THE USE OF DSM AND DMM TO SUPPORT SAE ARP-4754 DEVELOPMENT ACTIVITIES

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1 INTRODUCTION

ARP-4754 was created by SAE and published in the late 1996 to support the development of highly integrated or complex aircraft systems, especially those with intensive use of software (SAE, 1996). It is recognized by the aeronautical authorities as an acceptable means of compliance to system development activities. It has been adopted by the majority of the aircraft manufacturers as a *de facto* system development guide.

ARP-4754 defines a top down development approach starting with the definition of aircraft functions, allocating these functions to systems, and system functions to items that can be implemented by hardware or software. The three specification domains and the link between them are key elements in the ARP-4754 implementation. ARP-4754, as any standard, does not define a specific way to perform these specifications and links.

Our proposal is to use Design Structure Matrices – DSMs (Eppinger, 1991) to support the modeling of the three ARP-4754 specification domains and also use Domain Mapping Matrices – DMMs (Danilovic & Browning, 2004) to connect them. The intention is to apply techniques that can help engineers with the control of the system complexity. The DSMs/DMMs was the way chosen to make the system complexity evident.

2 THE ARP-4754 DEVELOPMENT ACTIVITIES

The activities of the system development process in the ARP-4754 can be divided into two groups: the development activities that are related to the specific phases of the development, and activities that happen along the development process, called integral processes. The system development activities are:

- Definition of aircraft functions
- Assignment of aircraft functions to systems
- System architecture development
- Assignment of system requirements to system items
- System implementation

The integral processes are:

- Safety assessment
- Development Assurance Level (DAL) assignment
- Requirements capture
- Requirements validation
- Implementation verification
- Configuration management
- Process assurance
- Certification authorities liaison

It is even possible to extend the concepts presented to some of the integral processes; but the focus here is only on the development activities. The development activities are detailed in the next sections.

2.1 Definition of aircraft functions

The first activity to be performed in ARP-4754 process is the identification of aircraft functions. Essentially, these functions define the aircraft characteristics without specifying how they will be implemented. There is not a single or standardized set of aircraft functions, or any regulatory imposition to include some specific function in the project. Aircraft manufacturers define their own aircraft functions depending on the characteristics of the aircraft. The more complex the project, the more aircraft functions may be required.

This activity aims to define a minimum set of functions that must be in the aircraft in order to assure the operation and safety conditions for takeoff, flight and landing. It also defines performance and comfort characteristics. A short list of aircraft functions is presented as follows.

1. Control thrust
2. Control flight path
3. Determine Orientation
4. Determine position and heading
5. Control aircraft on the ground
    - 5.1 Determine air/ground transition
    - 5.2 Decelerate aircraft on the ground
    - 5.3 Control aircraft direction on the ground
6. Control cabin environment
7. Provide power generation & distribution.

2.2 Definition of systems and system functions

The next step in the process is to define the systems that will implement the aircraft functions. To do this, the engineers have some normative references available. One of the most used by aircraft manufacturers is ATA 100 (ATA 100, 1999).

ATA 100 is constituted of 100 chapters (that is the reason for its title). Each chapter is divided into sections and each section is divided into subjects. The idea is to create a system taxonomy to support the aircraft development and also its maintenance tasks. One of the possible ATA 100 uses is the definition of the Maintenance Manuals that follow its chapter structure. Typical examples of systems as defined in ATA 100 are:

1. Environmental control system (ATA Chapter 21)
2. Communication system (23)
3. Electrical system (24)
4. Flight control system, primary and secondary (27)
5. Fuel system (28)
6. Landing gear (32)
7. Navigation and guidance system (34)
8. Oxygen system (35)
9. Pneumatic system (36)

Thus, according to the ARP 4754 top-down approach, each system may be broken down in one or more levels of subsystems. The last level in this decomposition process is the definition of system functions. For example, consider the Landing Gear system. It can be decomposed into other systems (subsystems) such as Brake System. The Brake system can still be decomposed into some system functions:

- 6.1 Brake system
    - 6.1.1 Decelerate wheels on the ground
        - 6.1.1.1 Manual activation
        - 6.1.1.2 Automatic activation

6.1.1.3 Anti skid

6.1.2 Decelerate the wheels on gear retraction

6.1.3 Differential breaking for directional control

6.1.4 Prevent aircraft from moving when parked

In parallel, as part of an interactive process, the system architecture is developed. In fact, the system architecture can be understood, in a few words, as a framework that supports the systems implementation. It is very common in the project design phase for many system architectures to have been developed. The reason for that is to evaluate the different characteristics of each of them looking for the best architecture to be implemented. Some of these architectures can emphasize performance aspects, safety, maturity of the technology being applied in the project, economic factors, etc. The final architecture to be implemented can be one of those proposed or a new one with a mix of the best characteristics of each.

