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Facilitating Quick Change Introduction in Aerospace Products with DSM-Based Risk Change Analysis and Clustering Technique

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Abstract: This paper shows how a Design Structure Matrix can support the re-design process of an aircraft cabin interior component - stowage. It presents an approach to identifying challenges of design change introduction in aircraft products and demonstrates how a modular product design can address them. First, the stowage is modeled with a DSM and a risk analysis is performed on the baseline design. Specific stages of the Change Prediction Method (Clarkson et al., 2004) are used to evaluate interfaces between product components in different design domains. Furthermore, DSM serves as an input for clustering operations, which are a foundation for modular stowage design. As a result, a modular product architecture is created including new re-designed interfaces. The results show that the modular design approach can reduce the risk of change while increasing product customization and the number of configuration alternatives.

Keywords: Design Structure Matrix (DSM), Change Prediction Method (CPM), Change Risk Analysis, Modular Design, Product Architecture, Interface, Clustering

1 Introduction

Product change can be driven by various factors such as new technologies, manufacturing improvements, or supplier changes (Gullander, 2023). However, customer needs can be considered as the main driver for change introduction into the design and product structure. Despite the fact that the aerospace industry differs from other sectors with the complexity of the product, airworthiness requirements, and production volumes, it has to follow the market trends and offer product customization and high variability to the customers. According to the engineering team working at Heart Aerospace and their broad industry experience, such a change process can take up to 6 months considering only requirements update, re-design, and certification. The challenge for aerospace companies is to reduce this time as much as possible through various design and process improvements introduced at any stage of development. It calls for identifying the weak points of the process and defining advancement opportunities. This paper will advocate DSMs as a key approach to executing a structured change risk analysis. Additionally, it will demonstrate the benefits resulting from modular product architecture reflected in the change risk reduction as well as an increase in product customization and variability. Work presented in the paper was performed at Heart Aerospace interiors department. Interior cabin stowage was selected for the analysis. Stowage is a cabinet placed in the front of the passenger cabin used as a storage unit during flights. It was recommended for analysis by the design engineers from Heart Aerospace because it acts as an option selected by the customer and comes in different versions. The design of the stowage can change many times during its lifecycle hence a robust change introduction process is required. This paper contributes to practice showing a use case of DSM, CPM and clustering methods combined and applied in aerospace industry. Proposed methodology was proven useful in creating modular product structure, which can be beneficial for design change introduction into aerospace products.

2 Related work

Change is an integral part of engineering design. Many researchers and industry engineers recognized the importance of change management, as it has a direct effect on redesign time and product cost. Identifying the need for change early in the design process and understanding the interfaces existing between different product domains is crucial in reducing the change impact (Clarkson et al., 2004). The main idea for analysis was built on the work of Clarkson, Simons, and Eckert (Clarkson et al., 2004). They investigated the change behavior using a case study of a complex rotorcraft design. By developing a model of this system, they were able to predict a change risk utilizing concepts of likelihood and impact. The product divided into subsystems acted as input for the analysis and was represented by a DSM. The authors defined likelihood as the average probability that a change in the design of one subsystem will lead to a design change in another by propagation across their common interfaces. Likewise, the impact was defined as the average proportion of the design work that will need to be redone if the change propagates (Clarkson et al., 2004). Those two values combined give a direct risk of a specific design change.

Modular product architecture can be considered as a solution for challenges outlined through change process analysis. This concept became a research subject investigated by several scholars, who presented the benefits of modular products in terms of change introduction, an increase in variability, and product customization. K. Ulrich (Ulrich, 1995) states that such product structure facilitates localizing required change to the minimum possible number of components. According to Ericsson and Erixon, modularity is one common way of providing flexibility that enables product variations and technology development without changes to the overall design (Ericsson and Erixon, 1999). Furthermore, Bonvoisin et al. (Bonvoisin et al., 2016) described breaking down product complexity as a means to reduce development time by allowing parallel design which leads to shorter time-to-market and reduced costs. The benefits of the modular design approach are also visible in terms of company organization and product development management aspects (Ulrich, 1995), (Bonvoisin et al., 2016). Deciding on product architecture and the level of modularity is crucial for the entire company and impacts the whole product lifecycle.

