Managing chemical risk during design in aeronautics: from technical product data to exposure assessment

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Abstract

Environmental regulatory frame gets reinforced and now applies to activities and also to products. REACh regulation presents strong challenges to the industry, notably traceability of hazardous substances during products life cycle. This article presents a method mutually developed by an Industrial Engineering Laboratory and an aeronautic equipment company which aims at answering both of REACh and industrial objectives. Based on traceability process, the method should be used to guide designers choosing less hazardous design solutions. Method's core is built around chemical risk assessment and can be run with data strictly coming from technical bills. Traceability measurement appears here not as only as a compulsory data, but can also become a relevant design indicator. Method's application case shows at last the benefits and the different points that should be improved in order to furnish an efficient tool for designers.

Key words: *REACh, design for environment, chemical risk, aeronautics.*

1. Introduction

Transportation, and all the different means used for, represent an important target for environmental impacts reduction. Aerial transportation enters a new era by seriously taking environmental aspects into account. This approach is especially enhanced through the answers to REACh regulation requirements. The article focuses on one particular REACh requirement: traceability. Our purpose is to present a method to be used during design process, in order to prevent design teams from hazardous materials choices. The added value of this method is to go further than complying traceability duties: substances quantification is used as a design parameter. After a description of the method's development context and objectives, the calculation modalities will be presented. An application case will practically show the method's potentialities. Results would then be discussed trough positive points and improvement axes.

2. Sustainability matters and transportation: the aeronautics case

2.1. Environmental impacts and economical constraints

Aerial transportation is still an irreplaceable transportation mode, permitting goods and persons transport in short time delivery. Thus, this transportation sector is often identified as a huge source of environmental impacts. Aerial transportation activities are linked with different types of environmental impacts, which we propose to classify into extrinsic and intrinsic categories. Extrinsic impacts could cover all the impacts related to activity consequences typically, due to effluents flows (gas emissions, noise). Intrinsic impacts match with the product itself and the potential environmental risk which can occur from it composition.

Sustainable transportation should be a subtle match between economical and technical needs and environmental impacts limitation. This match is one of the main objectives of environmental regulation, which is enhanced by industrial initiatives.

2.2. Regulatory frame and environmental impacts control

Extrinsic impacts related to aerial transportation are controlled by different regulations and agreements. ACARE[1] organization proposes the objective of reducing green houses gases emissions and noise emissions to 50% in 2020. Intrinsic impacts are a progressively increasing matter for these industries. REACh regulation asks for an effective management of all incoming chemicals in industry processes, but also for traceability of "Substances of Very High Concern" (SVHC) in any

[1] Advisory Council for Aeronautics Research in Europe

manufactured product put in the market. This regulation frame imposes a new consideration of technical answers management, due to the multiplicity of needs. As illustrated in figure 1, we propose to present links between aircraft engines and equipments whole life cycle and regulation requirements. This representation helps us to distinguish the different impact sources and the relatives regulations requirements.

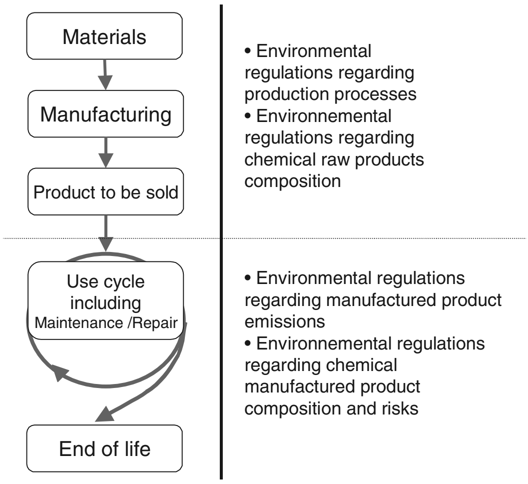

Figure 1: Manufactured product life cycle and environmental regulation requirements

3. REACh regulation: a new challenge for industries, an opportunity for ecodesign

3.1. Chemicals management all along products life cycle

We propose to synthesize in figure 2 REACh requirements, actions that should be taken, and risks, for any company putting product on the European market.