2.3 Definition of system items

The next level of detail, as defined in ARP 4754, is the system items specification. The system item definition is strongly related to the system architecture. Thus, different architectures can request different items.

A system item is considered as a unit that receives some data, makes its processing, and produces an output. A shutoff valve, a brake electronic unit, pressure pumps are examples of items. The system items can be classified into two major groups: software and hardware. The decision to implement the system functions in software or hardware relies on a project decision. Functions implemented by software are becoming more frequent based on several aspects, such as making the updates in the systems easier than replacing boxes. The practical consequence of this is the possibility of introducing more airborne functions without jeopardizing other important aircraft characteristics such as the aircraft weight.

3 USING DSM/DMM TO MAP ARP-4754 ACTIVITIES

Here the static DSM (Browning, 2001) is being proposed as a way to better visualize the connections existing among aircraft functions, systems, and system items. The DMM is being proposed as a way to connect these domains.

The first step in the proposed approach is modeling the aircraft level functions in a DSM. After that, another DSM is used to model the system level interactions and, finally, to model the system items. These three DSMs are linked by two DMMs. The first DMM is used to connect the aircraft functions domain to the system domain, and the second one is used to connect the system domain to the system items domains. In summary, for each ARP-4754 major activity, there is a DSM supporting the corresponding activities, and to connect the different domains, DMMs is used. Figure 1 presents a diagram with the ARP-4754 development activities and corresponding DSM/DMM.

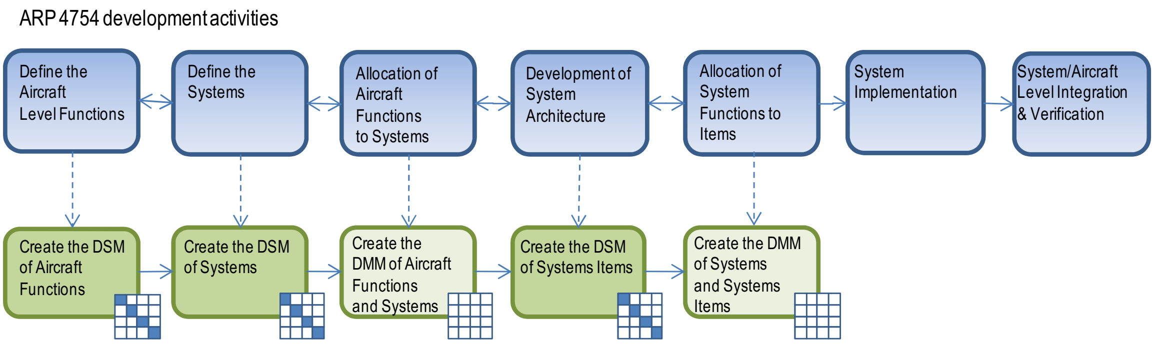

Figure 1. DSM and DMM in the ARP-4754 development activities

Aircraft functions and systems DSMs contain only conceptual elements. The system items DSM contain physical and conceptual components. Just as an example, consider the system level activities. Section 2.2 presents 9 systems and particularly details the Landing Gear system. Based on the proposed approach, these components can be used to create the DSM of systems as presented in

Figure 2. The other DSMs are constructed in the same manner. The resulting DSM can be considered as a “partial DSM” since it contains only some of the aircraft systems.