3 Methodology outline

The aim of the change analysis and clustering operations was to build a foundation for modular design and create a modular product architecture. Those were obtained through the re-design of product interfaces. First, the DSM is used to perform change process analysis and complete the risk assessment of a pre-defined set of stowage changes. Product components and their interactions with other design domains are populated in DSM. Following the concept presented by Clarkson, Simons, and Eckert (Clarkson et al., 2004), an evaluation of interfaces is performed, and a multi-domain product risk matrix is obtained in the end. To propose alternative architectures, the DSM clustering algorithm developed by Thebeau (Thebeau, 2001) was used. The results of clustering indicated the interfaces and components recommended for further investigation and re-design.

3.1 Change risk analysis

In this paper, an analysis of cabin interior stowage was performed. Four different design domains were taken into consideration: product components, affected documents, tests, and reports, as well as PLM functions. Each domain was divided into subsystems and populated into a DSM. Interactions between components were determined and marked in matrices as shown in fig. 1.

Dependency		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Structure assembly	1		X		X	X		X	X	X	X	X	X	X	X	X	X	X	X
Door panel assembly	2	X		X	X	X	X								X	X	X		X
Door catch/latch	3		X																X
Door hinges	4		X																X
Latch strike	5	X	X																X
Bump 1	6	X	X																X
Bump 2	7	X																	X
Edge Trim	8	X																	X
Coat hanger	9	X																	X
Light assembly	10	X																	X
Tie rods	11	X																	X
Floor attachment	12	X												X					X
Installation fasteners	13	X											X						X
Color (Finishing)	14															X		X	X
Material	15														X			X	X
Placards&markings	16	X	X							X	X				X	X			X
Literature pockets	17														X	X			X
Bolts/rivets/bonding	18	X	X		X	X	X	X	X	X	X	X	X	X			X	X	

Figure 1. Product DSM – dependencies assessment.

Each dependency was evaluated in terms of likelihood and impact. Specific values for both of those parameters were assigned by an experienced design engineer through a series of interviews. Impact index was defined as the time needed to perform a design change to a given component and was scaled according to Table 1. The likelihood parameter was a combination of two indices: interface complexity and historical data scaled according to Tables 2 and 3.

Table 1. Redesign time.

Time	Value
short: 0,5-4h	0.25
medium-short: 5-16h	0.5
medium-long: 17-30h	0.75
long: 31-80h	1.0

Table 2. Interface complexity levels.

Complexity	Value
few and simple	0.3
few and complex	0.7
many and simple	0.8
many and complex	1.0

Table 3. The number of component changes during the product lifecycle.

Historical data	Value
0-5 times	0.2
6-12 times	0.5
13-25 times	1.0

Likelihood was calculated as the weighted average of interface complexity and historical data parameters, with weights equal to 1 and 2 respectively. The historical data index was determined by collecting real historical data through interviews. Owning to this it was assumed to be a more reliable measure, hence it had a higher weight in likelihood calculation. Likelihood and impact combined resulted in a direct risk for each identified interaction. They were summarized in the product risk matrix shown in fig. 2.

