Learning TRIZ with application on case studies

"Failure is not an option"

- Apollo 13 case study -

(Structured Innovation)

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Abstract.

This case study is about a severe accident during a NASA mission to the Moon in April 1970. As TRIZ concepts are not easy to explain to trainees, this approach is using and building on the experience on simulation e.g. the Titanic case by Ellen Domb for easy learning through application on a "real" problem.

No one died on this third mission to the Moon, however the landing on the Moon was cancelled. In hindsight, one of the astronauts called this mission a "successful failure". However, the rescue of the astronauts has been widely recognized as successful problem solving.

The participants use different OTSM-TRIZ and classical TRIZ tools during the simulation including prototyping to help the crew survive the journey and return safely.

Starting from the situation description with data and fact sheets, the participants participate in several training elements for TRIZ methods, which are then applied to the problem. Prototyping is added to the TRIZ problem solving to foster interactivity and development of fast solutions, feasibility checks and also customer feedback.

Keywords: Apollo 13, Resources, TRIZ, OTSM-TRIZ, Contradiction, Ideality, TONGS Model, TOM's Model, IFR, Most Desirable Result, Inventive Principles, Problem Graph, Element-Name-Value Model, ENVP, Active Parameters, Passive Parameters, Structured innovation, Simulation Game. Fast Prototyping.

1 Introduction

Apollo program was the third human spaceflight program after the early program Mercury end of the 1950's and beginning of the 1960's. The complete National Aeronautics and Space Administration (NASA) program was - as mentioned in [5]" later dedicated to President John F. Kennedy's national goal of "landing a man on the Moon and returning him safely to the Earth" by the end of the 1960s, which he proposed in an address to Congress on May 25, 1961".

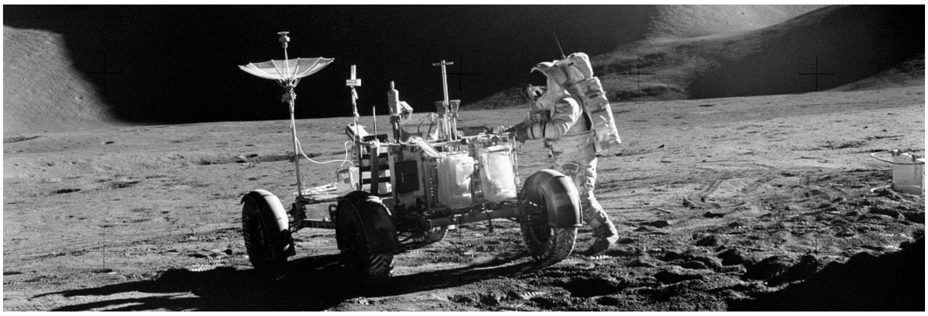

Fig. 1. Apollo - Astronaut and Moon Rover.

Apollo 13 was the third mission to the Moon after a successful first landing on the Moon. The Apollo 13 case is well known by public and the simulation is therefore easy to explain to the participants.

Educational objectives and competencies

The simulation game enables the participants to use structured problem solving by applying TRIZ tools in their daily working environment. TRIZ provides a structured way of working on innovation challenges and inventive problem solving, for technical and technological challenges.

In the first Phase, the simulation participants understand the IS (initial situation), define the team's goals with the ideal result and the most desirable result by using OTSM-TRIZ with TOM's model, an adapted version of the TONGS model.

During the next phase, tools like the 'Network of Problems' and the concept of contradictions are applied to translate the understanding of the initial problem into a model of existing problems and challenges.

In the following steps defined contradictions lead to the TRIZ Inventive Principles with generic concepts. These concepts are than translated into specific solution concepts.
With the concepts of resources, the formulation of a 'Network of Problems', definition of the contradiction model and the application of 'Inventive Principles', the participants

come to understand the core tools of TRIZ. With the overall approach they gain a broader view of the overarching concept of structured innovation. In addition, the participants gain valuable insights regarding the problem-solving approaches taken by the NASA astronauts and the Mission Control Center team to solve this challenging problem.