					6. Landing gear					
					6.1 Brake system					
					6.1.1 Decelerate wheels on the ground					
			Functions 1 to 5 were colapsed	6.1.1.1 Manual activation	6.1.1.2 Automatic activation	6.1.1.3 Anti skid	6.1.2 Decelerate the wheels on gear retraction	6.1.3 Differential breaking for directional control	6.1.4 Prevent aircraft from moving when parked	Functions 7 to 9 were colapsed
Functions 1 to 5 were colapsed										
6. Landing gear	6.1 Brake system	6.1.1 Decelerate wheels on the ground	6.1.1.1 Manual activation			1	1		1		
			6.1.1.2 Automatic activation		1				1		
			6.1.1.3 Anti skid		1	1			1		
		6.1.2 Decelerate the wheels on gear retraction									
		6.1.3 Differential breaking for directional control			1		1				
		6.1.4 Prevent aircraft from moving when parked			1						
Functions 7 to 9 were colapsed										

Figure 2. Partial DSM for systems

4 CONCLUSION

The DSM is a very flexible technique to model systems and the interactions among their elements. The approach suggested used DSM/DMM just as way to map the components of the three activity levels in the ARP-4754. Typical algorithms usually applied in DSMs, such as clustering and tearing, were not explored here. However, they can be used to optimize some elements interactions. It is also important to notice that ARP-4754 encompasses not only development activities, but safety activities, too. The particular area of safety, not explored here, is of special interest to the authors that are developing research about this subject.

The DSM/DMM techniques are not new. The literature provides many examples of its applications. However, our contribution consists in establishing a connection between a well-accepted standard to aircraft systems development, in this particular case ARP-4754, and DSM/DMM techniques.

The proposed approach can be used to support many engineering activities. Just to mention some, the traceability among the several decomposition levels is one example. Other important application is related to the failure propagation analysis. Some systems functions apparently disconnected, when following the links moving from the system level to the aircraft function level, sometimes it is possible to identify that they are connected by an aircraft function in common.

The approach presented is being discussed regarding its applicability in real projects. Effort and computational support are some points in consideration. Anyway, the preliminary results using subsets of project data are satisfactory.

The combination of DSM/DMM provides a clear identification of the interactions among the elements in the different levels of ARP-4754 activities, making the complexity of its interactions evident.

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The Use of DSM and DMM to Support SAE ARP-4754 Development Activities

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Index

- Introduction
- ARP-4754 Process
- Proposed approach
  - Definition of aircraft functions
  - Definition of systems and systems functions
  - Create a DMM for aircraft functions and systems
  - Definition of system items
  - Create a DMM for system and system items
- Conclusions

Introduction

- ARP-4754 is well know standard used in the development of highly integrated or complex aircraft systems, especially those with intensive use of software.
- ARP-4754 defines a top down development approach starting with the definition of aircraft functions, allocating these functions to systems, and system functions to items that can be implemented by hardware or software.
- Design Structure Matrices –DSM and Domain Mapping Matrices –DMM provide a clear way to identify interactions among the system elements in different levels.
- The proposal here is to use Design Structure Matrices – DSMs to support the modeling of the three ARP-4754 specification domains and also use Domain Mapping Matrices – DMMs to connect them.
- The intention is to apply techniques that can help engineers with the control of the system complexity. The DSMs/DMMs was the way chosen to make the system complexity evident.

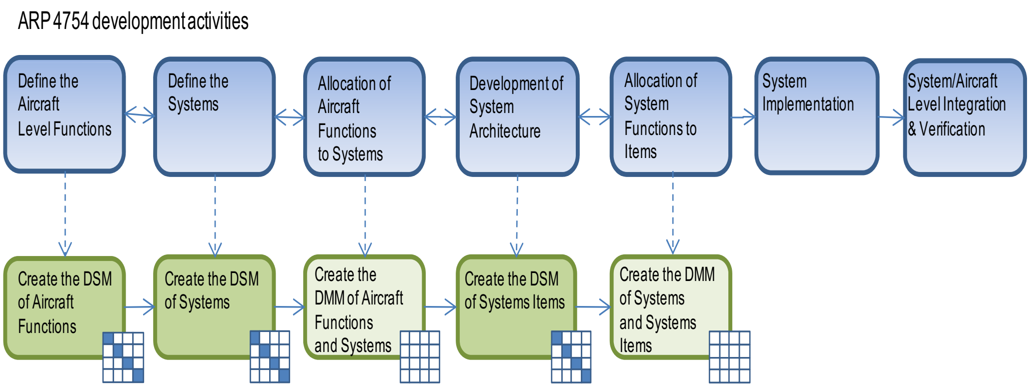
ARP-4754 Process

- The activities of the system development process in the ARP-4754 can be divided into two groups: development and integral processes.
- The first development activity to be performed in ARP-4754 is the identification of aircraft functions. Essentially, these functions define the aircraft characteristics without specifying how they will be implemented.
- Since defined the aircraft functions they need to be allocated to the aircraft systems. Aircraft functions can be hosted in a single "box", in more traditional system architectures, but can also be spread in several units.
- The next level of detail, as defined in ARP-4754, is the system items specification. The system items definition is strongly related to the system architecture. The system architecture can be understood, in a few words, as a framework of items that supports the system implementation.
- The integral processes are not discussed in this presentation.

