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## A comparison of Classical TRIZ and OTSM-TRIZ in dealing with complex problems

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### Abstract

A comparison between Classical TRIZ and OTSM-TRIZ is presented in order to evaluate differences in using either method when facing complex problems. The case study considered for this purpose is the development of a new type of Gondola for stratospheric ballooning, in which OTSM-TRIZ has been used in order to manage the complexity of the system. Considerations regarding methodologies have been then expressed and grouped into three topics of comparison, in which main differences between the assessed approaches have been listed and explained, identifying OTSM-TRIZ as a valid tool in facing complex problems.

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*Keywords:* : TRIZ, OTSM-TRIZ, Gondola, LDB, Inventive problem solving;

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### 1. Introduction

Due to the typical way Long Duration Ballooning (LDB) experiments are conceived and executed, a new Gondola is designed and manufactured for each experimental campaign, since after landing, strong damages occur to the frame of the structure dedicated to the protection of the equipment.

In order to achieve an innovative layout able to solve problems associated with such rigid reticular structures, the designer has to take into account not only the mechanical performance of the Gondola, but also its design and manufacturing costs, as well all those requirements related to the whole mission.

The proposed topic is characterized by a considerable level of complexity due to the high number of mutually connected variables which affect this kind of application. Consequently, when solutions are proposed for any identified problem, all of characteristics and properties of Gondola have to be carefully considered, since a lot of connections between functional elements are present in the system. Thus, the adoption of tools for the systematic resolution of the overall problem is required, avoiding a trial and error approach, and then reducing both design time and costs. Tools offered by Classical TRIZ, and in particular ARIZ85C, are certainly a valid aid for the

designer, providing a systematic method to solve inventive problems; nonetheless Classical TRIZ tools reveal to be not adequate to tackle the complexity of problems like those encountered in the design of the Gondola. A careful overview of TRIZ literature suggested to adopt OTSM-TRIZ models and techniques to manage this project.

In this paper, after describing the most relevant design tasks of the Gondola project, authors, on the basis of the experience gained in this case study, propose a comparison of Classical TRIZ with OTSM-TRIZ for managing complex problems, highlighting criticalities and benefits of the examined tools. A comparative table has been realized, in which most relevant differences between both approaches are presented, and then each of these has been accurately discussed in relation to the specific practical case.

The outcome of the design task is a new type of platform with a high degree of versatility coupled with a high level of reusability, capable to be used for multiuser payloads flights, and so capable to intensively reduce costs. The result is a candidate platform for one of the next balloon experiments funded by the Italian Space Agency (ASI). It has been presented at the 20th ESA Symposium on European Rocket and Balloon Programs and Related Research [1].

## 2. Stratospheric platforms: State of the art

Over the years, in the field of LDB stratospheric experiments, the adoption of constructive solutions in the form of rigid reticular-type Gondola of large dimensions has become a consolidated tendency (figure

- 1) [2], thanks to their simplicity in design phase. Using this kind of solution means to accept many negative characteristics, such as problems of transportability, complexity of construction, and limited versatility.

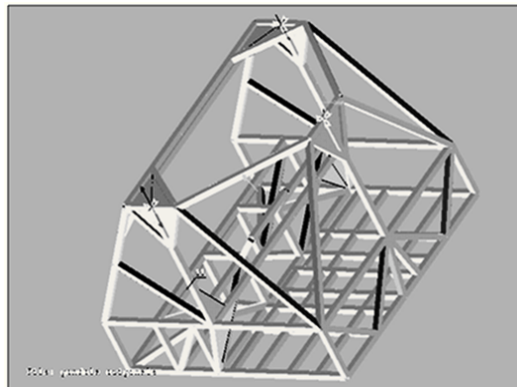


Fig. 1. An example of rigid welded reticular frame currently used in LDB flights

Moreover, the scientific world which uses balloons to record measurements beyond the atmosphere needs both frequently scheduled campaigns and an optimized organization capable of reducing flight costs.