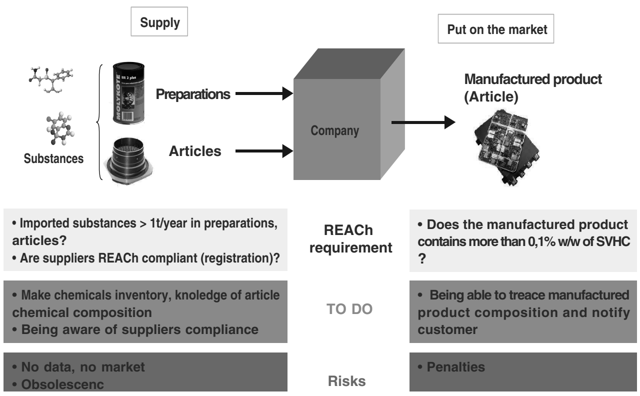

Figure 2: REACh's impacts on product manufacturing

REACh rules chemicals use in manufacturing industries from upstream to downstream.

Incoming chemicals, which can be contained in mixtures or materials, have to be identified and authorized for specific use and exposure (Title 2 and 5 of REACh regulation,[1]). Manufactured products which are supposed to contain hazardous chemicals have to be declared and related chemical risk has to be identified, as it can appear during parts or total duration of its life cycle (Article 33 of REACh [1]).

Two of the main consequences for industries are potential obsolescence of incoming chemicals used to manufacture products and traceability process.

3.2. Using traceability requirements as a springboard towards design for environment

Let's focus on manufactured product. Companies have to notify any SVHC presence in their products to customers. As this requirement is merely expressed, it hides a very complex industrial reality. Manufacturers have to go back to the details of material and processes bills. However, this process does not always exist. Some software and Enterprise Resource Planning (ERP) software packages actually start to propose solutions to trace manufactured product's part composition and to calculate final SVHC's manufactured product rate. Going further, we consider that in order to reduce chemical risk of downstream product, SVHC rates should be used as an indicator during product's design, as weight, for example. But a rate is not sufficient to guide designers. The problematic is to know how the design team could use this new indicator: we propose a new method which aims at giving them clues to use SVHC rates, to more finely evaluate chemical risk linked to the presence of SVHC and to identify solutions to limit and reduce it so far as possible. This method does not require any specific knowledge about chemical risk

REACh should not only be considered as a full restrictive regulation, but also as an opportunity to go further on the design of environmentally-friendly products. Part of the challenges lies in offering efficient methods and tools to designers.

4. A method to turn chemical risk assessment into a decision parameter during design process

4.1. Method development context

The proposition of the method proceeds from a collaboration between designers, environment support and industrial engineering researchers. The presented work comes from a PhD thesis, which began in 2007. lead by a full time employee at Safran Electronics.

4.2. Application field of the method

4.2.1. Product's life cycle steps The method should answer the preoccupations related to the presence of SVHC in the manufactured product. The methods aims at evaluation manufactured product chemical risk during its use and end of life cycle phase. Hypothesis is made that chemical risks related to production processes are already controlled through specific environmental regulations.

4.2.2. Method's unit The smallest unit the method applies to is defined as a Part Number (P/N). P/N can be identified as a single article and can be used as a spare part. Final manufactured product is made of the assembly of a few sets, each set is an assembly of different P/N. This unit has been chosen because it's the most common product's part denomination by designers, notably in aeronautics.

4.3. General structure of the method

The general structure of the method has already been described [2] and consists in the next main steps:

- Extraction step : relevant identified data from design bill (material, processes),
- Qualification step: identification of substances danger and classification according to a list
- Quantification step: chemical risk assessment based on a method taking danger and exposure parameters into account. Chemical risk is expressed as a score.
- Decision making step: according to a score matrix, chemical risk level is assigned to a treatment priority.

As described in [2], the method lies on a simplified chemical risk assessment method, which has been initially developed for production plants. Some adaptations had to be proposed due to different application field, notably for exposure parameter. In order to cope with the temporal dimension and the variable accessibility of parts during the product's life cycle, we introduced new parameters. In the other hand, danger remains similar during all the products life's cycle, because it's an intrinsic characteristic of the substance.

