Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 39 (2016) 179 – 184

www.elsevier.com/locate/procedia

TFC 2015 – TRIZ FUTURE 2015

An Approach to identify the readiness level of a Solution Concept in The Inventive Design Method

Thongchai Chinkatham[a,]*, Achille Souili[a], Ali Taheri[a], Denis Cavallucci[a]

[a]*LGECO / INSA Strasbourg, 24 Boulevard de la victoire, 67084 Strasbourg Cedex, France*

* Corresponding author. Tel.: +33637-493-207; *E-mail address:* thongchai.chinkatham@insa-strasbourg.fr

Abstract

It is generally known that the ranking of ideas during creative sessions creates two majors problems. The first is to undervalue a promising idea and thus wash away business priorities. The second is to overstate a false good idea that will be the underlying cause of unnecessary expenses. Although the subject of ranking ideas is spread and common in studies and research, it still poses an obvious contradiction: the level of definition of an idea must be precise to secure investments and imprecise to preserve its innovative role. In our research on this topic, we endeavored to highlight a new path that would both simplify engineers access to formal calculation (such as to give credibility to an idea by removing the blur surrounding it) while preserving potential inventive margins by identifying for each concept its degree of feasibility. However, this second part was not clearly defined in our research. In this paper, we present a complementary aspect of our approach. Its underlying idea is to associate each index to a TRL (Technical Readiness Level) that is likely to assess in an objective and formal way its maturity with a recognized scale in industrial environments. A case study and a discussion of the results of the contribution will be discussed at the end of the paper.

Peer-review under responsibility of Scientific committee of Triz Future Conference

Keywords: Inventive Design Method; Risk/Failure analysis; TRL; Knowledge Base; Decision making

1. Introduction

It is generally recognized that creative sessions result in the production of ideas which, for a large majority of them, have either no value or no future [1]. More modestly called “shelf-ideas”, what poses problems to the company is not that these ideas do not give rise to action in R&D, but rather the fact that there is still a doubt that in this large population, “good” ideas are not well identified in advance in projects. Thus, they are not subject to premature rejection. This desire to solve the problem is due to the fact that historically, the company always remembers ideas that were expressed before and then forgotten (or badly evaluated), but will prove after in the future to be successful for a more inspired competitor. Conversely, the company also has equally bitter memories of ideas that aroused the enthusiasm of most employees, but were proving over development actions that followed to be dead ends which weighted in the expected return on investment in R&D activities.

By formulating our analysis as a contradiction, we get that an idea must be both precisely defined (with all necessary information for the decision) and tolerate imprecision so as not be the subject of a time consuming computer algebra which would even slow down the further innovation process. In addition to the second part of this contradiction, such a reasoning also applies to list of ideas and thus increases calculation time and resources needed to accomplish it. In this case, this contradiction is even more accentuated.

In the context of Inventive Design, ideas are defined more formally than in conventional activities of creative session. As a result of a defined process, their name becomes “Solution concepts”.

A solution concept must be understood as an idea whose accompanying information document it in sufficient details so that an objective estimation becomes possible.

Peer-review under responsibility of Scientific committee of Triz Future Conference
doi:10.1016/j.procir.2016.01.185

In our previous work, we defined the limits of such a statement and proposed a finer approach based on the formal calculation feasibility of solution concepts. However, recent experiments on R&D projects have shown that:

1) A solution concept has not only to evolve into a parametric model, but also need to be associated to an existing analytical model so that an analysis can be conducted.
2) The evaluation and solution concepts selection mechanisms must take joint decision-making objectives while in an inventive step, the variability of the nature of concepts entails a great difficulty in identifying shared decision-making criteria.

Keeping these limitations in mind, we developed a new IMR approach (Identifying, mapping and Ranking) (Fig.1) whose objective is to assist the designer in the concepts selection and evaluation tasks based on the level of risk which its development arouses. This approach is largely based on the existence of a scale widely used now in enterprises: The technology readiness level (TRL). Each solution concept is associated with a TRL by the risk that characterizes it. In this way, we postulate that a change will take place in the perception of the assessors. They will better assess the chances of success of a success than its capabilities to meet objectives of a functional specification.

The structure of this paper is divided into the following: the second section recalls the state of the art on the subject of the rapid estimation by formal calculation of concepts. A third section presents our experimental approach on an industrial study and analysis of its results. Finally, in the last section, we discuss these results and expose the perspectives of such work to the reader.