Until now, the common approach used to save costs is simply to ensure that each balloon is launched when its payload hosts a number of experiments that weights just a little less than its maximum lifting capacity, except in the event that mutual incompatibility between various instruments makes impossible to do so. Considering the hypothesis of using a single platform for many research teams, the problem of the compatibility among equipments implies serious difficulties in the management of their different requirements. Due to this problem, the typical way LDB flights are planned is based on a heavy customized design of the Gondola, which makes it usable for only one specific experimental set. Another problem that causes the impossibility to reuse the platform is due to the rate of damage that occurs during the landing phase; a brief description can clarify the entity of possible damages:

- First step: the balloon is deflated and un-hooked to reduce the flight height from more than 35000m to 20000m; at the same time the parachute is released, but due to the low density of the air, the descent happens in free fall.

- Second step: opening of the parachute at about 20000m, where the density level of the air is enough to deploy it.
- Third step: the parachute carries the Gondola to the ground with an approximate velocity of 5m/s (18 km/h).  
In addition to the parachute also crush pads are disposed under the frame in order to soften the impact, but this is not yet sufficient to prevent the un-reversible damages which usually make impossible to reuse the Gondola.  
It is easy to deduce that after more than 15000m of free fall, also the opening phase of the parachute, owing to its dynamic effects, is a critical condition to be taken into account in design process, when the structural strength of the frame is investigated. The standard adopted by NASA in this case consists in considering two load cases:
  - First, a vertical mass acceleration equal to 10g is applied;
  - Then, an acceleration equal to 5g applied along a direction having an angle of 45° with respect to the vertical axis is considered.

These are very hard conditions for the structure considering that it has to be lighter as much as possible in order to maximize the load capacity, which usually has an order of magnitude of 10000N.

These considerations are about the overall characteristics of standard Gondolas and related problems, but for each flight, the designer has to ensure several other important requirements which are summarized below.

Gondolas, which often have solar panels in order to recharge instrumentation's batteries, have to be periodically re-oriented in flight by means of a special device called Pivot [3] which connects the frame with the balloon. Moreover during its orbit the structure has to be continuously oriented, for example, to ensure the right observation angle between an optic device and a specific star. Thus the moment of inertia of the structure respect to the Pivot axis must be kept as low as possible in order to ensure rapid and precise movements.

Another important characteristic to take into account is the necessity to maintain the right altitude: the balloon is subjected to temperature variations during the flight, which in turn causes altitude variations. To tackle this problem a simple procedure is used, which consists in adding a ballast capable to be released in a controlled way. The location of the ballast in the frame of the Gondola has to be carefully considered as the center of Gravity (COG) of the whole structure must ensure a correct balance of the structure itself during the entire flight.

All of the peculiarities described above have to be guaranteed, also when facing the improving step requested by IFAC CNR (Institute of Applied Physics "Nello Carrara" of the Italian National Council of Research). They ask an optimization of the Gondola frame design, in order to achieve Gondolas easy to assemble, transport and modify to host different combinations of a given number of experiments, once these have been selected by a scientific authority.

### 3. Case study

#### 3.1. Brief introduction to Classical TRIZ and OTSM-TRIZ

As recalled in section 1, the objective of the paper is to assess differences between Classical TRIZ tools and OTSM-TRIZ techniques in managing complex problems. Classical TRIZ [4] and one of its development, OTSM-TRIZ, are the methodologies chosen by authors for the comparison; these are considered in literature as structured approaches to the resolution of problems, such as many other methodologies, theories and tools.

TRIZ's body of knowledge offers, on the one hand, an algorithm to be used for addressing inventive problems in engineering, namely ARIZ, and on the other hand, a set of methods and tools to increase the efficiency of ARIZ itself. ARIZ has been developed through several steps, and the last version of ARIZ accepted by Altshuller was ARIZ-85C [5].

OTSM-TRIZ (the Russian acronym for the General Theory of Powerful Thinking) is a particular development of TRIZ, which according to Khomeiko, has been proposed by Altshuller himself since 1975 [6]. Such new method is still under development and has been required to overcome some limitations of ARIZ, as the authors will try to demonstrate with the present paper.