5. Chemical risk assessment: proposition of parameters calculation from technical data

5.1. General calculation mode

5.1.1. Basis method application to one substance For any substance i, according to the INRS method [3], chemical risk ($\mathbf{R_i}$) is a function between the parameters "danger" ($\mathbf{D_i}$) and "exposure" ($\mathbf{E_i}$), related to a figure varying between 0 and 5:

$$\mathbf{R_i=f(D_i,E_i)}$$

E_i is defined as a function between the parameters "substance i quantity" ($\mathbf{Q_i}$) and "substance i's exposure frequency" ($\mathbf{F_i}$), defined as ratio and related to a figure varying between 0 and 5:

$$\mathbf{E_i=g(Q_i,F_i)}$$

5.1.2. Basis method application to one substance I and a part number $\mathbf{(P/N)_j}$ during use step We identified that, when applied to a product's life cycle, frequency parameter depends on two elements:

- **Time:** during use phase, the product can be dismantled for maintenance or repair. It is possible to predict the occurrence of maintaining or repair operations. This value is not directly related to $(P/N)_j$, but to the assembly $(P/N)_j$ belongs to. This value is called "Temporal Acessibility" and quoted $\mathbf{AT_e}$; because it is set ("ensemble") specific. AT_e is a time ratio between set removal duration and total life cycle (from use to end of life) duration.
- **Physical access:** even if the product's dismantling can be predicted, the exposure won't be the same according to the part accessibility. This value is called "Temporal Acessibility" and quoted $\mathbf{AP_j}$, because it is (P/N)j specific. AP_i is an adimensional value, varying on the interval [0,1].

Ei,j, assigning the exposure of a substance i on a(P/N)j, should be described as:

$$\mathbf{E\ i,j = g(Q_{i,j},AT_e),}$$

in order to be homogeneous with the expression of E_i.

According to these new elements, the chemical risk of a substance i, for any (P/N)j during use phase, quoted as $(R_{\ i,j})_{use}$, should be expressed like :

$$\mathbf{(Ri,j)_{use}=AP_j\ .f(D_i,\ E_{\ i,j})}$$

5.1.3. Basis method application to one substance I and a part number (P/N)j during end of life step In that case, we consider that we don't have to take into account frequency factor, because End of Life dismantling operations are supposed to only occur once during whole product's life cycle. Exposure is only due to the accessibility of the part:

$$\mathbf{(R_{\ i,j})_{EOL}=AP_i.f(D_i,Q_i)}$$

5.2. Quantity (Qi,j) calculation

Even if software and ERP providers are still developing traceability solutions, we can propose a way to guide calculation of **Qi,j** value when not disposing such softwares. As documented in [4], the company should have a database collecting used materials and processes for their manufactured products and linking them to composing substances. Thanks to design bill, one knows type of material and also used production process, characterized through the chemical nature of the consumables.

Qi,j expression is :

$$\mathbf{Q_{i,j} = m_{i,j} / m_{(P/Nj)}}$$

With $m_{(P/Nj)}$: total P/Nj mass

m_i substance i mass in the P/Nj

In order to run the method, Qi,j value has to be translated into the scale value varying 0 to 5. We suggest, according to REACh regulation, to make this scale match with the 0,1%w/w threshold, as illustrated in table 1:

Table 1: Qi,j classification

Qi,j	$M_{i,j}/M_{(P/Nj)}$
0	<0.1%
1	0.1%-1%
2	1%-10%
3	10%-33%
4	33%-100%

5.3 Temporal accessibility (AT_e)calculation

$\mathbf{AT_e}$ is calculated thanks to data provided by the Maintening manual. We made the hypothesis that the manufactured product is dismantled during maintaining and repair operation. $\mathbf{AT_e}$ can be expressed the following way:

MTBF: Mean Time Between Failure

MTTR: Mean Time Between Repair

$$\mathbf{AT_e = MTTR / MTBF}$$

In order to run the method, AT_e value has to be translated into the scale value varying 0 to 5. We propose a scale based on INRS proposal, which values are collected in table 2.