Duration and number of participants

The simulation can be adapted for a duration of 2 to 6 hours. The minimum number of participants is four, including the simulation moderator. The simulation can be carried out with large-scale setups for an indefinite number of participants. The ratio of players to moderators, however, should be limited to 10:1.

Material list and preparation

Any environment can be set up for this simulation game. A common wall, laptop and projector help to provide content for the participants. The team agrees on a time frame for the game (between two and six hours) and the setup is then planned accordingly. Besides that, there are no specific requirements for the room/space to be prepared. Optional prototyping material can be taken from standard office facilities, e.g. paper, cardboard, pens, scissors, glue and tape. Otherwise, prototyping is done with the material at hand, or with whatever materials can be retrieved from the game environment. All template needed need to be prepared by the training group.

Instructions for the simulation

1.1 Requirements and general rules of the simulation

- **Important**: The trainer team is familiar with the TRIZ tools and techniques applied during the simulation.
- The trainer(s) can provide methodological support and is available for queries at all times.
- The trainer team have is familiar with the content of the "Case_presentation.pdf [9]" including all templates used.
- The trainer(s) delivers short training sequences along the simulation
- Sample solutions to be found in the "Case presenation.pdf" [9]
- The trainer team can facilitate the progress of a group of people.
- Several teams work on the simulation exercise, but there is no competition. All participants are working on a common solution to rescue the astronauts.
- Each educational sequence is followed by the application of the described concept during the case study.
- The solutions found must be validated by the Lunar Module Engineer.

1.2 Roles for the simulation team

Each participant gets a nametag with name and role on it. We use their real names. These roles must be assigned before the simulation starts.
Roles & Responsibilities are freely available at [7].

1.3 Trainer instructions

Trainers act as points of contact, but they do not spoil the game by providing solutions. If there is uncertainty about eventualities and feasibilities, trainers make a decision and communicate accordingly to allow the game to continue.

A list of events helps the trainers to ensure that the game remains dynamic and stimulating. The events are in the sequence as they have occurred in the real situation.

List of events covered and to work on during the simulation:

- **Simulation phase 1**: Explosion and fluctuations in electrical power
  - → Tool to be applied: TOM's Model a derived TONGS Model [4]

- **Simulation phase 2**: Increasing carbon dioxide in the air
  - → Tool to be applied: Resource Analysis

- **Simulation Phase 3:** How to separate the lunar module a safe distance away from the CM just before re-entry
  - → Tool to be applied: Network of Problems; Contradiction Model and Altschuller Matrix

2 The simulation

2.1 Phase 1: The accident

Apollo 13 lift-off occurred on the 11th of April 1970 at 13.13 Central US daylight time.

The spaceship was approximately 205,000 miles (330,000 km) from Earth on the journey to the Moon. [1] [2]

As in [6] Sy Liebergood from Mission control decide to request to the crew a stir of the hydrogen and oxygen tank prior to sleep to avoid a possible alarm he expected caused by an unprecise reading of the measurements. This stir up the mixture is needed to allow the mission control center a more precise tank quantity measurement.

Oxygen and hydrogen are mixed and react in the three fuels cells to provide electrical power to the service module. Astronaut Haise acknowledged the request and switched the fans on.

Two minutes later - at 03:07:53 Coordinated Universal Time (UTC) (55:54:53 Ground Elapsed Time) - the astronauts heard a “pretty large bang”.

The first thoughts from the crew has been that a meteoroid might have struck the Lunar Module. Communications and telemetry to Earth were lost for a few seconds, until the system automatically corrected by switching antenna to wide-beam mode. [3]

Now, with the accident - the simulation starts!