### 3.2. Description of the case study

The study began from the analysis of the original Gondola structure by using the Problem Flow Network (PFN) approach. After that, according to OTSM-TRIZ guidelines, the problem solving process started from building the Network of Problems (NoP). Such a method allows to deal with complex problems, since the overall one is decomposed in a set of sub-problems (Pb), often easier to be solved. Any elementary solved problem brings to at least one solution which is called partial (PS) since it doesn't solve the global problem but only one of its sub-problems or even a part of it. These partial solutions could come from an inventive session or, for example from a knowledge base investigation like a patent analysis or a literature search. Any gathered PS, very often generates one or more new elementary problems, thus the analysis and decomposition of the overall problem creates a network constituted by elementary problems and partial solutions. Such network has been built by the authors with the aim to solve the overall problem of the Gondola by focusing their attention on one sub-problem at a time and, at the same time, monitoring all interactions that single sub-problems and generated solutions have with the whole system.

The overall problem chosen for the case study is the whole reticular Gondola. As described before, domain experts recognized four main problems:

- The versatility of the structure has to be improved in order to host different experiments;
- The new structure has to be easy to carry from the workshop to the launching site;
- The payload must be maximized;

The moment of inertia in respect to the pivot axis has to be minimized [2]. This list of problems has been transformed in a Network of Problems (fig. 2).

Main nodes were firstly tackled in a direct manner, adding partial solutions as in a normal design phase, or adding known solutions in the fields of mechanical engineering. Then, same problems were faced from different points of view, analyzing them with a multi-screen approach, seeking roundabout problems and trying to resolve them not only in a compensative manner (central column of the system operator), but also with actions of prevention or mitigation (respectively column of the past or the future of the schema) [7]. In order to analyze all the solutions belonging to identified problems, they have been added to the network to find any new possible generated sub-problems, and also to check all of possible interactions with other branches of the network. The same process has been repeated for all the problems until the NoP has reached a satisfactory level of detail.

The next step has focused on the extraction of disclosed or hidden contradictions. The model of each contradiction was done using the OTSM-TRIZ template. It distinguishes, in accordance with ARIZ guidelines, two types of contradictions called technical and physical, according to Classical TRIZ nomenclature. Therefore, first extracted contradictions were those related to key-problems; subsequently all others ones were modeled. Some of the contradictions were easily identifiable, but others were extracted by analyzing special sequences of nodes, as for example a Pb-PS-Pb sequence or a loop. Contradictions were organized within the network in order to highlight those related to key-problems, because those ones have to be analyzed and solved for first. Naturally those were faced one by one, since there is no instrument between the various available both in TRIZ Classic and in OTSM-TRIZ, that allows the resolution of more than one contradiction at the same time. New solutions were added again in the Network of Problems, in order to seek any incompatibility with other branches of the net, in order to find a convergence of partial solutions toward one or more implementable concepts.