Components	Product risk matrix																		
Product components		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Structure assembly	1		0.28		0.18	0.18		0.06	0.12	0.33	0.17	0.18	0.18	0.15	0.23	0.28	0.23	0.23	0.15
Door panel assembly	2	0.23		0.12	0.18	0.18	0.06								0.45	0.28	0.23		0.30
Door catch/latch	3		0.22																0.22
Door hinges	4		0.28																0.22
Latch strike	5	0.45	0.43																0.28
Bump 1	6	0.38	0.11																0.11
Bump 2	7	0.38																	0.11
Edge Trim	8	0.75																	0.15
Coat hanger	9	0.50																	0.14
Light assembly	10	0.50																	0.33
Tie rods	11	0.45																	0.14
Floor attachment	12	0.68												0.28					0.28
Installation fasteners	13	0.70											0.18						0.15
Color (Finishing)	14															0.28		0.45	0.14
Material	15														0.45			0.45	0.14
Placards&markings	16	0.47	0.14							0.22	0.11				0.23	0.14			0.15
Literature pockets	17														0.45	0.28			0.14
Bolts/rivets/bonding	18	0.47	0.18		0.09	0.13	0.13	0.09	0.13	0.18	0.37	0.25	0.25	0.37			0.23	0.23	
Documentation		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Requirement Listed in the Valispace	19	0.19	0.11		0.06	0.06				0.11	0.11	0.06	0.06		0.19	0.11	0.19	0.19	0.33
Requirement Approved in the Valispace	20	0.38	0.22		0.12	0.12				0.22	0.22	0.12	0.12		0.38	0.22	0.38	0.38	0.22
Requirement Validated in the Valispace	21	0.38	0.22		0.12	0.12				0.22	0.22	0.12	0.12		0.38	0.22	0.38	0.38	0.22
Requirement Verified in the Valispace	22	0.93	0.60		0.40	0.40				0.60	0.60	0.40	0.40		0.93	0.60	0.93	0.93	0.60
MBD (3D) Installation level component	23	0.70	0.30	0.20	0.20	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.45	0.47	0.30	0.70	0.70	0.45
Placards & Markings drawings	24	0.68	0.43							0.43	0.43				0.68	0.43	0.68		0.43
Trim & Finish Specification - technical	25														0.70	0.45		0.70	0.45
Trim & Finish Specification - customer	26														0.70	0.45		0.70	0.45
Interior Options Guide - customer	27	0.70	0.45	0.30	0.30	0.30	0.30	0.30	0.30	0.45	0.45				0.70	0.45	0.70	0.70	
General Arrament, Stowage S1	28	0.38	0.22	0.12	0.12	0.12	0.12	0.12	0.12	0.22	0.22	0.12	0.12	0.22	0.38	0.22	0.58	0.38	0.22
Stowage, System Architecture	29	0.58	0.33	0.18	0.18	0.18	0.18	0.18	0.18	0.33	0.33	0.18	0.18	0.33	0.58	0.33	0.58	0.58	0.33
Wiring Diagram	30	0.45									0.28								0.28
Weight & Balance Report	31	0.47	0.30	0.20	0.20	0.20	0.20	0.20	0.20	0.30	0.30	0.20	0.20	0.30	0.47	0.30	0.47	0.47	0.30
ICD – Interface Control Document	32	0.70									0.45	0.30	0.30	0.45					
Materials coupon (layers, layers for flammability test)	33	0.38	0.22	0.12	0.12	0.12	0.12	0.12	0.12	0.22	0.22				0.38	0.22	0.38	0.38	
Static Test article	34	0.77										0.23	0.23	0.43					
Tests and reports		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Flammabilty test	35	0.70	0.45	0.30			0.30	0.30	0.30	0.45	0.45				0.70	0.45	0.70	0.70	0.45
Static test	36	0.58										0.18	0.18	0.33					
Cabin Inspection	37	0.68	0.43				0.28	0.28	0.28								0.68	0.68	
Stress analysis	38	0.58	0.33	0.18	0.18	0.18				0.33	0.33	0.18	0.18			0.33	0.58		0.33
Interior Certification Program	39	0.93																	
Stowage Stress Analysis Report	40	0.70	0.45	0.30	0.30	0.30			0.30		0.45	0.30	0.30	0.45					0.45
Stowage Static Test Plan	41	0.90										0.37	0.37	0.57					
Stowage Static Test Conformity	42	0.45										0.18	0.18	0.28					
Stowage Static Test Report	43	0.90										0.37	0.37	0.57					
Stowage Flammability Test Plan	44	0.90	0.57	0.37			0.37	0.37	0.37	0.57	0.57				0.90	0.57	0.90	0.90	0.57
Stowage Flammability Test Conformity	45	0.45	0.28	0.18			0.18	0.18	0.18	0.28	0.28				0.45	0.28	0.45	0.45	0.28
Stowage Flammability Test Report	46	0.90	0.57	0.37			0.37	0.37	0.37	0.57	0.57				0.90	0.57	0.90	0.90	0.57
Cabin Inspection Plan	47	0.90	0.57				0.37	0.37	0.37								0.90	0.90	
Cabin Inspection Conformity	48	0.45	0.28				0.18	0.18	0.18								0.45	0.45	
Cabin Inspection Report	49	0.90	0.57				0.37	0.37	0.37								0.90	0.90	
PLM		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Part Number reidentification	50	0.06	0.11	0.06	0.06	0.06	0.06	0.06	0.06	0.11	0.28	0.06	0.06	0.11	0.23	0.11	0.19	0.19	0.11
Customer options	51	0.45	0.28	0.18						0.22	0.28				0.47	0.28	0.45	0.45	
Product Structure	52	0.38	0.11	0.06	0.06	0.18	0.18	0.18	0.18	0.22	0.30	0.18	0.18	0.28	0.47	0.28	0.45	0.45	0.28

Figure 2. Product risk matrix.