2. Technical background

In this section, we review the IDM framework. Then, we investigate certain work related to the proposed methodology.

2.1. Inventive Design Method: IDM

The Inventive Design Method (IDM) [3-5] was developed to solve classical TRIZ (Theory of Inventive Problem Solving) [6,7] limits and consequently address wider and more complex problematic situations specifically in the concept generation stage. The four major steps of IDM are: 1) Analysis of the initial situation, 2) Contradiction formulation, 3) Synthesis of Solution Concepts, 4) Choice of Solution Concepts to develop.

In the third step, the key components of the contradictions are used as input to generate Solution Concepts assisted by computer- based TRIZ techniques. This framework has already been published and has been developed into a software prototype called STEPS (Systematic Tool for Efficient Problem Solving) [8].

The main components of each Solution Concept are: 1) A description template, which describes an abstract context, general properties, performance functions and a Model of Problem, and 2) A sketch of the Solution Concept, which is synthesized from a Model of Solution, hypotheses and a technical systems' laws of evolution.

The context of concepts developed with the help of IDM (in this paper called Solution Concepts) is incomplete, conflicting and produces uncertain information [9] due to the resolution of contradictions and the differences in knowledge domain between the Model of Solution and the Model of Problem. In addition, the differences between each Solution Concept are diverse. As a result, it becomes more difficult to evaluate then select which Solution Concepts to refine for more in-depth development.

2.2. Concept evaluation and selection in TRIZ based design

Early evaluation stages usually comprise informal meetings held by experts. This stage generally involves producing instinctive judgments based on experience and tends to lack accuracy [10]. In many existing qualitative evaluation and selection methods (see design model [11-13]), evaluation criteria are usually taken from the design requirement, which is strongly influenced by customer preferences or decision makers' experience. In inventive design, the evaluation stage will be viewed only as a hypothesis for the improvement of technical systems. Rantanen and Domb [14] proposed defining the evaluation criteria from the concept of ideality, where each solution offered is evaluated and compared with the ideality of known solutions by a simple pairwise comparison. Orloff [15] suggested a few practical techniques to verify the solution, such as the ideal final result, a functional ideal model, essential rules and the algorithm for verification of a solution. Rousselot et al. [5] proposed measuring the degree of adequacy between a problem model (Evaluation Parameter – Problems) and a Solution Concept. The evaluation techniques used in inventive design rely on a qualitative approach. The most effective technique to evaluate and select a Solution Concept for inventive design still lies in challenging the inventive design-research link.

2.3. Risk/Failure analysis and Technology Readiness Level in the early stage of design

In various field of engineering, risk/failure analysis is a part of decision making process. It is divided into two branches: 1) qualitative risk/failure analysis is centred on identification of failure and revelation of failure scenario, and 2) quantitative risk/failure analysis is based on probabilistic calculation or estimation of metric value which decision is made. In traditional risk/failure analysis methods used during design include Fault Tree Analysis (FTA), Failure Modes and Effect Analysis (FMEA), Event Tree Analysis (ETA), Reliability Block Diagram (RBD), and Probabilistic Risk Assessment (PRA). These methods quantify risk and reliability, determine the initial cause of a failure, and enumerate system consequences in the event of failure [16].

Several authors [17, 18] proposed applying the risk/failure in the early stage of design. The relation of component-function-failure mode/rate [19] is identified and populated as a database. However, the application is still limited to the conceptual design of a system.

Technology Readiness Levels (TRLs) are a systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology. The System Readiness Level (SRL) [20] is an improved version of TRL. SRL is a multiplication between TRL of a system and the Integration Readiness Level (IRL) of systems. The application of SRL is relied on the system design.

2.4. Reflection On Technical Background & Motivation

As mentioned above, the diversity of Solution Concepts and their newness usually lead to the difficulty in evaluation and selection. Generally, a Solution Concept or a concept in design could be viewed as a system model that consists of sub-systems, components, and relations among them. In this way, the Solution Concept could be considered as the integration of existing component and new component in the system architecture. The influence of the new element could be identified in term of risk/failure. This influence may produce the negative effect or cause a failure to the overall system.

From this reflection, the diversity problem among solution concepts is resolved by mapping their maturity as the System Readiness Level. Moreover, the reliability of the Solution Concept could be identified via the risk/failure of additional component at the earlier stage. Considering all these points, the informed decision making could be made. Our proposed approach and result are presented in the next section.