2.2 “Initial situation described, and problem defined”

Usage of the TOM’s model

TOM’s model is a derived TONGS Model from [4] used to quickly gain an understanding of the initial and current situation, the result to be achieved and the barriers to be overcome.

2.3 Phase 2 – The CO2 problem

The toxic carbon dioxide exhaled by the astronauts is no longer being extracted. The carbon dioxide filters in the LM are overloaded, as they were only designed for two astronauts. If the problem is not solved, the astronauts Lovell, Swigert and Haise will have problems breathing, and will suffer and die. There has been filters in the CM and LM, but their connection is not compatible. Sequence from the film “Apollo 13” could be shown. (Round filers and square filters not fitting together)

2.3.1 Usage of the concept of resources

A qualified TRIZ solution is a solution that uses existing resources to solve a problem. One should not add anything from outside unless necessary. Within our case study we are limited by the problem-solving resources we have inside and outside the spaceship. The resources available in the spaceship are provided and prototype building is applied.

2.3.2 Fast prototyping with existing resources

- Impressions and insights from the prototyping (visualisation, haptics and interaction with the prototype)
- Technical knowledge about feasibility and obstacles after and during the building of the prototype
- Intuitive development
- Unbiased feedback from customers and others

- Basis for targeted, open discussions with the target group
- Evaluation of the feedback, optimisation and, if necessary, rejection of the idea

Fig. 5. Prototyping helps to validate concepts and inspires communication.

2.4 Simulation Phase 3 - Problem modelled, and contradiction defined

Event – Separation of the LM from the CM before Earth re-entry

In the real case, the decision was taken not to land on the Moon and to bring the astronauts back to Earth as quickly as possible.

Current situation: We are back in the Earth orbit now. The spaceship consists of the Lunar Module, Command Module and Service Module.

Before re-entry, the LM (Lunar Module) must be separated from the Service Module. It is too risky to use the rocket engines to separate the modules from each other. So, a way must be developed to separate the spaceship from the LM to a safe distance from each other without using the rocket engines.

2.4.1 Initial 'Network of Problems and Solutions' explanation

The 'Network of Problems and Solutions' is a concept that is part of the OTSM-TRIZ [4] methodology. It is a tool to understand the problems and existing solutions of a complicated problem situation. In the simulation we use a simplified, shortened version.

The following steps help to build an initial 'Network of Problems and Solutions':

- Review the list of problems and solutions

- Build the network of problems
- Add further existing problems/barriers for the separation problem
- Add potential partial solutions and their resulting problems, if any.
- Draw up the network according to the rules (see Figure 6).
- If a solution is satisfying, the problem is solved.
- A sequence ends with a problem or a partial solution.

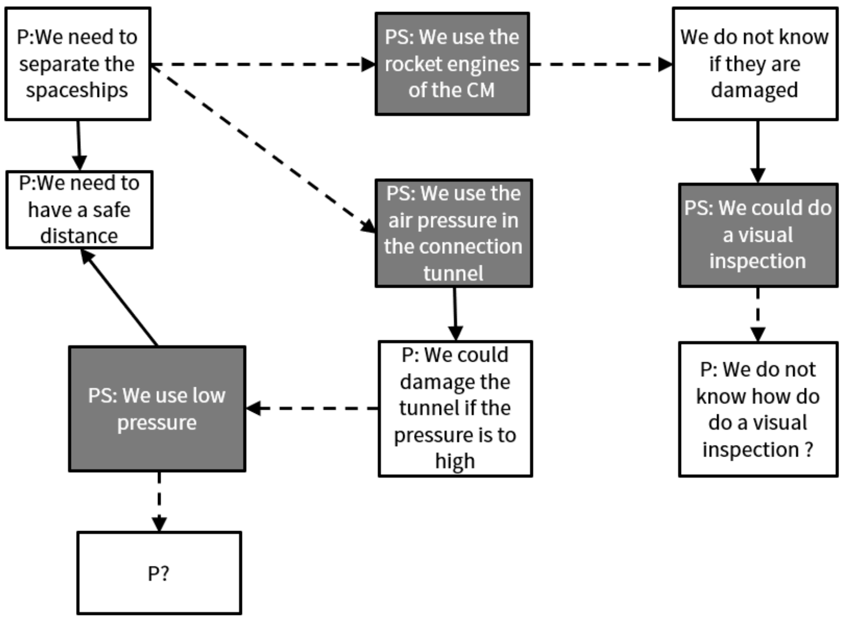

Fig. 6. Initial Network of Problems and solutions.