Table 2: AT_e classification

Ate	MTTR/MTBF
1	<1%
2	1%-4%
3	4%-16%
4	16%-40%
5	>40%

5.4. Physical accessibility (AP_j) calculation

$\mathbf{AP_j}$ varies from 0 to 1. $\mathbf{AP_j}$ is determined in a qualitative way by designers, in function of the product state: AP_j for non accessible part is 0, AP_j for totally exposed part is 1. Objective characterization is in progress.

6. Application case: Electronic control unit

6.1. Product presentation and life cycle

Electronic Control Unit (ECU) is an aircraft engine equipment which regulates aircraft engine functions thanks to pilot orders and functional data (pressure, speed…), collected in real time, related to the engine. Figure 4 illustrates ECU.

Figure 4 : Electronic Control Unit

ECU consists in three main parts:

- Box : this mechanical part is mainly made with metallic alloys. It protects the electronic part from severe environment (vibration, electromagnetic field …),
- Printed cards: this is the core of the ECU. Printed cards are made of many thousands of components, fixed on both face of the card,
- Connectors: these are very specific types of connectors, used to link ECU to captors through harnesses.

Figure 5 illustrates ECU's lifecycle.

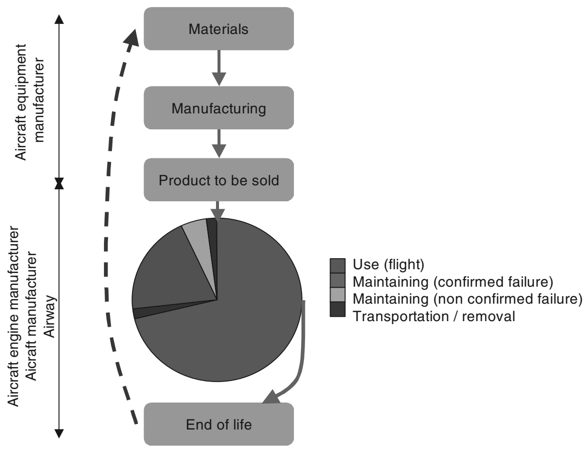

Figure 5: Electronic Control Unit's Life Cycle (time phases)

6.2. Required data for method's application

The method is applied to Printed Cards (PC) materials. We consider chemical major composition of the card and will compare the results as the PC are considered as parts of the ECU (sub assembly) or as a single P/N (spare parts). General data about total flight time, MTBF and MTTF are obtained from Maintaining sector. All data about material mass come from the analysis of design bills and calculation made in a previous work [2], based on a processes and material database. All chosen data are supposed to be known at the design phase. Data have been modified due to industrial confidentiality and the method is applied on a few substances

Data used to run the method are summarized in table 3 and table 4.

Table 3 : General data about ECU

ECU total mass (g)	4500
Total flight hours (h)	120 000
MTBF (h)	500
MTTF (h)	160

Table 4 : General data about Printed Cards

Polyimide (g)	780
Copper (g)	430
Lead (g)	8

6.3. Class determination and results

According to the different parameters classification, we propose to assign the following classes to PC's constituents. Values are collected in table 5, 6 and 7.

Table 5: Danger Classes

Material	**Danger Class**
Polyiamide	**1**
Copper	**1**
Lead	**4**

Table 6: Quantity classes
(material mass/reference mass)

Material	**ECU reference**	**PC reference**
Polyimide	17,3%⇔ **3**	63,4 %⇔ **4**
Copper	9,56%⇔ **2**	34,9%⇔ **4**
Lead	0,18%⇔ **1**	0,65%⇔ **1**

Table 7: Accessibility classes

Accessibility	**ECU**	**PC**
ATe	4	4
AP use	0	0
AP Maintaining	0,5	1
AP End of life	1	1

AP determination is qualitative and differs as the reference is ECU or PC. Indeed, both ECU and PC aren't accessible during use phase (flight): AP = 0. Considering maintaining phase, ECU is opened and PC are left in the box; we decided to quote AP= 0,5. However, during PC maintenance, the assembly is wholly manipulated, we decided to quote AP = 1 during this phase. At last, considering end of life and making the hypothesis of a general dismantling operation, we decided to both quote for ECU and PC, AP = 1.