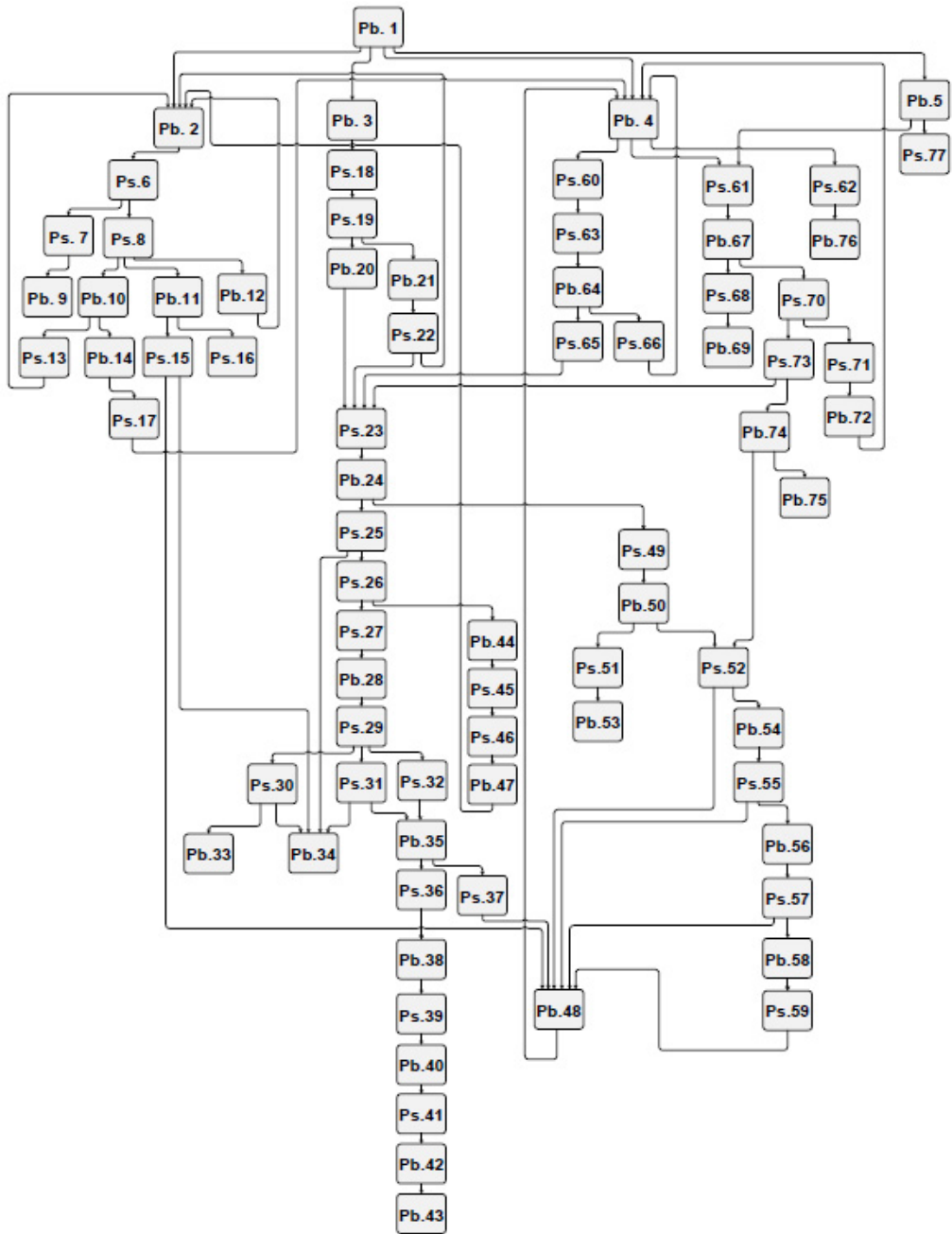


Fig. 2. The Network of Problems

Table 1. Problems and Partial solutions list

Pb or Ps ref.	Description	Pb or Ps ref.	Description
Pb 1	Reticular Gondola	Pb 40	Not realizable with all section
Pb 2	Versatility to different experiments	Ps 41	Only parallel faces sections
Pb 3	Transportability	Pb 42	Limited choice of sections
Pb 4	Maximize payload	Pb 43	Low resistance to secondary moments
Pb 5	Minimize Inertia Moment resp. Pivot axis	Pb 44	Design costs
Ps 6	Variable shape and dimension	Ps 45	Reusing design results
Ps 7	Frame change	Ps 46	Parameterized design process
Ps 8	Same frame with variable length elements	Pb 47	Limited structure's variations
Pb 9	Design costs	Pb 48	Increase of structure's mass
Pb 10	Leaving ref. config. when dimensions increase	Ps 49	Utilize spider with 4 spherical joints
Pb 11	Variability of the anchor system for instruments	Pb 50	Perpend. between Pivot axis not guaranteed
Pb 12	Limited variability of the structure	Ps 51	Necessity of additional instr. in assembly
Ps 13	Preserve a predefined ratio between frame sides	Ps 52	Prismatic and telescopic bars
Pb 14	Preserve struct. integrity when dim. rises	Pb 53	Increase of mounting difficulties
Ps 15	Variable anchor system	Pb 54	Tension concentration in universal joints
Ps 16	Possibility of anchorage in all base points	Ps 55	Free U. Joints in assembly, but locked in
Ps 17	Reduction of the load	Pb 56	Wasteful bending moment on bars
Ps 18	Demountable structure	Ps 57	Add. of reinforce latticing after Pivot reg.n
Ps 19	Bolted rigid reticular structure	Pb 58	Adapt. of latticing to various Pivot positions
Pb 20	Moments transmission trough joints	Ps 59	Adapt. joints to anchor latticing to telescopic
Pb 21	Production costs	Ps 60	Lighten the frame
Ps 22	Exploitation of reusable parts and cheap elements	Ps 61	Elimination of balancing masses
Ps 23	Realization of spherical joints	Ps 62	Reduction of ballast
Pb 24	Diff. to realize nodes with more than 2 elements	Ps 63	Reduce frame's elements sections
Ps 25	Joints with opportunely oriented hinges	Pb 64	Increase structural efficiency
Ps 26	Reticular structure with cylindrical joints	Ps 65	Reduced structural strength
Ps 27	Joints and elements coupled by pins	Ps 66	Reduced load
Pb 28	Management of manufacturing tolerances	Pb 67	Balancing of the structure
Ps 29	Backlash recovery	Ps 68	Mass arrang. in order to fix C.O.G. under
