Motor is too low.	Seat speed is too low.	Angle deviation by commutation system intermittently connects (L1, L3 and L2 instead of L1, L2 and L3).	
Commutation System	Commutation system transports the electrical current between coil pairs of the electromagnetic converter.	Angle deviation by commutation system intermittently connects (L1, L3 and L2 instead of L1, L2 and L3).	Torque and rotating velocity of Seat Motor is too low.	Brush card body bends in contact area of the carbon brush.	X
Brush Card Base Body	Brush card body transports forces between spring and motor body to hold in brush spring system in x, y, z position (support commutating contact point).	Brush card body bends in contact area of the carbon brush.	Angle deviation by commutation system intermittently connects (L1, L3 and L2 instead of L1, L2 and L3).	Brush Card Base Body Wall Thickness is specified too thin.	X

Figure 11: Non-Verifiable Functions

The second area of failure for both methodologies is the failure to only include "root causes" in the Failure Cause column of the Design FMEA. This condition exists for both methods when doing Assembly and Subassembly DFMEAs. Figure 11 provides examples of this condition.

Seat Motor DFMEAs Created Using AIAG VDA and SAE DFMEA Method

DFMEA	Function	Failure Mode	Failure Effects	Failure Cause	Non-Root
Seat Motor	Convert electrical energy to mechanical energy according to parameterization.	Torque and rotating velocity of Seat Motor is too low.	Seat speed is too low.	Angle deviation by commutation system intermittently connects (L1, L3 and L2 instead of L1, L2 and L3).	X
Commutation System	Commutation system transports the electrical current between coil pairs of the electromagnetic converter.	Angle deviation by commutation system intermittently connects (L1, L3 and L2 instead of L1, L2 and L3).	Torque and rotating velocity of Seat Motor is too low.	Brush card body bends in contact area of the carbon brush.	X
Brush Card Base Body	Brush card body transports forces between spring and motor body to hold in brush spring system in x, y, z position (support commutating contact point).	Brush card body bends in contact area of the carbon brush.	Angle deviation by commutation system intermittently connects (L1, L3 and L2 instead of L1, L2 and L3).	Brush Card Base Body Wall Thickness is specified too thin.	

Figure 12: Non-Root Causes

The third area of failure is definition of the probability of the objectionable incident due to the cause. Both methodologies define Occurrence as the probability of the Failure Cause.

The final area of failure is the failure to assess and use Residual Risk to prioritize improvement actions and determine when the design should be released for manufacture. The Action Priority method cannot be used determine Residual Risk because of the inclusion of the Detection Rating in the AP level determination. In a Process FMEA one can implement Detection Controls to inspect and contain each out of specification product. If it were a safety related product, a potential safety issue could be exchanged for a scrapped part thus reducing risk.

Unfortunately, no similar opportunity to reduce risk exposure exists in the design process. Once the design is

released for a product, there is no opportunity to reevaluate the design for each product is produced.

9 SUMMARY AND CONCLUSION

This standardization on either the AIAG VDA Handbook or J1739TM-JAN2021 DFMEA methods will result in the implementation of a DFMEA methodology that is both ineffective in managing design risk and inefficient to use.

Some companies are going to have customers who require them to use either the AIAG VDA or J1739TM-JAN2021 DFMEA format. While it is not possible to create an effective DFMEA using either the AIAG VDA or J1739TM-JAN2021 DFMEA methods, it is possible to populate the AIAG VDA and SAE forms using a different method with data that provides the user with an effective DFMEA that is "form compliant" while containing the required information to effectively manage design risk. The methodology on how to do this is a topic for a separate paper.

This paper has only concentrated on the DFMEA. Since the AIAG VDA and J1739TM-JAN2021 DFMEA methodologies only drive to root causes of failure when the Focus Element for the DFMEA is a Component, Assembly and Subassembly DFMEAs will not provide the necessary information to personnel responsible for proper performance of the Process FMEA.

A review of the AIAG VDA and J1739TM-JAN2021 PFMEA methodologies show that they also have major issues that should prevent their use in the efficient performance of effective PFMEAs.

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Richard Harpster is president of Harpco Systems Inc. which he founded in 1987. Harpco Systems specializes in providing software, training and consulting for Risked Based Product Lifecycle Management (RBPLM™). Over the past 33 years Richard has helped numerous companies implement improved design and manufacturing systems on a wide variety of products from automotive components to molecular assays to detect diseases such as Prostate Cancer and HIV. He is a recognized expert in the application of Failure Mode and Effects Analysis and invented several new concepts including the linking of Design FMEAs to Process FMEAs which became an automotive industry standard in 2008, eighteen years after he first introduced the concept to Ford Motor Company Climate Control Division. His latest inventions in the field of RBPLM™ include Requirements Risk Assessment™ (RRA™), Multiple Integrated Cause Analysis (MICA™) and Rapid Integrated Problem Solving (RIPS®). He has published several papers on the topic of RBPLM™.

Prior to starting Harpco Systems, Richard spent 14 years at Ford Motor in a wide variety of positions including Senior Design Engineer, Superintendent of Plant Maintenance and Plant Manager. His education includes a B.S.E.E. from Penn State University, M.S.E.E from the University Of Detroit and an M.B.A. from Eastern Michigan University. Richard is a registered professional engineer in the State of Michigan.