The data used to assess chemical risk using the combination of Danger, Quantity and Accessibility classes as explained in previous sections. Results are recorded in table 8 and 9 and figure 6.

Table 8: Method assessment results for Printed Card

Printed card	Danger class	Exposure Class			Risk i	Risk use	Risk Maintainin	Risk End of
		Qi	ATe	Total E				
Polyimide	1	4	4	5	100	0	100	100
Copper	1	4	4	5	100	0	100	100
Lead	4	1	4	3	10000	0	10000	10000

Table 9: Method assessment results for ECU

ECU	Danger class	Exposure Class			Risk i	Risk use	Risk Maintainin	Risk End of
		Qi	ATe	Total E				
Polyimide	1	3	4	4	30	0	15	30
Copper	1	2	4	4	30	0	15	30
Lead	4	1	4	3	10000	0	5000	10000

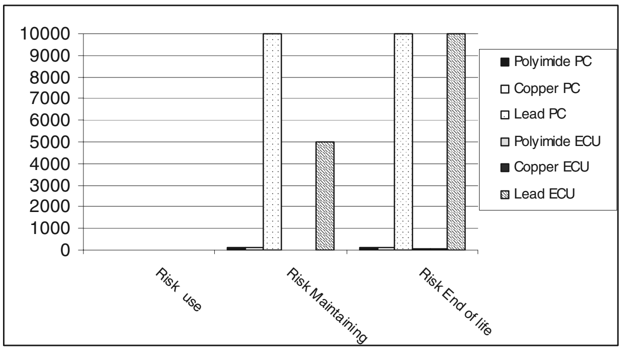

Figure 6: Chemical risk comparison according to ECU or PC reference

The major risks are present during maintaining and end of life phases, and especially linked to lead toxicity. However, the risk does not have the same intensity as the ECU or PC is considered. It is quite obvious that the manipulation of PC presenting lead brazing involves chemical risk. But, as we can see, maintaining operation of ECU also present a risk due to lead presence, even if the PC are not totally extracted from the box.

This point is interesting and should be pointed out during the design of maintaining operations. Moreover, lead substitution should be an important scope for substitution options at last. Indeed, solution taking lead mass reduction or exposure reduction should be studied by design team in a first approach, before R&D sectors propose a substitution solution.

7. Discussion

7.1. Positive points

The application case shows that the method answers two main objectives:

- use of data extractible from technical documents (material and process bill, maintaining information)
- chemical risk assessment for different product's life cycle phase.

The results are easily interpretable by designers and offer a complete view of the chemical risk linked to a substance. Thus, designer could have a more relevant analysis about the different ways to reduce chemical risk by adjusting mass or exposure parameters.

7.2. Improvement clues

The more evident improvement clue stands in the methods ergonomy simplification. When assessing several materials and substances, the use of manual calculation becomes restraintful for designers, who need quite immediate results. The method application should be automated, and the one of the proposed clue is to provide a database linking for a substance i, Quantity, Physical and Temporal Accessibility, to a P/N_j.

Physical accessibility is qualitatively defined. In order to avoid subjective interpretations, AP should be linked to accessible surfaces calculation and also human body surface to be in contact assessment (finger, hand …)

By the way, Temporal Accessibility should reflect the different types of failure. We smoothed the data by only using MTBF and MTTR values. A deeper investigation about the different values used by maintaining and repair sector to qualify these operations time distribution should be made.

8. Conclusion

No one can today ignore their duties to reduce environmental impacts in their activities or through the products they put on the market. Even though high environmental objectives are fixed, the regulation texts are not delivered with tools to apply and comply the requirements. REACh regulation is a good example. Pointing out very high objectives of traceability in products, this new requirement is complex to comply but can also be considered as a springboard for design activity anticipate environmental matters. Through the presentation of a new chemical risk assessment method, which lies on the traceability process, we propose to offer a new and simple tool which permits the designers to understand the evolution of one hazardous substance risk during the product's life cycle, and to anticipate solution to reduce the risk by a set of substitution quantity or exposure reduction measures. The application of the methods shows its relevance and improvement clues have been raised.

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Acknowledgement: We would like to thank Boris Clouet, Engineer trainee, for his help.