Ps 30	Central backlash recovery system	Pb 69	Functioning of instruments
Ps 31	Local backlash recovery system	Ps 70	Mobile ballast and Pivot
Ps 32	Buttonholes	Ps 71	Mobile ballast on sliding guides
Pb 33	Difficulties in centering central elements	Pb 72	Heaviness of the structure caused by guides
Pb 34	Constructive complications	Ps 73	Telescopic bars and spherical joints
Pb 35	Assembly problems	Pb 74	Impossible static solution
Ps 36	Hybrid buttonholes – holes	Ps 75	Lock spherical joints and bars in flight phase
Ps 37	Hybrid local – central	Pb 76	Keeping of the flight altitude
Pb 38	Necessity to overlap elem. holes & joint's holes	Ps 77	Pyramidal structure
Ps 39	Manufact. strategy (e.g. group manufacturing)		

#### 4. Comparison

In this paper the authors' effort has been to highlight differences between results obtained using Classical TRIZ and OTSM-TRIZ respectively. The main purpose is to point out the potentialities that the network approach of OTSM-TRIZ ensures and therefore the benefits arising from the application of this method to complex and interconnected problems. It is worth notice that for both methods a deep knowledge of

the problem to be solved is essential in order to manage the analysis of the problem itself and even to avoid the generation of useless solutions.

As first topic of discussion, authors have examined how to get the problem definition. When dealing with complex problems, this initial phase is very important because it brings to the definition of contradiction(s) which represents the starting point of the whole problem-solving process. Exploring the way Classical TRIZ deals with the choice of the problem to be solved, it is evident the lack of a tool that allows the problem solver to perform the initial analysis in a systematic manner, except for the part 0 of Ariz 85A. A good rule is to try to break down the complex problem in a set of "elementary" easier problems to solve, and therefore there are several tools and different models that allow carrying out this task. Besides, once the user has faced this set of problems he has to decide which try to solve. It is worth notice that even the number of problems to choose might increase: in fact, each one could be approached in an alternative manner choosing any other solving way inside of other boxes of a System Operator.