3. Development of the approach

The proposed approach has been intentionally used as a decision-making aid and tool. It aims to assist designer in identifying the readiness level of a Solution Concept. Additionally, the influence of a new element to the overall system will be considered and represented along with the readiness level.

Fig. 1 depicts the overall approach and detail of each step is as follows:

3.1. Identifying

The system architecture is identified and constructed regards to the model in Fig. 2. As every artefact serves a certain purpose or functionality. This purpose is realized by the objects defining the structure model. Where more than one object is involved, the relations between them become important to perform the accurate functionality. In this paper, *Object* may be a system, a sub-system, a component, and a body/section of a component. The *Relation* will be referred to as the physical part of the conjunction or the integration between objects. The product of this conjunction may provide an *effect*. The Effect is defined as an outcome of an action in a system, mechanism, which is based on a natural (physical) phenomenon. We note that, the completeness of system architecture model is resulted in the accuracy of evaluation and selection. In the other hand, time and resources needed will be increased.

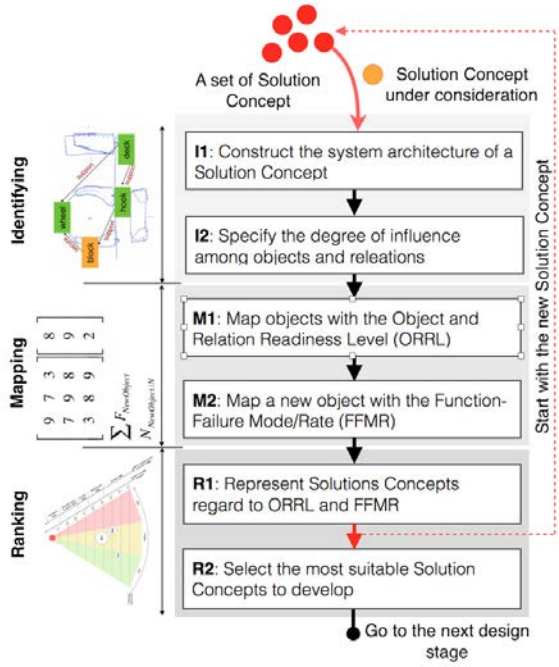


Fig. 1. An approach to identify the readiness level of a Solution Concept.

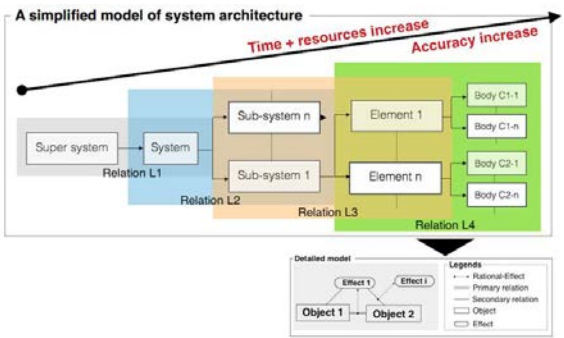


Fig. 2. Simplified model of system architecture.

After **Step I1**, the influence level of objects and relations in the Solution Concept is specified. The classification of this influence level is:

1) **Group 1 (Green)**, the element or the relation doesn't pose any negative effect to the overall system.
2) **Group 2 (Yellow)**, there are some possibilities that the element or the relation may cause the problem to the system. But it may have a clue to prevent or resolve the

problem. For example, modifying the dimension of object, changing the material used, etc.

3) **Group 3 (Red)**, the knowledge or information is lacked to prevent the problem that caused by the object and the relation.

The new object and its relation (function) added into the system is identified and specified. This relationship will be used to identify the function failure mode/rate of a new object that influence the overall system.

3.2. Mapping

The objects and relations in the **Step I2** are mapped with the Object Readiness Level (ORL) and Relation Readiness Level (RRL) respectively. The definition of each level shown in Table 1.

Table 1. Definition of each level of ORL and RRL.

Level	Object Readiness Level (ORL) adapted from TRL
1	Basic principle observed and reported.
2	Concept and/or application formulated. (*phenomena model exist*)
3	Analytical and/or experimental critical function and/or characteristic Proof of Concept (*analytical and/or numerical model exist*)
4	Object and/or physical prototype is validated in a laboratory and relevant environment. (*full simulation model and/or physical prototype exist*)
5	Actual object completed, qualified through test/demonstration and proven through successful operations. (*Existing artefact*)
Level	**Relation Readiness Level (RRL) adapted from IRL**
1	An *interface* (physical connection) has been identified with sufficient detail to allow characterization of the relationship.
2	There is some level of specification to characterize the *interaction* (ability to influence) between objects through their interface.
3	There is *compatibility* (common language) between objects to orderly and efficiently integrate and interact.
4	There is sufficient detail in the *quality and assurance* of the integration between objects.
5	There is sufficient control between objects necessary to establish, manage, and terminate the integration.