Proposed approach

- The approach herein presented suggests the modeling of the aircraft level functions in a DSM.
- After that, another DSM is used to model the system level interactions and, finally, the system components are modeled.
- These three DSMs are linked by two DMMs. The first DMM is used to connect the aircraft functions domain to the system domain and the second one is used to connect the system domain to the system items domain.
- In summary, for each ARP-4754 major activity, there is a DSM supporting the corresponding activities; to connect the different domains DMMs are used.

Proposed approach



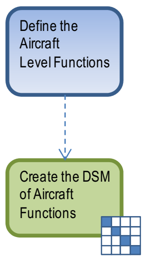
Definition of aircraft functions

- The first activity to be performed in ARP-4754 process is the identification of aircraft functions.
- This activity aims to define a minimum set of functions that must be in the aircraft in order to assure the operation and safety conditions for takeoff, flight and landing.
- A short list of aircraft functions is presented as follows:
  1. Control thrust
  2. Control flight path
  3. Determine Orientation
  4. Determine position and heading
  5. Control Aircraft on the ground
     - 5.1 Determine air/ground transition
     - 5.2 Decelerate aircraft on the ground
     - 5.3 Control aircraft direction on the ground
  6. Control cabin environment
  7. Provide power generation & distribution.

Definition of aircraft functions

		1. Control thrust	2. Control flight path	3. Determine orientation	4. Determine position and heading	5. Control aircraft on the ground: 5.1 Determine air/ground transiti	5. Control aircraft on the ground: 5.2 Decelerate aircraft on the ground	5. Control aircraft on the ground: 5.3 Control aircraft direction on t ground	6. Control cabin environment	7. Provide power generation and distribution
1. Control thrust			1			1				1
2. Control flight path		1		1	1					1
3. Determine orientation										1
4. Determine position and heading										1
5. Control aircraft on ti ground	5.1 Determine air/ground transition									1
	5.2 Decelerate aircraft on the ground	1				1				1
	5.3 Control aircraft direction on the ground	1			1	1				1
6. Control cabin environment										1
7. Provide power generation and distribution										

The aircraft functions represented in a DSM.



Definition of systems and systems functions

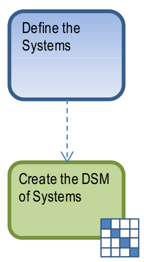
- In the same way as the connections among aircraft functions can be modeled using DSMs, the aircraft systems also can. For this, it is necessary to define the aircraft systems. Even possible have different designations to the systems some normative references that can be used in this case. One of the most used by aircraft manufacturers is ATA 100.
- It were selected some systems in the ATA to develop an example.

1. Environmental control system
2. Communication system
3. Electrical system
4. Flight control system, primary and secondary
5. Fuel system
6. Landing gear
7. Navigation and guidance system
8. Oxygen system
9. Pneumatic system
10. Auxiliary power unit
11. Thrust reverse
12. Indicating / Recording systems
13. Standard practices and structures
14. Propellers / Propulsors

Definition of systems and systems functions

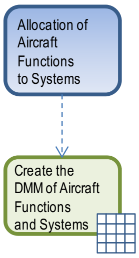
	1. Environmental control system	2. Communication system	3. Electrical system	4. Flight control system, primary and second	5. Fuel system	6. Landing gear	7. Navigation and guidance system	8. Oxygen system	9. Pneumatic system	10. Auxiliary power unit	11. Thrust reverser	12. Indicating / Recording systems	13. Standard Practices and Structures - Ger	14. Propellers / Propulsors
1. Environmental control system			1			1		1					1	1
2. Communication system			1										1	
3. Electrical system						1				1			1	1
4. Flight control system, primary and secondary			1			1	1						1	
5. Fuel system			1										1	
6. Landing gear			1										1	1
7. Navigation and guidance system			1										1	
8. Oxygen system			1										1	
9. Pneumatic system			1										1	
10. Auxiliary power unit					1	1							1	
11. Thrust reverser			1			1			1					
12. Indicating / Recording systems	1	1	1	1	1	1	1	1	1	1	1			1
13. Standard Practices and Structures - General				1		1								
14. Propellers / Propulsors			1	1	1	1				1			1	

The aircraft systems represented in a DSM



Create a DMM for aircraft functions and systems

- As per ARP 4754, the aircraft functions must be allocated to systems. To perform this allocation it was used a Domain Mapping Matrix (DMM).