OTSM-TRIZ instead doesn't require the choice of a single problem: in fact, the initial analysis is done by building the entire NoP, where not only all problems arising from the breaking up of the main issue are collected but also those new problems arising from searching for roundabout problems and the new sub-problems raised by partial solutions are added to the net. Working on this latter family of sub-problems, increases the effectiveness of the method because it allows accepting those partial solutions commonly discarded because generating new problems. Such acceptance may partially change the focus of the problem solving activity from the upper troubles to these original new ones. It may happen that such analysis will lead to the definition of unknown problems or in any case never considered up to now, even for a professional in the technical field. Another advantage of the PFN approach of OTSM-TRIZ is that choosing the problem which focus the attention on is no more required, because its logic is to work simultaneously on the network as a whole, and therefore to manage in the best way all possible interactions among various sub problems, even if belonging to different branches of the network.

Taking the case of Gondola as a reference, it is immediately evident that the initial situation appears quite complex. If one would have had to try to resolve the re-design problem of the Gondola with the help of Classical TRIZ, he would have immediately found a great difficulty: effectively, the main problem has been divided into 4 sub problems, defined together with experts in the field. However each of these cannot be considered as a mini-problem to deal with Ariz-85C, so a breakdown of the four key problems into many sub problems would have been required. This further decomposition would have created even more uncertainty in the choice of starting problem.

The approach performed with OTSM-TRIZ, instead, has eliminated any ambiguity linked to the choice of the problem, because it enabled the authors to deepen simultaneously all aspects of the Gondola without having to focus exclusively on one problem at a time. This has enabled to highlight some connections between different branches, that with a different approach could not be underlined, as for example the problem regarding the necessity to use four universal joints with a spider to connect telescopic bars in place of only one spherical joint when Pivot regulation occurs (see Pb 23 in Fig. 2); this problem would never been identified if the designer had developed only a solution devoted to increase the structural efficiency without considering the possibility of adjusting Pivot axis.

The next topic of comparison concerns the definition of a contradiction. Classical TRIZ, among all its instruments, does not offer, even in this case, a systematic method for the definition of the contradiction which is the starting point for Ariz-85C. Therefore, when the conflict is not immediately clear, it could happen that only the expert problem solver has the ability of extracting the first technical contradiction, which is the trigger for the step 1.1 of ARIZ-85C. Another problem that might arise at this stage concerns the presence of more than one contradiction. As is well-known, TRIZ instruments are not "adapted" to work simultaneously with more than one contradiction, but at the same time.

Classical TRIZ does not offer any instrument to hierarchically sort them. Therefore the problem is which contradiction has to be firstly considered.

In the context of OTSM-TRIZ, instead, even the concept of technical contradiction was transformed into a network. In fact, not only a single contradiction that arises from the Network of Problems is taken into account, but a new real Network of Contradictions in which all the contradictions extracted from the NoP can be

collected. Thus a kind of transition has been made to roll by from the NoP to the Network of Contradictions that can be seen as a poly-contradiction of Classical TRIZ. Construction of the new network starts from identification of contradictions related to those key problems that could be highlighted within the NoP: hence they will define the first contradictions of the network. Then all other contradictions belonging to the same branch of NoP will be added, creating a dependency of the contradictions arising from the sub-problems compared to those of key-problems thus having a useful criterion for selecting the most impacting contradictions.

Switching back to the case of the Gondola: if analysis was conducted with Classical TRIZ, as shown above, no one of the problem present in the initial list could have been defined as mini problem, and therefore extracting directly a contradiction would not have been possible. Proceeding with the analysis and the breakdown of one of the key-problems would have brought certainly to a contradiction, and perhaps even to more than one. At that point, anyway, the problem of which contradiction analyze first and how to manage any relationship between them would arise. Instead of expanding all various aspects of the problem and defining only at the end a set of contradictions which were organized in the network, the OTSM-TRIZ approach has enabled, where possible, to choose which examine as first: according to cause-effect relationships among the displayed contradictions, the root conflict has been chosen as the first to be dealt with. In this way if such contradiction is solved, all the others are not anymore relevant for the scope of the problem.