Individual risk assessment for each interface allowed for determining the total risk for specific change. Following the method presented by Koh, Caldwell, and Clarkson (Koh et al., 2013) three indices were calculated: ICL (incoming change likelihood), ICI (incoming change impact), and OCR (outgoing change risk). The last index defined the scale of how one system will affect other systems when changed. It was calculated according to Formula 1 and indicated the total risk of change for each product component.

$$OCR = \frac{\sum risk\ column\ entries}{total\ number\ of\ components - 1} \qquad (1)$$

Total change risk was calculated as a sum of OCRs carried by each component included in a specific change option and shown in fig. 3.

Affected system	Change options							OCR
	Width	Lit. pockets	Shelves	Doors	Lights	Color	Material	
Structure assembly	x	x	x		x	x	x	0.50
Door panel assembly	x			x		x	x	0.20
Door catch/latch	x			x				0.06
Door hinges	x			x				0.06
Latch strike	x			x				0.06
Bump 1	x			x		x	x	0.08
Bump 2	x					x	x	0.08
Edge Trim	x					x	x	0.08
Coat hanger	x		x					0.13
Light assembly	x		x		x			0.16
Tie rods	x		x					0.08
Floor attachment	x							0.09
Installation fasteners	x							0.11
Color (Finishing)		x				x		0.25
Material		x				x	x	0.17
Placards&markings	x		x	x	x			0.28
Literature pockets		x				x	x	0.29
Bolts/rivets/bonding	x	x	x	x	x	x	x	0.20
Total change risk	2.17	1.41	1.36	0.93	1.14	1.85	1.59	

Figure 3. Change options risk.

3.2 Clustering

Integration analysis utilizing a clustering algorithm is a way to support modularization (Browning, 2001). Clustering is based on reordering rows and columns of a DSM that includes product components and interactions between them in order to group the components with the most interactions into modules while minimizing interactions between modules. A clustering algorithm developed by Thebeau (Thebeau, 2001) was used in this thesis. It was a MATLAB code with clustering macro and preset parameters. The DSM including product components and interactions between them used for change process analysis acted as an input for the clustering algorithm. Adjustments of the code included extracting the integrative components: bolts/rivets/bonding and placards/markings from the analysis to achieve better results. The interactions with integrative components were recommended for separate analysis out of the clustering method. According to suggestions given by the author 10 runs were performed in order to achieve a sufficient database for clusters analysis and choose the best modular division for the considered product. Clusters' likeness analysis was performed following the procedure described by Thebeau (Thebeau, 2001). It was based on comparing clusters generated in each run with clusters from other runs and calculating the average total likeness of the analysis. This parameter represented the level of similarity between achieved results. The more similar the results were between each other, the more optimal the analysis was. The average total likeness of the clustering performed in this thesis was equal to 88%. It was considered a high value, compared to around 70% achieved by Thebeau for clustering of the elevator system. This parameter indicated that the clustering was optimal and could be investigated further. It is worth noting that the high value of likeness was caused by a relatively low number of components in the investigated product, reducing the number of possible clustering solutions and balancing the randomness included in the algorithm. Clustering indicated modules within the product structure and helped to identify interfaces between modules. Those were shown in fig. 4.