The Solution Concept Readiness Level is determined via (1). In parallel, the Function-Failure Mode/Rate of the new objects and relations is determined via (2). The snippet of database used as reference is presented in Fig. 3.

$$SCRL = [RRL]_{N\times N} \times [ORL]_{1\times N} \quad (1)$$

$$FailMode/Rate_{Function-SC} = \sum (FailMode/Rate_{NewElement}) \quad (2)$$

	galling and seizure	impact	latch-up	noise	other	Overstress of incorrect current magnitude	rupture
actuate	7.7E-3	0	0	5.0E-4	2.3E-2	1.2E-1	6.0E-4
allow	8.0E-4	0	0	4.0E-4	7.0E-4	8.0E-4	1.0E-4
change	1.4E-2	0	0	8.6E-3	1.5E-2	1.5E-2	1.7E-2
channel	0	0	0	0	0	0	0
collect	1.0E-4	0	0	0	0	1.9E-3	0
condition	0	0	0	0	0	8.0E-4	0
connect	0	0	0	0	2.0E-4	0	1.0E-4

Fig. 3. The snippet of Function-Failure Mode/Rate database [21].

This approach is resumed with the next Solution Concept to be considered. After all Solution Concepts have been tested, the ranking and selecting process will be implemented.

This approach is resumed with the next Solution Concept to be considered. After all Solution Concepts have been tested, the ranking and selecting process will be implemented.

3.3. Ranking

The results obtained in Step M2 are mapped as the viewpoint of system architecture life cycle [22] along with the potential function failure mode/rate of new elements in the Solution Concept. An example of result is shown in Section 4. Finally, the most appropriate Solution Concepts will be selected and further developed in the next design process.

4. Case Study

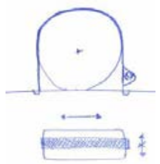
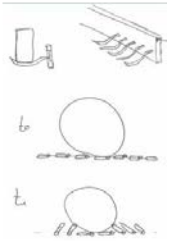
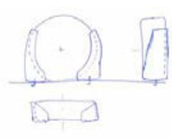
In this section, a design project undertaken with our partner, *Lohr Industry* [23] (a trailer manufacturer) will be used as case study to demonstrate the utility of our proposed approach.

4.1. Context of the design project

The objective of this design project is to develop a new car wheel blocking system during transportation. The primary objective of the improvement is to facilitate truck drivers' securing operations and to reduce time spent securing vehicles. These objectives are related to the number of components, weight and complexity of the system to be installed. The original car wheel blocking system is shown in Table 2.

From the set of problems characterizing the case study, a set of 22 Solution Concepts were proposed by the team using the IDM methodology and STEPS software. Once an evaluation and selection was made, a rough sketch and description of three Solution Concepts were prepared and ranked, as shown in Table 2.

Table 2. Original car wheel blocking system and a set of Solution Concepts.

An original car wheel blocking system	
	The vehicle being transported must be secured to the transport vehicle using appropriate lashing equipment, tensioning devices and blocks. Normally, the wheels of the vehicle should be lashed and blocked by means of components on the vehicles' or trailers' axles or chassis.
A sketch and description of the Solution Concepts after evaluation based on Step 4 of the IDM framework.	
	**SC 1.3.4 (Rank: 1): Strap modification** **Description:** The strap is made of a material allowing longitudinal but not lateral slide. A tensioning device, either different or identical to the current system, is used to tighten the strap once in place. This can be done through an electrical or pneumatic power source.
	**SC 1.1.5 (Rank: 5): Deck modification** **Description:** In the new configuration, the vehicle is transported on curved semicircular bars, aligned one behind the other in a fish bone pattern. When the vehicle is at rest, a strap is placed on the tire and attached to the curved bars that rotate up to press against the tire. All bars, except those under the tire, rotate up once the vehicle is stationary, blocking it in place.
	**SC 1.2.2 (Rank: 8): Wedge modification** **Description:** This system is characterized by a rigid body in form of a shell. Its geometry is designed to adapt to and support different sizes of tires. It exceeds the lateral axis of the tire to restrain vertical force, which removes the need for lashing and blocking pads and transverse forces, with a wedge shape on the two sides of the tire. Note: Install 2 shells/wheel

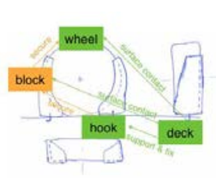
4.2. Application of the proposed approach

Solution Concept 1.2.2 was considered using the methodology proposed in Section 3.