Concept of contradiction:

This concept has been developed by Genrich Allschuller [10].

If you improve one parameter, another parameter is often affected in a negative way. For example, if you want a stable table, you can make the top surface of the table thicker and heavier. However, this leads to increased weight and makes the table hard to transport. Improving one parameter (stability) degrades another parameter (weight). This is called a contradiction.

Partial solution and the contradiction: (High) Air pressure was used to pressurise the connection tunnel between the modules.

The solution concept of using air pressure is not satisfying as there is a contradiction: The pressure must be high to get a high force **(Parameter 10: Force)** to bring the LM to a safe distance, however, if the pressure is too high, it will damage the connection tunnel **(Parameter 13: Stability of the object composition)** and expose the modules to outer space.

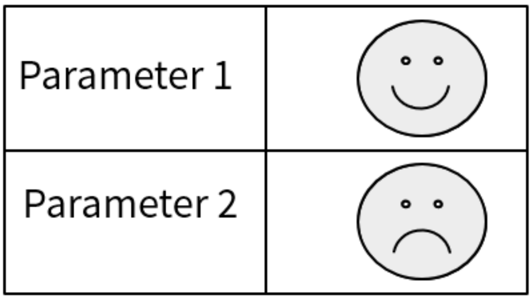

Fig. 8. Template - Contradiction.

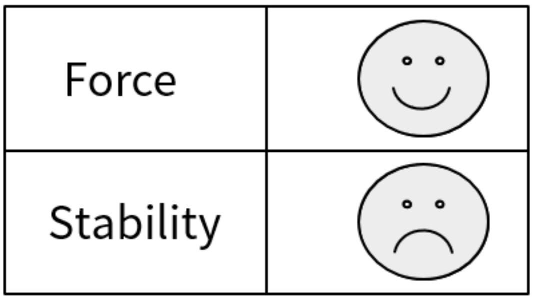

Fig. 9. Contradiction for Air pressure.

Case (15 minutes): The team works with the predefined contradiction as provided in Figure 9.

2.4.2 Solution principles and standard solutions identified

Vast numbers of solutions have been developed throughout the history of mankind. Reusing some of these solutions can help to speed up problem-solving processes. The TRIZ contradiction matrix was developed by G. Altschuller summarizing well-known solutions for generic problems to be reused in an easy and time-efficient manner.

The Altschuller matrix places the improving parameter in the column and the degrading parameters in the top row. At the intersection of a column parameter and a row parameter, one will get a short list of Inventive Principles. These principles suggest a common solution as a concept for a specific solution to overcome the contradiction.

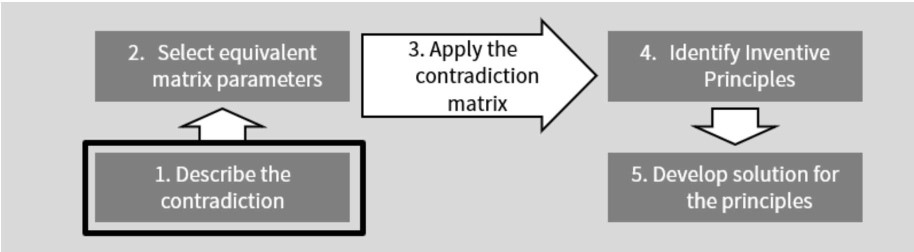

Fig. 10. Steps from the contradiction to the solution.