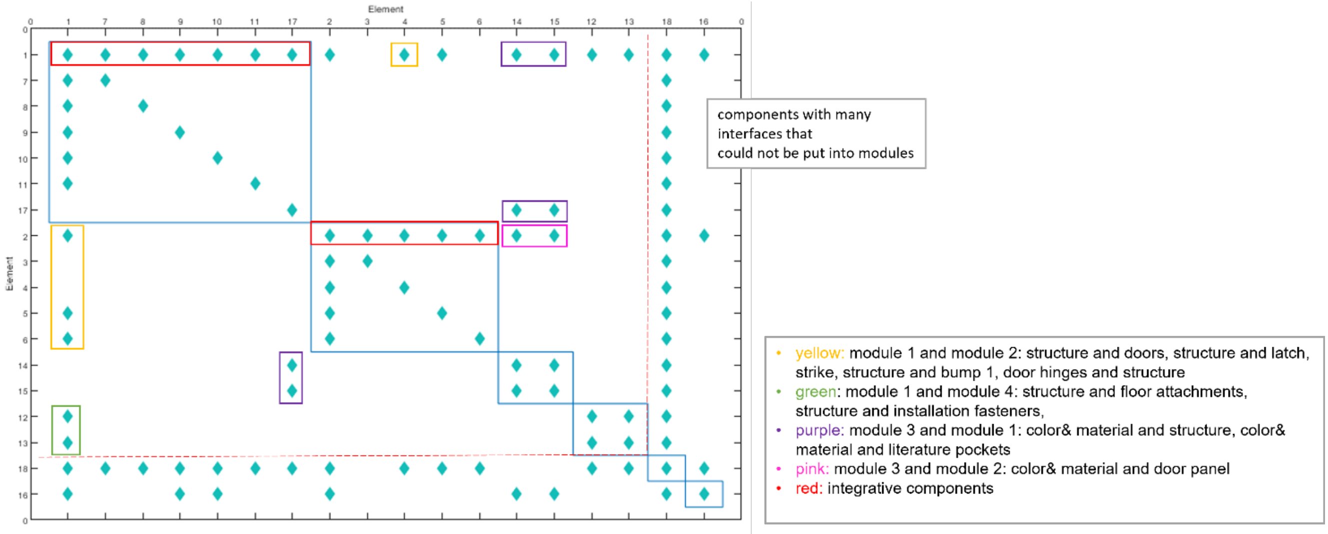

Figure 4. Modules and interfaces identified through clustering.

3.3 Re-design process

Clustering operations facilitated the division of the product into modules and indicated which interfaces should be selected for detailed investigation. Owning to this a new modular product structure emerged. Six high-risk interfaces within modules and four high-risk interfaces between modules were identified using results from change process analysis. Each interface was investigated individually together with an interior design expert engineer. Discussions during interviews allowed to collect detailed information about standard design solutions for stowage interfaces such as: used materials, specification of fasteners, requirements for sealant or resin, manufacturing, and installation techniques. Currently applied design solutions were presented by the interviewed engineer using installation drawings, components offered by suppliers available online as well as hand sketches. Such an approach supported determining which interfaces could have been improved to reduce the change risk and which could not have been modified. Decision making process was not strictly structured and down selection of interfaces suitable for the redesign was performed during brainstorming session with design engineer. Whenever an interesting idea of a design improvement appeared, it was recommended for more detailed investigation. Few criteria for the selection were identified as:

- complexity of the interface design – simple and uncomplicated interfaces were not redesigned, only the ones that offered room for improvement were selected,
- number of interfaces - components with many interfaces were considered as suitable for redesign, at least one interface for those components could have been easily improved,
- interfaces identified as suitable to accommodate different components – example of coat hanger interchangeable with shelves showed how one interface can cover two functions of the stowage.

Finally, five out of ten interfaces were selected and new design solutions, reducing the likelihood and impact of change, were proposed. Those were achieved through investigating smart solutions available on the market, reviewing articles (Duncanaviation.Aero, 2021), and searching for interesting information in the aerospace design industry. Furthermore, past design experience helped create new types of interfaces between some components. All of those were consulted and evaluated by the interior design engineer in terms of the possibility of implementation and potential issues. Results of the redesign process were described in section 4 and schematic sketches were prepared to visualize the new design solutions for comparison with standard interface design.

4 Results

The re-design process resulted in a new design of selected interfaces. Schematic drawings were prepared to visualize the concepts. In fig. 5 an example of a re-designed interface between the side wall and coat hanger interchangeable with the shelf is shown. It is worth noting that the same sliding guide can be used to install both components, and there is no side panel modification required to change between the coat hanger and shelf option. The summary of all design improvements is listed in fig. 6.