4.2.1. Identifying

The system architecture of Solution Concept 1.2.2 is shown in Table 3. The object is divided into two group (Group 1 and 2), same as the relation.

Table 3. System architecture of Solution Concept 1.2.2.

System model	Description
	*Object Group 1*: wheel, deck, hooks *Object Group 2*: block *Relation Group 1*: wheel-deck(surface contact), deck-hook(support & fix), deck-block(surface contact) *Relation Group 2*: hook-block(secure), block-wheel(secure)

4.2.2. Mapping

Table 4 presents the Solution Concept Readiness Level (SCRL) and Function-Failure Mode/Rate of new element added into the system.

Table 4. Solution Concept Readiness Level and Function-Failure rate/Mode.

Solution Concept Readiness Level				
Object	**RRL**	**ORL**	**SCRL**	**Normalized**
Wheel	5 5 5 2	5	3.16	SCRL = 2.81
Hook	5 5 4 3	5	3.04	**$SCRL_{Normalized}$ = 0.7025**
Deck	5 4 5 3	5	3.04	
Block	2 3 3 5	2	2.00	
Function - Failure Mode/Rate of new element in the Solution Concept				
Block-secure-wheel: Secure solid – impact deformation – failure rate = 1.1E-3 Fails/MHours **SC_{FFMR} = 1.1E-3 Fails/MHours** **Bubble scale** = Proportion of new objects/all object = (2/4) **= 0.5**				

We repeat **Step I1** to **Step M2** with the Solution Concept 1.3.4 and 1.1.5 respectively. Then go to the ranking step.

4.2.3. Ranking

The Scale of each bubble is determined via the proportion of new elements per the overall element in the system architecture model.

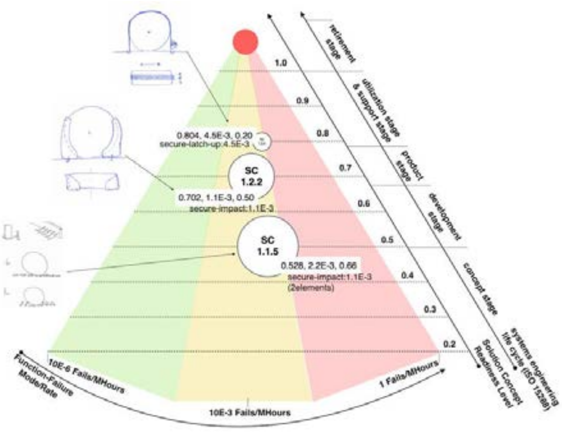


Fig. 4. System Readiness Level and Function-Failure Mode/Rate of Solution Concept 1.1.2, 1.1.5, and 1.3.4.

From Fig. 4, Solution Concept 1.3.4 is represented as the highest readiness level but with the highest degree of probability to fail in the view point of function-failure mode/rate (secure solid-latch up). The position of SC1.2.2 and 1.1.5 is differ from the evaluation based on IDM framework. This difference is coming from the influence of new components added into system and the relation between components.

The results obtained presents the effect of changing of the new system. While there are many modification or addition in the system, the readiness level must be reduced and the probability of failure will be increased. We agree that, the accuracy of evaluation and selection of the proposed approach is still depending on the expertise of the decision-maker. But on the other hand, the representation of result in this way may lead to the more inform decision and the prediction of the successful of implementation could be made in the early stage of design.

5. Conclusion and future work

To summarize our paper, the starting point of our reflection was to improve the quantification of doubt surrounding any loosely defined solution concept to better identify issues in later stages of the innovation pipeline. In addition to a previously published approach, the correlation between three areas has linked the solution concepts to TRL levels already well-established in the industry. As, we also saw in the case study, this correlation has upset the scheduling of initially prioritized concepts to see some of them emerge despite the fact that, initially without this correlation, they were considered as “shelf-ideas”. We postulate that a better identification of the gap between the definition of a solution concept as to its feasibility (in our paper, it is associated to the notion of risk) contributes minimally to rehabilitate it in the eyes of policy makers. We also believe that in order to improve the link between an Inventive Design activity productions and the whole company, the relationship with TRL greatly contributes to clarify the impact of such activity and its role in industrial innovation pipeline.