		1. Environmental control system	2. Communication system	3. Electrical system	4. Flight control system, primary and secondary	5. Fuel system	6.1.1.1 Manual activation	6.1.1.2 Automatic activation	6.1.1.3 Anti skid	6.1.2 Descelerate the wheels on gear retraction	6.1.3 Differential breaking for directional control	6.1.4 Prevent aircraft from moving when parked	7. Navigation and guidance system	8. Oxygen system	9. Pneumatic system	10. Auxiliary power unit	11. Thrust reverser	12. Indicating / Recording systems	13. Standard Practices and Structures - General	14. Propellers / Propulsors
							6. Landing gear													
							6.1 Brake system													
							6.1.1 Decelerate wheels on the ground													
Aircraft functions 1 to 4 were colapsed																				
5. Control aircraft on the ground	5.1 Determine air/ground transition			1						1								1		
	5.2 Decelerate aircraft on the ground			1	1		1	1	1								1	1	1	1
	5.3 Control aircraft direction on the ground			1	1				1		1							1		
Aircraft functions 6 to 7 were colapsed																				

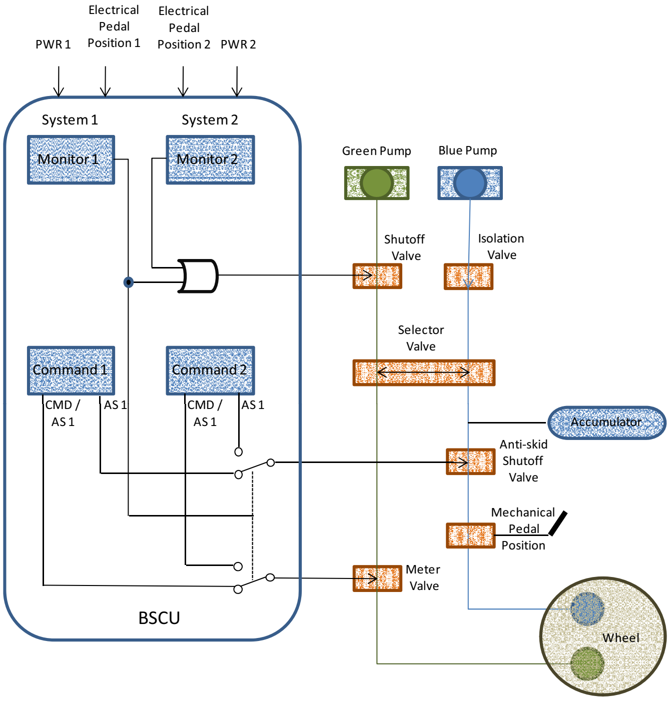
Definition of system items

- Similarly to aircraft functions and systems, the system architecture items also have their interactions represented by DSMs.
- It is possible, during the design phase, to have different architectures, exploring specific aspects of each. Thus, it is also possible to have different DSMs to the systems items, one for each architecture.
- To discuss this concept it presented an example considering the system “6.1 Brake system”.
- The proposed architecture is composed of a computer (Brake System Control Unit – BSCU) that receives the pedals position (Electrical Pedal Position 1 and 2) and commands the system (PWR 1 and PWR 2). The BSCU accounts for:

  Anti-skid command
  Brake command
  Pilot annunciation
  Provide functional integration among the system components
  Provide functional interface with other aircraft systems

Definition of system items

A Brake System architecture



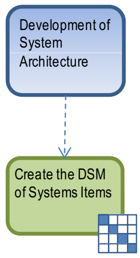
Definition of system items

- The Shutoff valve is commanded by BSCU and accounts for applying hydraulic pressure on the braking discs.
- The Meter Valve accounts for keeping the pressure to the demanded level under control and for providing regulation for the Anti-skid system function.
- The Accumulator provides an emergence reserve of hydraulic pressure.
- The Anti-skid Shutoff Valve is commanded by the BSCU and is used for controlling hydraulic pressure in order to prevent a possible locking of the wheels.
- The brake pedal is the interface between the pilot and the brakes providing mechanical and electrical commands to the system.
- The Wheel brakes account for providing friction force to the wheels.
- Finally, every time the pressure in the green line goes below a specified threshold, the Selector Valve is activated connecting the blue line.