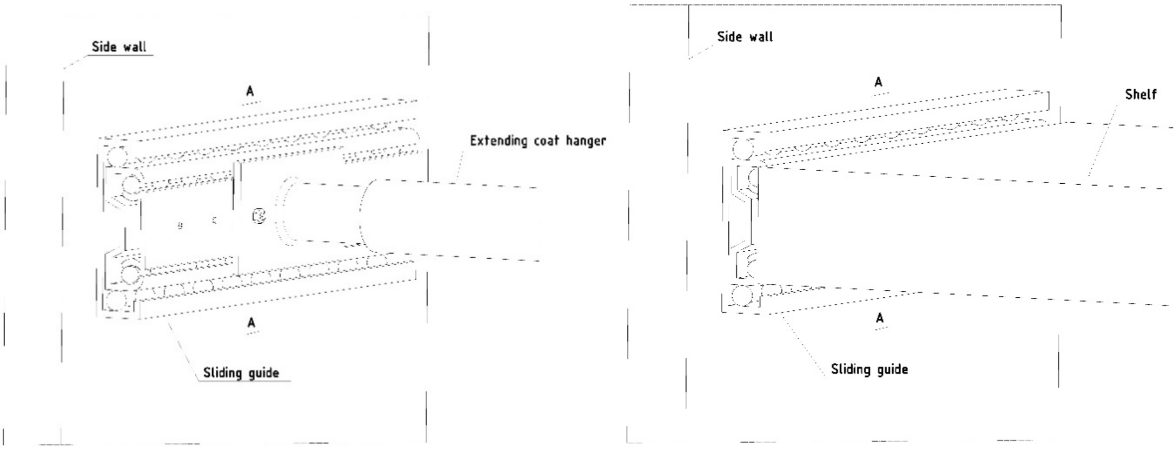

Figure 5. Sidewall and coat hanger (left) or shelf (right) installation. Interchangeable components are installed using the same sliding guide and countersunk screws.

Mod. No.	Module	Component	Interface	High risk within module	High risk betwee	Baseline risk	Improved risk	Baseline design	Improvements	Notes/Redesign benefits
1	Structure equipment kit	Coat hanger	structure	☑		0.50	0.11	coat hanger installed with screws and nuts on the wall, coat hanger with only one length option	DESIGN: sliding rails with interfaces allowing to accommodate both shelves and coat hangers, extending coat hanger to cover stowage width range	shelves interchangable with coat hanger can be offered as an **additional option** for customer
		Light assembly	structure	☑		0.50	0.22	one top panel with cutout for light assembly, additional top panel without cutout	DESIGN: plastic plug is used to simulate the light assembly	allows to have only one top panel, the only implication is in the BOM (plug and light assembly have to be both included), however, this is covered by **150% BOM** and **configuration management module in PLM system**
		Literature pockets	structure	☑		0.23	0.19	one aft panel with inserts and holes for literature pockets installation, additional aft panel without inserts and holes	DESIGN: previous holes with inserts in the structure panel	possibility to add components **without** stowage **de-installation** and **PNs change**
3	Finishing	Color&material	structure		☑	0.38	0.28	structure panel painted, deinstallation from aircraft required when color is changed, each panel painted separately	DESIGN: hydrographics and vinyl wrap method	the whole structure can undergo the process, colors and materials have their own PN in separate module, there is no need to change the PN of other modules, a wide range of colors and materials is offered to the customer, **easier and cheaper application**
			lit. pockets			0.45	0.19	certification of few material combination	DESIGN: certify component in many colors and materials	wide range of materials and colors availabe as an **option to customer**
4	Floor	Floor attachment	structure		☑	0.68	0.11	floor attachments installed in the floor panel with screws, floor panel has cutouts to install the floor attachments	DESIGN: QCTL (quick change track lock system) used	**no effect** on structure when stowage width changes

Figure 6. Re-design proposal of high-risk interfaces.

Newly designed interfaces were re-evaluated using the same change risk assessment method. Likelihood and impact parameters were lowered by one level for selected dependencies. It resulted in new values of direct risk populated in the product risk matrix. All the above changes were evaluated and approved by an interior design expert engineer. The results were shown in fig. 7. In total 22 interfaces were re-evaluated, and the risk reduction is visible in the cells marked with bold frames.

Components		Product risk matrix																	
Product components		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Structure assembly	1		0.28		0.18	0.18		0.06	0.12	0.06	0.11	0.18	0.12	0.15	0.23	0.28	0.23	0.19	0.15
Door panel assembly	2	0.14		0.12	0.18	0.18	0.06								0.19	0.11	0.23		0.30
Door catch/latch	3		0.22																0.22
Door hinges	4		0.28																0.22
Latch strike	5	0.28	0.43																0.28
Bump 1	6	0.22	0.11																0.11
Bump 2	7	0.22																	0.11
Edge Trim	8	0.50																	0.15
Coat hanger	9	0.11																	0.14
Light assembly	10	0.22																	0.33
Tie rods	11	0.28																	0.14
Floor attachment	12	0.11												0.28					0.28
Installation fasteners	13	0.45											0.18						0.15
Color (Finishing)	14															0.28		0.38	0.14
Material	15														0.45			0.38	0.14
Placards&markings	16	0.30	0.14							0.12	0.11				0.23	0.14			0.15
Literature pockets	17														0.19	0.11			0.14
Bolts/rivets/bonding	18	0.47	0.18		0.09	0.13	0.13	0.09	0.13	0.18	0.37	0.25	0.25	0.37			0.23	0.23	

Figure 7. Re-evaluated product risk matrix.