Acknowledgements

First of all, we would like to thank INSA Graduate School of Science and Technology of Strasbourg (France) and Regional Council of Alsace (France) for financially supporting this project. Secondly, we wish to thank the partner company, Lohr Industry for their authorization to publish results of the design project we collaborated on.

References

[1] Brainstorming, brainstorming rules and decision making VL Putman, PB Paulus - The Journal of creative behavior, 2009 - Wiley Online Library
[2] TEAM STORM: demonstrating an interaction model for working with multiple ideas during creative group work J Hailpern,
[3] C. Zanni-Merk, D. Cavallucci, F. Rousselot, An ontological basis for computer aided innovation, Comput. Aided Innov. 60 (2009) 563–574. doi:10.1016/j.compind.2009.05.012.
[4] C. Zanni-Merk, D. Cavallucci, F. Rousselot, Use of formal ontologies as a foundation for inventive design studies, Comput. Ind. 62 (2011) 323–336. doi:10.1016/j.compind.2010.09.007.
[5] F. Rousselot, C. Zanni-Merk, D. Cavallucci, Towards a formal definition of contradiction in inventive design, Comput. Ind. 63 (2012) 231–242. doi:10.1016/j.compind.2012.01.001.
[6] G.S. Al’tshuller, Creativity as an Exact Science: The Theory of the Solution of Inventive Problems, Gordon and Breach Science Publishers, New York, 1984.
[7] G.S. Al’tshuller, L. Shulyak, S. Rodman, The Innovation Algorithm: TRIZ, Systematic Innovation and Technical Creativity, Technical Innovation Center, Inc., Worcester, MA, 2007.
[8] STEPS j Time To Innovate – Method and software for innovation based on TRIZ. http://www.time-to-innovate.com.
[9] Decision Making for TRIZ. (n.d.). Retrieved from http://www.triz-journal.com/decision-making-triz/
[10] M. Ferioli, E. Dekoninck, S. Culley, B. Roussel, Understanding the rapid evaluation of innovative ideas in the early stages of design, International Journal of Product Development 12 (2010) 67–83.
[11] S. Pugh, Total design: integrated methods for successful product engineering, Addison-Wesley Pub. Co, Wokingham, England ; Reading, Mass, 1991.
[12] Engineering Design: A Systematic Approach, 3rd ed., Springer, London, 2007.
[13] D.G. Ullman, The Mechanical Design Process, 3rd ed., McGraw-Hill, Boston, MA, 2003.
[14] K. Rantanen, Simplified TRIZ: new problem solving applications for engineers and manufacturing professionals, 2nd ed, Auerbach Publications, New York, 2008.
[15] Michael A. Orloff, Inventive thinking through TRIZ: a practical guide, 2nd ed, Springer, Berlin ; New York, 2006.
[16] R. Houssin, A. Coulibaly. Safety-based Availability Assessment at design Stage, Computer And Industrial Engineering,Volume 70, Pages 107–115, April 2014. DOI: 10.1016/j.cie.2014.01.005
[17] Tumer, I. Y., Stone, R. B., Bell, D. G., & others. (2003). Requirements for a failure mode taxonomy for use in conceptual design. In DS 31: Proceedings of ICED 03, the 14th International Conference on Engineering Design, Stockholm.
[18] Lough, K. G., Stone, R., & Tumer, I. Y. (2009). The risk in early design method. Journal of Engineering Design, 20(2), 155–173. http://doi.org/10.1080/09544820701684271
[19] Stone, R. B., Tumer, I. Y., & Van Wie, M. (2005). The Function-Failure Design Method. Journal of Mechanical Design, 127(3), 397. http://doi.org/10.1115/1.1862678
[20] Sauser, B., Verma, D., Ramirez-Marquez, J., & Gove, R. (2006). From TRL to SRL: The concept of systems readiness levels. In Conference on Systems Engineering Research, Los Angeles, CA.
[21] O’Halloran, B. M. (2013). A framework to model reliability and failures in complex systems during the early engineering design process.
[22] ISO/IEC 15288:2008 - Systems and software engineering -- System life cycle processes. (n.d.).
[23] Lohr Industry, http://www.lohr.fr