Definition of system items

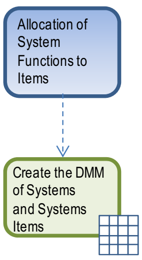
		1.1. Monitor 1	1.2. Monitor 2	1.3. Command 1	1.4. Command 2	2. Green pump	3. Blue pump	4. Shutoff valve	5. Isolation valve	6. Selector valve	7. Acummulator	8. Anti-skid shutoff valve	9. Mechanical pedal position	10. Meter valve	11. Wheel disks
1. BSCU	1.1. Monitor 1	■						1							
1. BSCU	1.2. Monitor 2		■					1							
1. BSCU	1.3. Command 1			■								1		1	
1. BSCU	1.4. Command 2				■							1		1	
2. Green pump						■		1		1				1	
3. Blue pump							■		1	1		1	1		
4. Shutoff valve								■		1				1	1
5. Isolation valve									■	1		1	1		1
6. Selector valve										■		1	1	1	1
7. Acummulator							1				■				
8. Anti-skid shutoff valve		1										■	1		
9. Mechanical pedal position													■		1
10. Meter valve		1												■	1
11. Wheel disks															■

The system items represented in a DSM.



Create a DMM for system and system items

- Once more, it is necessary to connect two domains: the system and items domains.



				1.1. Monitor 1	1.2. Monitor 2	1.3. Command 1	1.4. Command 2	2. Green pump	3. Blue pump	4. Shutoff valve	5. Isolation valve	6. Selector valve	7. Acummulator	8. Anti-skid shutoff valve	9. Mechanical pedal position	10. Meter valve	11. Wheel disks
Functions 1 to 5 were colapsed																	
6. Landing gear	6.1 Brake system	6.1.1 Decelerate wheels on the ground	6.1.1.1 Manual activation						1						1		1
6. Landing gear	6.1 Brake system	6.1.1 Decelerate wheels on the ground	6.1.1.2 Automatic activation	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6. Landing gear	6.1 Brake system	6.1.1 Decelerate wheels on the ground	6.1.1.3 Anti skid	1	1	1	1	1	1					1			
6. Landing gear	6.1 Brake system	6.1.2 Decelerate the wheels on gear retraction				1		1	1	1	1	1	1			1	1
6. Landing gear	6.1 Brake system	6.1.3 Differential breaking for directional control		1	1	1	1	1	1	1	1	1	1	1	1	1	1
6. Landing gear	6.1 Brake system	6.1.4 Prevent aircraft from moving when parked				1			1				1		1		1
Functions 7 to 14 were colapsed																	

Conclusions

- The DSM/DMM are very flexible techniques to model systems and the interactions among its components.
- The approach proposed suggests the use of DSM/DMM just as way to map the components of the three process levels in ARP 4754.
- It is also important to notice that ARP 4754 encompasses not only development activities, but safety activities, too. The particular area of safety is of special interest to the authors that are developing research about this matter.
- The use of DSM provides a clear identification of the interactions among the systems elements.
- The DMM support is very important in a multi-domain scenario. The links between aircraft functions and system domains; and also between systems and system items domains allow making the connections among them evident.

Conclusions

- The proposed approach can be used to support many engineering activities. Just to mention some, the traceability among the several decomposition levels is one example. Other important application is related to the failure propagation analysis. Some systems functions apparently disconnected, when following the links moving from the system level to the aircraft function level, sometimes it is possible to identify that they are connected by an aircraft function in common.
- The approach presented is being discussed regarding its applicability in real projects. Effort and computational support are some points in consideration. Anyway, the preliminary results using subsets of project data are satisfactory.
- The combination of DSM/DMM provides a clear identification of the interactions among the elements in the different levels of ARP-4754 activities, making the complexity of its interactions evident.