As a result of the risk reduction for each component and excluding some components from change options, the total change risk and the number of affected instances for the new design were reduced. The comparison graphs can be visible in fig. 8 and 9. A decrease in change risk up to 47% can be noticed for improved design in comparison to the baseline design.

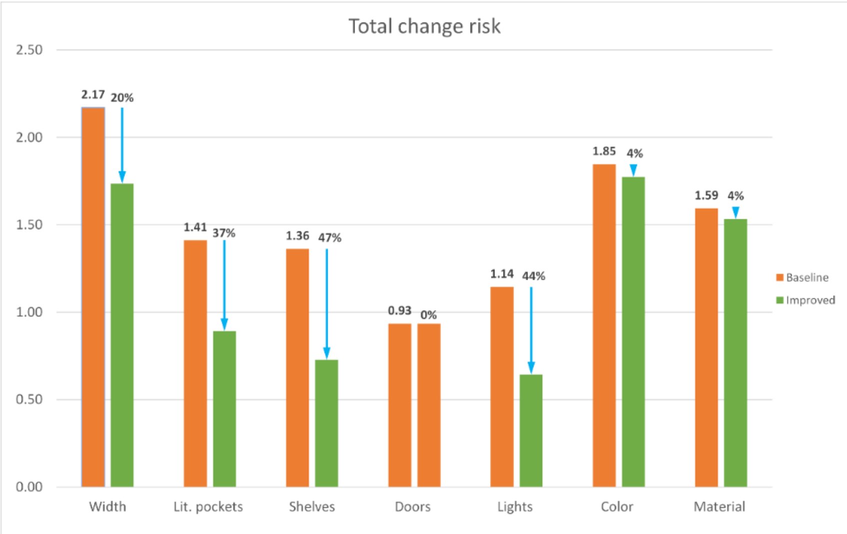

Figure 8. Risk reduction for new design.

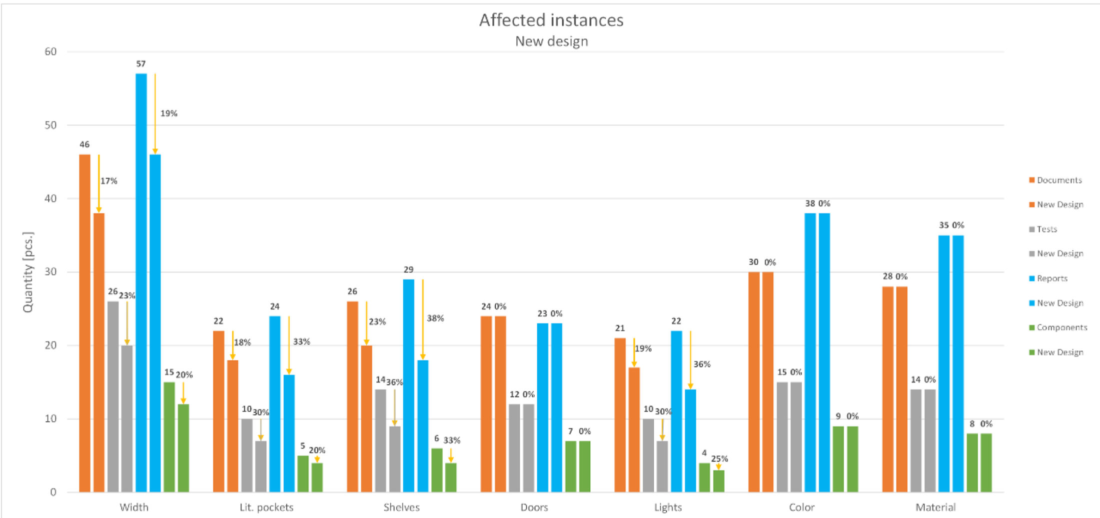

Figure 9. Affected instances for the new design.

5 Validation

At the beginning of the work, the possible issues and high-risk interfaces were discussed with the design engineer, based on his previous experience and general knowledge of the product. The results of the initial change risk analysis were consistent with the predictions he made. Risk reduction shown in section 5 validated the modular design of the product as sufficient for quick change introduction. Further validation of the proposed approach could include calculating the number of documents, tests, and reports affected by the change of real stowage when the aircraft is manufactured and introduced into service.