2.4.3 Solution concepts defined, and feasibility assessed.

Now one translates proposed generic solution concepts into a specific solution concept. If more than one solution is available, we need to filter the best one based on selection criteria such as e.g. time for implementation, efforts required for implementation and more. After selection the solution is prototyped.

2.5 End of the game

"Failure is not an option" ends when one of the following events occurs:

- The set time frame for the game is over.
- All teams have ended their effort to safe the Apollo 13 team, because:
  - The team has been successfully solved all problems.
  - There is a deadlock situation with no remaining options.

2.6 Experience & Reflection on the simulation

In the case study we have used known techniques from TRIZ. There is nothing very new, however we have added the concept of fast prototypes as used by other methods. In our simulation workshops with about 100 trainees in the last years using the Titanic case [8] and the Apollo case the participants came mainly from industry. The Apollo case study has tried to overcome the more "negative" study using the Titanic- where many people lost their lives with a more optimistic one. On Apollo 13 now one has died on for a few days the world was coming very close together independent from borders and political differences.

The feedback had a mean of 4,2. The trainees have enjoyed the case study. Most successful have been simpler approaches like e.g. application of the concept of resources for solution generation. Contradictions have been more difficult, however by using prepared template the learning curve has been very high. Measuring the knowledge level and the ability of application of TRIZ Tools by filling the participants gave us a rating with a mean of 4. The concepts of contradiction and the usage was seen a more difficult to apply in their daily work.

3 Summary

Methods from scientific or industrial fields of application are powerful tools that are rarely used to their full potential. One of the reasons for this lack of application in practice is the lack of application when methods are taught. Typically, examples are very theoretical and not detailed enough for the user to understand in detail. If real life examples are provided, these examples are merely discussed in the target audience.

Simulation games like the Apollo 13 case "Failure is not an option" or the Titanic Case as initially developed by Ellen Domb [8] et al. are proven to create practical insights and application competencies in the target audience. Emotions, social interaction and practical experiences are the key factors used to trigger learning.
In comparison to the Titanic case – where the event is seen a catastrophe with a lot of victims, the Apollo case has a positive outcome, which gives the simulation a more positive view.

TOM's Model, Resource Analysis, Network of Problems and Solutions and Contradiction Modelling are used as exemplary methods to make a very important point in invention and innovation projects: structured problem solving, and innovation approaches are clearly superior to unstructured brainstorming as they are typically used today in terms of economical use of resources, in terms of time required to find satisfying solutions and in terms of solution quality. In the Apollo 13 case, the problem solvers get a quick overview with challenges to be solved within a time limit as the spaceship was damaged and losing resources that were essential for survival. During the simulation the participants understand the pressure that was on the Mission Control staff.
The participants also recognize the power of the resources concept including fast prototyping for problem solving as the NASA crew was forced to use it.

Acronyms and Explanations

OTSM	Russian acronym for "General theory of powerful thinking"
OTSM-TRIZ	TRIZ Methodology extended by OTSM tools and principles.
TOM's Model	Adaption of the OTSM TONGS model [4]. In TOM's model the solution level starts with the ideal solution. By moving defined steps back from ideality, one can define the "most

	desirable result". IS situation description is supported by 5 Why and 2How's concept.
Technical system	Anything that performs a main function is called a technical system. E.g. a table is a technical system.
Element	Part of a system. E.g. the table top is an element of a table.
Active parameter	Parameter in the ENVP-Model which can be directly influenced and has several beneficial settings.
Passive parameter	Resulting parameter, leading to a technical contradiction.
Partial solution	A solution which solves a problem not complete and contains remaining problems
LM	The Lunar Module – the Moon landing device.
CM	Command Module – docked with the SM – the Service Module. Used for re-entry from space into the Earth's atmosphere.
IS	Initial situation – the current situation with all negative effects.

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