The last topic in comparison is related to the management of the generated solutions. In case of resolution of a complex problem, to support the generation of solutions, Classical TRIZ offers a series of instruments to facilitate the problem solver task. If the problem is complex, contradictions to solve will be several and varied, and even more solutions will be generated. Seldom a solution will completely fit the problem, thus there is a need to manage solutions which gradually are produced. To this purpose Classical TRIZ doesn't provide any suitable instrument for managing solutions, even if Part 7 of ARIZ provides a set of hints to check and to estimate the generated solution concepts. A new problem that could arise is the compatibility that a solution must ensure with the rest of the system under analysis. In fact, assuming that the main problem has been broken down in a set of more elementary problems, each of these will be resolved using one of the Standard Solutions or applying an Inventive Principle in presence of a contradiction, but the developed solutions have not to be in conflict with the other parts of the system that already have been or still to be analyzed. Again, Classical TRIZ does not offer any tool to manage such complex situations.

OTSM-TRIZ instead, with its typical network approach, allows the user to insert the solutions generated at each step of the problem solving process within the Network of Problems. In this way, it is possible to manage all the so called "partial" solutions generated that, by definition, aren't able to solve completely the main problem. With this type of representation it is always possible to check the compatibility of a given solution with respect to the other key-problems or sub-problems or with other PS present in the network, verifying any birth of additional contradictions.

Considering solutions linked to the case of the Gondola, it may be useful to refer to the figure of the NoP (figure 2). In fact it is clear how high is the number of partial solutions in the whole map and, specially, how these are interconnected with problems belonging to different branches. If OTSM-TRIZ approach hadn't been used, this overview of interconnection between solutions and problems would not have been certainly guaranteed by instruments of Classical TRIZ, and therefore important information would be lost. For example the issue mentioned in topic one, in which, when trying to solve all key- problems at the same time with OTSM-TRIZ, the solution 73 is immediately connected with problem 24 which belong to another branch of the NoP (see figure 2 and table 1), making possible to manage the same problem from two different points of view simultaneously.



Table 2. Summary of the comparison between Classical TRIZ and OTSM-TRIZ

Topic of comparison	Classical TRIZ	OTSM-TRIZ
Problems	<ul style="list-style-type: none"> <li>to start with using ARIZ-85C the problem has to be already defined in the formality of a mini problem</li> <li>if several mini problems are present there isn't a structural way to rank them and to choose the first to address with.</li> <li>low probability to extend the "space" where find the key problem to solve</li> </ul>	<ul style="list-style-type: none"> <li>the breaking down of the main problem is an integral part of the process. It brings to the building of NoP</li> <li>there is no need to choose one problem to start: the problem solving process could be carried out for more than one problem at a time</li> <li>a good and new key problem to solve could arrive at an advanced stage of the Pb-PS chain</li> </ul>
Contradictions	<ul style="list-style-type: none"> <li>lack of a structured method to find a contradiction behind a not well defined problem</li> <li>lack of a method to rank a list of contradictions</li> <li>lack of tool to manage several contradictions</li> </ul>	<ul style="list-style-type: none"> <li>contradictions arise from the analysis of the NoP</li> <li>the contradictions related to key problems are the first to solve</li> <li>the network approach lets to deal with several contradictions even if each of them will be solved one at a time</li> </ul>
Solutions	<ul style="list-style-type: none"> <li>lack of tool to manage several solutions</li> <li>checking for the suitability of a solution with the rest of the system is quite impossible</li> </ul>	<ul style="list-style-type: none"> <li>all the generated solution are collected in the NoP</li> <li>collecting the solutions in the NoP makes the check of the suitability of a solution with the rest of the system easier</li> </ul>

## 5. Conclusion

A comparison between classical TRIZ and OTSM-TRIZ has been presented in order to evaluate differences when facing complex problems. To undertake this work a particular case study has been considered, the development of an innovative platform for stratospheric ballooning.

The analysis has been conducted by subdividing it into three topics of comparison, namely under the point of view of problems, contradiction and solutions distinctively. The result of this activity is that Classical TRIZ remains a very powerful instrument to be used in problem solving, but when complex problems with a certain number of interconnections among functional parameter arise, OTSM-TRIZ gives additional useful tools for the management of the overall problem; practical examples referring the case study are mentioned and a table in which the comparison has been summarized, is showed.

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