6 Conclusions

This paper presents an application of the change prediction method and clustering technique for an aerospace product. Such an approach facilitates and improves the redesign process, which is essential for quick change introduction. The methodology was developed based on previous work performed in the field of change propagation, change risk assessment as well as modularization. A change risk analysis was outlined, followed by a clustering technique application. The results of those operations served as inputs for the redesign of the stowage interfaces and the significant risk decrease confirmed the validity of the method. Modular product structure emerged as a suitable architecture for products that require many modifications during their lifecycle.

To summarize the key findings and outline the contribution to the research and company, the following conclusions regarding the proposed approach were drawn:

- Modular design was proven useful for quick change introduction, enabling greater ease in the customization of the product and configuration of the cabin interior.
- The proposed methodology presents the structured redesign process which allows controlling the product from the early development stages.
- The paper presents means to collect detailed data on the product in an organized way, which allows for a deep understanding of the product on a comprehensive level.
- Utilizing the approach, the potential changes can be predicted and effectively integrated into the design from the beginning. As a result, a broader range of configuration options can be offered to the customers.
- The approach can serve as a tool for the marketing department to estimate the cost of possible configurations and create customer catalogs.
- The modular product structure was proven to have a positive effect on time allocated for PLM system operations - more leveled BOM reduces the number of part numbers required for re-release.
- The approach can help map the product or a system into groups. It can support the management team in making more informed decisions on team division and identifying optimal communication channels.
- The presented methodology could be applied to other interior components in order to analyze them and break down for design improvements and modularization.
- The limitation for utilizing this methodology to other products would be the number of components – extensive amount of product parts would require software application to shorten the time of analysis.

In order to manage and develop the proposed methodology in the company, some recommendations for the future were listed:

- Such an approach might require a skilled systems engineering team.
- Software for CPM including indirect risk analysis should be deployed to yield a closer approximation to the real-world change risk and improve the inputs for the redesign.
- The special focus should be given to the granularity of the product division and the quality of data gathered as inputs. Those are essential to achieve accurate results both in change risk analysis and clustering.

Further validation of the proposed method is recommended and could be realized through a case study on a prototype of the stowage. Applying this methodology to other interior components can support creating more detailed guidelines for product division and structurize the analysis further. Although the redesign process may require increased effort and time allocation when applied to other interior elements, this work presents evidence that such a process can be executed fast and efficiently. To summarize, the presented approach was proven beneficial for design change introduction and should be considered as a standard process practiced in the company as well as further developed through additional research.

References

Bonvoisin, J., Halstenberg, F., Buchert, T., Stark, R., 2016. A systematic literature review on modular product design. Journal of Engineering Design 27, 488–514. https://doi.org/10.1080/09544828.2016.1166482

Browning, T.R., 2001. Applying the design structure matrix to system decomposition and integration problems: a review and new directions. IEEE Trans. Eng. Manage. 48, 292–306. https://doi.org/10.1109/17.946528

Clarkson, P.J., Simons, C., Eckert, C., 2004. Predicting Change Propagation in Complex Design. Journal of Mechanical Design 126, 788–797. https://doi.org/10.1115/1.1765117

Duncanaviation.Aero. 2021. Duncan Aviation Continues To Expand Interior Finish Solutions.

Ericsson, A., Erixon, G., 1999. Controlling design variants: modular product platforms. Society of Manufacturing Engineers.

Gullander, L.,2023. How to Manage Change in Your Configurable Product Platforms? Modular Management Blog. https://www.modularmanagement.com/blog/how-to-manage-change-in-your-strategic-product-platforms

Heart Aerospace 2023. Learn more about the ES-30. ES-30. https://heartaerospace.com/es-30/

Koh, E.C.Y., Caldwell, N.H.M., Clarkson, P.J., 2013. A technique to assess the changeability of complex engineering systems. Journal of Engineering Design 24, 477–498. https://doi.org/10.1080/09544828.2013.769207

Thebeau, R.E., 2001. Knowledge management of system interfaces and interactions for product development processes, Masters thesis, System Design and Management Program, Massachusetts Institute of Technology.

United Nations, 2023. For a livable climate: Net-zero commitments must be backed by credible action. Climate Action.

Ulrich, K., 1995. The role of product architecture in the manufacturing firm. Research Policy 24, 419–440. https://doi.org/10.1016/0048-7333(94)00775-3

Ulrich, K.T., Eppinger, S.D., Yang, M.C., 2020. Product design and development, Seventh edition. ed. McGraw-Hill Education, New York, NY.

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